ELEMENT1

Leading the construction industry towards a zero emissions future

RDR2-05-BAM

March 2025

Contents

1. Executive summary

Figure 1 Demonstration event attendees

Purpose of the report

This report outlines the ELEMENT1 project (July 2023 to March 2025), supported by the Red Diesel Replacement Phase 2 Programme under the Department for Energy Security & Net Zero (DESNZ) Net Zero Innovation Portfolio (NZIP). The initial awarded grant is £4,872,653, final grant is £4,539,897 and total project cost is £6,227,914. The project aims to eliminate diesel fuel use on UK construction sites by providing a scalable, commercially viable, and globally applicable low-carbon alternative based on hydrogen.

Project approach

ELEMENT1 is an ambitious innovative approach to help reduce the construction industry's reliance on diesel. The diverse consortium is committing to collaborating to deliver a significant body of work in a short timescale. Within the project, the four modified excavator prototypes provide an opportunity to learn as a team and share knowledge with the wider industry. The project will pave the way for further research and development work and greater collaboration, including working closely with OEMs to deliver benefits to the construction industry.

Project overview and problem outline

ELEMENT's project addresses the challenge of replacing diesel fuel on construction sites with hydrogen and electric-powered alternatives.

- Hydrogen powered plant may be better suited to remote/rural areas where fuel deliveries can be effectively managed
- Electric powered plant may be optimal in urban areas due to available charging infrastructure and tighter emissions/noise restrictions.

Hydrogen and electric equipment are not yet commercially available and adopted at scale. Given the significant investment in the existing fleet of diesel-fuelled plant, a phased transition is necessary. To address this, ELEMENT1 developed dual fuel technology to convert existing construction equipment to use hydrogen, displacing some diesel and reducing greenhouse gas emissions. By developing and deploying key end-to-end infrastructure, ELEMENT1 facilitates the introduction of 100% hydrogen-powered equipment, such as generators and plant.

ELEMENT1's achievements

- An end-to-end solution supplying green hydrogen to sites, meeting sector requirements for purity and pressure, on-site storage, and refuelling hydrogen-powered equipment
- Converted four items of construction equipment to dual fuel
- Sourced commercial generators that operate using hydrogen
- Addressed barriers to hydrogen use on-site, including skills and training needs, health and safety, and other regulatory issues
- Conducted a full demonstration of the end-to-end system on several construction sites
- Assessed site productivity and end-to-end emissions from dual fuel-powered equipment against a baseline of diesel-only equipment.

Key findings and results

ELEMENT's first demonstration took place at BAM's Victoria North project in Manchester, from October 2024 until March 2025, with modified excavators also deployed at two other sites.

- Excavators: Four excavators converted to dual fuel by ULEMCo. Plantforce provided two Kobelco SK210 machines, and Flannery provided two CAT320 machines
- Hydrogen Power Unit (HPU): GeoPura's HPU replaced a diesel generator at the Victoria North site, supplying power to the site office, welfare, and drying room
- Dispenser: GeoPura deployed a hydrogen dispenser powered entirely by the HPU, marking their first off-grid hydrogen refuelling solution
- Mobile Refueller: ULEMCo developed HyTanka®, a mobile refueller supplying hydrogen to site plant.

Emissions and Productivity Data

We collected emissions and productivity metrics to evaluate the sustainability and efficiency of hydrogen-fuelled excavators compared to conventional diesel-fuelled machinery. Real-time sensors and data loggers captured emissions metrics such as CO_2, NO_x, and fuel usage, while productivity metrics focused on machine efficiency, work output, number of cycles, engine power, and maintenance frequency. The data confirmed that hydrogen dual fuel excavators match the performance of diesel-only machines under similar conditions.

Site-specific factors like work activities, weather, terrain conditions, plant downtime, and duty cycles were recorded daily. Site diary forms provided additional qualitative data. Regular updates ensured the data was refined and accurate. The collected metrics were analysed and compiled into reports for consortium partners' validation.

Conclusions

We developed an end-to-end model for dual-fuel-construction equipment, including hydrogen production, delivery, storage, and on-site supply, deployed on three construction sites.

Diesel Displacement:

- Diesel displacement is defined as the percentage of energy coming from hydrogen rather than diesel over the given time period of use.
- The HPU displaced 100% of the diesel generator used to power the site office and welfare units at Victoria North.
- On the modified excavators, during the physical demonstration phase of the project:
- The highest daily diesel displacement rate was 30% on a Kobelco machine at Brighouse on 6 March 2025
- The maximum daily diesel displacement was 15% for the CAT320 machines
- Overall, the average daily diesel displacement of the excavators including the periods of the operation when they run out of hydrogen, was around 10% for the CAT320 machines and 20% for the Kobelco SK210, however all machines showed an upward increasing trend over the period due to improvements achieved through optimisation of the engine control unit and software.

Refuelling:

- As hydrogen use on construction sites becomes more common, reliance on specialist resources for refuelling will decrease, optimising dual fuel running
- Refuelling specialists from GeoPura and ULEMCo performed this task, with occasional supervised refuelling by plant operators, leading to gaps in dual fuel running due to specialist availability
- The mobile refueller, HyTANKa®, faced development challenges but was successfully deployed in the final two weeks of the project.

ELEMENT1 demonstrates that the use of hydrogen as a fuel, with dual fuel conversion for construction equipment, is a viable approach to decarbonising the industry.

During the project pilot 291kg of hydrogen was consumed by the excavators and 1,283 kg of hydrogen was consumed by the HPU (displacing a diesel-fuelled generator used to power a remote site office and welfare facility). In total 1,574kg hydrogen was consumed during this trail. Assuming that 1kg hydrogen displaces 3.27 litres diesel in excavators, and that 1kg hydrogen used in the HPU produces the same amount of energy as 5.9 litres diesel in a conventional generator 8,586 litres diesel were saved (equivalent to 23.0 tonnes CO_2).

Diesel displacement rates of up to 30% were achieved for the modified excavators. If this figure was applied across a thousand items of plant working 1,800 hours annually CO_2 emissions would be reduced by up to 5,600 tonnes per year and a much larger reduction would be possible if applied across the rest of the UK construction industry. Further Research & Development (R&D) funding will enhance results and scalability.

