Lowering your emissions through innovation in transport and energy infrastructure

PROJECT

# REPORT

## Hydrogen Farm of the Future

Final Report

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### *Prepared for:*

James Wade-Iles
Innovation Engineer
Energy Innovation Centre (EIC)

and

Lewis Kirkwood
Innovation Manager
Northern Gas Networks (NGN)
1100 Century Way
Leeds LS15 8TU

lkirkwood@northerngas.co.uk

### *Prepared by:*

Peter Speers
Principal Technical Specialist & Project Manager, Cenex,
Matt Ward
Technical Specialist, Cenex,
Richard Gueterbock
Foodchains on behalf of RASE

Approved by:

Steve Carroll
Head of Research and Technical Services

Company Details

Cenex
Holywell Building
Holywell Park
Ashby Road
Loughborough
Leicestershire
LE11 3UZ

Registered in England No. 5371158

Tel: 01509 642 500
Email: info@cenex.co.uk
Website: www.cenex.co.uk

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# Contents

# Abbreviations

| | |
|---|---|
| AQ | Air Quality |
| APC | Advanced Propulsion Centre |
| BEV | Battery Electric Vehicle |
| bioCNG | Bio Compressed Natural Gas |
| CapEX | Capital Expenditure |
| CHP | Combined Heat & Power |
| CNG | Compressed Natural Gas |
| $CO_2$ | Carbon Dioxide, which in this report includes other greenhouse gases on a $CO_2$ equivalence basis ($CO_2e$) |
| DF | Dark Fermentation |
| DIA | Direct Investment Agreement |
| DUKES | Digest of UK Energy Statistics |
| ECH | East Coast Hydrogen |
| EIC | Energy Innovation Centre |
| EV | Electric Vehicle |
| FC | Fuel Cell (Vehicle) |
| FCEV | Fuel Cell Electric Vehicle |
| GHG | Greenhouse Gas |
| $H_2$ | Hydrogen |
| H2ICE | Hydrogen-Diesel Dual Fuel Internal Combustion Engine |
| Ha and /Ha | Hectare and per Hectare |
| HGV | Heavy Goods Vehicle |
| HRS | Hydrogen Refuelling Station |
| IfA | Innovation for Agriculture |
| km | Kilometre |
| kW/MW/GW/TW | Kilowatt/Megawatt/Gigawatt/Terawatt |
| kWh | Kilowatt Hour |
| LHV | Lower Heating Value |
| MPG | Miles per Gallon |
| NGN | Northern Gas Networks |
| NOx | Nitrogen Oxides |
| NRMM | Non Road Mobile Machinery |
| OEM | Original Equipment Manufacturer |
| OpEx | Operational Expenditure |
| PiV | Plug-in (Electric) Vehicle |
| PM | Particulate Matter |
| RAG | Red Amber Green |
| RASE | Royal Agricultural Society of England |
| RHI | Renewable Heat Incentive |
| SMR | Steam Methane Reforming |
| TCO | Total Cost of Ownership |
| TRL | Technology Readiness Level |

# Executive Summary

Cenex, partnered with the Royal Agricultural Society of England (RASE), responded to a market enquiry by Northern Gas Networks (NGN) through the Energy Innovation Centre (EIC) on understanding the possible demand for hydrogen in an agricultural setting.

Through engagement with agricultural stakeholders and examining the technological and financial attractiveness of hydrogen compared to gas and (red) diesel, this *Hydrogen Farm of the Future* report aims to understand the potential use cases for hydrogen in the farming sector, the scale of potential demand among farms, and the viability of farming as an early adopter of hydrogen.

## Farm Energy Use

This project began by conducting research and engaging with stakeholders to establish the high-level energy requirements (electricity, diesel, gas and other fuels) of UK arable, horticultural and animal husbandry farming activities:

- For **arable** crops, **electricity** (for crop drying) and **machinery** fuel use dominate.
- For **protected horticulture**, *gas/fuel oil* for heating dominates. It is significant that the scale of energy use/Ha is significantly higher than for outside crops (GWh/Ha vs. kWh/Ha).
- In terms of animal husbandry
  - For **pigs**, **electricity** for heating & lighting dominates.
  - For **cows and beef & sheep**, **mobile** energy use dominates.
  - For **dairy**, **electricity** for milking and cooling dominates, but there is also significant **mobile** energy use.
  - **Poultry** energy use per head is much lower than the others.

## Potential Hydrogen Farm Use Cases: Agricultural Machinery and Heating

The study looked at three potential agricultural hydrogen use cases with a focus on Technology Readiness Levels (TRLs) 6 and above (i.e., technologies that have been demonstrated and are at, or approaching, market readiness). In all the use cases, it is likely that a mix of alternative fuels will be required for a full agricultural net zero transition.

***Hydrogen Vehicles and Farm Machinery (Fuel Cell and Internal Combustion Engine)***

The candidate replacement fuels available are renewable biofuels (as liquid or gas) including on-farm biomethane generation\supply, electricity, and, potentially, hydrogen.

Given that red diesel remains the farm fuel of choice there will be very limited deployment of alternatively fuelled vehicles on farms before 2030 in the absence of Government intervention.

From 2030 onwards:

- **Electric vehicles (EVs)** will become an option for **lower power (< 100hp) farm applications** assuming reliable on-farm electrical supply is available.
- **Fuel cell electric vehicles (FCEVs)** may also become an option for **higher power (>100hp) farm applications.** They will also cost more than diesel vehicles, and without subsidies will be more expensive to fuel than EVs. As such it could be the late 2030s before reasonable economic performance, combined with policy drivers, leads to significant uptake. Their requirement for high purity hydrogen is a further barrier to deployment.
- **Hydrogen internal combustion engine vehicles (H2ICEs)** are suitable **for high powered (100 hp and above)** operation and can operate on lower purity hydrogen than FCEVs. Given JCB's leading role in UK powertrain development, their interest in hydrogen ICE vehicles may mean that this technology gains early traction in the UK. To unlock future innovation and deployment funding Government needs to classify H2ICE as a net zero emission technology.

***Heating and Grain Drying***

Glasshouse horticulture, grain drying and high intensity farming (such as the heating requirements for pig and poultry housing) are amongst the most energy intensive farming practices. The candidate replacement fuels available are also renewable biofuels (as liquid or gas) including on-farm biomethane generation\supply, electricity, and, potentially, hydrogen. Heating options are:

- **Gas fuelled direct burners** which, if switched to hydrogen, would require $CO_2$ enrichment, which is a common and well-understood technology.
- **Hot water pipes fed by a boiler**, which would generally be employed with $CO_2$ enrichment as described above.

At present, there is no agricultural use of hydrogen in these applications.

***Hydrogen Production and Storage***

There is considerable interest in the possibility of producing hydrogen fuel locally on-farm, similar to the generation of biogas on-farm from organic waste.

- **Electrolysis** is the only high TRL technique for hydrogen production that is viable for on-farm installation at present. However, cost-effective hydrogen production and dispensing through small-scale on-site electrolysis has yet to be achieved.
- **Anaerobic digestion (AD)** is a well-known process for producing biogas, which can be upgraded to biomethane for possible use in vehicles, or injection into the gas grid. Research (low TRL) is ongoing on how the AD process can be adjusted to increase the concentration of hydrogen relative to biomethane in biogas (or generate it through dark fermentation). The results have indicated that this can be achieved, but the economics remain challenging.
- **Hydrogen storage, distribution and refuelling:** Hydrogen is generally dispensed to vehicles by pressurised gas delivery, although some work is underway to use liquid hydrogen as a HGV fuel. There are significant barriers to the use of onsite generated hydrogen as an agricultural fuel:
    - *Cost and reliability* Hydrogen refuelling stations remain expensive (generally costing of the order of £millions per permanent installation), complex, bespoke systems with even state of the art systems achieving availabilities of around 95%.
    - *Purity* FCEVs require very pure and dry hydrogen. H2ICEs can use lower purity hydrogen.
    - *Regulatory, safety and planning* aspects of hydrogen refuelling are onerous, with permanent installations requiring years of preparation. The business and operability case for smaller on-farm gas fuel storage and fuelling systems remains unproven.

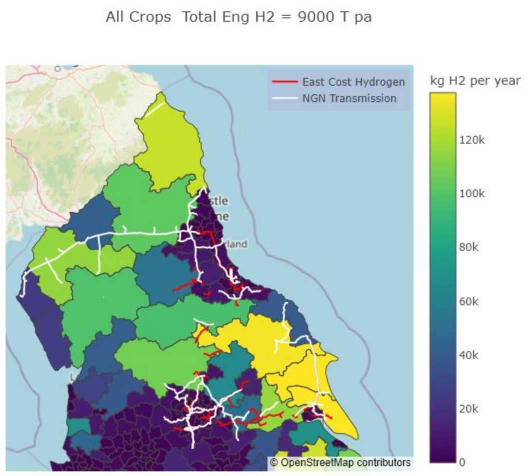
## Financial and Technical Feasibility of Hydrogen Use Cases

Analysis of financial attractiveness and technical viability of hydrogen in agricultural use for heating and machinery based on the price of, and availability of, hydrogen compared to that of gas and (red) diesel showed that:

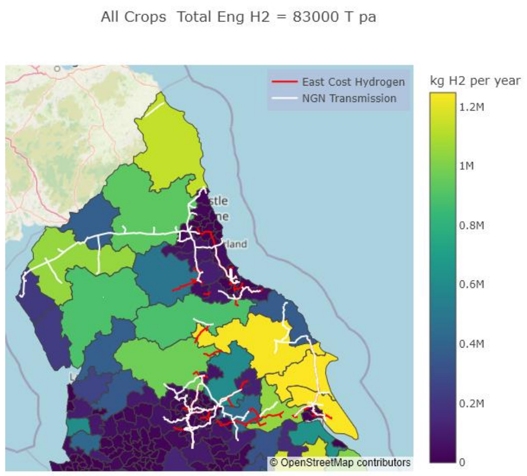
- Pipeline-delivered hydrogen is likely to become a financially competitive fuel for protected horticultural heating from the late 2030s onwards.
- The business case for use of hydrogen in agricultural machinery is less clear, and will depend on:
    - The cost and technology readiness of applicable hydrogen technologies, particularly H2ICE,
    - The medium-long term availability of (red) diesel, and
    - The cost and performance of biomethane and electricity as alternatives in each application.

## Mapping Possible Future Hydrogen Demand

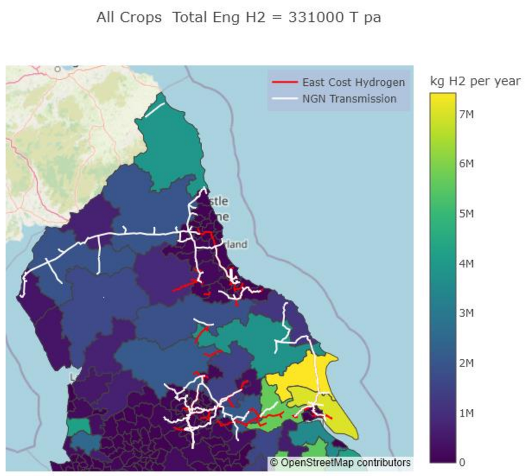
Project analysis of hydrogen uptake was used to map the potential future uptake of hydrogen in heating and agricultural machinery over time. Figures (a-c) below show the hydrogen demand projected by the model, by constituency, for all crop types in 2030, 2040, and 2050. Figure (d) shows *the maximum possible* total energy demand on all farms in each constituency (i.e., if all machinery and heating energy use was moved to hydrogen). The maps focus on NGN's region of operation and overlaid are NGN's transmission pipelines, and the proposed East Coast Hydrogen network.



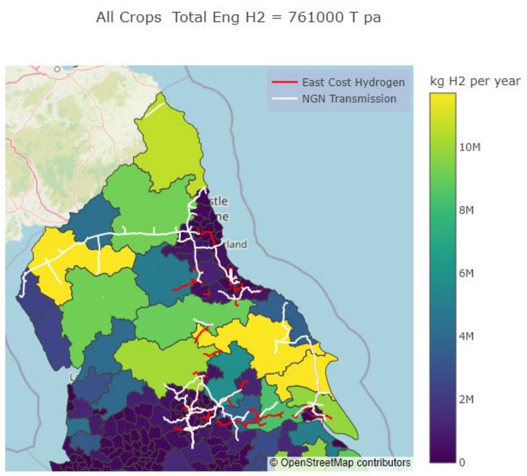

(a) 2030




(b) 2040




(c) 2050




(d) Maximum possible demand

*Total Potential Demand by Modelled Year.*
*Overlaid Are the NGN Transmission Network and the Proposed East Coast Hydrogen Network.*
*Note that the scale differs in each of the maps to reflect the growing amount delivered.*

The geographic analysis suggests that there is potential demand across much of the north. Much of the area along the east coast and towards the Scottish border is covered by the existing pipe network. However much of the area across the Pennines and into the Lake District is not covered by the existing or planned network. The highest area of demand in the area around Hull up to east of York. This is due to large areas of horticulture and arable land, which are amongst the most likely to adopt.

The figure shows that the *maximum possible* hydrogen demand across England by 2050 is 761 kt. For comparison, the UK Hydrogen Strategy projects a demand from industry alone of up to 105

TWh\3,200 Gt of hydrogen annually by 2050, or over 4,000 times higher (although this is from the whole of the UK, not just England).

## Recommendations

There is no immediate business case for hydrogen deployment in agriculture. Any future use of hydrogen in farming will be part of a national medium-long term transition away from fossil fuels that is bound up with wider policy and strategy on issues such as energy and food security and therefore requires intervention from the Government.

The following recommendations from the study analysis and farmer engagement address: general measures to promote the uptake of all alternative fuels, specific measures to promoting hydrogen uptake, and, briefly, the future use of biogas\biomethane and electricity as alternatives to hydrogen.

***Uptake of Alternative Fuels in Agriculture***: As a priority Government needs to engage with the agricultural sector to tackle its reliance on fossil fuels and to formulate an agreed transition plan to alternative fuels.

- **Gradual phase-out of red diesel**: Government needs to set a clear timeline with the industry for a phased withdrawal of red diesel tax to facilitate the transition.
- **Farmer education and outreach**: Farmers are interested in alternative fuels and are already deploying on-farm generation. Alternative fuel technologies will require a medium-long term business case to be demonstrated. Dedicated outreach events and continued engagement with the farming community by organisations such as RASE and NFU Energy are essential to carry the agricultural sector on the needed transition away from fossil fuels.
- **Better data on-farm energy use:** Relatively few farmers can accurately quantify all their energy use (electricity, gas and fuel), nor assign usage to a specific farming activity. Relatively simple self-reporting of annual fuel use by farmers will provide a valuable evidence base to track changes as alternative fuels are introduced.

***Measures to Promote the Uptake of Hydrogen in Agriculture:*** If sufficient hydrogen can be made available to agricultural users, report analysis showed that: pipeline-delivered hydrogen is likely to become a competitive fuel for protected horticultural heating from the late 2030s onwards, but the business case for use of hydrogen in agricultural machinery is less clear.

At present however, there is little or no agricultural equipment available on the market that can use hydrogen, nor is hydrogen available for farmers to use. Suggested measures to promote longer-term uptake include:

- **Classify H2ICE as a net zero-emission agricultural and NRMM fuel** to stimulate the UK market for hydrogen-powered farming machinery.
- **Dedicated hydrogen agriculture demonstration trials:** There should be consideration of dedicated large-scale funding for demonstration of hydrogen heating for horticulture, and hydrogen machinery and associated in-field refuelling infrastructure on farms incorporating both fuel cell and H2ICE equipment where available. The trials must produce publicly disseminated results on operability, practicality, emissions benefits and the business case to provide an evidence base for further growth and promotion of the technology in farming.
- **Further investigation of the hydrogen horticultural business case:** Given that several existing large-scale horticultural gas users in the Yorkshire and NGN region are connected directly to the grid, protected horticulture offers ready-made future trial potential for hydrogen heating to stakeholders such as NGN. Given the relatively low level of potential future demand compared to industry, however, further detailed analysis of the business case for linking horticultural users to the East Coast Hydrogen network is needed.
- **Hydrogen pricing:** Specific tax breaks and incentives could be developed to promote hydrogen use in agriculture, and as a NRMM fuel in general. In particular hydrogen pricing mechanisms are needed to offset the price differential with (red) diesel to provide market certainty to potential market entrants and technology deployers.

- **Rural hydrogen generation and vehicle refuelling:** Stakeholder engagement showed that there is considerable interest in, and activity towards, producing hydrogen fuel locally on-farm, similar to the generation of biogas on-farm from organic waste. A dedicated funding stream to investigate the feasibility of on-farm supply , with a particular focus on establishing whether it is possible to provide operable, affordable and safe on-farm solutions to clean, store and refuel hydrogen for agricultural machinery use should be considered.
- **Planning and regulation:** Streamlined planning processes would enable faster development of hydrogen projects, including for small-scale generation, in rural areas.

***Measures to Promote the Uptake of Non-Hydrogen Alternative Fuels in Agriculture***

Although the study was focused on use cases for hydrogen in agriculture, it is likely that a portfolio of fuels including biogas\biomethane, electricity and hydrogen will be required in a full net zero transformation of farming. Development and deployment of these fuels in agricultural settings is essential to provide a comparative evidence base as to which technology is appropriate for a given farming application. Therefore, there is a need for support for:

- **Dedicated on-farm demonstration trials of biogas\biomethane:** The on-farm trials must produce publicly disseminated results on operability, practicality, emissions benefits and the business case to facilitate like-for-like comparison with hydrogen in agricultural use cases.
- **Feasibility of on-farm biomethane vehicle refuelling and emissions**: The wider use of biomethane as a vehicle fuel on farms has been held back by the lack of available, affordable and safe on-farm solutions to clean, store and refuel biomethane for agricultural machinery use. There are solutions coming onto the market and these need to be trialled and concerns addressed about fugitive emissions from the production, storage and combustion of gas.

# Foreword

## Northern Gas Networks

The agricultural sector in the UK is undergoing significant transformation, driven by the need to reduce carbon emissions and increase sustainability, while maintaining operational efficiency. With the government's commitment to achieving net-zero carbon emissions by 2050, there is growing pressure on all sectors, including agriculture, to adopt cleaner, greener technologies. Among the promising solutions is hydrogen, which has the potential to replace traditional fossil fuels like diesel in key farm operations such as transport, grain drying, and heating.

This report, funded by Northern Gas Networks via the Ofgem Network Innovation Allowance, explores the future possibilities of integrating hydrogen into UK farms, focusing on its role in decarbonising critical agricultural processes.

Farms are already at the forefront of renewable energy innovation, with on-site electrical generation and many producing biomethane from organic waste. This biomethane can be used directly on-site to generate electricity or heat, or it can be injected into the gas grid. However, hydrogen has the potential to offer an even more versatile and sustainable alternative, by utilising renewable energy sources, such as wind or solar to produce green hydrogen through electrolysis. Farmers can drastically reduce their reliance on red diesel and other fossil fuels, helping to meet environmental targets while also improving the resilience and sustainability of their operations.

One of the key areas of focus in this report is the potential for hydrogen to replace diesel in farm transport. Farming relies heavily on the red diesel subsidy to power their fleet of vehicles for tasks ranging from drilling crops to the transportation of livestock. Switching these vehicles to hydrogen could significantly reduce greenhouse gas emissions from the sector. Additionally, hydrogen’s role in grain drying and heating is another area of interest, particularly as these processes are typically energy-intensive, reliant on fossil fuels and are impacted by international fuel prices.

**Lewis Kirkwood, Innovation Manager for Northern Gas Networks, adds**

“*Our network serves 2.9 million homes and businesses across the north of England, and encompasses vast amounts of agricultural land within Yorkshire, Northumberland and Cumbria.*

*“As an energy business, we believe it’s vital that as the UK looks to decarbonise moving towards the net zero targets that we facilitate a fair and just transition for all residents.*

*“Farming is an extremely important industry to maintain UK food security and the retention of productive land. We commissioned the project to understand the role that hydrogen could play within the farming sector and the viability for on-site production. Not only for the benefit of the farmers but also for the surrounding communities, where farming is engraved in their heritage.’*

*“This report delves into these possibilities, assessing the technical, economic, and environmental implications of hydrogen adoption on UK farms, and provides recommendations for stakeholders in the agricultural and energy sectors.”*

## David Skaith, Mayor of York and North Yorkshire

*"The UK has long been a global leader in agriculture and food production, and as we look to the future, it is essential to harness our strengths to shape the farming landscapes of tomorrow. Regions like York and North Yorkshire have a crucial role to play in this work. With a rich heritage of farming, a high concentration of food production businesses, and extensive research and development assets, we are uniquely positioned to lead the way in tackling the challenges of food security, sustainability, and innovation—not just for one region, but for the entire country.*

*Food and farming are at the heart of York and North Yorkshire's agenda as we prioritise long-term growth and resilience through strategic planning and investment. Engaging directly with farmers is essential to informing this work, which is why initiatives like our Grow Yorkshire partnership play a crucial role. By bringing together farming organisations, we can ensure that farmers have a voice. By working with mayors, farmers will be able to influence government investment decisions, focusing on where it is needed most, securing a productive future for British farming for generations to come.*

*As a nation, we must be ambitious in our environmental goals. The UK has set its sights on achieving net-zero carbon emissions, and closer to home, our rural communities are central to our vision to go beyond and reach carbon-negative status. As the first rural Mayoral Combined Authority, we need to take our farmers with us on this journey. By embracing low-carbon technologies and sustainable farming practices, we can ensure that agriculture remains both viable and environmentally responsible. I have visited farms and have seen firsthand that our farmers are ready to lead this transition, but they need the right support and investment to make it a reality.*

*This timely study explores the technical and economic feasibility for the future on-farm use of hydrogen in vehicles and rural heating. It also highlights the potential for smaller scale farm production of alternative gas fuels including hydrogen and the need for rural off grid energy supply. Access to locally generated renewable energy is crucial for our farmers, particularly those in our beautiful national parks, who struggle with access to the national grid and our wider energy networks.*

*For the York and North Yorkshire region to be at the heart of this study is also a recognition of activity being undertaken by local government, universities and the private sector to develop the gas fuel and hydrogen economy in the region.*

*The national transition to clean fuels must include the future fuel needs of agriculture and our rural communities. Farmers are not only food producers but also key players in the UK's journey to sustainability. Our Route-Map to Carbon Negative recognises the urgent need for agriculture to decarbonise, including transitioning on-farm machinery to cleaner energy sources. British farmers will continue to produce high-quality food while reducing reliance on fossil fuels and minimising their environmental impact.*

*With its vast natural resources, expertise, and commitment to innovation, the UK can be a global leader in sustainable agriculture. The launch of this hydrogen study is a significant step in exploring viable solutions for reducing fossil fuel dependence on farms. As we look ahead, it is crucial that we support our farmers, invest in clean energy, and ensure that rural communities remain at the forefront of the nation's transition to a greener, more sustainable future."*

# Project Partners

## Cenex

Cenex was established as the UK's Centre of Excellence for Low Carbon and Fuel Cell technologies in 2005.