1.1. Graphical abstract

Figure 2 Project timeline, key development activities and outcomes

Glossary/Abbreviations/Acronyms

ADR - Agreement concerning the International Carriage of Dangerous Goods by Road

ADT - Articulated Dump Truck

ATEX - ATmosphères EXplosibles

COMAH - Control of Major Accident Hazards Regulations

CRL - Commercial Readiness Level

DSEAR - Dangerous Substances and Explosive Atmospheres Regulations 2002

EC79 - Regulation (EC) No 79/2009 on type-approval of hydrogen-powered motor vehicles

ECU - Electronic Control Unit

FEA - Finite Element Analysis

FEED - Front End Engineering Design

FMEA - Failure Mode and Effects Analysis

FTE - Full Time Equivalent

GHG - Green House Gas

HAR1 - Hydrogen Allocation Round 1

HAZOP - Hazard and Operability Study

HGV - Heavy Goods Vehicle

HMI - Human Machine Interface

HPU - Hydrogen Power Unit

HSE - Health & Safety Executive

HVO - Hydrotreated Vegetable Oil

HyTanka® - Mobile hydrogen refueller developed by ULEMCo

ICE - Internal Combustion Engine

IVA - Individual Vehicle Approval

MCP - Manifold Cylinder Pallet

MEGC - Multi Element Gas Container

NO_x - Nitrogen Oxides

NRMM - Non-Road Mobile Machinery

OBD - On-Board Diagnostics

OEMs - Original Equipment Manufacturers

PDI - Pre-Delivery Inspection

PED - Pressure Equipment Directive (PED 2014/68/EU)

PEMS - Portable Emissions Measurement System

PM - Particulate Matter

Port-a-Bull™ - ULEMCo Auxiliary Tank Pack

PPE - Personal Protective Equipment

RAMS - Risk Assessment Method Statements

RDR - Red Diesel Replacement

SHEQ - Safety, Health, Environment and Quality

Sox - Sulphur Oxides

THC - Total Hydrocarbons

TPED - Transportable Pressure Equipment Directive (TPED 2010/35/EU)

TRL - Technology Readiness Level

TRU - Transpennine Route Upgrade

UKCA - UK Conformity Assessed

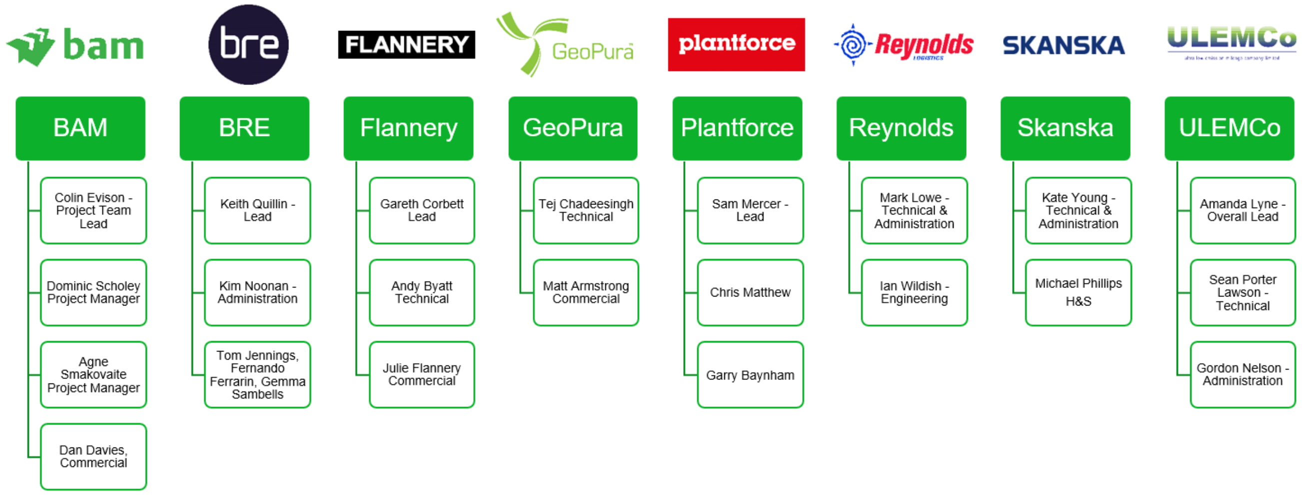
WP - Work Package

2. Background

2.1. Project consortium

Several partners were involved in Phase 1 of the RDR Programme. They came together to form the ELEMENT1 consortium, crystalised by a ‘Hydrogen in Construction’ event held at Skanska’s office on 17 November 2022. The consortium contained the expertise and capability to design, develop and deliver an end-to-end hydrogen fuel solution for construction sites.

Figure 3 Project consortium and key team members



BAM - Tier 1 civil engineering contractor, project lead - providing demonstration sites

SKANSKA - Tier 1 civil engineering contractor, advice and guidance for the end-to-end solution

Flannery - Plant hire company. Provision and operation of construction plant

Plantforce - Plant hire company. Provision and operation of construction plant

Reynolds - Experts in the safe movement of fuels, liquids and gases. Hydrogen transport logistics

GeoPura - Power generation through zero-emission fuels and clean power technologies. Hydrogen production and dispensing

ULEMCo - Advancing sustainable transport solutions, on replacing diesel with hydrogen. Using their dual fuel technology to convert construction plant