Today, Cenex lowers emissions through innovation in transport & associated energy infrastructure and operates as an independent, not-for-profit research and technology organisation (RTO) and consultancy, specialising in the project delivery, innovation support and market development.

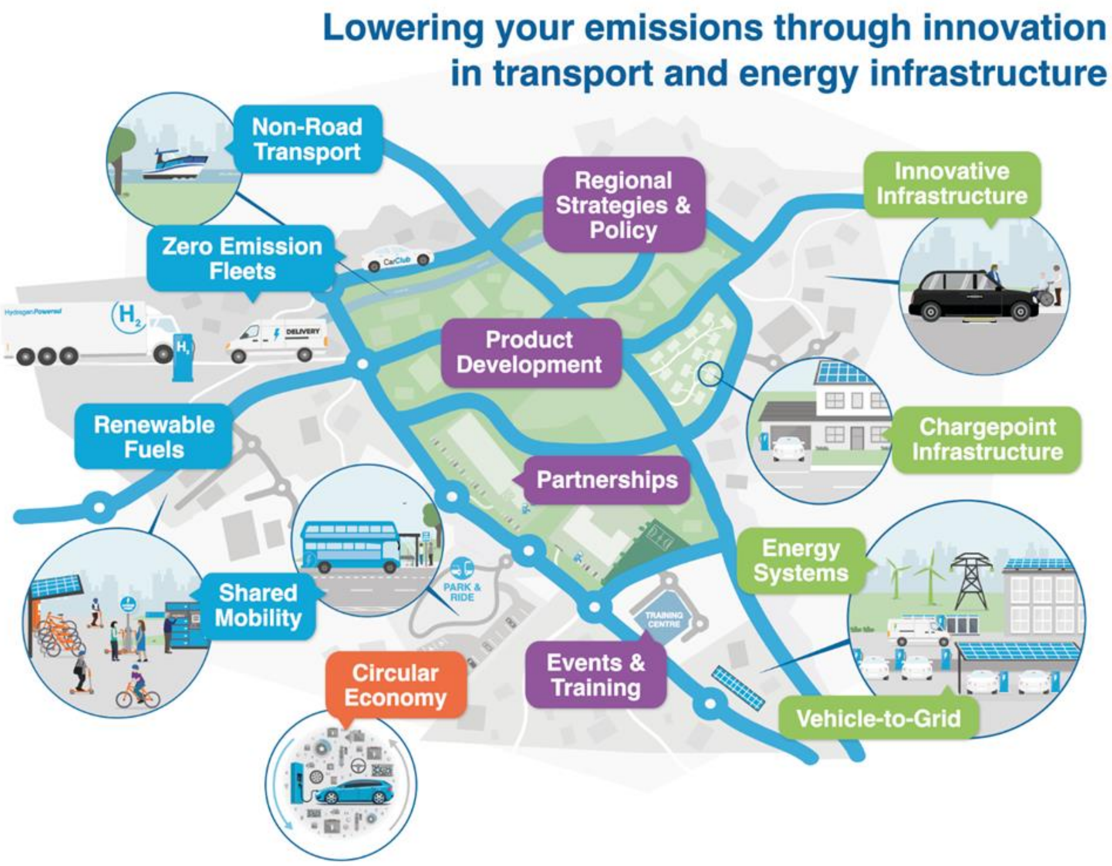
Employing over 40 people, the Cenex head office is in Loughborough, with additional bases in Belfast, Northern Ireland, as well as a sister company Cenex Nederland, based in Amsterdam. The Cenex group of companies (both Cenex and Cenex Consultancy Services in the UK and Cenex Nederlands in Amsterdam) are all non-profit mission-led organisations.

We also organise Cenex-Expo, the UK's premier transport decarbonisation and Connected and Automated Mobility event comprising three exhibition halls and a two-day seminar programme demonstrating the latest technology and innovation.

Cenex's independence ensures impartial, trustworthy advice, and as a not-for-profit we are driven by the outcomes that are right for you, your industry and your environment, not by the work which pays the most or favours one technology.

As trusted advisors with expert knowledge, Cenex are the go-to source of guidance and support for public and private sector organisations along their transition to a zero-carbon future and will always provide you with the insights and solutions that reduce pollution, increase efficiency and lower costs.

To find out more about our recent work and expertise, visit: www.cenex.co.uk.



## Royal Agricultural Society of England (RASE)

The agricultural contribution to the study has been led by Cenex's project partner, the Royal Agricultural Society of England (RASE) and its sister charity Innovation for Agriculture (IfA) with support in Yorkshire provided by the Yorkshire Agricultural Society (YAS).

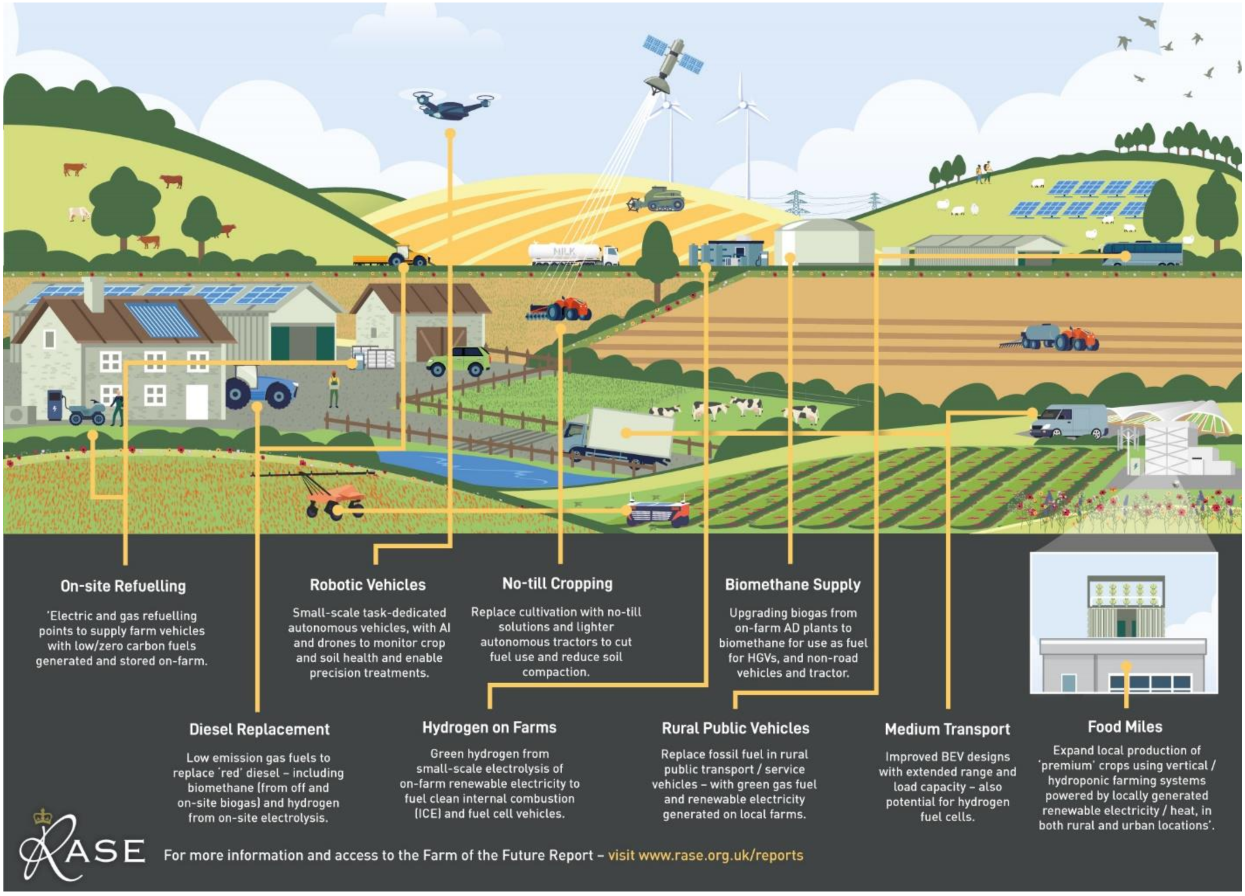
Granted its Royal Charter in 1840, RASE is an independent charity dedicated to identification of and communicating innovation opportunities of commercial value to UK agriculture. RASE played a leading role in rapid agricultural progress of the 19th and 20th Centuries and ran 160 Royal Agricultural Shows. Its current focus is on promoting sustainable innovation.

Acknowledging the demand for on-the-ground and farmer-led knowledge exchange activity, in 2013 RASE partnered with 15 regional Agricultural Societies to form a new charity called Innovation for Agriculture (IfA). IfA is fully focused on delivering knowledge exchange (a two-way and bottom-up approach to sharing information), rather than simple knowledge transfer (a more linear, top-down way of passing knowledge from 'scientific experts' to end users).

IfA knowledge exchange programmes include multi-stakeholder farm health teams where farmers, workers and advisors collaborate to solve farm-specific challenges, plus farm walks and peer-to-peer learning, facilitated workshops, on-farm demonstration events and study tours, to showcase innovation and practical applications of science and technology on-farm.

RASE has significant expertise in food supply chain decarbonisation, also producing multiple reports under the "Farm of the Future" banner that are available from http://www.rase.org.uk/reports. RASE and IfA work closely to identify and share agricultural solutions, technologies and practices which will help farm businesses adjust to the systems change required by net zero targets.

The suit of *Farm of the Future* reports included a paper on *Decarbonising Farm Vehicles and Future Fuels* produced with support from Cenex, based on their global expertise on clean fuels and powertrains. RASE and other partners seek to address the lack of focus in Government policy on the practical requirements for fuel and energy use in the agricultural sector.



# 1 Introduction – Why is There a Need to Look at Hydrogen in Farming?

## 1.1 UK Agriculture: Emissions, Economic and Regulatory Challenges

The 2022 RASE *Farm of the Future* report[1] noted the significant challenges faced by agriculture in maintaining food production whilst playing its part in the UK national 2050 net zero transition. In brief, these include:

- **Emissions**: 2022 UK Government statistics[2] reported that agriculture accounts for 12% of UK greenhouse gas emissions, including 70% of nitrous oxide (primarily from soil fertilisation and manure) and 49% of methane emissions (from ruminants and manure management). In contrast, agriculture only accounted for 2% of carbon dioxide emissions, which include emissions from agricultural machinery and heating and cooling. Nevertheless, these are an important consideration in a true net zero transition.
- **Economic**: Whilst agriculture contributes less than 1% to the UK economy, it provides around 60% of all food and is responsible for around 70% of land use. If the UK is to maintain a healthy agricultural industry to maintain or even improve domestic food security, the ability to produce food economically must be maintained and, where possible, enhanced as the sector moves to net zero.

  In 2022, the UK Government removed the red diesel rebate entitlement for most industries, including construction. At the time of writing (February 2025), agriculture is still permitted to use red diesel, but it is likely that this entitlement to 80% fuel duty rebate will be phased out over a number of years as part of the transition away from fossil fuels. In the absence of a transition to other energy sources this will increase farm energy costs and add to the economic pressures on farmers.
- **Regulatory:** The UK Government's plans for decarbonising road vehicles, which includes some of the smaller vehicles used by farmers, are clear. Under current proposals[3][4]:
  - All new cars and vans will need to be 100% zero emission by 2035, and no new petrol or diesel cars will be sold after 2030.
  - All new heavy goods vehicles (HGVs) under or equal to 26t will need to be 100% zero emission by 2035, and no new non- zero emission HGVs will be sold after 2040.

  The decarbonisation pathway for larger, more intensive and high-power operational requirements of agricultural non-road mobile machinery (NRMM) such as tractors however is less clear and remains under consideration by the Government. A 2023 report commissioned by the Department for Energy Security and Net Zero (DESNZ)[5] noted that industrial and agricultural non-road mobile machinery (NRMM) will likely need policy intervention if it is to decarbonise in line with UK climate ambitions.

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[1] RASE (2022): Farm of the Future: Journey to net Zero (online): https://www.rase.org.uk/content/large/documents/reports/farm_of_the_future-_journey_to_net_zero.pdf

[2] Defra (2024): Accredited official statistics. Chapter 11: Agri-environment: (online): https://www.gov.uk/government/statistics/agriculture-in-the-united-kingdom-2023/chapter-11-agri-environment

[3] DfT (2024) Phasing out the sale of new petrol and diesel cars from 2030 and Support for the Zero Emission Transition (online) https://assets.publishing.service.gov.uk/media/679382182de28ea2d392f37f/phasing-out-the-sale-of-new-petrol-and-diesel-cars-from-2030-and-support-for-the-zero-emission-transition.pdf

[4] DfT (2022) Outcome and response to the consultation on when to phase out the sale of new, non-zero emission HGVs, (online): https://www.gov.uk/government/consultations/heavy-goods-vehicles-ending-the-sale-of-new-non-zero-emission-models/outcome/outcome-and-response-to-the-consultation-on-when-to-phase-out-the-sale-of-new-non-zero-emission-hgvs

[5] ERM (2023) Industrial Non-Road Mobile Machinery Decarbonisation Options: Techno-Economic Feasibility Study (online): https://assets.publishing.service.gov.uk/media/658443f3ed3c3400133bfd4d/nrmm-decarbonisation-options-feasibility-report.pdf

## 1.2 Alternative Fuels and UK Farming

A major challenge for efforts to decarbonise the UK agriculture sector is that farmers are used to paying below market price for their vehicle fuel. With the long-term red diesel subsidy still in place, the lack of timescale for its removal is a factor in delaying the decarbonisation of agriculture, at a time when fossil fuel replacement is a net zero priority.

A number of alternative fuels and powertrains, including green hydrogen, were highlighted in the *Farm of the Future* Report. As a major user of heavy machinery and a key part of the non-road mechanised machinery (NRMM) sector farming is not yet ready for the transition away from fossil fuels for on-farm energy demand as agriculture is excluded from measures available to support the fuel transition in other sectors.

A further issue undermining deployment of novel fuel technologies in agriculture is that farms are generally commodity suppliers and 'price takers' rather than price setters. Farms and the land-based industries work on very low margins. Hence, they can be resistant to deploying novel technology that will have an inflationary impact on production costs.

## 1.3 Options for Replacing Fossil Fuels in Agriculture and the Food Supply Chain

As noted previously, the likely phase out of rebated (red) diesel means that the agricultural community needs to start looking now at medium-long term solutions to shift from fossil fuel usage.

*Farm of the Future*'s sister publication *Decarbonising Farm Vehicles and Future Fuels* stated that *"there are several key candidates for farming's 'fuel of the future', with electricity, biofuels (in liquid or gas form) and hydrogen being the most obvious ones. In some people's eyes, one fuel will predominate; others see the future relying on a combination of fuel technologies".*

## 1.4 Hydrogen as an Agricultural Fuel

As noted above, hydrogen is one alternative that offers potential as a low or zero emission farm energy source. The agricultural use cases considered in this study are:

- Agricultural machinery
- Heating
- Hydrogen production & storage.

The use cases are discussed in detail in Section 4, but it is worth noting here the barriers that must be overcome for hydrogen to achieve widespread usage in agriculture, which include:

- *Cost, availability and maturity*: at present hydrogen technologies are relatively immature and produced at low volumes which means they are considerably more expensive than diesel equivalents.
- *Cost and availability of clean hydrogen*: emission savings from hydrogen depend on whether $CO_2$ is emitted, and the source of the energy used, during its production. As shown in Figure 1. For true zero emission operation, green hydrogen must be used.

The next section looks at current initiatives that are set to rapidly grow the UK supply of low and zero carbon hydrogen, some of which could be supplied to agriculture.

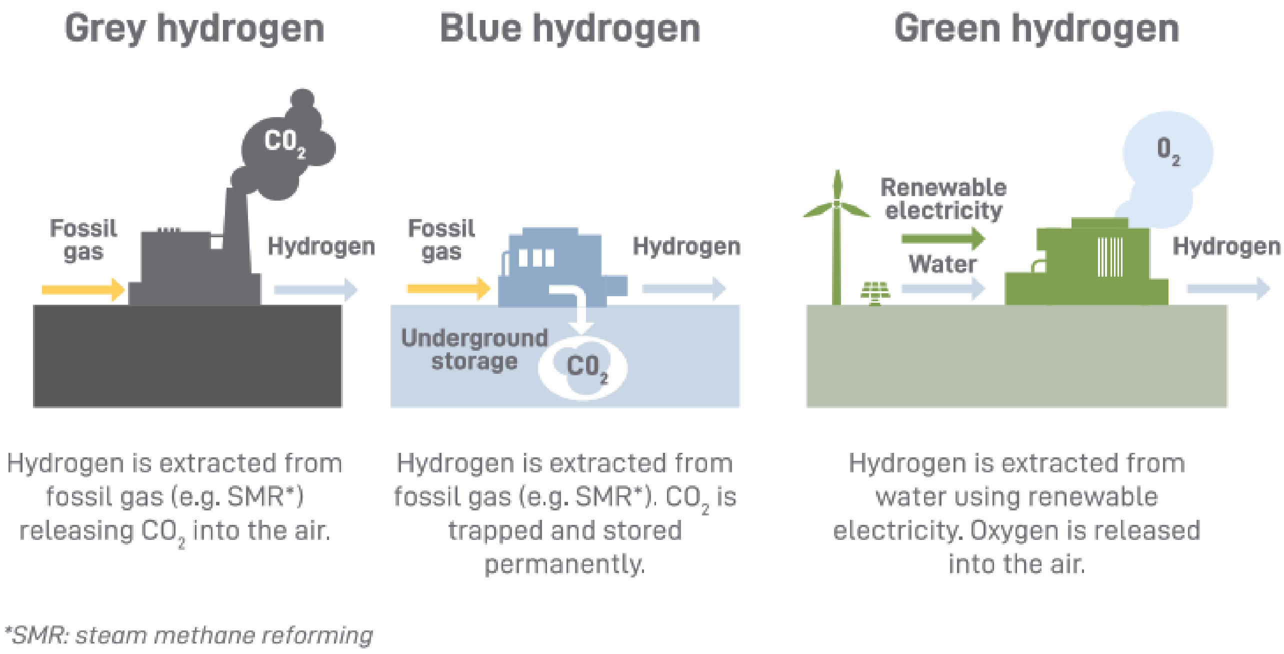


*Figure 1: Hydrogen Production Pathways[6]*

## 1.5 Increasing Hydrogen Availability: UK Hydrogen Strategy and East Coast Hydrogen

The UK Government has placed hydrogen at the heart of its industrial decarbonisation strategy and has ambitious targets to boost the availability of blue and green hydrogen .[7] The UK's 2030 target is 10 GW of low-carbon hydrogen supply, including 6GW of green hydrogen.


*Figure 2: East Coast Hydrogen 2037 Vision*

The East Coast Hydrogen (ECH) partnership[8] involves Cadent, National Gas and Northern Gas Networks, planning to link hydrogen production with industrial users.

The partners will use repurposed gas pipelines as well as new pipelines to supply 100% hydrogen in the north east. Starting with distributed hydrogen demand in Yorkshire, Tyneside and East Midlands its aim is to connect with other networks to develop a national hydrogen supply network. The 2037 ambition for the project is shown in Figure 2.

ECH aims to connect 11 GW of production and up to 4 TWh of storage by 2030, creating a valuable hydrogen supply chain for the region's businesses. The project will connect producers and storage providers to a range of customers, with the ambition of cutting up to 12 $MtCO_2$ emissions per year by 2037. A final decision from Ofgem on proceeding with the project is expected imminently.

[6] RASE (2022): Decarbonising Farm Vehicles and Future Fuels: (online): https://vm-01-crm02.altido.com/clients/rase-c3c5ffc2133a3eed/uploads/documents/website-report/Decarbonising%20Farm%20Vehicles%20and%20Future%20Fuels.pdf

[7] HM Government (2021): UK Hydrogen Strategy (online): https://assets.publishing.service.gov.uk/media/64c7ea74d8b1a70011b05e3a/6-7515_BEIS_UK-Hydrogen-Strategy_017-Print-content.pdf

[8] East Coast Hydrogen (2023) East Coast Hydrogen Delivery Plan: (online): https://www.eastcoasthydrogen.co.uk/wp-content/uploads/2023/11/East-Coast-Hydrogen-Delivery-Plan-Report.pdf

# 2 Hydrogen Farm of the Future: Introduction, Approach and Scope

## 2.1 Introduction

In November 2023, Cenex, partnered with the Royal Agricultural Society of England (RASE), responded to a market enquiry by the Energy Innovation Centre (EIC) and Northern Gas Networks (NGN) on understanding the possible demand for hydrogen in an agricultural setting. Cenex and RASE previously worked on farm-based energy demand and technology development trends in an agrarian context as part of *Farm of the Future* which was published in March 2022.[9]

This resulting *Hydrogen Farm of the Future* report aims to understand the potential use cases for hydrogen in the farming sector, the scale of potential demand among farms, and the viability of farming as an early adopter of hydrogen.

## 2.2 Approach

The project was delivered in Stages with linked Tasks as summarised below. This report summarises the findings and outputs of all Stages and, as such, is the final output of Task 3.2. The relevance of individual report sections to each of the Tasks is highlighted at the start of each section.

**Stage 1: Market Assessment**

- **Task 1.1**: literature review
- **Task 1.2**: initial stakeholder engagement

**Stage 2: Business Case and Geographical Analysis**

- **Task 2.1**: develop farm energy archetypes
- **Task 2.2**: farmer engagement to refine archetypes
- **Task 2.3:** review potential hydrogen use cases in the farming sector
- **Task 2.4**: seek and analyse data sources of farm types across the NGN territory using GIS tools

**Stage 3: Benefits Analysis and Reporting**

- **Task 3.1**: final stakeholder engagement regarding benefits and barriers
- **Task 3.2**: final reporting

## 2.3 Scope

The scope of work as outlined in the project Direct Investment Agreement (DIA) with the EIC was to focus on:

- Technology Readiness Levels (TRLs)[10] 6 and above (i.e., technologies and use cases that have been demonstrated and are at, or approaching, market readiness).
- Three potential agricultural hydrogen use cases that meet the TRL criterion:
    - Hydrogen vehicles and farm machinery (fuel cell and internal combustion engine).
    - Heating and on-site energy.
    - On site hydrogen production & storage.
- Engagement with the farming community and early adopters of hydrogen technologies in Yorkshire as the leading agricultural county in NGN's region.

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[9] RASE (2022): Farm of the Future: Journey to net zero (online): https://www.rase.org.uk/content/large/documents/reports/farm_of_the_future-_journey_to_net_zero.pdf

[10] NASA (2023) Technology Readiness Levels (online) https://www.nasa.gov/directorates/somd/space-communications-navigation-program/technology-readiness-levels/

# 3 Understanding Farm Energy Consumption

**Tasks covered:** 1.1, 1.2, 2,1 & 2.2: Literature review; develop farm energy archetypes and refine by farmer and stakeholder engagement.

**Key points:** This section describes the research and engagement carried out to establish the high-level energy requirements (electricity, diesel, gas and other fuels) of UK arable, horticultural and animal husbandry farming activities. This data is used in a subsequent section to estimate and map future potential agricultural hydrogen demand.

## 3.1 Introduction – Sourcing Farm Location and Energy Data

Initial project research consulted several potential sources of farm crop and animal husbandry energy data, notably:

- *Farm Energy Use: Results from the Farm Business Survey: England 2011/12* (Defra, UK data)[11]
- *Handbook of Energy Utilization in Agriculture* (Pimental, US data)[12]

Since the objective was to produce a simple set of archetypes suitable for UK farms and amenable to further analysis, issues noted with sources above were:

1. *Defra Farm Energy Use data*:
    - Did not have data for protected horticulture, which is of high relevance to the project.
    - Animal data was given per hectare (\Ha), whereas most livestock farm energy is given per head.
2. *Pimental data* was:
    - From the USA, where agricultural practices, and particularly farm sizes, are often very different to those in the UK.
    - Too granular to allow for simple archetype definition.

Given the concerns with the sources discussed above in terms of farm energy archetype definition and noting that that the final outputs of Stage 2 of the study include GIS maps of potential hydrogen demand in the NGN region, it was decided that farm location data (which is not available in the data sources discussed above) would be used to define the archetypes. The approach adopted was therefore to:

1. Source data on farm location and type to define the archetypes.
2. Find UK farm energy data consumption estimates per Ha\head of livestock to populate the archetypes using UK sources.

## 3.2 Deriving Farm Archetypes from Farm Location Data

Defra's *Annual Statistics on the Structure of the Agricultural Industry*[13] dataset presents annual land and crop areas, livestock populations and agricultural workforce estimates broken down by farm

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[11] DEFRA (2013): Farm Energy Use: Results from the Farm Business Survey: England 2011/12: National Statistics Publication (online): https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/230090/fbs-energyuse-statsnotice-16aug13.pdf

[12] Pimental, D. (2017): Handbook of Energy Utilization in Agriculture: Routledge Taylor Francis Group

[13] DEFRA (2024): Detailed annual statistics on the structure of the agricultural industry at 1 June in England and the UK (online): https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june

type, size and region. Sample farm type data for Yorkshire (the main focus region for the study) broken down by Local Authority area is shown below.

| Local Authority[2] | Number of holdings | Total farmed area (hectares) | Cereals (hectares) | Arable crops excl. cereals (hectares) | Fruit and vegetables (hectares) | Grassland[3] (hectares) | Cattle & Calves [4] | Sheep & lambs | Pigs | Poultry |
|---|---|---|---|---|---|---|---|---|---|---|
| Kingston upon Hull, City of | 5 | 474 | # | # | 0 | # | # | # | # | # |
| East Riding of Yorkshire | 1,847 | 201,115 | 113,899 | 33,396 | 9,871 | 29,805 | 47,485 | 84,159 | 639,651 | 3,047,823 |
| North East Lincolnshire | 56 | 6,185 | 3,610 | 1,048 | 123 | # | # | # | # | # |
| North Lincolnshire | 478 | 59,487 | 28,930 | 14,308 | 2,410 | 7,478 | 6,020 | 14,129 | 73,372 | 5,529,526 |
| York | 245 | 17,664 | 8,744 | 2,364 | 72 | 5,302 | 8,022 | 11,846 | 10,543 | 77,191 |
| Craven | 891 | 100,126 | 528 | 69 | # | 96,814 | 52,201 | 466,493 | 2,568 | 135,989 |
| Hambleton | 1,471 | 113,858 | 48,516 | 11,731 | 314 | 45,027 | 79,014 | 202,069 | 287,525 | 3,513,607 |
| Harrogate | 1,234 | 105,277 | 23,585 | 6,955 | 343 | 64,083 | 76,140 | 288,944 | 152,964 | 938,752 |
| Richmondshire | 833 | 103,598 | 14,973 | 4,150 | 87 | 80,006 | 43,702 | 355,273 | 54,359 | 1,088,061 |
| Ryedale | 1,148 | 110,974 | 44,329 | 11,323 | 927 | 46,267 | 48,592 | 200,140 | 224,938 | 976,139 |
| Scarborough | 669 | 52,794 | 11,724 | 4,150 | 386 | 32,952 | 37,066 | 128,741 | 32,657 | 115,866 |
| Selby | 455 | 47,448 | 25,407 | 9,599 | 958 | 7,756 | 11,364 | 26,041 | 41,834 | 274,868 |
| Barnsley | 269 | 19,277 | 5,149 | 1,373 | # | 11,857 | 15,554 | 42,529 | 8,879 | 77,204 |
| Doncaster | 342 | 34,853 | 15,398 | 8,906 | 226 | 7,121 | 7,537 | 11,784 | 25,265 | 51,580 |
| Rotherham | 138 | 13,821 | 7,235 | 2,553 | # | 2,816 | 2,511 | 1,183 | 4,863 | 50,796 |
| Sheffield | 184 | 15,351 | 935 | 149 | 22 | 13,762 | 7,842 | 28,685 | # | 7,824 |
| Bradford | 443 | 18,896 | 196 | # | # | 17,943 | 15,200 | 58,585 | 9,893 | 49,787 |
| Calderdale | 433 | 15,958 | # | 33 | # | 15,164 | 10,542 | 56,208 | 2,058 | 13,358 |
| Kirklees | 440 | 20,061 | 2,244 | 360 | 7 | 16,684 | 19,628 | 38,662 | 2,488 | 73,878 |
| Leeds | 342 | 24,016 | 7,949 | 2,680 | 133 | 11,210 | 11,409 | 25,809 | 10,640 | 253,331 |
| Wakefield | 203 | 17,447 | 9,415 | 3,294 | 151 | 3,626 | 6,612 | 3,006 | 23,069 | 1,528,296 |
| **Yorkshire and The Humber** | **12,126** | **1,098,678** | **373,190** | **118,866** | **16,094** | **516,667** | **506,814** | **2,045,048** | **1,613,521** | **17,880,385** |

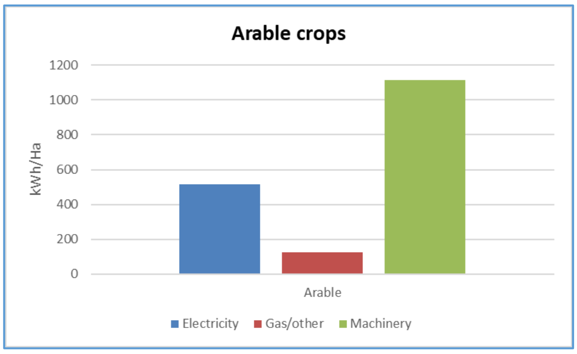
*Figure 3: Defra Local Authority Agricultural Dataset*

The Defra data represents the best, and most granular, farm location and production data available to the project. The farm types in the data were therefore used to define the study farm archetypes listed below.

- Arable
- Protected horticulture
- Livestock\animal husbandry
    - Dairy
    - Beef & sheep
    - Poultry
    - Pigs

## 3.3 Farm Energy Use Data

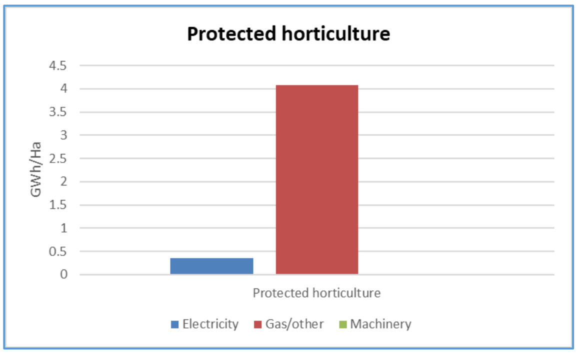
Research into other UK data sources and reports that quantified farm energy use in line with the archetypes above[14] revealed a 2007 report from Warwick HRI for Defra[15] with sufficiently granular data for the purposes of this work. The following graphs and commentary summarise the electricity, gas/other and machinery energy use for the farm archetypes sourced from the Warwick HRI data:



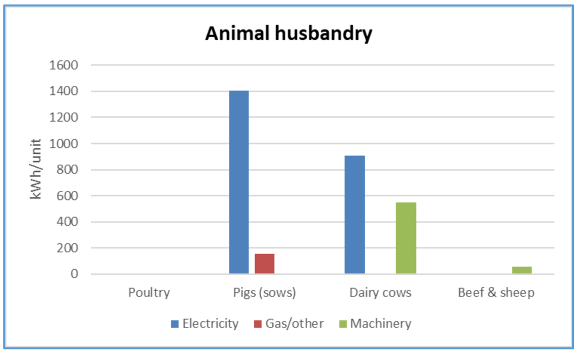

- The graph presents an area-weighted average of the energy inputs for **arable** (wheat, barley, oats, others cereal, potatoes, other arable) from the Warwick HRI data.
- In general, *electricity* (for crop drying) and *machinery fuel use* dominate **arable** energy demands.

14 CXC (2023): Decarbonisation of mobile agricultural machinery in Scotland (online) https://www.climatexchange.org.uk/media/5645/cxc-decarbonisation-of-mobile-agricultural-machinery-in-scotland-jan-2023.pdf

15 Warwick HRI (2007): Direct energy use in agriculture: opportunities for reducing fossil fuel inputs (online) https://ukerc.rl.ac.uk/pdf/AC0401_Final.pdf




- For **protected horticulture**, *gas/fuel oil* for heating dominates.
- The scale of energy use/Ha is significantly higher than for field crops (scale is GWh, not kWh) as the heating data relates to greenhouse area, not overall farm size.




- For **pigs**, *electricity* for heating & lighting dominates.
- For **cattle** (primarily beef) **& sheep**, *mobile energy* use dominates.
- For **dairy**, *electricity* for milking and cooling dominates, but there is also significant *mobile energy* use.
- **Poultry** energy use per head is much lower than for other housed livestock, with an approximately equal split between *electricity* and *gas/oil* fuel use (for heating & lighting).

Other inputs required for farm mapping and energy use modelling in Task 2.4, such as:

- Typical farm sizes.
- Grazing Livestock Units (GLU, to convert livestock data given in energy use/head to energy use/Ha to facilitate analysis and mapping).
- Machinery capital costs/Ha for different activities.

were sourced from the latest edition of the John Nix Pocketbook,[16] the acknowledged and widely used reference source of UK farm data.

## 3.4 Farmer Engagement

### *3.4.1 Methodology*

Considerable effort was put into reaching farmers and getting their opinions on alternative fuels and the transition to net zero. This included very successful future fuels seminars each attracting around a hundred attendees at the Great Yorkshire Show and at Askham Bryan College.

To gain specific quantitative data from stakeholders, an online stakeholder survey was conducted. The survey was promoted on:

- RASE's website, mailing list and partner channels.
- At a successful exhibition in the Innovation Zone at the Great Yorkshire Show, organised by YAS, in July 2024 on *Harvesting Tomorrow's Energy: Transformative Tips for Farm Fuel Efficiency* which attracted a large number of visitors .

The survey asked for inputs on:

- Farm size.

[16] Redman, G. (2023): John Nix Pocketbook for Farm Management for 2024. 54th edition. Agro Business Consultants

- Primary and, where applicable, secondary farming enterprises undertaken, aligned with the farm archetypes discussed in Section 3.3:
  - Crops and energy crops grown.
  - Types of livestock kept.
- Diesel, gas and electricity usage and seasonality of energy usage.
- On site energy generation.
- Free-text comment.

### 3.4.2 Survey Outputs

***Responses***

- 414 responses were received, of which:
  - 160 provided *some* quantitative data on energy use.
  - 116 provided sufficiently granular data for further analysis.

***Survey farm energy data compared to other sources***

The graph below compares the data obtained from the survey responses to other sources for arable farming:

- *All survey* refers to the 116 quantitative responses notes above
- *Filtered survey* refers to 56 remaining responses after entries were removed by visual inspection, for reasons including:
  - Duplicate entries.
  - Eight responses that showed clear signs that they had been autogenerated by an AI chat engine.
  - Entries that either did not contain credible data or were significant outliers.

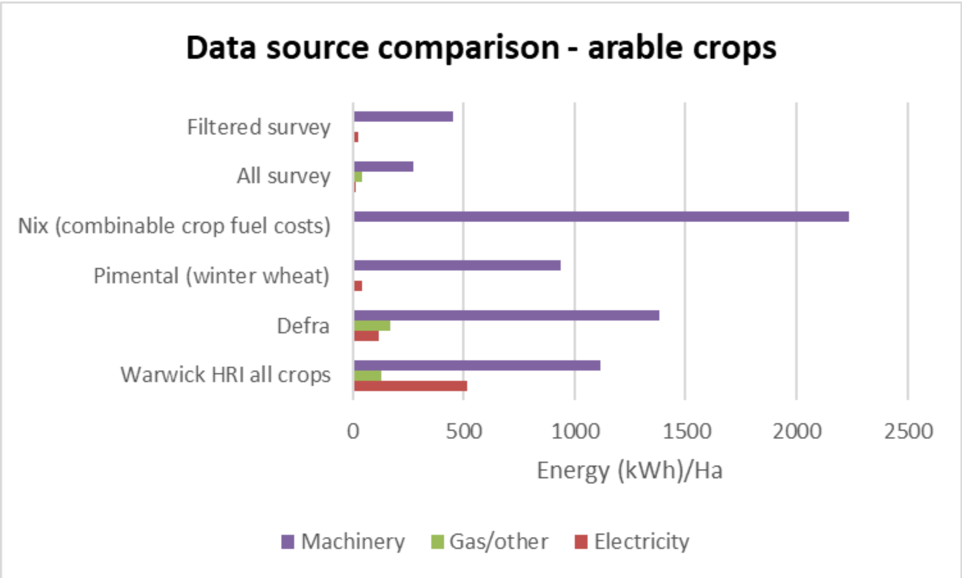



*Figure 4: Comparison of Arable Energy Use/Ha from Data Sources Consulted in the Study.*

The graph shows that:

- *Qualitatively*, the survey reinforced the farm energy archetypes discussed in Section 3.3. I.e. for arable crops, most of the reported energy use was for farm machinery.

- *Quantitatively* however, the survey data did not match the other sources and had considerable variation even within farms nominally of similar sizes. Further inspection reveals *confounding factors* in the data such as:
    - Secondary farming enterprises: excluding farms with secondary enterprises from the filtered survey data reduced the number of responses from 56 to 9.
    - Use of energy crops & AD, which will have a significant impact on the energy values provided by the farmers.
    - Other uses of fuel (e.g., for standby power).

*These factors mean that it is very difficult for farmers (and therefore survey analysis) to assign energy use to a specific crop or activity. This is an issue that needs to be addressed with some urgency.*

Comparing the non-survey data sources in Figure 4 shows that the Warwick HRI, Defra & Pimental data to be in reasonable agreement on machinery fuel use. *Therefore, given the alignment of the Warwick HRI data with the farm archetypes and geographic data discussed in* Section 3.3*, the study proceeded with the Warwick HRI data as the best UK data available for crops & animals to feed into the modelling and analysis presented in the next section.*

## 3.5 Conclusions

While the study did not use quantitative data from the farm survey (which in hindsight was perhaps too complex and ambitious to facilitate processing to obtain the desired quantitative outputs) it did reveal interesting qualitative points that will be developed in the study's conclusions.

Most notably, it was clear that relatively few farmers can accurately quantify all their energy use (electricity, gas and fuel), nor assign it to a specific farming activity as most have diverse activities. This has been noted in other work,[17] and in previous Cenex work with construction machinery users, and suggests that relatively simple self-reporting of annual fuel use by farmers (for example, as part of the annual Defra Farm Survey) would be a valuable means of baselining current energy use and tracking changes as alternative fuels are introduced.

[17] CXC (2023): Decarbonisation of mobile agricultural machinery in Scotland (online) https://www.climatexchange.org.uk/media/5645/cxc-decarbonisation-of-mobile-agricultural-machinery-in-scotland-jan-2023.pdf

# 4 Hydrogen Use Cases in Farming

**Tasks covered:** 2.3: Review hydrogen use cases in the farming sector, specifically hydrogen vehicles, heating and on-site hydrogen production & storage with TRLs 6 and above.

**Key points:** Describes the hydrogen use cases listed above and compares their current status and readiness for agricultural deployment with biogas\biomethane and electric fuelled alternatives. It is likely that a combination of alternative fuels will be needed for the farming net zero transition.

## 4.1 Introduction – Uses of Hydrogen and the Liebreich Hydrogen Ladder

Two questions must be addressed when considering the adoption of hydrogen in the farming use cases presented above:

1. Whether farming is the most appropriate use of hydrogen, which – at least in the early stages of a developing future zero carbon energy system – may be in relatively short supply and needed more in other hard-to-decarbonise sectors?
2. If hydrogen isn't the most suitable alternative fuel for these agricultural use cases, what other options are?

Reproduced below, Michael Liebreich's Hydrogen Ladder[18] offers the best-known attempt to answer both questions:

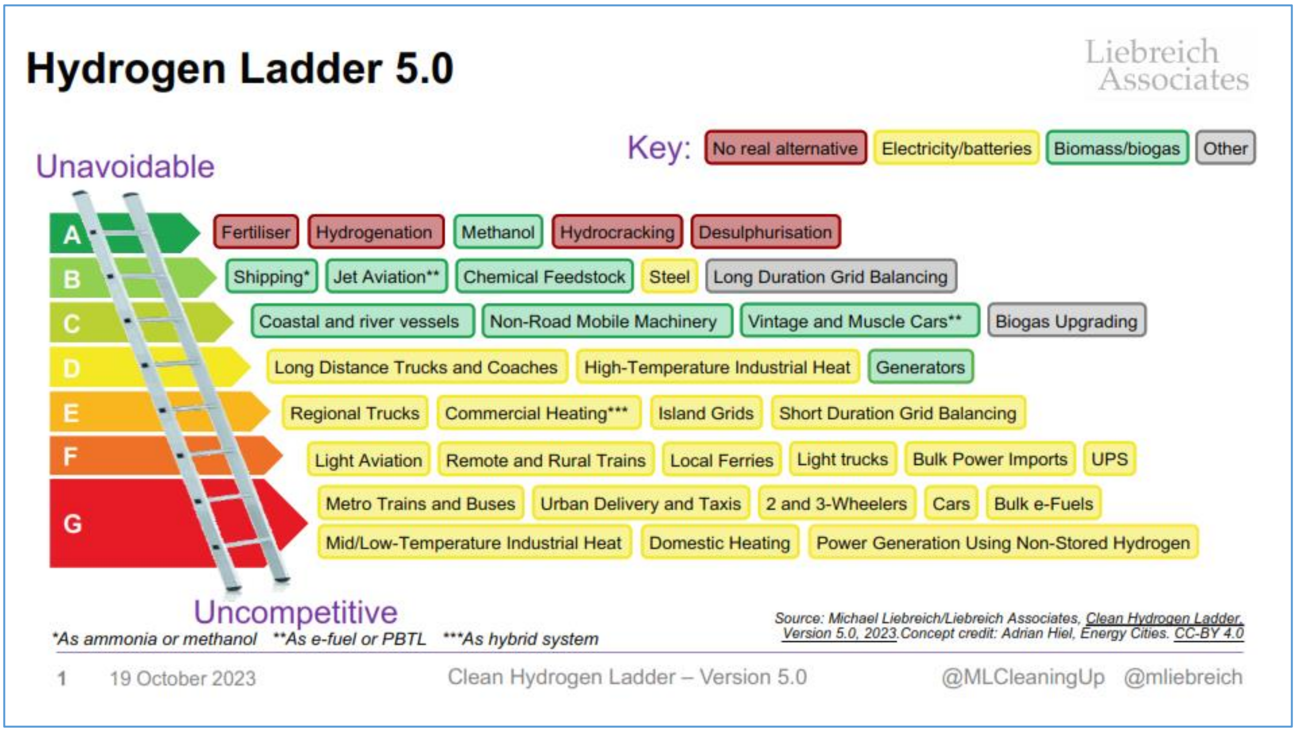



*Figure 5: Liebreich Hydrogen Ladder*

According to Leibreich, "the Hydrogen Ladder is designed … to show how likely it is that any proposed use case ends up being a significant user of hydrogen (perhaps via one of its derivatives) in a decade or so, say 2035". The unavoidable use cases offered by Leibreich – essentially decarbonisation of current large-scale industrial hydrogen use – align with priorities of the UK

[18] Michael Liebreich/Liebreich Associates (2023), Clean Hydrogen Ladder, Version 5.0, 2023 (online) https://www.liebreich.com/hydrogen-ladder-version-5-0/; https://www.linkedin.com/pulse/hydrogen-ladder-version-50-michael-liebreich/

Government's Hydrogen Strategy.[19] It is indicative of the relative lack of domestic production that fertiliser production, which is vital to agriculture, is not mentioned in the UK strategy.

Three Ladder use cases are of relevance to the agricultural use cases considered here:

- Category C (defined by Liebreich as *some hydrogen market share likely*): *Non-road mobile machinery (NRMM, incorporating agricultural machinery*) and *biogas upgrading.*
- Category E (defined by Liebreich as *niche hydrogen market share possible*): *Commercial heating.*

In terms of potential alternatives, Liebreich cites:

- Biomass/biogas as the primary alternative to hydrogen for NRMM and *agricultural machinery*.
- Electrification as the main alternative for *commercial heating*. This is assumed to be as part of an electric/hydrogen hybrid system that primarily relies on electricity and only uses hydrogen when the electricity grid is overloaded and no other alternative exists.
- Reaction of $CO_2$ with locally produced hydrogen to form power and biomass to liquid (PBtL) fuels such as methane or methanol as part of *biogas upgrading*. According to a review commissioned by the UK Government,[20] advanced gasification technologies such as PBtL are generally of TRL 6-8 but, given that they are in general best carried out as larger-scale processes that are likely to be carried out off farm, they will not be considered further here.

The next sections provide further discussion of technology and product developments in the three use cases considered by the study. They also give case study examples provided by RASE where these technologies are already being developed or trialled in an agricultural context.

## 4.2 Agricultural Machinery

### 4.2.1 Technology Options

This section considers the available technology options for agricultural NRMM based on UK-authored technology roadmaps.

The Cenex/RASE co-authored report *Decarbonising Farm Vehicles and Future Fuels*[21] report considered in detail the transition of farming vehicles to alternative powertrains and fuels as a replacement pathway for red diesel in internal combustion engines (ICE).

- Candidate replacement fuels available are electricity, renewable biofuels (as liquid or gas) including on-farm biomethane generation\supply and, potentially, hydrogen.
- Candidate alternative powertrain technologies are battery electric (BEV)/plug-in vehicles (PiVs), hydrogen fuel cell vehicles (FCEV) and hydrogen internal combustion engines (H2ICE).

Given the continued momentum of battery electric vehicles in the car and small van sector, it is likely that smaller farm vehicles such as quad bikes, pickups and even robotic on-farm devices will follow this technology path. Therefore, they will not be discussed further here.