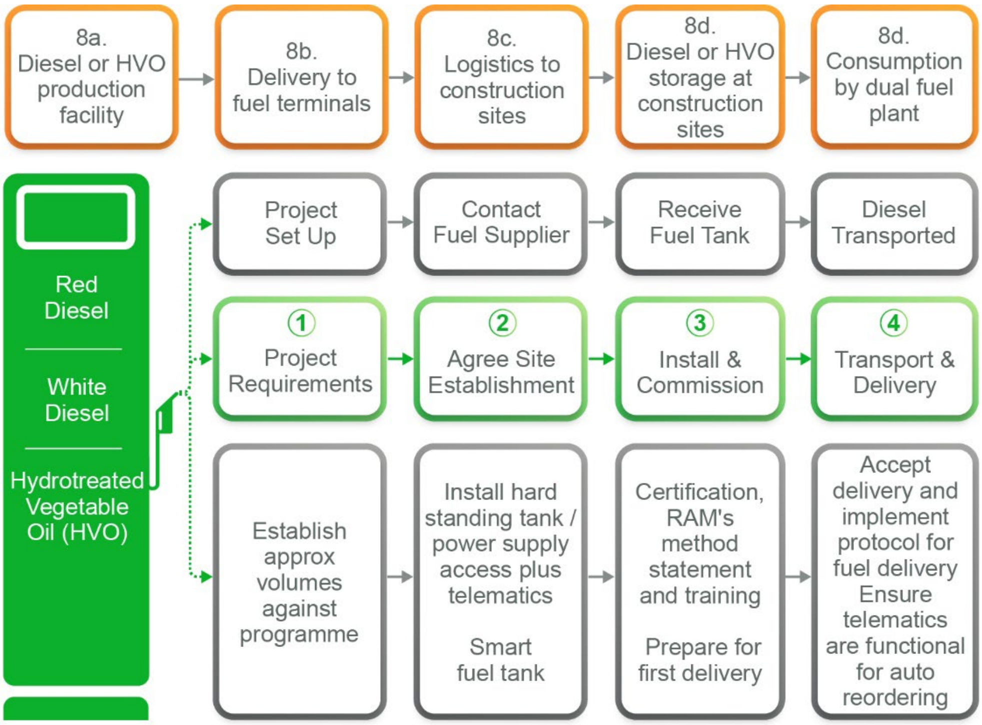
BRE - Research and Technology Organisation. Independent assessments and metrics

2.2. Project background

The UK infrastructure construction sector uses >1bn litres/annum diesel:

- The wider construction sector accounts for approximately 14% of the UK's diesel consumption (ONS, 2024)
- based on an analysis of diesel usage on BAM sites carried out under the RDR programme about two-thirds of this diesel is used to power construction plant with about one-third used to fuel generators that produce electricity for power, lighting, and heating.
- Approximately 14 million tonnes of CO_2 are emitted annually (ONS, 2024).

Figure 4 Existing diesel supply chain process map



There are 25-30,000 items of operated diesel-fuelled plant (5t and greater) in the UK (CPA, 2021). Key machine types are:

- excavators (>50%)
- bulldozers (12%)
- dumpers and Articulated Dump Trucks (26%)
- telehandlers and others.

Most items are owned by hire companies, with contractors hiring items of plant equipment as needed, either fuelled or with a separate fuel supply arrangement. Leading plant hire companies replace their assets every 5-7 years.

Construction plant manufacturers are currently developing both hydrogen and electric-powered alternatives to diesel plant. The likelihood is that both forms of power will be needed in addressing the wide range of scenarios for site construction:

- Hydrogen-powered plant may be better suited where a grid connection is not available and tethered or battery powered plant is not feasible
- Electric powered vehicles may be optimal in urban areas due to available charging infrastructure and tighter emissions/noise restrictions.

Hydrogen and electrically powered machines are not immediately available on a commercial basis at scale. Given the significant capital investment in the existing fleet of diesel-fuelled construction equipment, a phased transition to these new technologies will be necessary.

The ELEMENT1 approach recognises and uses this capital investment. Converting this fleet to run on dual fuel enables the continued use through the remaining service life. The approach also enables infrastructure for hydrogen production, supply, on-site storage and distribution to be rolled over a period of years in line with plant conversion. In turn, it mitigates construction contractors' and plant owners' risks in converting to a hydrogen-only solution as plant can operate on diesel should hydrogen not be available, or supplies be interrupted.

ELEMENT1 is working on a scenario where, by 2040, all plant and generators (other than some legacy machines) operating on infrastructure projects will be 100% hydrogen or electric powered (introduced from about 2030). Hydrogen-powered generators will be rolled out at scale from 2025. Conversions to dual fuel will extend the life of the existing fleet and improve the impact of new equipment while providing a sustainable business case for companies providing hydrogen and supporting supply, storage, distribution and refuelling solutions for construction.

Our scenario indicates that up to 20,000 items of plant will be suitable for dual fuel conversion between 2025 and 2040. We anticipate that hydrogen will become a commodity, meeting quality, pressure and embodied carbon requirements. Supply, storage, and distribution solutions will be provided using business models similar to those for diesel.

3. Project Overview

3.1. Scope, aims and objectives

The ELEMENT1 project aimed to develop, demonstrate, and assess an end-to-end solution for using hydrogen as an alternative to diesel on construction sites. This includes the manufacture, supply, distribution, and use of hydrogen to power construction plant and equipment.

The end-to-end solution includes:

- Off-site hydrogen production by GeoPura (meeting sector requirements for purity and pressure)
- Supply of green hydrogen to construction sites, and on-site storage and distribution to operating construction equipment involving:
    - Hydrogen production via electrolysis using renewable electricity (green)
    - Off-grid hydrogen compression (i.e. no electrical connection to grid)
    - Multi-Element Gas Containers (MEGC) moved by Reynolds Logistics
    - ULEMCo bowser (HyTANKa®)
    - Protocols for hydrogen delivery, compression and dispensing
- The conversion, by ULEMCo, of four excavators supplied by Flannery and Plantforce (non-road mobile machinery (NRMM)) from solely diesel power to hydrogen dual fuel. This was achieved using ULEMCo's globally unique, patented approach, which allows hydrogen to be mixed with diesel directly in a conventional engine. The hydrogen is supplied from onboard gas tanks, displacing a significant proportion of the liquid fuel.
- The use of 100% hydrogen fuelled generators on site supplied by GeoPura
- Full demonstration on BAM construction sites and assessment by BRE (against a baseline of plant operating using diesel only) of the end-to-end solution on operating construction sites
- The identification of barriers to hydrogen fuel use on-site including skills and training needs, Health & Safety and other regulatory issues.

3.2. Project schedule and work packages

ELEMENT1 developed and demonstrated an end-to-end solution for hydrogen production, supply, storage, distribution and use, delivered in 7 Work Packages (WP). We also fully demonstrated and assessed the end-to-end solution on an operating construction site.

WP1: Stakeholder interaction, exploitation and dissemination. WP1 brought together participants and stakeholders to help target project activity, support business model development.

WP2: Requirements and metrics. WP2 involved R&D work to identify requirements for the end-to-end solution and its component parts. It addressed the scale/scope of the demonstration and requirements for the end-to-end solution. It also addressed KPIs and metrics needed to quantify and assess benefits and challenges.

WP3: Hydrogen production and supply to site. Based on stakeholder needs, this WP identified hydrogen requirements and barriers impacting production and supply capability. Based on these requirements R&D work was undertaken to refine the design and capabilities of GeoPura's off grid hydrogen compression solution to enable hydrogen to be stored and supplied at the optimum pressures for refuelling plant on-site. A proof-of-concept off-grid hydrogen compressor was also developed and tested prior to demonstration in WP6.

WP4: Hydrogen road transport, on-site storage, distribution and on-site refuelling. This WP developed a solution to transport and store hydrogen at pressures needed to optimise construction plant refuelling efficiency. It also included developing a bowser to dispense hydrogen to construction plant operating on site.

WP5: Conversion of construction plant to dual fuel. This involved work to design systems (vehicle-specific engine conversion, on-board fuel storage) to enable the conversion of target construction plant to dual fuel use. Four excavators were converted to dual fuel (including optimisation and testing) ahead of the demonstration phase of the project in WP6. The conversion of the excavators was conducted by ULEMCo with diesel supplied and paid for by BAM. This included two Kobelco SK210 machines supplied by Plantforce and two Caterpillar 320 machines supplied by Flannery.

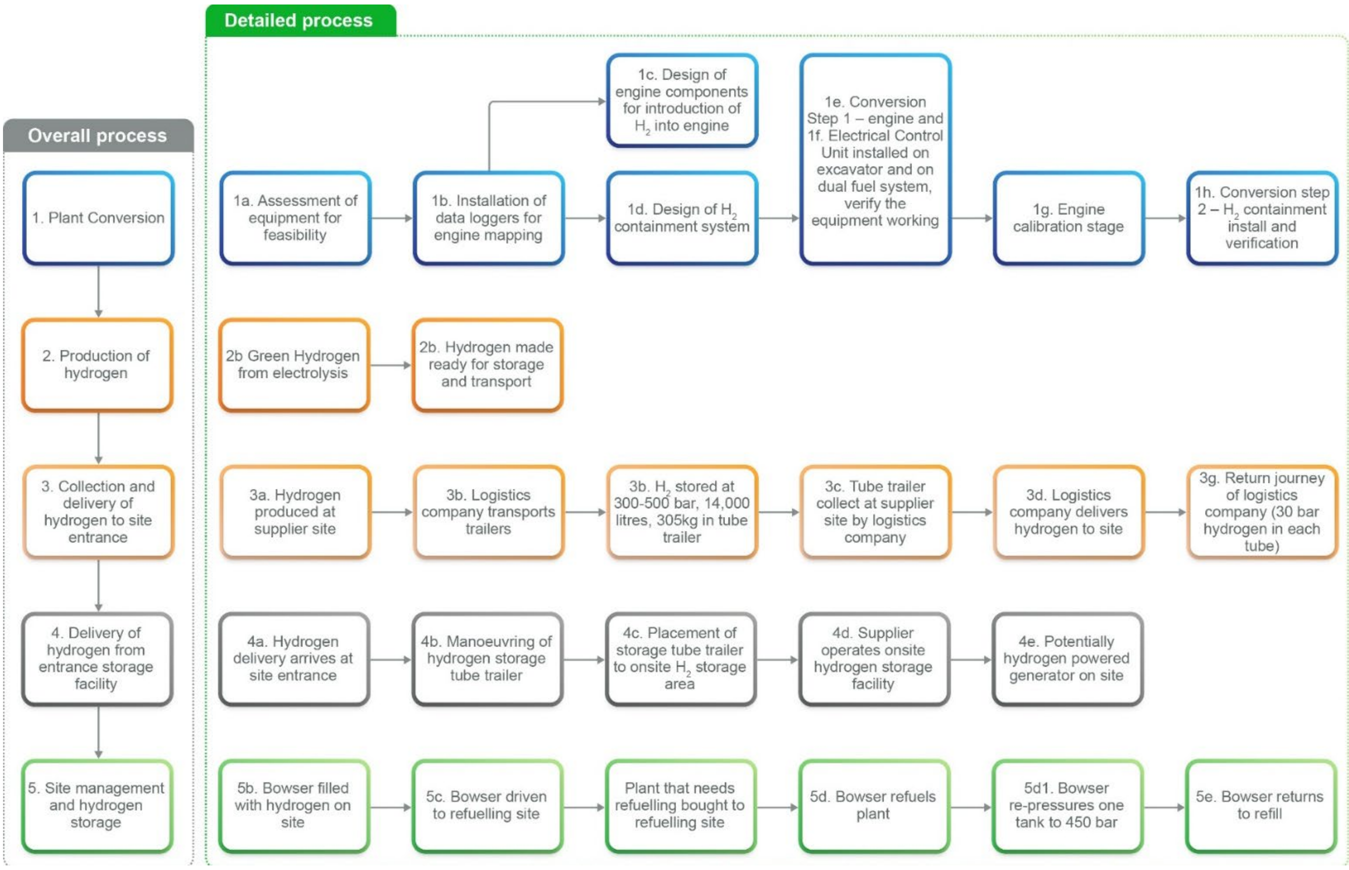
WP6: Conduct and assess end-to-end demonstration. This WP delivered a full demonstration of the end-to-end solution enabling the deployment of dual fuel plant operating on construction sites. The demonstration included quantified assessments of productivity and efficacy, emissions, and issues such as training and skills need.

WP7: Project management, coordination and reporting. This included overall project coordination, planning, and monitoring of project progress. It also involved risk management and mitigation, as well as financial management. Additionally, it ensured coordination between participant organisations, construction teams on demonstration sites, and through hydrogen production and associated supply chain partners.

4. Design Considerations, Technical Development and Challenges

4.1. End-to-end process design

Figure 5 Overall design



HAZOP(s) and any other Health & Safety considerations

The use of hydrogen on construction sites is a novel concept, and construction personnel have limited experience handling this fuel. Consequently, there are currently no specific Health & Safety standards or regulations for using hydrogen as a fuel on construction sites. However, existing regulations like the Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) and The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009 apply to the production, storage, and transport of hydrogen. As hydrogen is classed as a dangerous substance, the regulations for storing and transporting hydrogen in the UK must be followed. Consequently, any construction site using hydrogen as a fuel must comply with these requirements.