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[19] HM Government (2021): UK Hydrogen Strategy (online): https://assets.publishing.service.gov.uk/media/64c7ea74d8b1a70011b05e3a/6-7515_BEIS_UK-Hydrogen-Strategy_017-Print-content.pdf

[20] BEIS (2021): Advanced Gasification Technologies – Review and Benchmarking: (online): https://assets.publishing.service.gov.uk/media/615ec02be90e07197867ea85/agt-benchmarking-task-2-report.pdf

[21] RASE (2022): Decarbonising Farm Vehicles and Future Fuels: (online): https://vm-01-crm02.altido.com/clients/rase-c3c5ffc2133a3eed/uploads/documents/website-report/Decarbonising%20Farm%20Vehicles%20and%20Future%20Fuels.pdf

Larger farm vehicles such as tractors as well as self-propelled sprayers and harvesters are likely to follow the decarbonisation pathway set for NRMM. The UK's Advanced Propulsion Centre's (APC's) *Commercial Vehicle and Off-Highway Roadmap* is reproduced below[22].

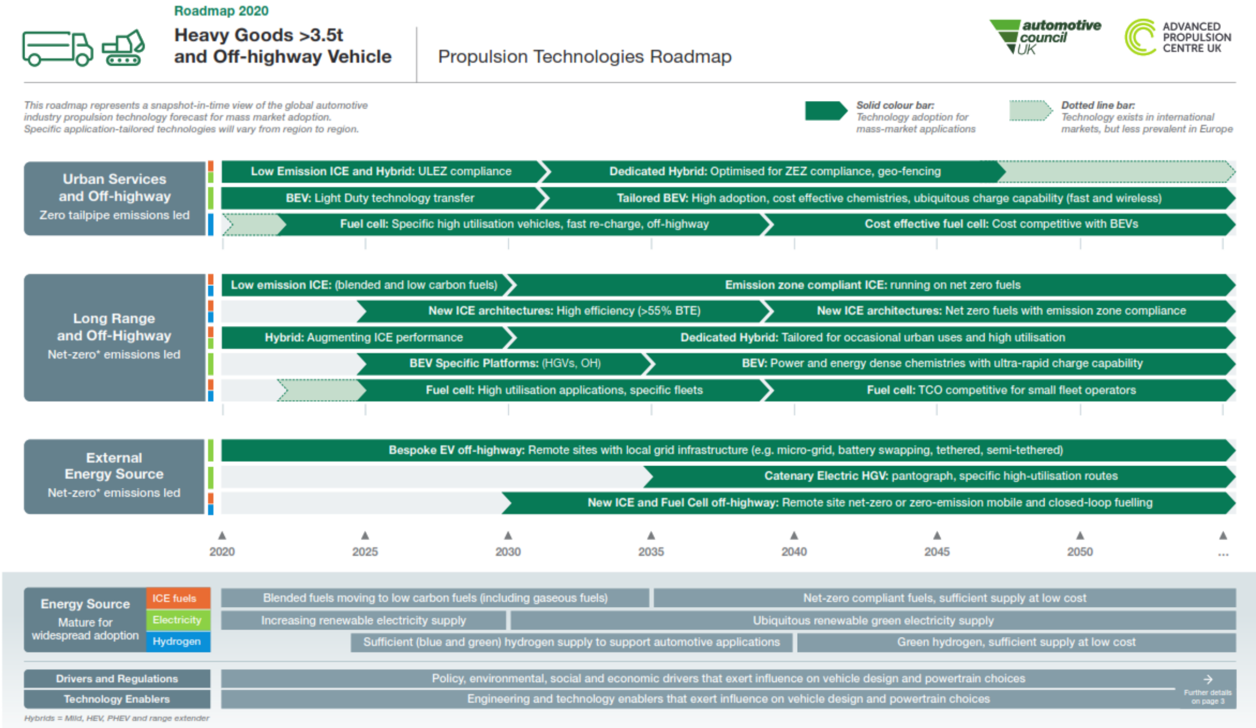


*Figure 6: APC Commercial Vehicle and Off-Highway Roadmap*

Key points to note from the roadmap include:

***Plug-in (battery electric) vehicles***

- There will be limited deployment of PiVs before 2030 due to a lack of product availability and unattractive total cost of ownership (TCO) compared to diesel.
- If battery costs continue to fall as per recent trends, this technology may begin to see wider deployment for less-powerful tractors with lighter-duty cycles, depending on timing of a red diesel ban. Near farm operations, potentially in conjunction with battery swapping, may allow extended operation.
- Heavier (100 hp+) tractors and self-propelled machines are likely to remain challenging for BEVs in the absence of significant battery energy storage breakthroughs, or the widespread adoption of battery swapping.
- As the grid continues to decarbonise PiVs will give zero emission operation.

***Fuel cell vehicles***

- There is likely to be limited deployment of FCEVs before 2030 due to a lack of product availability and unattractive total cost of ownership (TCO) performance compared to diesel.
- Heavier (> 100hp) vehicles and machines are the most likely areas for deployment.

[22] APC (2021): Heavy goods >3.5t and Off-highway Vehicle Roadmap 2020: Narrative Report: Advanced Propulsion centre UK (online): https://www.apcuk.co.uk/wp-content/uploads/2021/09/https___www.apcuk_.co_.uk_app_uploads_2021_02_Exec-summary-Product-Roadmap-HGV-and-Off-highway-final.pdf

- FCEVs are likely to cost more than diesel vehicles for some time to come, and without subsidies will be more expensive to fuel than PiVs. As such it could be the late 2030s before reasonable economic performance, combined with policy drivers, leads to significant uptake.
- Localised deployments in conjunction with on-site hydrogen production may be possible, operating as a closed loop system. However, the economics of production of, and guaranteed availability and purity of hydrogen required for FCEV operation (generally 99.999% purity), mean that there are considerable technological and economic challenges to overcome before this becomes a mainstream commercial option.
- True zero emission operation will only be possible with green hydrogen produced from renewable sources unless combined with carbon capture and storage or offsetting to mitigate fugitive emissions.

**A case study of Toyota's hydrogen fuel cell Hilux which was developed in the UK appears in the Appendix**

***ICE vehicles – hydrogen (H2ICE) or methane***

- There is likely to be limited deployment of hydrogen ICEs before 2030 due to a lack of product availability and unattractive cost performance compared to diesel.
- Heavier (> 100hp) vehicles and machines are the most likely areas for deployment.
- Early ICEs may be dual-fuel vehicles which can burn a blend of hydrogen (or methane – see below) and diesel. This can offer limited carbon savings in proportion to the source of, and quantity of, hydrogen used but could help to provide a pathway for the future deployment of H2ICE powertrains including the development of in-field refuelling systems.
- Given JCB's leading role in UK powertrain development, their interest in hydrogen ICE vehicles may mean that this technology gains early traction in the UK. This point is discussed further in the next section.
- Methane/biomethane (either standalone, or as dual diesel/methane) combustion is another alternative for future ICEs.
- True zero-emission ICE operation will only be possible with green hydrogen unless combined with carbon capture and storage or offsetting to mitigate fugitive emissions.

**Case studies of UK biomethane provider AD Fuels and UK biomethane tractor developer New Holland appear in the Appendix**

### 4.2.2 A Focus on Hydrogen ICE

A recent report from the Hydrogen Delivery Council\Hydrogen Internal Combustion Engine Sub-Group on behalf of DEZNZ notes that conventionally fuelled ICEs are a significant UK development and manufacturing strength, and that H2ICEs offer similar potential for the future.[23]

Co-authored by leading UK-based NRMM (non-road mobile machinery) supplier JCB, the report highlights the potential applications of H2ICEs in construction and agriculture (it also notes that some agricultural NRMM such as tractors drives on the roads for short distances).

The report contends that H2ICEs:

[23] Hydrogen Delivery Council\Hydrogen Internal Combustion Engine Sub-Group (2024), The role of hydrogen internal combustion engines in non-road mobile machinery (online) https://www.apcuk.co.uk/wp-content/uploads/2024/11/H2ICE-Task-and-Finish-Group-Report-Content_Oct-2024_final.pdf

- Offer the lowest cost approach to decarbonising NRMM as H2ICEs will have a similar capital cost and durability to conventional ICEs.
- Give a swifter path to NRMM decarbonisation than alternatives such as FCEVs or other battery powertrains that have significant cost and weight impacts.
- Provide similar, or better, efficiency as conventional ICEs.
- Yield significant UK employment and GVA benefits compared to other alternative NRMM alternative technologies , as well as retaining existing skill sets and supply chains.
- Eliminate $CO_2$ emissions and greatly reduce NOx and PM (particulate matter) emissions. The report includes data from tests of a JCB H2ICE backhoe loader over regulated cycles that shows the emissions to be significantly below diesel Stage V NRMM limits.

The final bullet point highlights one of the main barriers to the wider uptake of H2ICE vehicles and other gas-fuelled ICE vehicles, which is that they are not currently considered true zero emission technology due to their potential NOx and PM emissions (and concerns over fugitive emissions from the production, storage and combustion). As such, these technologies have generally not been eligible for innovation and deployment support funding from the UK Government in recent times. Noting this, and the current total cost of ownership gap between immature hydrogen farm technologies and the (red) diesel incumbent, the report recommends that:

- H2ICE should be classified and promoted as a net zero emission technology for NRMM, which would unlock future innovation and deployment funding.
- Specific tax breaks and incentives should be developed to promote H2ICE NRMM, including demonstration funding, and hydrogen pricing mechanisms to offset the price differential with (red) diesel.

**A case study of JCB's hydrogen ICE technology and its potential use in farm and other rural applications appears in the Appendix**

## 4.3 Space Heating and Grain Drying

### *4.3.1 Farm Use Cases and Energy Requirements*

The Farm Advisory Service[24] identified glasshouse horticulture, grain drying and high intensity farming (such as the heating requirements for pig and poultry housing) as three of the five most energy intensive practices in their guide to *Energy Improvements for High-Use Farms* (the two remaining high energy use cases identified were dairy farming and cold storage). The difference in the scale of energy usage/Ha between protected horticulture and all other farming applications (GW versus kW) was noted in Section 3.

### *4.3.2 Space Heating*

In terms of glasshouse horticulture, stakeholder consultation during this project has indicated that, in Yorkshire, horticulture producers use natural gas from the grid for their heating requirements.

Glasshouse heating requirements vary between 18°C (night) and 24°C (day).[25] The heat is provided by two main methods:[26]

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[24] FAS (2024a): Energy Improvements for High-Use Farms: Farm Advisory Service (online): https://www.fas.scot/downloads/energy-improvements-for-high-use-farms/

[25] DryGair (no date): Greenhouse Humidity and Temperature What Are the Optimal Set Points? (online): https://drygair.com/blog/optimal-humidity-temperature-greenhouse//

[26] GVZ Glasshouses (no date): Greenhouse Heating Systems (online): https://www.gvzglasshouses.co.uk/greenhouse-heating-systems/

- Indirect heat from a gas-fuelled heat air jet engine-shaped cylinders that heat air as it passes over a naked flame contained within it. Called $CO_2$ burners, these also provide $CO_2$ to the greenhouse which facilitates crop growth (combustion of 1m$^3$ of gas provides approximately 1.8kg of $CO_2$).[27] If $CO_2$ burners were not used (as would be the case with hydrogen heating), $CO_2$ would have to be added separately – a well-known existing process.[28]
- Hot water pipes fed by a (gas) boiler, which would generally be employed with $CO_2$ enrichment as described above.

As noted in Section 4.1, Leibreich puts commercial heating (which is taken here to include the glasshouse space heating requirements) as a potential future niche application of hydrogen as part of an electric hybrid system. Clearly, use of electricity in this application relies on the availability of a sufficiently sized and reliable electricity grid connection at point of use.

The UK Government continues to collect evidence on hydrogen heating, particularly the imminent H100 Fife neighbourhood trial,[29] before committing to a policy in 2026 on whether, and how, hydrogen will contribute to heating decarbonisation – particularly that of domestic heating.[30]

### *4.3.3 Grain Drying*

The heating demands for grain drying are higher than those for livestock barn heating as the required temperature is much higher; for example, optimum drying temperatures for wheat range from 60-100°C. The FAS report states that ADAS estimates that high-temperature grain dryers require 55 litres of oil per hectare of crop dried.

There are three main on-farm grain drying technologies used in the UK [31]

- Continuous flow dryers use fans that pull high temperature (up to 100°C) air though a moving column of grain to discharge dried grain at bottom. The air is heated using gas or oil and the process is energy intensive, although many farms now supplement this with a baseload of heat from biomass boilers.
- Batch dryers operate at lower temperatures (up to 40°). Often a baseload temperature is supplied by biomass hot water systems supplemented by an oil burner.
- Storage dryers generally have drying floors which blow air through the crop. The drying is slower, and correspondingly less energy intensive than other systems. Biomass heating is commonly used.

A 2022 Canadian study investigated the options for replacing fossil fuel use in grain drying and poultry barn heating.[32] The study concluded that whilst hydrogen has the potential to replace LPG and natural gas in both applications, much development work remains to be done on hydrogen burners before they become a mainstream commercial product in these applications: i.e., its current TRL is significantly below the 6-9 range targeted by this study.

For grain drying, the main barriers noted were economic, particularly as dryers are only in use for a few weeks each year. The cost of installing additional hydrogen storage and compression equipment

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[27] Dutch Greenhouses (no date): $CO_2$ enrichment in greenhouses (online): https://dutchgreenhouses.com/en/climate/co2-enrichment

[28] Air Liquide (no date): $CO_2$ enrichment in greenhouses (online): https://uk.airliquide.com/solutions/co2-enrichment-greenhouses

[29] SGN (no date) A world-first green hydrogen gas network in the heart of Fife (online): https://www.h100fife.co.uk/

[30] UK Government (2024): Hydrogen heating: overview (online): https://www.gov.uk/government/publications/hydrogen-heating-overview/hydrogen-heating-overview--2

[31] NFU Energy (2021): Technology Review Report for AHDB Cereals (online): https://projectblue.blob.core.windows.net/media/Default/Research%20Papers/Cereals%20and%20Oilseed/2021/GrowSave%20Grain%20Drying%20Technology%20Review%202021.pdf

[32] Zen Clean Energy Solutions (2022): Hydrogen Feasibility Study in High Emissions Components of Ontario Agriculture (online): https://ifao.com/wp-content/uploads/2022/11/IFA001_Feasibility-Study_FINAL.pdf

was cited as adding significant capital expenditure (CapEx) to any proposed installation or retrofit. Operating costs would be highly dependent on the source of hydrogen used and the availability of, and possible future carbon pricing of, fossil or other fuel alternatives.

The study stated that (as of 2022) “There is no technology available on the market today to retrofit grain dryers or poultry barns to run on hydrogen”.

Electricity (heat pump) or biomass fuelling offer possible alternatives to hydrogen for these applications. One example is the 6.2MW ground source heat pump installed at a farm in Scotland which claims to deliver 400% efficiency for heating at 45°C, 325% for chilling at 1°C and a total energy efficiency of 725% with an ability to dry 30kT of grain.[33] The potential use of heat pumps in drying (and heating) applications was noted in a recent comprehensive report on rural electrification.[34] The report also pointed out the significant potential impact on the electricity network of any concerted transition to electrification of these applications, particularly in rural settings.

## 4.4 On-site Hydrogen Production and Distribution

### 4.4.1 Farm Use Cases

Potential uses of hydrogen produced on-site at a farm (here using the example of renewable electrolysis) are summarised in Figure 7 below:

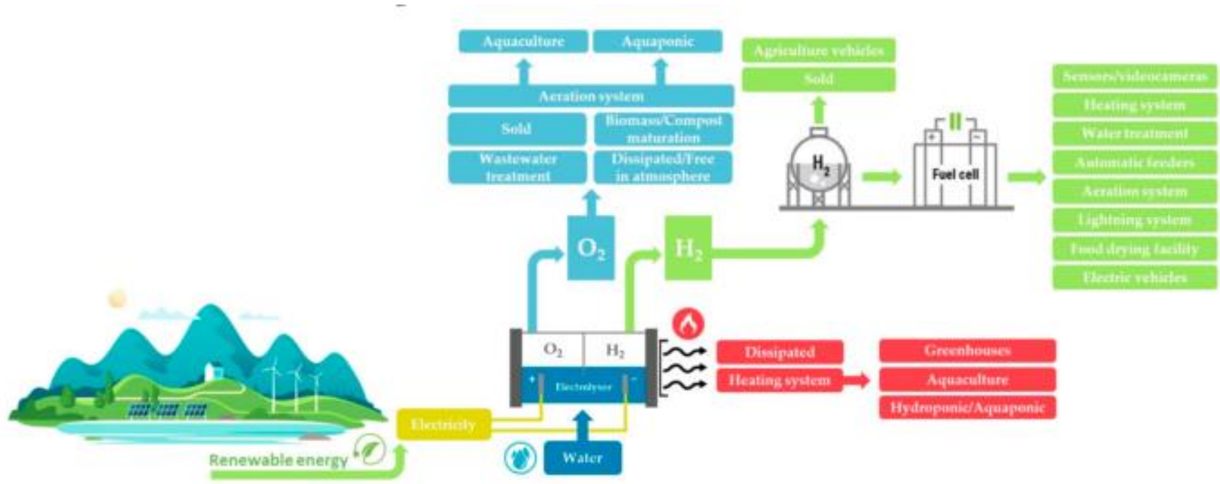


*Figure 7. Farm on-site production and use of green hydrogen and by-products[35]*

### 4.4.2 Technology and Deployment Options

***Hydrogen refuelling systems and storage***

Hydrogen is generally dispensed to vehicles through pressurised gas delivery, although some work is underway, notably by Daimler, to use liquid hydrogen for fuel heavy duty vehicles. Filling a FCEV with hydrogen is a broadly similar experience to filling an ICE vehicle with diesel or petrol.

- A typical passenger car FCEV operates with 5-6 kg of hydrogen on board stored in pressurised tanks at 700 bar, giving the vehicle a real-world range of between 400 and 500 km on a single fuel.

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[33] Calibrate Energy (2021): Substantial heat pump installation installed to dry 30,000 tonnes of grain (online): https://www.calibrateenergy.co.uk/the-wheat-from-the-chaff

[34] EA Technology (2024): Rural Electrification Project Report

[35] Maganza A, Gabetti A, Pastorino P, Zanoli A, Sicuro B, Barcelò D, Cesarani A, Dondo A, Prearo M, Esposito G. Toward Sustainability: An Overview of the Use of Green Hydrogen in the Agriculture and Livestock Sector. Animals (Basel). 2023 Aug 8;13(16):2561. doi: 10.3390/ani13162561. PMID: 37627352; PMCID: PMC10451694

- Larger vehicles have more space available to store the fuel, and therefore generally use cheaper 350 bar gas storage. A 25kg, 350 bar storage system is often used for buses and heavy-duty vehicles.

A typical hydrogen refuelling station (HRS) setup is shown below in Figure 8[36]. In the refuelling process, low-pressure $H_2$ (generated on-site or transported in) is compressed to a higher pressure (typically ~ 900 bar) and cooled (to -40° if the station complies with the SAE J2601 standard[37]) before being dispensed to the vehicle.

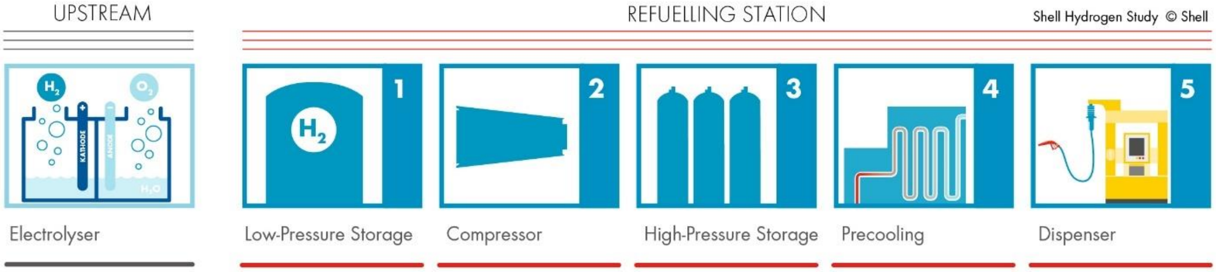


*Figure 8. Schematic of a typical hydrogen refuelling station*

There are currently two main technical issues encountered with HRS:

- **Cooling**: $H_2$ is an unusual gas because it has a 'reverse Joule -Thompson effect'; i.e., unlike common aerosol gases, it heats up when it expands. The increase in temperature makes the rapid refuelling of vehicles problematic. The refueller must include cooling facilities; specifically, $H_2$ must be precooled to -40° before dispensing if the station complies with the SAE J2601 standard[38]. If the cooling system is not sized and controlled appropriately, the number of vehicles that can be fuelled at a given pump will reduce. The cooling unit limits how many vehicles can be fuelled rapidly[39] (or, more accurately, the total amount of hydrogen dispensed, which may be more relevant for farm machinery).
- **Compression**: compressors have typically been the primary source of failure in HRS.[40] As high-pressure $H_2$ compressors are produced in larger numbers and novel compression techniques are refined, compressor failure rates are expected to improve. Additionally, compressor costs have traditionally been the highest capital and expenditure for new HRS[41].

HRS remain expensive (generally costing of the order of £millions per large-scale permanent installation), complex, bespoke systems produced in relatively low volumes (reportedly there were around 1,000 operational HRS worldwide at the end of 2024, of which 294 were in Europe)[42], with even state of art systems achieving availabilities of around 95%. Despite the vast knowledge of

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[36] McCarthy, N. (2021): Interreg North Sea Region: HyTrEc2: Deliverable 3.5: Hydrogen Transport Legislation and Standards in the NSR: Interim Report: Interreg North Sea Region (online): https://northsearegion.eu/media/19500/hydrogen-transport-legislation-and-standards-in-the-nsr-final.pdf

[37] SAE (2010a): Fuelling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles: SAE International (online): https://www.sae.org/standards/content/j2601_201003/

[38] SAE (2010b): Fuelling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles: SAE International (online): https://www.sae.org/standards/content/j2601_201003/

[39] Quin, N. and Brooker,P. (2014): Hydrogen Fueling Stations Infrastructure: Electric Vehicle Transportation centre (online): http://fsec.ucf.edu/en/publications/pdf/fsec-cr-1986-14.pdf

[40] Speers, P. (2018): Hydrogen Mobility Europe (H2ME): Vehicle and Hydrogen Refuelling Station Deployment Results, 2017: World Electric Vehicle Journal: MDPI (online):https://www.mdpi.com/2032-6653/9/1/2/htm

[41] Parks, G. et al (2014): Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs: National Laboratory of the US Department of Energy Efficiency & Renewable Energy (online): https://www.nrel.gov/docs/fy14osti/58564.pdf

[42] LBST (2025): Milestone reached: over 1,000 hydrogen refuelling stations in operation worldwide in 2024 (online): https://www.h2stations.org/wp-content/uploads/2025-02-12_Press-Release-2025_LBST-H2stations_HRS_EN.pdf

hydrogen best practice in an industrial setting, encouraging hydrogen as a fuel for public use has been problematic. For many HRS projects completed in the past, local civil authority planning regulations, compliance, and safety (RCS) have hindered the uptake of hydrogen as a mass-market transport fuel. Local and regional authorities are beginning to make efforts to improve the knowledge base for hydrogen technologies, but HRS planning and commissioning of permanent installation can take two or more years.[43]

### *Hydrogen production*

The two high TRL techniques for hydrogen production relevant to on-farm installation are electrolysis and the production of hydrogen by additional processing of biogas generated from anaerobic digestion.