If the amount of hydrogen on the construction site is five tonnes or more then the COMAH Regulations apply (The Control of Major Accident Hazards Regulations 2015. Guidance on Regulations L111 (hse.gov.uk)). This regulation provides information on the general duties of operators of all establishments, safety reports, emergency plans, functions of the competent authority and action to be taken following a major accident.

For the project demonstrations, we designed new construction machinery with reference to ISO 12100 Safety of machinery — General principles for design — Risk assessment and risk reduction, which outlines basic terminology, principles, and a methodology for achieving safety in machinery design. Certification to ISO standards, including ISO 12100, ISO 9001, and ISO 4001, helps construction organisations demonstrate assurance and promote Health & Safety.

Throughout the project, we maintained a risk register which was a live document detailing all the risks identified throughout the project. The risk register identified type of risk, owner of the risk, description of risk, impact/consequence, methods for mitigating risks and whether the risks had been resolved. See Section 8 for more details.

For the site deployment for ELEMENT1, we decided that the handling of the hydrogen would remain with those partners who have organisational and personnel knowledge and experience of handling it in a safe manner. As hydrogen becomes more widely used in construction, it is expected that construction site personnel will be suitably trained to re-fuel plant themselves in a similar way that there is widespread capability of handling diesel, and HVO liquid fuels.

4.2. Overview of technical development of the solution/system

Consents, permitting applications and other regulatory approvals / considerations

Hydrogen storage on construction sites is governed by ATEX, DSEAR and PED/TPED regulations. GeoPura, with their significant experience in the use and storage of hydrogen has designed the storage compounds to comply with these regulations. Currently, access to these compounds is restricted to GeoPura personnel only. This will no doubt change in the future when the contractor’s competency of handling hydrogen improves.

The movement of the hydrogen delivery vehicles using MEGC on the HGV trailer was planned and executed by Reynolds Logistics. This type of transport task is within their normal operation parameters and did not present any challenges. Reynolds was engaged in the planning of the site layouts and visited the site in Manchester to confirm that there was sufficient space and suitable ground preparation for the vehicle movements.

4.3. Conversion of machines to dual fuel (WP5) - ULEMCo

ULEMCo was previously involved with Phase 1 of the Red Diesel Replacement scheme by leading project ZECHER (Zero carbon hydrogen construction equipment for real-world use) in 2022-23. On this project, ULEMCo successfully converted a Soilmec SR30 piling rig operated by Cementation Skanska to run on hydrogen dual fuel. The dual fuel system was evaluated at Skanska’s Bentley Works site in Doncaster and was assessed on both diesel and HVO fuels.

The machine was later demonstrated on HS2's Euston site in April 2023 to install four 30-metre piles over three days.

Machines to be converted and rationale

20tonne, 360-degree excavators are a common size of excavator in the UK plant hire fleet and are the 'workhorse' of the construction industry. For example, Flannery have 397 machines in the 20-25t class which represents around 30% of their large excavator fleet within a total machine fleet of 7900 machines. We chose to convert these machines to dual fuel because, once successfully demonstrated, this would lead to the largest quantity of machines to be targeted for conversion following completion of the ELEMENT1 project.

Hydrogen, stored in tanks on the excavators, was injected into the engine air intake and the liquid fuel injection rate modified accordingly using an additional Electronic Control Unit (ECU) fitted to the machine.

Figure 6 Plant conversion

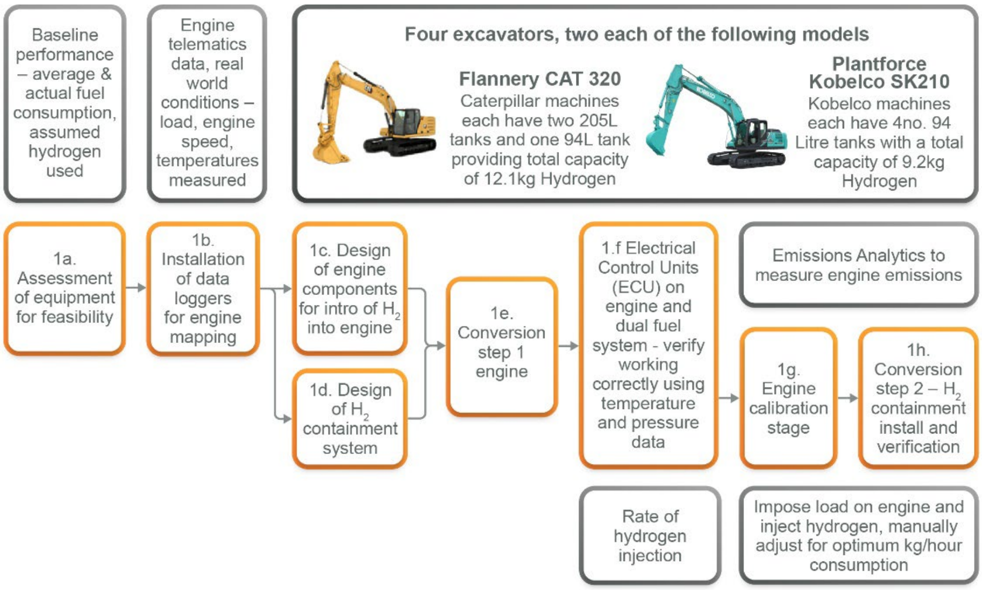


Figure 7 One of the CAT320 machines converted for dual fuel

Figure 8 Optimum safety was the driver for the Kobelco SK210 excavator tank pack design

Health & Safety considerations

ULEMCo designed tank packs are always designed with safety in mind. All fabricated metal components are made to avoid sharp edges and engineering drawings contain clear instructions for manufacture.

The tank packs for the excavators were designed to eliminate risks for those working on top of the excavators, specifically avoiding snagging or trapping points for clothing or limbs. New handrails were designed as a part of the tank packs to replace old grab points or introduce new ones to ensure ease of access and optimum safety.