### *Electrolysis*

Although water electrolysis is a well-established technology, cost-effective hydrogen production and dispensing through on-site electrolysis has yet to be achieved. A recent Dutch study indicated that, even for large-scale (100-200MW) electrolysers, the current minimum production cost of green hydrogen is between £10-£2/kg (€12-€14/kg).[44] This price point is not a sustainable business model, as research by Cenex typically indicates that cost-comparative hydrogen for use in fuel cell vehicles must achieve approximately £5 per kg to achieve similar price performance to road diesel. Competing with red diesel pricing will require a lower price point at the dispenser, which at present seems unrealistic for small-scale electrolyser systems.

The H2ME project was a flagship European project. It created the first truly pan-European network and the world's largest network of hydrogen refuelling stations. The emerging conclusions report from this project are some of the most comprehensive and rigorous documents on the practicalities of deploying hydrogen infrastructure that are publicly available. The H2ME findings were that at times of low electricity demand, it is possible to produce cost-effective hydrogen through small-scale on-site renewable energy, but this is "…*highly dependent on consistent baseload demand and energy market prices*." However, HRS need to increase in size and utilisation rate to be cost-effective. In the short-medium term, small-scale on-farm HRS may be prohibitively expensive.

### *Anaerobic digestion*

As discussed previously, AD is a well-known process for producing biogas, which can be upgraded to biomethane for possible use in vehicles, or injection into the gas grid. The biomethane gas can be converted to high purity hydrogen by conventional processes such as steam methane reforming[45]. However, retrofitting hydrogen-producing methane cracking to relatively small AD units (production under 400 $m^3$/hr) is unlikely to be economic.[46]

Research (low TRL) is ongoing on how the AD process can be adjusted to increase the concentration of hydrogen relative to biomethane in biogas. The results indicate that this can be achieved, but the economics remain challenging.[47]

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[43] Speers, P. (2024): Hydrogen Mobility Europe (H2ME): HRS Safety, Regulations, Codes and Standards .Lessons Learned(online): https://h2me.eu/wp-content/uploads/2023/07/H2ME2-D5.22-Public-FV-Safety-and-RCS-lessons-learnt-%E2%80%A6.pdf

[44] TNO (2024): Evaluation of the Levelised Cost of Hydrogen Based on Proposed Electrolyser Projects in the Netherlands (online): https://publications.tno.nl/publication/34642511/mzKCln/TNO-2024-R10766.pdf

[45] Air Products (no date): Biogas to Hydrogen Upgrading Shikaoi Hydrogen Farm (online): https://www.airproducts.com%2F-%2Fmedia%2Ffiles%2Fen%2Fbiogastohydrogen-vehiclefuelwhitepaper.pdf

[46] Swartbooi, A.; Kapanji-Kakoma, K.K.; Musyoka, N.M. From Biogas to Hydrogen: A Techno-Economic Study on the Production of Turquoise Hydrogen and Solid Carbons. *Sustainability* **2022**, *14*, 11050. https://doi.org/10.3390/su141711050

[47] Zappi, A, et al. A review of Hydrogen Production from Anaerobic Digestion. *International Journal of Environmental Science and Technology* (2021) 18:4075–4090 https://doi.org/10.1007/s13762-020-03117-w

***Hydrogen distribution***

Several commentators state[48,49,50] that it is possible to produce cost-effective hydrogen through a 'hub and spoke' model. In the hub-and-spoke model, larger hydrogen electrolysers generate the hydrogen (assumed to offer economies of scale), and then hydrogen is distributed to spokes for end-user consumption. The exact size of the hydrogen production unit and the demands generated by end users required for cost-effective hydrogen production have yet to be established (for further discussion of the required costs of hydrogen see Section 5).

Led by Ryze Hydrogen, the ongoing H2-to-Site project, funded as part of the UK Government's Red Diesel Replacement competition,[51] aims to develop "production-ready modular hydrogen refuelling technologies … which are flexible to the needs of diverse construction sites", including a bowser capable of delivering around 120 kg of hydrogen. Although this offers potential promise for future small-scale hydrogen delivery to construction sites, and potentially farms, significant technical, regulatory and economic challenges must be overcome before it can be fully commercialised. Discussions with Ryze during this project have indicated that they see agriculture as a promising secondary application for the bowser, but that their modelling indicates that a daily hydrogen demand of 30-40kg/delivery/site is needed for economic operation.

In terms of economics of delivery to farms, the seasonality of agricultural energy demand presents a major challenge for a sustainable business model compared to the bowser's initial target market in construction – a point discussed further in Section 5.

**More details of novel hydrogen delivery systems with potential for farm use from Fuel Cell Systems & HyKit appear in the Appendix, along with details of hydrogen-fuelled generation and lighting systems from TCP Eco**

### *4.4.3 Current Hydrogen Technology Deployment Status*

Large-scale (MW) electrolysers are being deployed in increasing numbers as part of ambitious decarbonisation plans. For example, the European Union has a target for 100MW of electrolyser hydrogen production by 2030.[52] In the UK, the Net Zero Hydrogen Fund is supporting the development of large-scale electrolysis systems to be deployed from the late 2020s onwards.[53]

Several small-scale (kW) electrolyser systems were installed as part of hydrogen refuelling stations during projects such as H2ME as discussed above. However, almost all these stations have closed

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[48] Krupnick et al (2022): Hydrogen Hubs: Is there a recipe for success?: Resources for the future.org (online): https://www.rff.org/publications/issue-briefs/hydrogen-hubs-is-there-a-recipe-for-success/

[49] North Sea wind and power hub consortium (2021): Towards the first hub-and-spoke project (online): https://northseawindpowerhub.eu/files/media/document/NSWPH_Concept%20Paper_05_2021_v2.pdf

[50] DESNZ (2024): On Red Diesel Replacement competition: Phase 2 projects (online): https://www.gov.uk/government/publications/red-diesel-replacement-competition-successful-projects/red-diesel-replacement-competition-phase-2-successful-projects

[51] Singlitico et al (2021): Onshore, offshore or in-turbine electrolysis? Techno-economic overview for green hydrogen production into offshore wind power hubs: Renewable and Sustainable Energy Transitions (Volume 1, 100005): Elsevier (online): https://www.sciencedirect.com/science/article/pii/S2667095X2100005

[52] Hydrogen Europe (2023): Clean Hydrogen Monitor (online): https://hydrogeneurope.eu/wp-content/uploads/2023/10/Clean_Hydrogen_Monitor_11-2023_DIGITAL.pdf

[53] HM Government (2024): Net Zero Hydrogen Fund strands 1 and 2: summaries of successful applicants round 2 (April 2023) competition (online): https://www.gov.uk/government/publications/net-zero-hydrogen-fund-strands-1-and-2-successful-applicants/net-zero-hydrogen-fund-strands-1-and-2-summaries-of-successful-applicants-round-2-april-2023-competition#:~:text=RWE%20is%20developing%20multiple%20electrolytic,to%20be%20deployed%20by%202027

as the business case for relatively small-scale on-site generation and HRS operation, even allowing for the partial offset of CapEx by grants from the Clean Hydrogen Partnership, did not stack up.[54]

Examples of small-scale hydrogen production activities of relevance to farm use include:

- Hexla and Levidian deployed a prototype of Levidian's LOOP technology at Worthy Farm for the 2024 Glastonbury Festival. LOOP turns AD-produced biogas into clean hydrogen and graphene using electromatic radiation. Hexla is providing funding to support the development of industrial scale LOOP1000 units that, it claims, will produce the cheapest clean hydrogen in the world over the lifetime of the plant.[55]
- The H2Boost Project[56] aims to produce biohydrogen for the UK transport sector by integrating an advanced oxidation and enzymatic pre-treatment technology of bio-based feedstocks, conversion to bio-hydrogen by dark fermentation (DF) and down-stream processing of by-products via anaerobic digestion, microbial $CO_2$ capture and storage.
- HydroGlen Project at Glensaugh is a proposed grid-autonomous, green hydrogen farming project that aims to demonstrate that farmers can satisfy all electricity, heating, and transport fuel needs on site.[57]

**H2Boost and HydroGlen case studies appear in the Appendix**

- Several other companies generate hydrogen from green waste using biological production methods. Vinov Singh et al. (2018)[58] state that biological production routes for hydrogen can be less energy intensive and offer the hope of producing hydrogen more cost-effectively than electrolysis-based processing. However, biological-based processing has its own set of barriers to uptake to overcome. Biohydrogen production methods frequently require significant input biomatter pre-treatment before biohydrogen production can begin. The required preprocessing steps can be minimised by selecting "…*carbohydrate rich, starch or cellulose containing solid wastes and/or some food industry wastewaters*…" and resulting in cost-effective hydrogen production pathways. However, whether farm-based biowaste will suit this proposed 'minimum-cost' approach is unclear.
- Companies such as Boson Energy propose other biowaste to hydrogen processes[59]. Boson has completed early prototypes and demonstrator devices using high temperature thermolytic processing. Larger-scale roll-out of this technology is planned across the EU and should be monitored to assess its suitability over the next few years.

[54] Weeks, D (2024): Shell permanently closes light duty hydrogen fuelling stations: S&P Global (online): https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/electric-power/021224-shell-permanently-closes-light-duty-hydrogen-fueling-stations

[55] Levidian (2024): Hexla and Levidian bring pioneering climate technology to Worthy Farm (online): https://www.levidian.com/recent-press2/hexla-and-levidian-bring-pioneering-climate-technology-to-worthy-farm

[56] BDC (2023): BDC awarded further funding to research biohydrogen production for the UK transport sector (online): https://www.biorenewables.org/news-events/h2-boost-phase2/

[57] The James Hutton Institute (2021): HydroGlen Renewable Hydrogen Powered Farm (online): https://www.hutton.ac.uk/sites/default/files/files/publications/Glensaugh_HydroGlen_NonTech_Feasibility_March2021.pdf

[58] Vinod Singh, Y. et al (2018): Bio hydrogen production from waste materials: A review: MATEC Web of Conferences 192, 02020: The 4th International Conference on Engineering, Applied Sciences and Technology (ICEAST 2018) "Exploring Innovative Solutions for Smart Society" (online): https://www.matec-conferences.org/articles/matecconf/abs/2018/51/matecconf_iceast2018_02020/matecconf_iceast2018_02020.html

[59] Collins, L (2022): We will produce carbon-negative green hydrogen from non-recyclable waste at zero or below-zero cost: ReCharge (online): https://www.rechargenews.com/energy-transition/-we-will-produce-carbon-negative-green-hydrogen-from-non-recyclable-waste-at-zero-or-below-zero-cost-/2-1-1162744

- SYPOX in Germany[60] is a start-up that offers a containerised unit that can:
    - Compress and purify biogas to biomethane.
    - Steam methane reform the biomethane to hydrogen.
    - Purify and dry the hydrogen for vehicle use.

SYPOX offers units that it states can purify up to 400kg of hydrogen per day. The system uses electricity to power the conversion process. No cost of energy use data on the system was available in the literature at the time of writing.

## 4.5 Conclusions

Research of technology and deployment roadmaps has shown that hydrogen has medium-long term potential for use in agricultural heating and machinery applications, but that significant technological and economic challenges must be overcome if hydrogen is to become the farming fuel of choice for these applications. In addition, as the Leibreich Ladder (and the UK's Hydrogen Strategy) shows, the priority for the UK's transition to net zero is the replacement of current grey hydrogen with blue\green hydrogen in industrial processes, which is likely to limit the availability of low\zero carbon hydrogen in the short-medium term. In the longer term, hydrogen must also be technologically and economically competitive with the alternative energy sources discussed in this section – specifically electricity and biogas\biomethane – if it is to move beyond niche applications in agriculture.

As discussed in a recent EA Technology report,[61] *green electricity* offers an attractive prospect for decarbonisation of agricultural applications. Nevertheless, it shares many of the issues that hydrogen faces if it is to gain traction in this sector, specifically,

- Price volatility,
- The electricity grid's ability to provide for the remote, dispersed nature of rural activity,
- Seasonality and the ability of the rural electricity grid to meet high loads,
- The maturity and robustness of options such as battery electric vehicles and heat pumps in agricultural applications.

*Biogas* produced from anaerobic digestion is already widely used on farms to produce energy. Its wider use for that purpose, and its potential direct use on farms to power agricultural machinery, offers a direct alternative to hydrogen. As a gaseous fuel, biogas shares issues with hydrogen, such as:

- The ability of on-farm generation to meet periods of high seasonal energy demand,
- The current lack of available, and affordable, on-farm solutions to clean, store and refuel biomethane for agricultural machinery use,
- The fact that it is not considered a true zero emission technology as it is generally combusted to provide energy.

An additional significant issue with biogas noted previously are fugitive emissions from the production, storage and combustion of gas or biomethane.

Farms will have to switch to alternative fuels and energy sources to play its part in the UK's long-term decarbonisation. As discussed above, all the current potential farm energy decarbonisation options have issues, and it may be that the long-term future will be a combination of these options, depending on their technological and economic status. This will be discussed further in the *Discussion* and *Recommendations* sections later in the report.

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[60] SYPOX (no date): Biogas to Hydrogen (online): https://sypox.eu/biogas-to-hydrogen/

[61] EA Technology (2024): Rural Electrification Project Report

# 5 Modelling Potential Future Farm Hydrogen Demand

**Tasks covered:** : 2.4 seek and analyse data sources of farm types across the NGN territory using GIS tools.

**Key points:** This section describes analysis that looked at the financial attractiveness and technical viability of hydrogen in agricultural use for heating and machinery based on the price of, and availability of incumbents. It concludes by mapping potential maximum hydrogen demand through to 2050 across the NGN region if all current fuel and energy use is replaced by hydrogen.

## 5.1 Introduction

The modelling and analysis presented in this section aims to answer three questions:

1. How much hydrogen might be used in farming by replacing the current use of gas in heating and (red) diesel in agricultural machinery? A core assumption in answering this question is that any farming applications that currently use electricity will continue to use electricity in the future.
2. Where could it be used?
3. At a high level, when (if at all) might it become cost-competitive to use?

As previously stated, the analysis is based on bulk hydrogen delivery to the farm via, for example, the proposed East Coast Hydrogen network and focuses on the region covered by NGN.

## 5.2 Data Sources Used in the Analysis

### *5.2.1 Hydrogen Costs*

Using UK Government reports[62,63] three scenarios for bulk hydrogen generation and transport have been modelled. These are described in this list and the values are shown in Table 1 below.

Three scenarios were chosen from the sources to provide a low, medium and high range of costs:

- **Worst case**: Alkaline electrolysis, industrial retail energy cost, unfavourable sensitivity, high-cost trailer delivery.
- **Mid case**: Alkaline electrolysis, dedicated offshore energy costs, no sensitivity, low-cost trailer delivery.
- **Best case**: Alkaline electrolysis, dedicated offshore energy costs, favourable sensitivity, low-cost piped delivery.

*Table 1: Hydrogen Pricing Scenarios (per kg)*

| | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|
| **Worst case** | £ 9.87 | £ 9.67 | £ 9.47 | £ 9.40 | £ 9.34 | £ 9.31 |
| **Mid case** | £ 5.33 | £ 4.51 | £ 4.34 | £ 4.18 | £ 4.18 | £ 4.18 |
| **Best case** | £ 3.53 | £ 2.71 | £ 2.54 | £ 2.38 | £ 2.38 | £ 2.38 |

[62] BEIS (2021) Hydrogen Production Costs (online): https://assets.publishing.service.gov.uk/media/611b710e8fa8f53dc994e59d/Hydrogen_Production_Costs_2021.pdf

[63] DEZNZ (2023) Hydrogen Transport and Storage Cost Report (online): https://assets.publishing.service.gov.uk/media/659e600b915e0b00135838a6/hydrogen-transport-and-storage-cost-report.pdf

All scenarios use alkaline electrolysis as the lowest cost and most mature electrolyser technology. As Table 1 shows, in general high-volume pipeline delivery delivers lower cost hydrogen than smaller-scale delivery by tanker.

In addition, there is a potential saving in $CO_2$ emissions by transitioning from diesel or gas to hydrogen[64]. Based on UK Government transport investment appraisal guidance, a monetary value has been assigned to this saving[65], shown in Table 2.

*Table 2: Carbon Pricing for Diesel and Gas Fuels*

| | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|
| **£ per tonne $CO_2$** | £ 352.70 | £ 380.39 | £ 410.24 | £ 442.45 | £ 476.64 | £ 513.48 |
| **$CO_2$ £ per L Diesel** | £ 0.89 | £ 0.95 | £ 1.03 | £ 1.11 | £ 1.20 | £ 1.29 |
| **$CO_2$ £ per kWh gas** | £ 0.14 | £ 0.15 | £ 0.16 | £ 0.17 | £ 0.18 | £ 0.20 |

While the farmers themselves may not currently experience this cost, it is possible in the long term that these costs will be added to incentivise transition to zero emission fuels. Note, that this will eventually require the hydrogen to be generated using zero emission energy sources (i.e. green hydrogen, not blue) to maximise emission savings.

### 5.2.2 Transport

For a direct replacement of fuel (i.e. not including CapEx), the cost per unit of $H_2$ that is required to reach price parity against red diesel (45p/l subsidy), white diesel (no subsidy), or white diesel plus $CO_2$ cost has been calculated based on replacing the energy contained in the diesel with an equivalent amount of hydrogen, adjusted for the efficiency of conversion of each fuel to motive power. These results are shown in Table 3.

*Table 3: Equivalent hydrogen cost per kg to replace diesel*

| | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|
| **Red Diesel** | £ 2.89 | £ 3.11 | £ 3.37 | £ 3.66 | £ 3.92 | £ 4.19 |
| **White Diesel** | £ 4.38 | £ 4.59 | £ 4.85 | £ 5.14 | £ 5.41 | £ 5.67 |
| **White Diesel + $CO_2$ cost** | £5.27 | £5.54 | £5.88 | £6.25 | £6.61 | £6.96 |

Comparing to the $H_2$ costs in Table 1, to compete with red diesel costs, hydrogen cost per unit to the farmer would need to be better than the mid-case and approaching the best-case scenario. If the red diesel subsidy is removed, the required cost per kg for $H_2$ is comparable to the mid-case. This comparison is shown graphically in Figure 9.

[64] DfT (2024) Tag Data Book (online): https://www.gov.uk/government/publications/tag-data-book TABLE A3.2

[65] DfT (2024) Tag Data Book (online): https://www.gov.uk/government/publications/tag-data-book TABLE A3.3

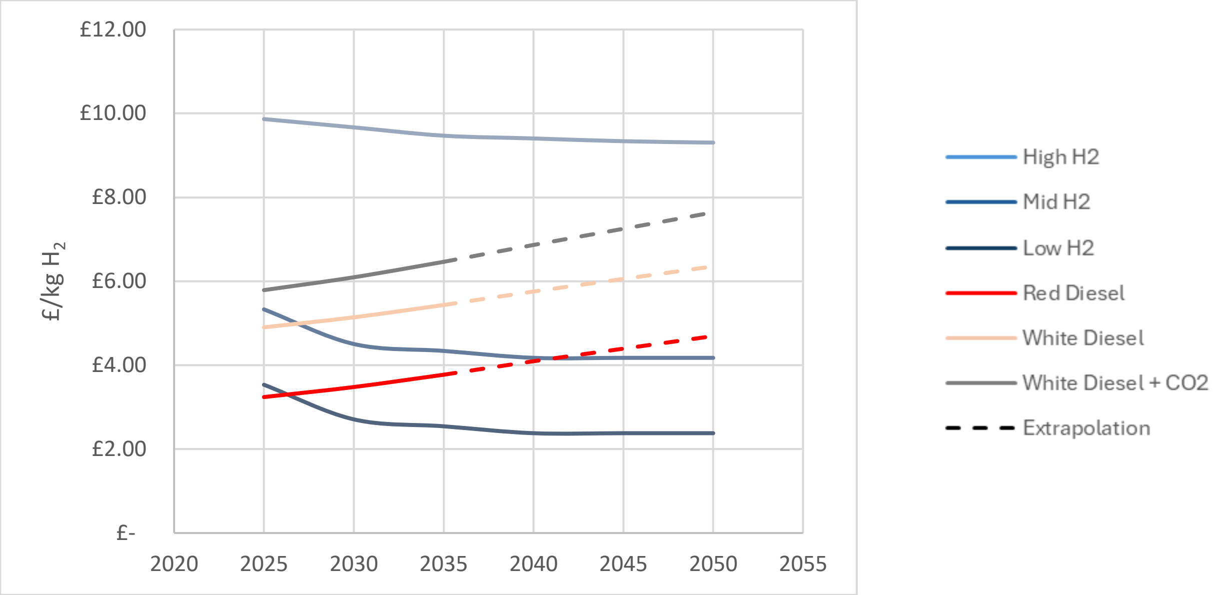



*Figure 9: Comparative Cost of Hydrogen and Diesel Scenarios*

If we consider that there is additional CapEx for purchasing hydrogen machinery, the size of the farm has a significant effect. In these cases, large-scale fuel users (e.g. large arable farms) have a better chance to make hydrogen fuelling work, but even then, would require the cost of hydrogen to approach the mid- or best-case scenario in Table 1. For smaller farms, the additional CapEx is almost impossible to recover as the saving per unit of fuel is low.

For replacing diesel with electric machinery, if there is a comparable CapEx, the current electric rates are slightly more attractive than red diesel and much better than white diesel. Currently the CapEx costs of electrical machinery are relatively high, but the additional competition of electric as a relatively mature technology in the automotive industry compared to hydrogen is another barrier that hydrogen fuel must overcome to remain competitive.

#### ***Summary***

For a financially feasible adoption of hydrogen on farms to replace diesel vehicles, the delivery cost per unit of hydrogen needs to be low – which, according to the Best Case scenario means hydrogen pipeline delivery. It is feasible to reach these levels, but the market needs support. In addition, the CapEx of hydrogen vehicles must become comparable with their diesel counterpart; if there is a significant additional cost of purchasing a hydrogen vehicle compared to a diesel replacement, it becomes very difficult to recover this difference in fuel savings even on large farms over the 10-year lifespan considered in this model.

Electric is also a financially viable potential replacement for diesel on farms. Assuming the electric machinery is suitable for farm duty cycles, which is possible for machinery operating at lower power (i.e., below 100 hp) if the CapEx of electric machinery approaches parity with diesel, electric unit costs are very favourable.

### *5.2.3 Heating*

Note: in this subsection, kWh is used rather than kg, as these are the typically expressed units for electricity and gas in heating applications. The conversion factor from kWh to kg of hydrogen is 33.3 kWh/kg (based on the lower heating value, LHV).

Replacing gas or electric heating with hydrogen has also been examined. Whether a farm is suited to transition or not depends on the split of electric to hydrogen.

Even ignoring the additional CapEx to install hydrogen capable heating systems (or assuming that the CapEx will be comparable to an equivalent gas or electric replacement), reaching cost parity for hydrogen is difficult in the current economic climate because the heating use case is OpEx dominated.

When a carbon cost is included on the gas prices, hydrogen becomes much more competitive compared to gas, although is still difficult to compete with electric. To reflect this within this project, from 2035 onwards, a portion of the $CO_2$ cost is added to the gas prices. These prices per kWh are shown in Table 4.

*Table 4: Cost per kWh of Electric and Gas Fuels[66]*

| | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|
| **Electric (DUKES)** | £ 0.09 | £ 0.11 | £ 0.12 | £ 0.10 | £ 0.10 | £ 0.09 |
| **Gas (DUKES)** | £ 0.02 | £ 0.02 | £ 0.03 | £ 0.04 | £ 0.04 | £ 0.05 |
| **Gas + $CO_2$** | £ 0.15 | £ 0.17 | £ 0.19 | £ 0.21 | £ 0.23 | £ 0.25 |
| **Final Gas Scenario** | £ 0.02 | £ 0.02 | £ 0.03 | £ 0.10 | £ 0.18 | £ 0.25 |

When the uncertainty around additional CapEx, and how feasible hydrogen will be in a heating capacity is considered, it is difficult for a hydrogen solution to compete with gas purely on price currently, so a dis-incentive on the current gas prices is needed to make hydrogen favourable. The best-case hydrogen costings in Table 1 (i.e., from pipeline delivery) are comparable per kWh to electric costs (per unit), whereas gas prices are projected to remain lower than even the best-case scenario for hydrogen. This is shown graphically below.

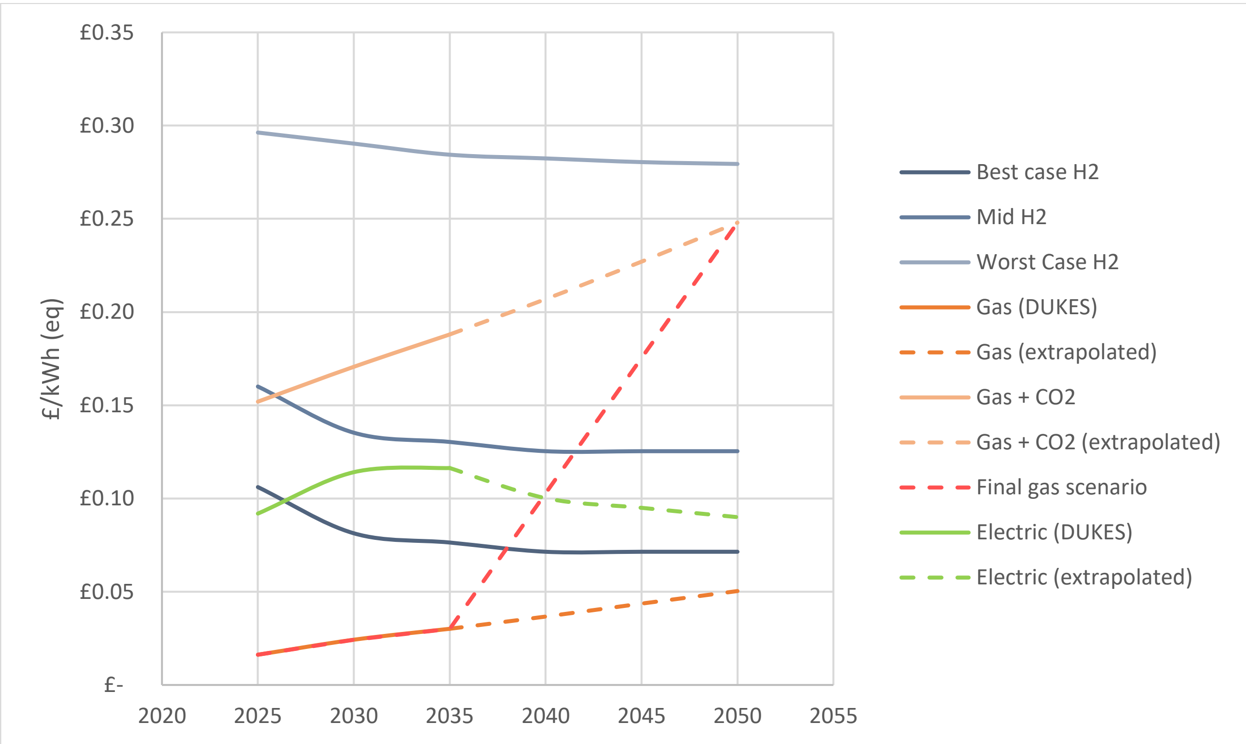



*Figure 10: Comparative Cost of Hydrogen, Electric and Gas Scenarios*

### *Summary*

Due to the relatively low gas prices per unit anticipated by the UK Government, it is difficult for hydrogen to compete, even in the most favourable scenario. At its lowest cost, hydrogen is still twice as expensive per unit compared to gas. However, when a carbon cost is added to gas prices, hydrogen becomes much more competitive. It is still difficult for hydrogen to compete with electric prices, but it could still be more cost-effective to convert gas burners to hydrogen and keep a lot of the existing infrastructure the same than incur the CapEx of converting the whole heating system to electric.

66 UK Government (2024) DUKES Digest of UK Energy Statistics (online): https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes

As a caveat, it should be noted that the long-term cost modelling of hydrogen prices is highly uncertain, particularly as the future cost of green hydrogen will be linked to the cost of the electricity used to generate it.

## 5.3 Feasibility Rating

### 5.3.1 Financial Feasibility Scenarios

In order to understand how the costs of hydrogen might become competitive, or even favoured, compared to incumbent fuels, scenarios for incumbent and hydrogen costs were compared for the different farm archetypes based on the type and amount of fuels that they use.

To compose the scenarios, energy usage for each farm type (from the Warwick HRI data as described in Section 3), as well as CapEx costs/Ha (taken from the John Nix handbook) were used to determine the required cost per unit of hydrogen to achieve price parity with the incumbent (diesel or gas). In each archetype, there is a best- and worst-case for the incumbent fuel, and a low and high value for hydrogen unit costs.

Capital cost to transition to hydrogen equipment is difficult to quantify due to the lack of current market availability of the technology and a corresponding lack of publicly available data. Data from the John Nix handbook provided a baseline cost per Ha for the incumbent technologies.

- In the best-case scenario, it is assumed that hydrogen equipment will reach price parity with the incumbents.
- In the worst case, a +50% cost is applied representing the fact that hydrogen is a developing technology and not yet in mass production.

The John Nix handbook also gives values for *average* and *high performing* farms. To account for the differences in farm size:

- Large farms are assumed to be *high performing* (as they can benefit from economies of scale) and so have the reduced CapEx per Ha.
- Small farms increase their CapEx per Ha by the same amount.

This leads to four elements that can be varied in each scenario:

- Incumbent worst case: white diesel, gas + $CO_2$ cost, matched $H_2$ CapEx
- Incumbent best case: red diesel, gas + $CO_2$ cost, increased $H_2$ CapEx
- $H_2$ worst case: Alkaline electrolysis, industrial retail energy cost, unfavourable sensitivity, high-cost trailer delivery
- $H_2$ best case: Alkaline electrolysis, Dedicated offshore energy costs, favourable sensitivity, low-cost piped delivery.

Combining the incumbent and hydrogen cases elements, and omitting non-meaningful scenarios that have the worst case as cheaper than the best case, yields the five scenarios listed in Table 5. The scenarios have been given a number 0-4 and a Red Amber Green (RAG) rating based on:

- The order of the required hydrogen cost to match the two incumbent scenarios (WORST INC, BEST INC), and,
- The possible range of delivery costs for hydrogen (WORST $H_2$, BEST $H_2$).

Table 5: Scenario Ratings

| # | Scenario Element Cost Order (low → high) | | | | Scenario Description |
|---|---|---|---|---|---|
| 0 | BEST Inc | WORST Inc | BEST $H_2$ | WORST $H_2$ | Even with CapEx subsidies, and favourable $H_2$, the required cost of $H_2$ is greater than the likely achievable cost |
| 1 | BEST Inc | BEST $H_2$ | WORST Inc | WORST $H_2$ | Favourable $H_2$ cost required to be competitive with incumbent |
| 2 | BEST $H_2$ | BEST Inc | WORST Inc | WORST $H_2$ | $H_2$ potentially competitive in favourable conditions |
| 3 | BEST $H_2$ | BEST Inc | WORST $H_2$ | WORST Inc | $H_2$ likely to be competitive with incumbent regardless, subsidies make it favourable |
| 4 | BEST $H_2$ | WORST $H_2$ | BEST Inc | WORST Inc | $H_2$ likely to be favourable compared to incumbent |

The results of the analysis for each of the Table 5 scenarios for each farm archetype are shown in Table 6. Any fields with NA showed minimal usage of the fuel in question in the Warwick data.

Under the assumptions used in this model, farm size is essentially irrelevant (other than producing a slight increase in favourability for large poultry farms compared to smaller ones) as both energy and CapEx data sources are expressed per Ha and, in any case, OpEx dominates the overall financial feasibility, so they have been omitted from the table.

Table 6: Economic Feasibility Ratings for Each Farm Type in Each Year Modelled

| | Transport | | | | | | Heating | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Farm Type** | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| **Arable** | 1 | 2 | 2 | 2 | 2 | 2 | 0 | 1 | 1 | 1 | 1 | 1 |
| **Horticulture** | 1 | 2 | 2 | 2 | 2 | 2 | 0 | 2 | 2 | 2 | 2* | 4* |
| **Grass** | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| **Cattle** | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Pigs** | NA | NA | NA | NA | NA | NA | 0 | 2 | 2 | 2 | 2 | 2 |
| **Lamb** | 1 | 2 | 2 | 2 | 2 | 2 | NA | NA | NA | NA | NA | NA |
| **Poultry** | NA | NA | NA | NA | NA | NA | 0 | 1 | 1 | 2 | 2 | 2 |

*The horticultural use case is OpEx dominated and essentially CapEx invariant, therefore both INC elements of the scenarios are essentially the same. The sharp transition from 2 to 4 occurs because the WORST H2 element of the scenario crosses both INC elements around 2046.

In general, based on this modelling, *on a purely financial basis*, it is unclear whether bulk supply of hydrogen will be viable in any farming scenario other than as a longer-term option for heating in protected horticulture compared to the diesel and gas incumbents. In general, OpEx dominates the use cases examined, and the cost of generating and delivering hydrogen is therefore key to determining the overall financial viability.

As an example, Figure 11 compares the best and worst cases for transport and heating to the three hydrogen delivery costs for a medium sized Arable farm. As can be seen, the cost per unit of hydrogen needs to approach the medium case to be competitive with the worst-case scenario for the incumbent (here chosen as white diesel). In summary, for hydrogen to be competitive, its price per unit will need to approach £4/kg.

This is the cost as paid by the user. Therefore, regardless of *who* is generating the hydrogen this is the cost that they will have to aim to sell at. It could come from a local supply, a 'hub and spoke' model, or from a centralised source (e.g. the proposed East Coast Hydrogen project).

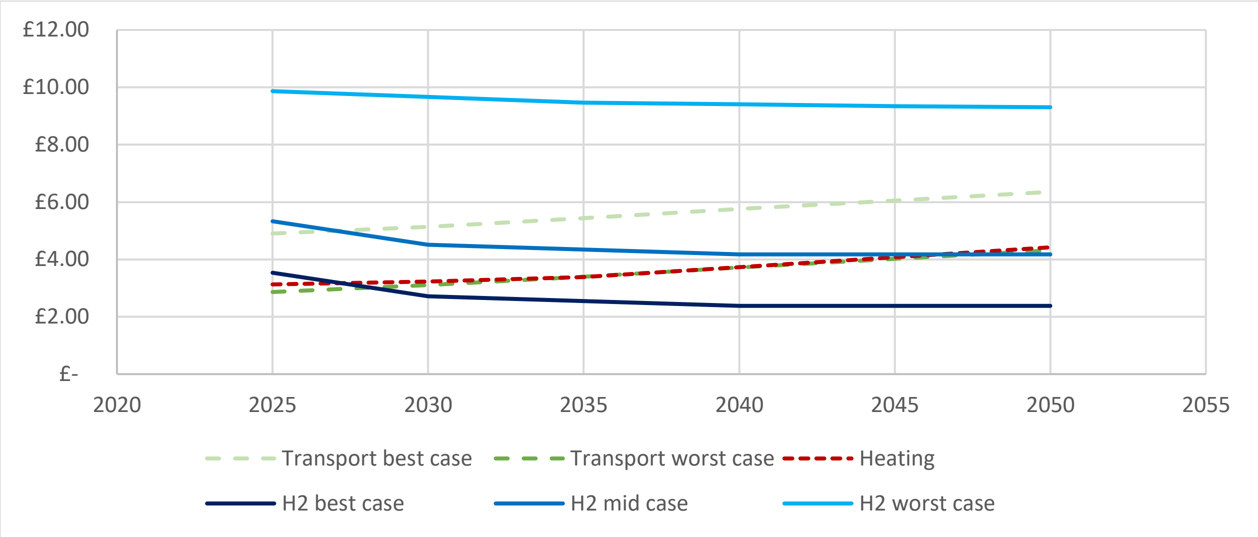



*Figure 11: Comparison of Resulting Financial Viability Scenarios to Hydrogen Cost Scenarios*

The notable exception is for heating use on protected horticulture farms. Many (including those in Yorkshire) use a large amount of gas currently and, in this OpEx dominated situation, will be very sensitive to gas prices and future availability. In this project, disincentives to gas use beyond 2035 are modelled by adding a $CO_2$ cost from 2035 onwards.

Based on our modelling, in the long-term horticultural glasshouse heating appears to present the best opportunity for hydrogen. Introducing hydrogen into existing gas installations could be easier than converting to electric particularly as, based on discussions with stakeholders in this project, the existing large-scale horticulture glasshouses in the NGN region are already directly connected to the gas grid. However, the unit cost of hydrogen must still be competitive with electric (£3 to £4/kg) to ease the path of farmers converting to hydrogen, rather than looking at electric options.

### 5.3.2 Market Availability

Even if the fuel cost itself is financially competitive, the use case must be ready to adopt and deploy hydrogen as a fuel. The market readiness of the hydrogen technologies considered in this report was discussed in detail in Section 4. Table 7 shows the technology market readiness scale assumed in this study based on the findings that draws on the findings presented in Section 4 (n.b., the 0-4 scale chosen here is *NOT* the same as the 1-10 Technology Readiness Level scale).

*Table 7: Market Availability Ratings*

| | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|
| **Transport Applications** | 0 | 1 | 3 | 3 | 4 | 4 |
| **Heating Applications** | 0 | 1 | 2 | 3 | 4 | 4 |
| 0 = Not proven in this application, 1 = Small-scale trials, 2 = Widespread trials, 3 = Growing deployment, 4 = Wide deployment | | | | | | |

### 5.3.3 Overall Feasibility of the Farm Use Cases

By multiplying the technical market availability and financial feasibility scores, a final score is calculated (max = 16), shown in Table 8. As stated previously, under the assumptions of this model, the farm size has little or no impact on the feasibility and so is omitted from the table.

*Table 8: Overall Feasibility Ratings for Each Farm Type and Year Modelled*

| | Transport | | | | | | Heating | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Farm Type** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| **Arable** | 0 | 2 | 6 | 6 | 8 | 8 | 0 | 1 | 2 | 3 | 4 | 4 |
| **Horticulture** | 0 | 2 | 6 | 6 | 8 | 8 | 0 | 2 | 4 | 6 | 8* | 16* |
| **Grass** | 0 | 1 | 3 | 3 | 4 | 4 | 0 | 1 | 2 | 3 | 4 | 4 |
| **Cattle** | 0 | 2 | 6 | 6 | 8 | 8 | 0 | 1 | 2 | 3 | 4 | 4 |
| **Pigs** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 8 |
| **Lamb** | 0 | 2 | 6 | 6 | 8 | 8 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Poultry** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 8 | 8 |

*The horticultural use case is OpEx dominated and essentially CapEx invariant, therefore both INC elements of the scenarios are essentially the same. The sharp transition from 8 to 16 occurs because the WORST H2 element of the scenario crosses both INC elements around 2046.

In general, there will be a limited market for hydrogen until 2035 onwards on any farm type. Beyond this, the increasing cost of incumbent fuels and reducing cost per unit of hydrogen makes hydrogen potentially competitive, particularly in horticultural glasshouse heating applications.

All these projections and scenarios have significant uncertainty in both the price of the incumbent fuels and hydrogen, so it is not possible to give a precise answer as to if or when hydrogen would be more likely to be adopted.

### 5.3.4 A Note on the Scenarios

It should be noted that modelling future hydrogen uptake is inherently challenging and subject to uncertainty. In particular, long-term hydrogen (and all fuel) prices are highly uncertain as the future cost of green hydrogen will be linked to the cost of the electricity used to generate it.

## 5.4 Geographic Analysis

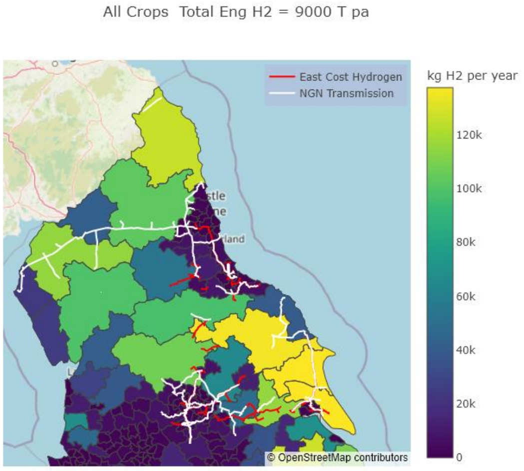
To develop adoption curves for each farm type in the NGN region, the total hydrogen demand (demand per unit area * area of farm type) is multiplied by a scaling factor representing how likely it is that hydrogen will be used in the given case. This scalar is calculated by dividing the overall feasibility rating (from Table 8) by 16 (the maximum score) and squaring the result.

An example calculation: North Northumberland (the northernmost constituency in the NGN region) has 52,250 Ha of arable land, and arable land would need an average of 53kg/Ha of hydrogen per annum to match the current energy usage, resulting in a total maximum arable demand of 2.7 million kg of hydrogen per year, assuming full adoption. Full adoption will depend on the pricing and availability of alternative solutions, so the scalar in 2040 applied is $(6/16)^2 = 0.14$, resulting in a potential hydrogen demand on arable farms in North Northumberland in 2040 of 388,000 kg per annum.

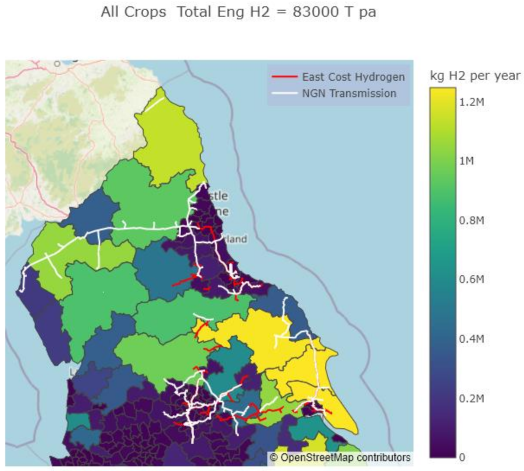
### 5.4.1 By Year

Figure 12 (a-c) show a potential hydrogen demand, by constituency, for all crop types in 2030, 2040, and 2050 based on the model presented in this Section; Figure 12 (d) shows the total energy demand on all farms in each constituency. This provides an estimate of the *maximum possible* hydrogen demand if all agricultural energy use considered in the study were switched to hydrogen i.e., assuming all heating and machinery energy use moved to hydrogen). Overlaid are NGN's transmission pipelines, and the proposed East Coast Hydrogen network. Note that the scale differs in each of the maps to reflect the growing amount delivered.

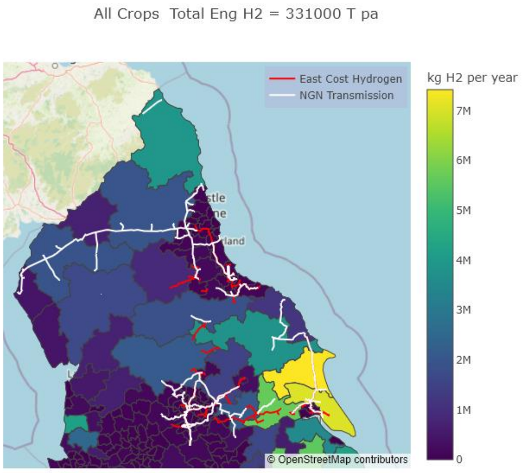
The geographic analysis suggests that there is potential demand across much of the north. Much of the area along the east coast and towards the Scottish border is covered by the existing pipe network. However much of the area across the Pennines and into the Lake District is not covered by the existing or planned network. The highest area of demand in the area around Hull up to the east of York. This is due to large areas of horticulture and arable land, which are amongst the most likely to adopt.



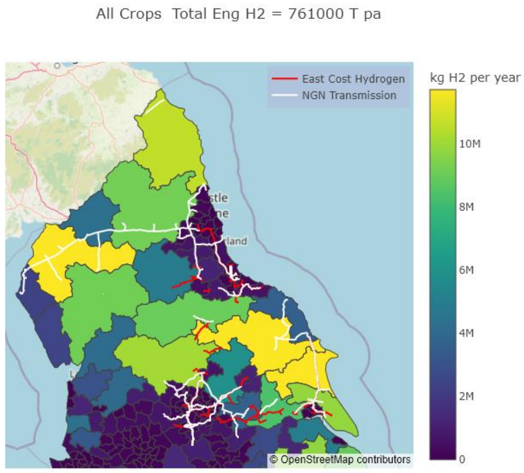

*(a) 2030*




*(b) 2040*




*(c) 2050*

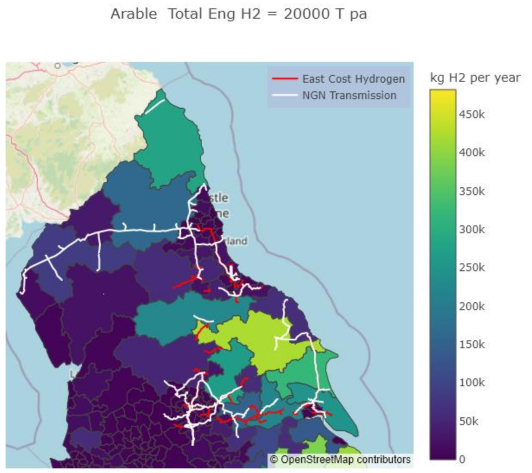



*(d) Maximum demand*

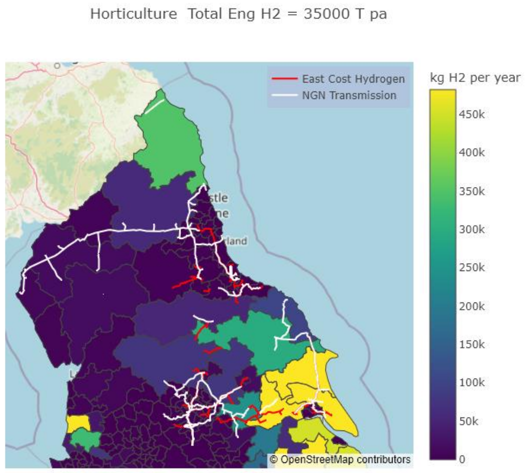
*Figure 12: Total Potential Demand by Constituency and Modelled Year*
*Overlaid Are the NGN Transmission Network and the Proposed East Coast Hydrogen Network.*
*Note that the scale differs in each of the maps to reflect the growing amount delivered.*

### 5.4.2 By Crop Type

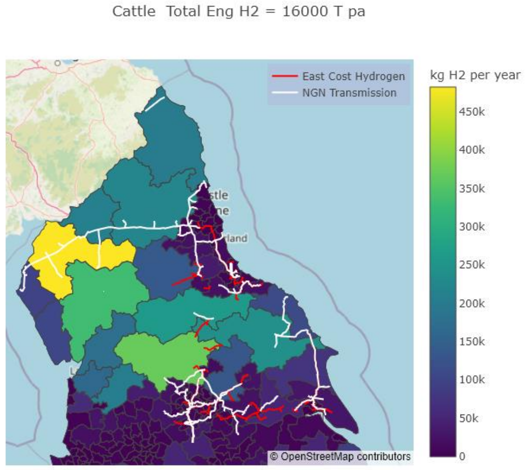
Figure 13 (a-f) show the potential hydrogen demand for each farm type across the NGN network in the 2040 case. Different areas of the region have varying intensities of farm type. The north and northwest areas have high levels of livestock (cattle and pigs), whereas the East Coast and towards Hull has more of arable and horticulture. Also evident is the relative lack of energy requirement in livestock (beef and lamb) farms. Intensive pigs have a high energy requirement per unit area, although a lot of this is currently electric for cooling, heating and lighting there is no incentive to replace this with hydrogen unless the pricing becomes favourable.