The tank packs were designed to maintain operators' field of vision and not interfere with the existing 360° camera systems.

Being located above the machines exhaust bays increases fire risks. To mitigate these risks, we diverted exhaust gases away from the tanks or added heat shields to the packs to prevent excessive heat reaching the cylinders.

ULEMCo is aware that collisions with plant equipment are real risks on construction sites. To prevent these collisions jeopardising the hydrogen systems, the tank packs were designed to fit within the footprint of the excavator body. The packs were also designed to withstand 10G vertical and 5G lateral load cases in line with construction machinery standards.

Maintenance and Serviceability

Due to the importance of maintenance for such valuable assets, the tank packs were designed to allow most maintenance to be conducted without removing the tank packs. For more substantial works where the packs need to be removed, lifting points are fitted to the packs allowing them to be easily craned on and off when needed.

Fill time for the hydrogen is around a 10-minute operation every two days

Hydrogen Containment Development

As we had no input from the excavator OEMs, we developed the hydrogen containment through reviews with plant hire companies, with multiple site visits to measure the excavators and assess installation locations.

To determine the hydrogen requirements for the machines, dataloggers were installed to record engine parameters. ULEMCo's Controls and Calibration team used this to replicate the engine map, and used a desktop calibration to estimate hydrogen consumption. The figures were fed back to the design team enabling them to finalise the designs.

Test jigs of the tank pack base plates were fabricated to confirm hole positions and ensure features on the machines would not interfere with the containment pack.

Lessons learned and justifications for choices made

During the project, routine checks revealed damage to a CAT machine's body structure. The machine was quarantined and returned to Flannery for a detailed assessment. ULEMCo and Flannery collaborated to design and fit an additional structure to support the added weight of the tank pack. This solution was replicated on the second CAT machine which was yet to start work in the trial. The modification resolved the issue and stabilised the hydrogen containment on the excavators.

This change was implemented at the start of 2025 and was regularly checked on both CAT machines until the project end. No similar issues occurred on the Kobelco machines. This was due to the different structures on the machines and the varied footprints of the two hydrogen systems. Future excavator conversions could benefit from greater engagement with the machine OEMs to ensure an effective and reliable solution is achieved consistently.

Regulatory approvals/considerations

Due to the absence of UK regulations for NRMM hydrogen systems at the time of this project, ULEMCo designed the hydrogen systems in line with existing regulations for road use, specifically EC79/IR35. They also consulted with key contacts in the plant machinery sector to understand typical construction machinery build standards. These discussions helped ULEMCo to design hydrogen systems capable of withstanding 10G vertical and 5G lateral loads, as well as requirements set out in EC79 using sound engineering practices.

4.4. Hydrogen storage and distribution on-site (WP4)

On-site storage – GeoPura

The hydrogen gas was stored on site in one of two Reynolds MEGCs, each capable of storing over 300kg when fully filled to 300Bar. This large quantity of flammable gas required separation from ignition sources, and protection from vehicular impacts and sabotage. Clearance distances were determined using GeoPura modelling based on DSEAR regulations.

Bowser – ULEMCo

ULEMCo's prototype hydrogen fuel bowser, HyTANKa®, can carry 140kg of hydrogen at 370Bar. HyTANKa® is built upon a construction specification DAF LF chassis and has passed all necessary tests and inspections for road going safety. Future evolutions of this vehicle are expected to have different specifications.

Bowser – GeoPura

The HyTANKa® was filled at one of GeoPura's hydrogen production sites, where an electrolyser produces green hydrogen using renewable electricity. The process followed is similar to filling the MEGCs with hydrogen.

Description of project work prior to deployment/demonstration

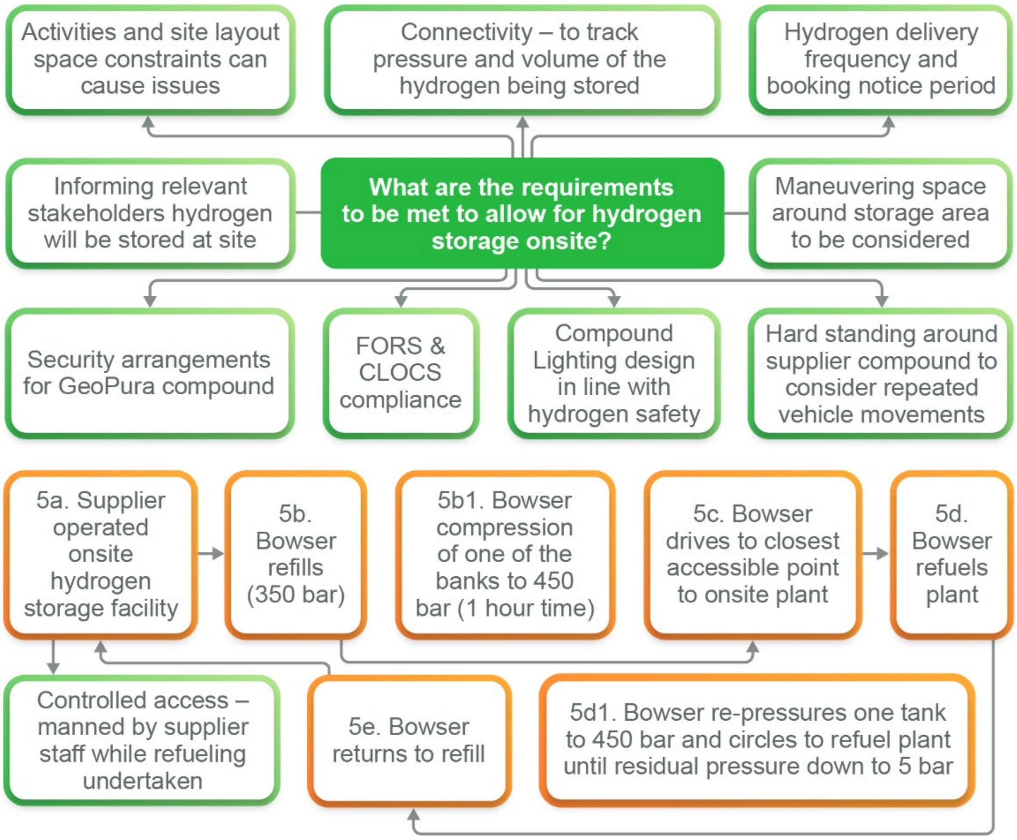
GeoPura conducted extensive pre-demonstration testing of the refueller at their electrolyser site in Croft Farm. This was facilitated, in part, using ULEMCo's Port-a-Bull™ unit which consists of four automotive hydrogen cylinders manifolded together. As this is very similar to the set-up on the excavators, it was invaluable and highly relevant testing.