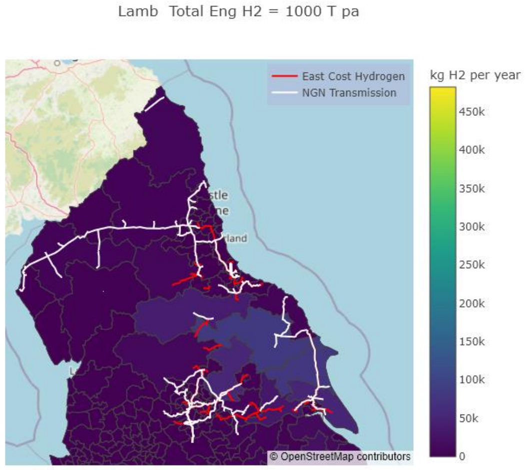

(a) Arable



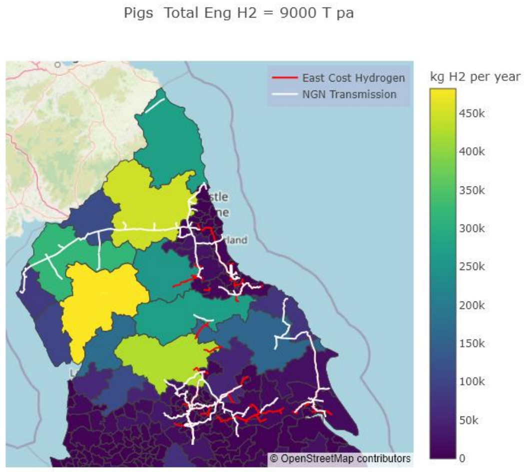

(b) Protected Horticulture



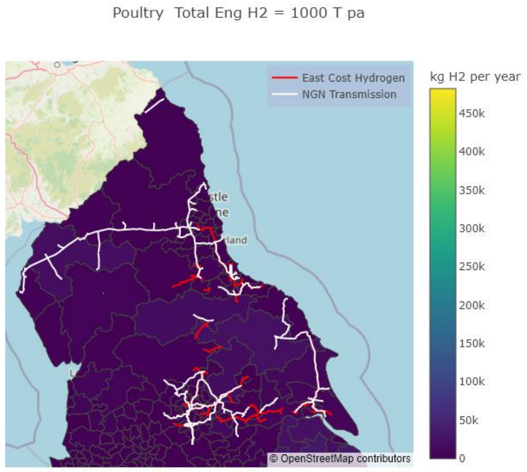

(c) Cattle




(d) Lamb




(e) Pigs




(f) Poultry

*Figure 13: 2040 Projected Demand by Constituency and Farm Type*
*Overlaid are the NGN Transmission Network and the Proposed East Coast Hydrogen Network*

### 5.4.3 Seasonality

The results above are all based on annual hydrogen demand, but energy demand will fluctuate throughout the year depending on the stage of the production cycle. Based on estimated energy profiles from survey participants and RASE industry experts, two example profiles are presented in Figure 14 for medium size arable (500 Ha) and dairy (400 head) farms.

The Arable farm energy use is much higher in August and September, as the crops are harvested and dried. Dairy farm energy use is reasonably consistent through the year. Seasonal spikes are important to bear in mind when sizing hydrogen delivery methods and for on-site generation.

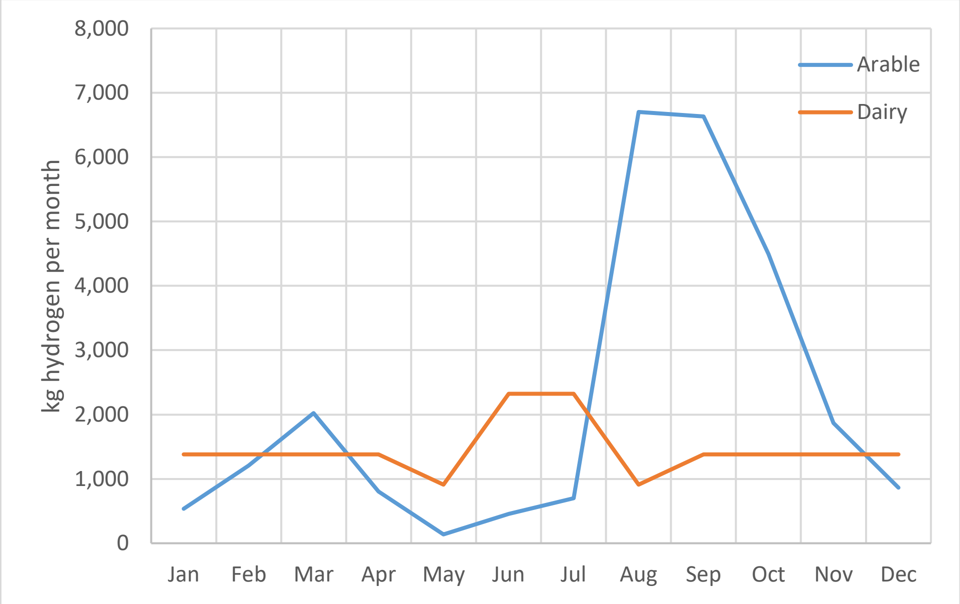



*Figure 14: Maximum Hydrogen Demand per Month for Mid-Sized Arable and Dairy Farms*

## 5.5 Conclusions

The analysis and modelling presented above has shown that the potential demand for hydrogen in farming applications is highly dependent on the unit costs of hydrogen, and future costs of diesel and gas, as well as the different production enterprise and activities being undertaken on each farm.

Under most scenarios presented in this report, to be competitive users must be able to purchase hydrogen for around £5/kg. There are scenarios (for example if there is a carbon tax on diesel, or if there is difficulty in using electric in farming applications) where the cost per unit could be a little higher to be competitive (up to £6/kg). In the medium-long term roadmaps and research suggest that hydrogen machinery total costs of ownership (and at least in the case of H2ICE, CapEx) will approach parity with the incumbent fuel if there is demand, and there will only be demand if the unit price is competitive. In general, the lowest cost green hydrogen will be provided by pipeline delivery.

The farm archetype that could be most suited to using hydrogen as an energy source, based on an OpEx-dominated use case, is protected horticulture. It uses huge amounts of energy to heat glasshouses, the majority of which is currently gas (at least in the NGN region). The unit cost of gas is currently low ($H_2$ equivalent £0.54/kg), so for this to make financial sense, there would likely need to be some additional cost on gas (carbon tax), and for hydrogen unit costs to be below £5/kg.

Arable cropping is also a potential option, replacing diesel with hydrogen in agricultural machinery. For hydrogen to be competitive with red diesel, the hydrogen unit cost would have to hit £3.20/kg. If the red diesel subsidy was removed, it would again have to hit £5/kg.

Other possible areas of use are in intensive livestock, although much of this is electric already, so there will be less incentive to transition to hydrogen unless the price can approach £3/kg.

In terms of *where* this demand might occur, arable and horticulture is mostly focused on the East Coast, which is reasonably covered by the existing network. The livestock areas are more focused along the Scottish border and into the Lake District, less covered by the existing gas network. With the exception of dairy farming, however, relatively limited demand is expected in these sectors.

### *Recommendations*

Farming applications for hydrogen are, in general, very uncertain to base significant future pipeline investment on alone. But if investment is not made, trailer and/or bowser delivery of hydrogen will make it even more difficult to reach price parity and therefore less likely for farmers to adopt. Several areas along the East Coast, or near the Scottish border have significant farming demand, and some have a gas pipeline already in place, so extending or feeding off this this could be a low-cost option.

Areas in the Lake District or on the west side of the Pennines also have some reasonable livestock farm energy demand, but given the uncertain use case and remote location, it would be difficult to justify a large investment in pipeline for a small number of farms. Finding other potential users alongside farms in these areas to aggregate demand would improve the case as would support for on-farm production.

Finally, to put the potential scale of future agricultural hydrogen demand in context from a supplier perspective, it is instructive to look at the maximum levels of hydrogen use modelled under the assumptions of this report compared to the levels of industrial offtake anticipated in the UK Hydrogen Strategy.[67] As shown in Figure 12, the *maximum* possible hydrogen demand (i.e., assuming all heating and machinery energy use moves to hydrogen) across England by 2050 is 761 kt. By comparison, the UK Hydrogen Strategy projects a demand from industry alone of up to 105 TWh by 2050. This equates to around 3,200 Gt of hydrogen annually, or over 4,000 times higher (although it is noted that this is from the whole of the UK, not just England).

[67] BEIS (2021) Hydrogen Analytical Annex (online): https://assets.publishing.service.gov.uk/media/611b34f9d3bf7f63a906871e/Hydrogen_Analytical_Annex.pdf

# 6 Discussion of the Findings

**Tasks covered:** : 3.1 & 3.2 final stakeholder engagement and reporting.

**Key points:** This section presents a brief summary and discussion on the findings of the analysis and stakeholder engagement of the project. The findings feed into the concluding recommendations presented in the next Section.

## 6.1 Study Analysis

The analysis presented in Section 5 looked at the financial attractiveness and technical viability of hydrogen in agriculture based on the price of, and availability of, incumbents and alternatives.

Given the current deployment status of hydrogen technologies and the lack of availability of green hydrogen, there is no short-term market for hydrogen technologies in agriculture.

In the longer term, if sufficient hydrogen can be made available to agricultural users:

- As a significant current user of natural gas for heating, pipeline-delivered hydrogen is likely to become a competitive fuel compared to natural gas for **protected horticultural** heating from the late 2030s onwards, particularly if (as is true in many cases) they are already connected to the gas grid.
- For **agricultural machinery**, the competitiveness of hydrogen is less clear cut and will rely on the availability of best-case cheap hydrogen and the phase out of fossil-derived red diesel.

Since farmers are beginning to look at alternatives to fossil fuel now as part of the transition to net zero, the next step should be to trial hydrogen in the use cases discussed above and compare it to the alternatives, which as noted in Section 4 include biogas\biomethane, biomass and electricity.

Trials should be conducted on commercial, college or research farms to understand the operability, practicality, economics and overall emissions and the alternatives in real farming deployments.

## 6.2 Farmer Engagement

The rural and agri-food sectors must not be excluded from national planning on fossil fuel and diesel replacement. The engagement part of this study has shown that there is a growing awareness within the farming sector of need to replace red diesel but plans to replace fossil fuels must reflect the operational and financial constraints that the industry faces in the next decade.

Hence, as discussed above, the potential role of hydrogen as a farm fuel needs to be put into context with the range of other fuel and powertrain alternatives. The challenges include the issue of how to supply the hydrogen to the sites that are not on the grid, as well as to sites such as horticulture that are grid connected. These two points are discussed further below.

### *6.2.1 On-Farm Hydrogen Generation*

The focus of the future fuels events held during the study was diesel replacement and the role of gas fuels including hydrogen. Event feedback showed that, in addition to large scale hydrogen production systems, there is considerable interest in the possibility of producing hydrogen fuel locally on-farm.

As discussed in Section 4.4, in general small-scale hydrogen production has not so far been demonstrated to be commercially viable, as exemplified by the closure of hydrogen refuelling stations with onsite generation by Motive Fuels in the UK and others, due to inability to offset the very high capital and operating expense of electrolysers to generate hydrogen with revenues from (or saving on) fuel expenditure. Other alternatives are, at present, of relatively low TRL so their financial and operability case is as yet unproven. However, in producing this report we have seen some interest in opportunities to explore on-farm generation which needs to be explored further.

### 6.2.2 Protected Horticulture

Glasshouses are used for a range of high value crops such as tomato, peppers, cucumbers and strawberries as well as specialist crops such as hemp. There are several larger growers in Yorkshire and the wider NGN region, some of which operate 5 to 10 hectares (Ha) of glass. As a significant user of energy (with a consumption of up to 5 MW/Ha of glass) the horticulture sector has been identified by NGN and by stakeholders consulted in this study as being a target sector for hydrogen supply. Most of these located close to the gas network are already using natural gas heating, but also generally require $CO_2$ to support crop growth.

While some operators were hit by the Ukraine energy crisis, many were more resilient than other rural businesses, having already invested in alternative clean energy systems such as biomass (many horticulture sites were early installers of biomass heating funded by the Renewable Heat Incentive, RHI) as well as heat pumps (often their lowest cost energy supply) and biogas.

Many sites also have CHP systems, with those that owned the engines able to insulate themselves from heating cost rises in the past three years based on sales of electricity to a high-cost market. With horticulture at the leading edge of energy efficiency in farming, there may be opportunities for hydrogen but only if it is competitive with their other options.

One significant barrier identified by stakeholders in the transition to hydrogen systems is that current natural gas and biogas CHP generators provide on-site access to $CO_2$, captured from flue gasses or produced directly by burners, which promotes plant growth and maximises yield. Transition to hydrogen would have to factor in the cost of buying in $CO_2$, although as noted in Section 0, such $CO_2$ enrichment is a common and well-understood technology.

The project team held discussions with several glasshouse operators including one that was already using heat from biogas CHP. While the wider farming operation is looking at the potential for use of gas fuels such as biomethane for tractor fuel as discussed further below, the value of hydrogen as a fuel for glasshouses is not yet on their investment horizon. This is dictated by current lack of fuel availability but also concerns about the cost and operational impacts that hydrogen bring.

For sites with access to anaerobic digestion (AD), the focus at present is on getting access to more biogas and for some upgrading this to bioCNG to capture $CO_2$ pre-combustion and to use the gas as a HGV, and potentially tractor, fuel. This also requires attention to the local storage and distribution of the biomethane and this should include delivery to field operations at busy periods.

In summary, given that there are a number of existing large-scale horticultural gas users in the Yorkshire and NGN region that are connected directly to the grid, protected horticulture offers ready-made future trial potential for hydrogen heating to stakeholders such as NGN. Given the relatively low level of potential future demand compared to industry, however, further detailed analysis of the business case for linking horticultural users to the East Coast Hydrogen network is needed.

# 7 Recommendations

## 7.1 Introduction

This study aimed to understand the potential uptake of hydrogen in the farming sector by considering the technical and economic feasibility of usage in agricultural machinery and heating.

Given the current relative immaturity of hydrogen technologies and the lack of current availability of hydrogen for on-farm use, there is no immediate opportunity. Any potential future use of hydrogen and other gas fuels in agriculture must be part of a national medium to long-term transition away from fossil fuels. This is bound up with wider policy and strategy on issues such as energy and food security and therefore requires intervention from the Government.

This concluding section presents recommendations for future work and actions for Government and other agencies that follow on from the study analysis. The recommendations look at: general measures to promote the uptake of all alternative fuels, specific measures to promoting hydrogen uptake and, briefly, the future use of biogas\biomethane and electricity.

## 7.2 Uptake of Alternative Fuels in Agriculture

Not all recent UK Government agricultural policy initiatives have been popular with the farming community, and in the aftermath of the energy crisis following the Ukraine invasion, many are struggling to maintain their businesses. As a priority Government engage with the agricultural sector to tackle its reliance on fossil fuel and to formulate an agreed transition plan to alternative fuels.

The response to this study from farmers and other stakeholders shows that there is an interest in the transition away from fossil fuels but speeding up the transition will require concerted action with appropriate policy levers and collaboration, with vehicle and fuel suppliers and farming organisations.

There are also concerns about the viability of specific solutions such as BEVs and FCEVs, given the needs of farmers and concern over weight, operability and inflationary impact. Also, there is a need for better policy maker engagement with farmers on the phasing out of internal combustion engines in rural and farm vehicles, given the limitations of alternative powertrains.

Suggested actions include:

- **Gradual phase-out of red diesel**: Government needs to set a clear timeline with the industry for a phased withdrawal of the red diesel tax break in agriculture, allowing farmers to plan and adapt while receiving financial assistance (in the form of direct payments, low-interest loans or tax relief) to facilitate the transition. This might involve integration with a carbon pricing mechanism during the process to make fossil fuel use in agriculture more costly, creating an economic incentive to transition whilst maintaining overall cost neutrality for the farmer, and avoiding unnecessary inflationary pressures on costs and food prices.
- **Farmer education and outreach**: Talking to stakeholders and running dissemination events during this project has shown that farmers are interested in alternative fuels and are already deploying on-farm generation and other alternative fuel technologies where a medium-long term business case can be shown for payback. Dedicated outreach events and continued engagement with the farming community by organisations such as RASE and NFU Energy is essential if the agricultural community is to be brought along with the required transition away from fossil fuels towards alternatives such as hydrogen.
- **Better data on-farm energy use:** The farm energy use survey and stakeholder engagement revealed that relatively few farmers can accurately quantify all their energy use (electricity, gas and fuel), nor assign it to a specific farming activity as most have diverse activities and multiple outputs within their business. This has been noted by others[68] and suggests that relatively simple self-reporting of annual fuel use by farmers (for example, as part of the

[68] CXC (2023): Decarbonisation of mobile agricultural machinery in Scotland (online) https://www.climatexchange.org.uk/media/5645/cxc-decarbonisation-of-mobile-agricultural-machinery-in-scotland-jan-2023.pdf

annual Defra Farm Survey) would be a valuable means of baselining current energy use, identifying where opportunities lie and tracking changes as alternative fuels are introduced.

## 7.3 Measures to Promote the Uptake of Hydrogen in Agriculture

This report looked at the financial attractiveness and technical viability of hydrogen in agriculture based on the price of, and availability of incumbents and alternatives. If sufficient hydrogen can made available to agricultural users, report analysis showed that:

- As a significant current user of natural gas for heating, pipeline-delivered hydrogen is likely to become a competitive fuel for **protected horticultural** and the provision of space heating in glasshouses from the late 2030s onwards.
- For **agricultural machinery**, the competitiveness of hydrogen is less clear cut and will rely on the availability of best-case cheap hydrogen and the phase out of fossil-derived red diesel (discussed above) if it is to achieve significant market penetration in this use case.

At present however, there is little or no agricultural equipment available on the market that can use hydrogen, nor supplies of hydrogen available for farmers to use. Suggested measures to promote longer-term uptake include:

- **Classify H2ICE as a net zero emission agricultural technology** as recommended by the recent report from Hydrogen Delivery Council\Hydrogen Internal Combustion Engine Sub-Group on behalf of DEZNZ. This would stimulate the UK market for hydrogen-powered agricultural machinery.
- **Dedicated hydrogen agriculture demonstration trials:** There should be consideration of dedicated funding for commercial-scale demonstration of hydrogen heating for horticulture, and hydrogen machinery and associated on-farm refuelling infrastructure incorporating both fuel cell and H2ICE equipment where available. The trials should operate on a similar basis to the ongoing Red Diesel Replacement competition in construction and mining,[69] producing publicly disseminated results on operability, practicality, emissions benefits and the business case to provide an evidence base for further growth of the technology in farming.
- **Further investigation of the hydrogen business case for horticultural users:** Given that several existing large-scale horticultural gas users in the Yorkshire and NGN region are connected directly to the grid, protected horticulture offers ready-made future trial potential for hydrogen heating to stakeholders such as NGN. Given the relatively low level of potential future demand compared to industry, however, further detailed analysis of the business case for linking horticultural users to the East Coast Hydrogen network is needed.
- **Hydrogen pricing:** Specific tax breaks and incentives could be developed to promote rural production and hydrogen use in agriculture, and as a NRMM fuel in general. In particular hydrogen pricing mechanisms are needed to offset the price differential with (red) diesel to provide market certainty to potential market entrants and technology deployers.
- **Rural hydrogen generation and vehicle refuelling:** This report has focused on relatively near-market solutions, and on large-scale hydrogen supply from pipelines or tube trailers to the farm. Stakeholder engagement showed that there is considerable interest in, and activity (such as the HydroGlen project discussed in Section 4.4) in producing hydrogen fuel locally on-farm, similar to the generation of biogas on farms from organic waste. A dedicated funding stream could be established to investigate the feasibility of smaller on-farm generation, with a particular focus on establishing whether it is possible to provide operable, affordable and safe on-farm solutions to clean, store and refuel hydrogen for agricultural machinery use should be considered.
- **Planning and regulation:** Planning continues to be a major restraint on rural renewables development. Streamlined planning processes and supportive regulations would enable

[69] DEZNZ (2024) Red Diesel Replacement competition: Phase 2 projects (online): https://www.gov.uk/government/publications/red-diesel-replacement-competition-successful-projects/red-diesel-replacement-competition-phase-2-successful-projects

faster development of local renewable hydrogen projects, including those for small-scale hydrogen generation, in rural areas.

## 7.4 Measures to Promote Uptake of Non-Hydrogen Alternative Fuels in Agriculture

Although this report has focused on uses case for hydrogen in agriculture, as noted previously it is likely that a portfolio of fuels will be required in the agricultural transition to net zero – specifically biogas\biomethane, electricity and hydrogen.[70] Key to the transition from red diesel on farms is boosting the demand for tractors with alternative powertrains, which requires greater confidence in the options available and on-farm demonstration.

Although detailed discussion of these fuels is not in scope of this report, the following actions are suggested, as their co-development is agriculture is essential to provide an evidence base as to which technology is appropriate for a given farming application:

- **Dedicated on-farm demonstration trials:** As with hydrogen, dedicated large scale demonstration funding should be made available for trials of biogas and electricity agricultural use cases. The trials should produce publicly available information on operability, practicality, emissions benefits and the business case to provide an evidence base for further growth of the technology in farming and to facilitate like-for-like comparison with hydrogen in agricultural use cases.
- **Feasibility of on-farm biomethane vehicle refuelling and emissions:** Although biogas is widely produced on farms from anaerobic digestion, the wider use of biomethane as a vehicle fuel on farms has been held back by the lack of available, affordable and safe on-farm solutions to clean, store and refuel biomethane for agricultural machinery use. Fugitive emissions from the production, storage and combustion of gas or biomethane are an additional concern which has held back progress in this field. Therefore, any deployment funding should be conditional on providing a robust public evidence base for the overall emissions benefit of biomethane as a fuel in an agricultural setting.

[70] RASE (2022): Decarbonising Farm Vehicles and Future Fuels: (online): https://vm-01-crm02.altido.com/clients/rase-c3c5ffc2133a3eed/uploads/documents/website-report/Decarbonising%20Farm%20Vehicles%20and%20Future%20Fuels.pdf

# 8 Appendix – Case Studies and Company Overviews

## 8.1 Introduction

This Appendix provides details of both existing hydrogen projects, and products and services with relevance to the agricultural sector. These were sourced directly from the organisations mentioned and are shared here as supplementary information in the form of case studies and promotional information.

## 8.2 Off-Grid Hydrogen Production and Distribution

### *8.2.1 H2Boost*

Led by the Biorenewables Development Centre, H2Boost was funded by the Department for Energy Security and Net Zero Hydrogen BECCS Innovation Programme to produce hydrogen with carbon capture, under the Net Zero Innovation Portfolio (NZIP). The consortium behind this project on microbial production of biohydrogen, included University of Leeds, Aardvark, AB Agri Ltd, CM90 Ltd, CyanoCapture, NNFCC, Maltings Organic Treatment Ltd, Qube Renewables and Ramboll UK Ltd.


**Off-Grid Hydrogen Supply**

The H2Boost project has demonstrated that dark fermentation (DF) can produce off-grid sustainable hydrogen in rural locations. The H2Boost facility operated at an organic waste treatment site in North Yorkshire. Enzyme pre-treated bio-wastes were broken down anaerobically to produce bio-hydrogen. Dark fermentation (DF)residues were fed to a modular AD unit. Microbial growth systems (algae and cyanobacteria) captured carbon using nutrients from digestate and $CO_2$ from the process.

A biogas boiler and CHP system provided hot water and heating. The system, designed, installed, commissioned in under two years, ran continuously for 54 days, producing 57.6 $m^3$ of hydrogen and capturing 18.98 kg of carbon.

The project assessed under-utilised, low-value waste streams and plant performance data informed technoeconomic and life cycle analysis, plus commercial design options (CapEx, OpEx, reliability).

**Future Development**

The project highlighted the scope for local hydrogen production from bio-residues, using off-grid hydrogen networks to enhance system resilience. While UK sustainable hydrogen supply targets will largely be met by centralised production, DF offers an alternative, less energy intensive approach.

Demonstration scale production of hydrogen using microbial processes is a first-of-a-kind integrated system. The H2Boost team is seeking further funding to improve the system, boosting yields and handling inhibitory components produced during DF. The team envisages a system which can stand alone or be retrofitted on existing AD sites, offering a sustainable rural hydrogen supply.

For a short video of the demonstration H2Boost activities visit : https://youtu.be/p6FaMGNqmG4.

### 8.2.2 HydroGlen Farm Project

The James Hutton Institute is Scotland's leading agri-food research institute looking at environmental, economic and social aspects of farming. Glensaugh Farm in north east Scotland is home to its Climate-Positive Farming Initiative.


*Figure 15: Glensaugh Farm*

Developed by rural energy specialists Water to Water, the HydroGlen project aims to create a 100% self-reliant, low-carbon farming operation in northeast Scotland. The pioneering project is showing how rural communities could become more self-reliant, green energy producers, ultimately generating all their fuel requirements.

**Off-Grid Hydrogen Supply**

Scotland's extensive renewable resources, particularly offshore wind, offer great potential for green hydrogen. The Scottish Government has targeted hydrogen output of 5 GW by 2030 and 25 GW by 2045, based on regional hydrogen hubs.

A platform for sustainable agriculture, Glensaugh Farm demonstrates innovation and novel farming practices. The HydroGlen project will combine on-site renewables with small-scale electrolysis plus hydrogen storage and refuelling, plus BEV charging.

The aim is for Glensaugh Farm to be energy self-sufficient, based on a 50kW wind turbine and 70kW of solar PV and to reduce emissions. Demand for electricity, heat and transport, will also be met by:

- **Battery Storage:** of excess electricity generated during peak production, ensuring a steady energy supply during periods of low renewable output.
- **Green Hydrogen:** produced from renewable electricity, hydrogen will be used in heating and power generation in fuel cells and as fuel for vehicles, alongside BEVs.

**Future Development**

The site will deliver off-grid supply of hydrogen. The HydroGlen project offers a pioneering approach to decarbonising the agricultural sector, deploying hydrogen technologies in a farm setting. The aim is to create a blueprint for rural communities to gain energy independence. With £6.2 million of funding from Scottish Government's Just Transition Fund and planning permission in place, the project should get underway in late 2025.

### *8.2.3 Fuel Cell Systems*

Fuel Cell Systems www.fuelcellsystems.co.uk is a leading UK provider of hydrogen refuelling systems  Its offerings include static, mobile and modular options. The recently installed advanced refuelling unit at Toyota's UK manufacturing site in Burnaston, Derby, is an example of the company's cutting edge technology.


*Figure 16: Fuel Cell Systems Hydrogen Refueller at Toyota Burnaston*

As UK partner of Enapter (winners of the 2021 Earthshot Prize), the company has developed a modular electrolyser container capable of delivering scalable green hydrogen production, even in rural or off-grid locations.

**Off-Grid Hydrogen Supply**

The company is working with partners to provide access to green hydrogen fuel, without needing a gas grid connection, with a range of systems (with refuelling capacity shown in the table below):

- **Modular Hydrogen Production:** HyPro electrolysers are modular, stackable systems (in 10ft or 20ft units), compatible with its refuelling system, offering complete refuelling solutions. Containerisation combines effective operation with ease of maintenance.
- **Modular Refuelling:** HyQube is a re-deployable hydrogen refuelling system for sites that require a small to medium sized fuelling capability. HyQube 500 (dispensing $H_2$ gas at 350 bar) has been installed on several UK sites including Toyota Burnaston.
- **Static refuelling:** HyFleet system enables refuelling of larger fleets at both 350 or 700 bar.

**HyFleet Refuelling Table**

| Vehicle | Tank Capacity (kg) | Vehicle Start Pressure (BAR) | Target Pressure (BAR) | Mass Dispensed (kg) | Refuelling Time (Mins) | Number of Vehicles Serviced by: Electrolyser Supply | Tube Trailer Supply | Tube Trailer Supply, with Additional HyFlow |
|---|---|---|---|---|---|---|---|---|
| Car | 6 | 5 | 700 | 6 | 3 | 40 | 60 | 120 |
| Van | 10 | 5 | 700 | 10 | 5 | 25 | 60 | 120 |
| Truck | 15 | 5 | 700 | 15 | 7 | 16 | 60 | 83 |
| Bus | 37 | 165 | 350 | 18 | 8 | 13 | 60 | 69 |
| HGV | 50 | 5 | 700 | 50 | 17 | 5 | 20 | 25 |

### Future Development

Fuel Cell Systems works with partners across industry. Its modular hydrogen refuelling systems are ideal for off-grid, rural applications, offering:

- Local off grid $H_2$ fuel production and refuelling at a smaller scale
- Systems integration - end-to-end production to refuelling solution
- Potential for expanding rural hydrogen refuelling infrastructure.

The company is keen to work with partners to install smaller-scale off-grid $H_2$ supply stations.

## *8.2.4 HyKit*

A joint venture between JCB, investment fund HYCAP and HydraB Group, HyKit has been established to develop and manufacture products to support off-grid green hydrogen distribution such as mobile compressors, storage solutions and modular, portable refuelling systems.


*Figure 17: King Charles III at JCB's Rocester Innovation Centre*

With farmers and construction companies are under enormous pressure to reduce carbon emissions the collaboration leverages JCB expertise in hydrogen engineering to create refuelling infrastructure tailored for heavy off-road machinery.

### Off-Grid Hydrogen Supply

HyKit is developing, modular agile infrastructure to move, store and utilise green hydrogen and aims to accelerate adoption of green hydrogen in sectors with significant decarbonisation challenges such as the replacement of fossil fuels. HyKit expects to play a significant role in off-grid transition to a hydrogen-based economy, by providing reliable and affordable hydrogen infrastructure.

Based on early solutions developed by JCB's hydrogen engineering division, systems will provide new infrastructure for future operators of hydrogen machinery, on locations such as building sites and, in due course, farms that lack effective power and gas grid connections. These sectors require robust and efficient equipment that meet tough operational needs but are non-inflationary.

**Future Development**

In 2025, HyKit will commence production of products that support adoption of hydrogen-powered machinery and vehicles. The company is seeking to address a specific need for mobile and off-grid distribution solutions to facilitate transport and dispensing of hydrogen in locations that lack fixed infrastructure, to enhance access to hydrogen fuel, particularly in underserved regions.

## 8.3 On-Farm Power Supply

### *8.3.1 TCP Eco*

TCP Eco (www.tcp-eco.co.uk) supplies generators and mobile equipment to the construction sector. Hydrogen fuelled portable generators are already used on several construction sites. TCP also supplies turn-key microgrid power solutions.

*Figure 18: TCP Ecolite at Askham Byran Future Fuels Seminar – October 2024*

Powered by BOC's Hymera fuel cell, TCP's hydrogen generation units are silent with zero emissions. During the study, a TCP lighting tower was deployed at Askham Bryan College.

**Technology**

With increasing hydrogen availability, fuel cell generators can replace diesel power units, reducing pollution while maintaining reliable power output.

- **Powerpacks** modular hydrogen generators are compact, reliable, easy to transport and offer emissions-free, off-grid power for building sites, farms or rural locations.
- **Site Lighting** the Ecolite lighting tower delivers energy-efficient illumination from clean gas fuel. With low energy demand, a unit can operate autonomously for over 120 hours. The lighting rig can also be reconfigured as a CCTV security tower.

**Decarbonisation**

TCP's hydrogen fuel cell range is suited to sites where renewable energy is hard to deliver:

- **Emissions** hydrogen fuel cell units curb $CO_2$ emissions at deployment location.
- **Capability** Extended run-times - 35 kgs of hydrogen can supply power for a month.
- **Infrastructure** Fuel cell units on off-grid sites provide a robust power source.
- **Adoption** TCP is demonstrating hydrogen's potential as a flexible clean fuel.

**Key Achievements**

At Askham Bryan, TCP's lighting rig gave a tangible demonstration of the effectiveness of hydrogen fuel cells as a mobile energy source. With advances in mobile plant design, clean gas fuels can decarbonise power supply in more remote locations.

**Future Prospects / Hurdles**

In hybrid microgrid deployments, hydrogen is proving to be the reliable, clean alternative to diesel generators. The high cost of hydrogen can be offset by integrating hydrogen systems with Solar PV or wind.

- **Fuel Policy**: Fuel cell units combined with rural hydrogen supply offer an alternative to rural grid reinforcement and can help meet farm and rural power supply needs.
- **Regulation**: While robust regulation for hydrogen transport is essential, it has been used as an industrial gas for over a century. Policy should support rural hydrogen supply.
- **Infrastructure**: Investment in off-grid green gas transport and refuelling capability will boost rural deployment of hydrogen and adoption in rural applications.
- **Viability**: For hydrogen to replace subsidised red diesel, costs must be reduced and a policy framework created for diesel phase-out and investment in alternatives.

**Market Expectation**

TCP is at the forefront of modifying site equipment to move away from fossil fuel. Advances in smaller fuel cell technology have raised expectations for hydrogen in rural applications. However, this is curtailed by cost, supply and operational viability concerns.

**Future Deployment**

TCP is already deploying smaller hydrogen generation units in rural site locations. As hydrogen fuel supply is scaled up and costs fall, efforts to boost rural decarbonisation will require funding to facilitate rural use of clean gas fuels. Investment in local, decentralised hydrogen generation offers an alternative to rural power grid extension.

## Farm Transport and Agricultural Machinery

### *8.3.2 JCB Hydrogen Internal Combustion Engine*

JCB is addressing specialist vehicle emissions with hydrogen engine technology, which cuts emissions in heavy non-road vehicles. JCB's engine aims to future-proof construction and farm vehicles without the complexity or inflationary impact of the alternatives.

**Background**

The agricultural sector, where diesel powertrains provide high-power output and durability, faces increasing pressure on its emissions. Limitations of battery systems on farms include weight, cost and refuelling times. With its hydrogen engine, JCB can transform rural diesel replacement while facilitating simple, quick, efficient gas refuelling. In its 80th year, having built a million back-hoe loaders, hydrogen powertrains are now a JCB option.

**Technology**

Diesel replacement for farm or non-road vehicles is closer with JCB's H2 internal combustion engine (ICE). Developed with proven technology in existing engine architecture JCB's engine:

- Emits zero CO2 during operation - water vapour is the primary byproduct.
- Matches diesel performance, without compromise on power or reliability.
- Offers fast refuelling, a critical operational advantage over BEV charge times.
- Provides adequate energy density for heavy workloads and rural deployment.

**Key Achievement**

Development of JCB's prototype H2 ICE for loaders and telescopic handlers has validated the potential for such H2 powertrains. The company is addressing delivery of green H2 fuel to sites with distribution pods for mobile hydrogen refuelling.

**Decarbonisation**

JCB's H2 engine addresses key challenges for deployment on farms or construction sites:

- **Emissions:** H2 ICE eliminates CO2 emissions during vehicle deployment.
- **Capability**: more flexible and avoids operational issues associated with BEVs.
- **Infrastructure**: use of ICE skills and supply chain, limits disruption and cost.
- **Adoption**: familiar technology benefits operators and maintenance teams.

**Future Prospects / Hurdles**

However, hydrogen IC technology faces regulatory and other hurdles:

**Fuel Policy**: JCB is offering a viable alternative to the national electrification focus that is ill-suited to construction, farming and rural needs. The H2 ICE should be classified as net-zero emissions for use in NRMM, to unlock future innovation and deployment funding.

**Regulation**: addressing regulatory hurdles over H2 transport and rural use will facilitate gas fuel use in areas without grid coverage that require virtual delivery pipelines.

**Infrastructure**: investment in gas fuel supply (inc. green H2) and rural refuelling capability is needed to boost adoption and on-farm demonstration of gas vehicles.

**Viability**: H2 is expensive compared to subsidised red diesel. A policy timetable is needed for both (red) diesel phase out and rural access to gas fuels, including H2.

**Market Expectation**

Hydrogen powertrains can reduce emissions for construction sites and on farms. JCB has the vision and influence to lead the adoption of green H2 fuel in farm vehicles, complementing other rural low-carbon vehicle technologies, including robotics.

**Future Deployment**

JCB's H2 ICE meets the specific needs of heavy-duty vehicles, ill-suited to battery or fuel cell powertrains. Combining sustainability with practicality, JCB should encourage other OEMs to develop rural H2 production and delivery solutions.  As infrastructure and supply are scaled-up and costs come down, H2 can support rural decarbonization but requires policy flexibility to facilitate rural transition to clean gas fuels.

### *8.3.3 Toyota*

A global leader in hydrogen fuel cell vehicles, Toyota developed its Hilux prototype at its engineering plant in Derby, with support from the UK's Advanced Propulsion Centre. The vehicle has been trialled in UK and other markets.


*Figure 19: The Toyota Hydrogen Hilux with a JCB Hydrogen Fueller*

**Background**

Toyota has pioneered hydrogen propulsion globally. Aware of power supply and operability concerns for BEVs in rural applications, Toyota is developing fuel cell powertrains for use in circumstances where hybrid electric, plug-in and BEV alternatives may be less viable.

**Technology**

The Hilux utility vehicle project was initiated at the Burnaston plant, with initial prototypes produced in 2023. Core drivetrain elements are from the Mirai, with hydrogen stored in high-pressure fuel tanks. The compact 128kW fuel cell produces electricity with zero tailpipe emissions. Excess and regenerated electricity is stored in a small hybrid battery mounted in the rear load deck (for the purpose of prototyping). Fuel cells have potential beyond road transport. Toyota is installing hydrogen powertrains in materials handling equipment, marine applications and stationary power generators.

- **Emissions:** fuel cells eliminate $CO^2$ and harmful emissions during operation.
- **Capability**: Hilux is robust, with 350 mile range and good load carrying ability.
- **Infrastructure**: linking fuel cell vehicles to rural fuel supply will help deployment.
- **Adoption**: Hilux can showcase fuel cell capability in a practical off-road vehicle.

**Key Achievements**

Toyota's prototype is close to matching the performance of fossil fuel powered Hilux variants, while protecting its rugged reputation. The project team are undertaking performance and durability trials to determine market demand. A key requirement for Hilux and industrial applications such as fork lifts will be competitive capex and opex costs.

**Future Prospects / Hurdles**

In sectors where BEV powertrain shortcomings will limit uptake, there is scope for fuel cells. Alongside cost, challenges include:

- **Fuel Policy**: more impetus is required for off grid hydrogen supply for internal combustion and fuel cell vehicles. An alternative to rural electrification can they address grid capacity issues?
- **Regulation**: regulatory support is required for distribution of hydrogen fuel to facilitate rural use, including through virtual delivery pipelines.
- **Infrastructure**: investment in off-grid green hydrogen refuelling capability is needed to boost the ability to replace diesel versions.
- **Viability**: Among non-BEV diesel replacement options, locally produced gas fuels can help replace diesel for rural applications.
- **Market Expectation** Fuel cells powertrains sales potential may be constrained by affordability with low margin businesses. Further development will bring down unit costs and enhance robustness for rural deployment.

**Future Deployment**

The Hilux is a significant part of Toyota's low-emission evolution. Utility vehicles with similar powertrains offer an alternative to BEVs for power constrained rural areas. With advances in modular fuelling systems, it should be possible to deploy hydrogen fuel in rural off-grid locations. Toyota is working with Fuel Cell Systems on hydrogen refuelling solutions, as well as companies like Energy Oasis on smaller scale on-site hydrogen generation.

## 8.4 Biomethane

### *8.4.1 AD Fuels*

AD Fuels is one of the leading European transporters of gas fuels including bioCNG and bioLNG, with a large truck fleet. They are also involved in the transport of biogenic $CO_2$ and are exploring the scope for virtual rural hydrogen distribution.


*Figure 20: AD Fuels Truck*

With circa 50% of the UK beyond the reach of the national gas grid network, there are limitations on the ability of the network to develop the reach for rural gas fuel supply, as is currently available for fossil fuels. Hence, there is a need for a virtual pipeline network for the green gas fuel sector.

**Off-Grid Green Gas Supply**

AD Fuels has been expanding rapidly, to meet demand for green gas fuels. They are the UK's leading independent road haulage provider of Liquified Natural Gas (LNG), Compressed Natural Gas (CNG) and Liquified Carbon Dioxide (LCO2).

Since 2014, AD Fuels have been transporting bioLNG for gas grid injection and are a trusted partner to many biogas producers across the UK AD sector.  This has opened the door for delivery of other green gases including biogenic $CO_2$ from AD plants.

AD Fuels supports OEMs involved in gas powertrains including New Holland and are involved in:

- Delivery of fuel from AD plants to farms operating gas powered tractors
- Developing on-farm supply, storage and distribution systems for gas fuels
- Supporting development of on-farm refuelling systems to meet farm needs.

**Future Development**

The expertise AD fuels have developed in working with BioCNG on farms can be transferred to other gas fuels including safe, cost-effective transport of compressed or liquified hydrogen for off-grid use. AD Fuels is developing the user case for effective rural gas fuel deployment including hydrogen.

### 8.4.2 New Holland

UK farmers need affordable, non-inflationary powertrain alternatives to diesel. New Holland's T6 (180hp) and T7 (270hp) Methane Power tractors are the world's first 100% gas powered tractors, designed and manufactured in the UK.

*Figure 21: New Holland Biomethane Tractor*

## Background

With increasing pressure to reduce vehicle emissions, biomethane (bioCNG) offers a viable alternative to diesel. Reducing reliance on fossil fuels requires robust, reliable and efficient powertrains, to deliver power and torque for cultivation and other tasks. New Holland’s gas tractors are powered by an adoption-ready, clean-burning fuel.

## Technology

An alternative to traditional diesel tractors with comparable power, T6 and T7 gas tractors can deliver up to 30% lower running costs while curbing on-farm $CO_2$ emissions:

- BioCNG ready-to-use renewable fuel can be supplied by on-farm biogas plants.
- Negative $CO_2$ emissions are possible with BioCNG from carbon negative sites.
- The high torque engine produces 99% less particulates than comparable diesel.
- Post combustion exhaust clean-up is simpler and cheaper than diesel tractors.

## Key Achievement

The New Holland T6 was the first production gas tractor (launched in 2023) after a decade of development supported by the UK’s Advanced Propulsion Centre (APC). Performance is comparable to diesel, offering farmers a robust and versatile machine.

## Decarbonisation

The novel bioCNG IC engine addresses key challenges for deployment on farms:

- **Emissions:** Emissions reduced by at least 80%, if using farm supplied biomethane.
- **Capability**: able to meet farm operational needs, unlike the BEV alternatives.
- **Infrastructure**: manufactured on existing production line and easy to maintain.
- **Adoption**: can replace diesel but requires a plan to phase out red diesel subsidy.

## Future Prospects / Hurdles

The main challenge is access to gas fuels in rural areas that have no gas-grid access:

**Fuel Policy** with limitations on-farm vehicle electrification potential (cost, weight and grid capacity), bioCNG should be endorsed as an interim fuel suited to farming needs, that can initiate replacement of red diesel and transition to cleaner fuels.

**Regulation** regulatory flexibility is required on gas fuel transport for in-field use in mobile refuelling systems. Gas tractor OEMs must address the IC powertrain ban.

**Infrastructure** investment in rural, on-farm gas distribution and in-field refuelling capability, requires funding support as part of agriculture's net zero transition.

**Viability** Despite being adoption ready, bioCNG can't compete with the cost of subsidised red diesel. Faster adoption requires a red diesel phase-out plan.

**Market Expectation**

BioCNG can curb farm vehicle emissions alongside other low-carbon powertrains but more support is required for rural gas fuels including local infrastructure, to help pave the way for wider deployment of hydrogen IC engines.

**Future Deployment**

On-site (off-grid) renewable energy is needed to power farm machinery. Replacing fossil fuels will require a mix of battery, biofuel and gas powertrains, plus fuel supply systems suited to farming operations. New Holland's gas tractor range offers a practical solution for farms looking to cut emissions and future fuel costs, accelerating a reduction in farming's reliance on fossil fuels.

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Cenex

Holywell Building,

Holywell Park,

Ashby Road,

Loughborough,

Leicestershire,

LE11 3UZ

**Tel:** **+44 (0)1509 642 500**

**Email:** **info@cenex.co.uk**

**Website:** **www.cenex.co.uk**

**Twitter:** **@CenexLCFC**

**LinkedIn:** **Cenex**