The testing allowed us to undertake a number of tasks:

- Fill an automotive receptacle and cylinders using the GeoPura refueller for the first time- good validation.
- The Port-a-Bull™ system has a capacity of 7.3kg at 350 Bar - reasonably close to the tank capacity on the excavators, so it allowed us to learn what kind of fill times we could expect when refuelling.
- We used this to optimise the fill speed - we now had a relevant tank size and ambient temperatures to work with. We were able to monitor the tank temperatures & pressures when filling the Port-a-Bull™ and this allowed us to be more aggressive in our fill rates of the excavators during the trial.

GeoPura also deployed a similar refuelling set-up on another site earlier in the summer of 2024, which allowed them to gain valuable experience of developing layouts that suited customer sites while still following the relevant pieces of legislation.

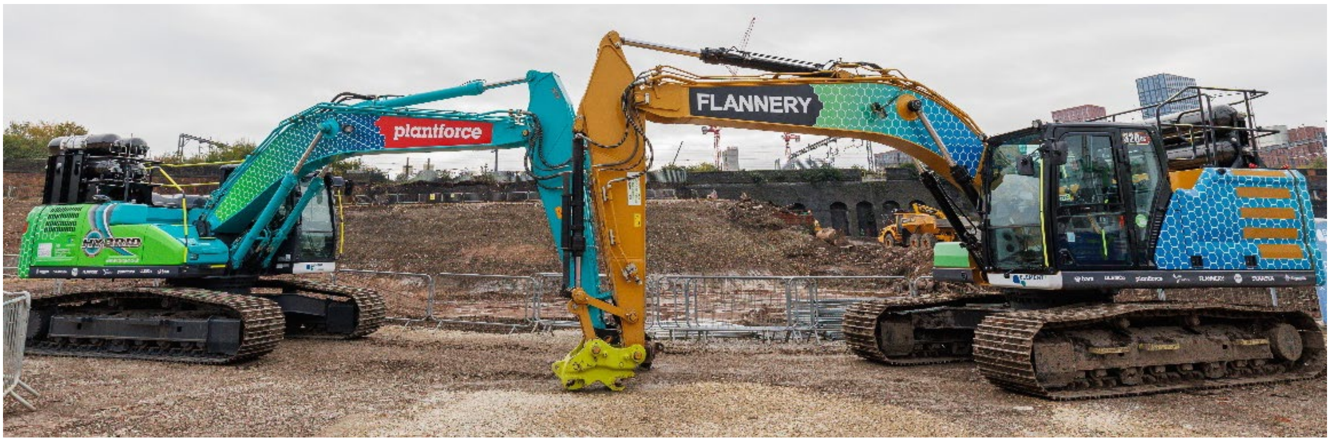
Figure 9 Site management and hydrogen storage



Before the first deployment at Victoria North, Manchester, BAM consulted with their insurers, Chubb and Aon. Subsequently a site visit was held to continue the discussion and show the site deployment to the insurers. The team successfully responded to the questions raised.

During the demonstration event in Manchester, an HSE representative attended at our invitation, enabling us to share our work to ensure a safe deployment on site and discuss how we may scale the use of hydrogen in construction in the future.

Figure 10 Two of the modified excavators on site during the demo event

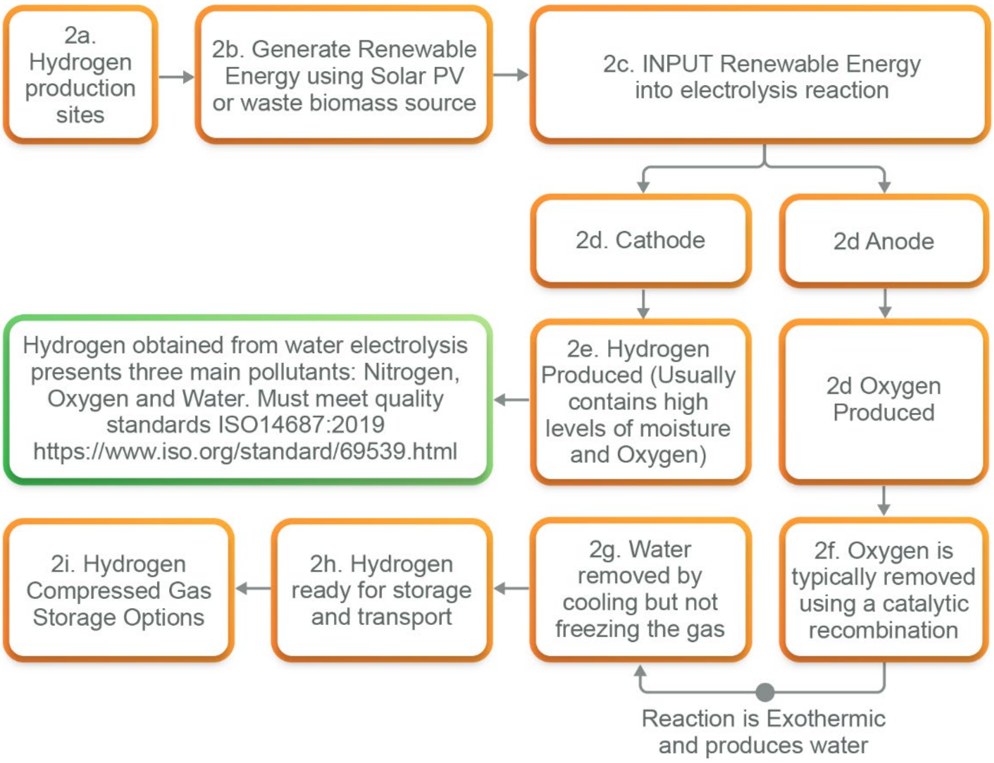


4.5. Hydrogen production and supply (WP3 work)

Hydrogen production (GeoPura)

GeoPura's facility at Croft Farm supplied hydrogen for the project. Located about 1 mile from the centre of Carcroft, and 6 miles from Doncaster, their site spans approximately 1150 square metres. It is an active hydrogen production site with a 1MW electrolyser working that produces hydrogen at around 30Bar. The site also has compression systems that increase the hydrogen pressure from 30Bar to around 300Bar. A MEGC is used to receive and store the compressed 300Bar hydrogen.

Figure 11 The hydrogen production process



Transport and delivery (Reynolds Logistics)

Reynolds Logistics managed the collection and transportation of MEGCs from Croft Farm, Doncaster to the demand site at Victoria North, following Hazardous Goods Regulations/ADR. Three MEGCs, each capable of holding 300kg at 350Bar were provided by Reynolds Logistics and used for the project. One was stationed at the demand site, another in the production site being prepared for filling, and a third was kept as a contingency at our site in Ellesmere Port in case of any supply chain disruption. The movement of units proceeded smoothly, with GeoPura providing at least two days' notice when attending the site to couple the unit to the HPU. Pre-delivery risk assessments and planning was done prior to the site going live which provided useful context to the site configuration. The final phase of the deployment included operation by ULEMCo of the HyTanka® (hydrogen fuel bowser) which distributed hydrogen to the machines on site in March 2025.

Figure 12 Collection and delivery of hydrogen to site entrance

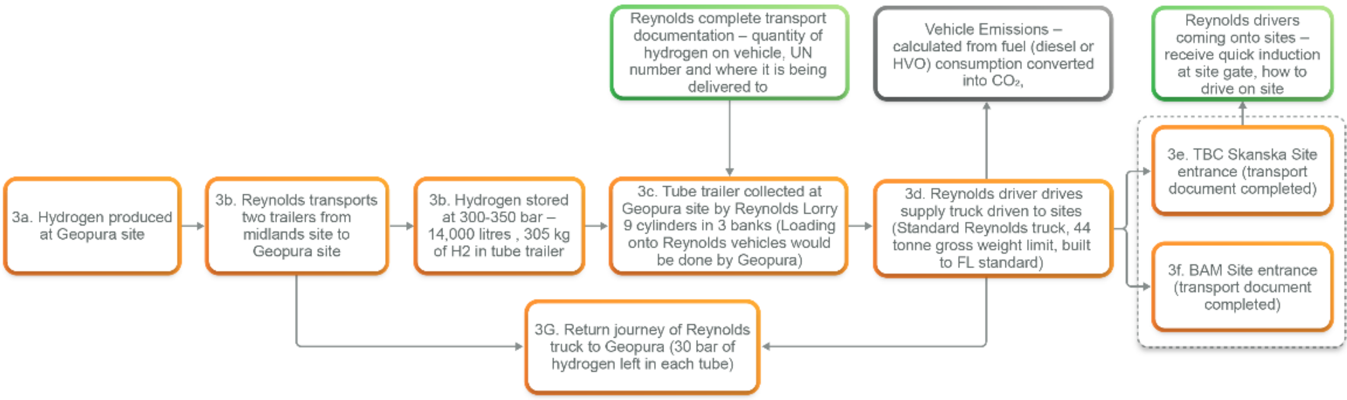
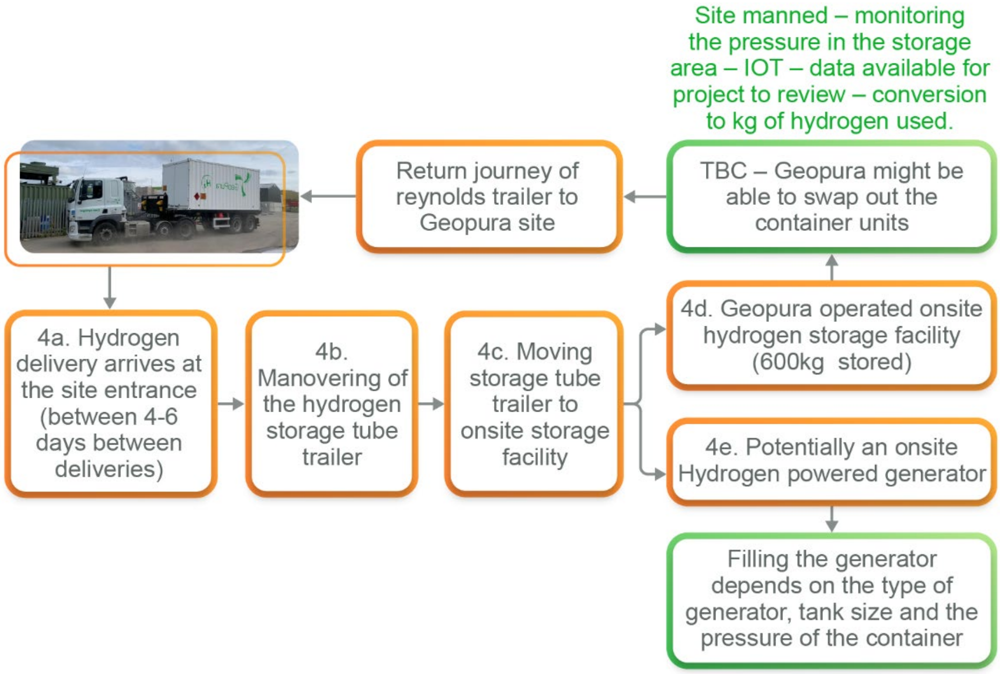


Figure 13 Delivery of hydrogen from entrance to storage facility



Health & Safety considerations

The MEGC, mounted on a road-going HGV trailer, was delivered to site by Reynolds Logistics. Before deployment at Manchester Victoria North, the Health & Safety Manager at Reynolds visited the site to verify the suitability of the access and hardstanding.

Once in place the MEGC was equipped with stair access and handrails to provide safe access and egress to the controls and connection points.

Figure 14 Multi Element Gas Container (MEGC)

Figure 15 Vehicle movement planning for MEGC deliveries

Summary of technical development work

The movement of MEGCs did not require or present any technical development challenges and is normal activity for Reynolds Logistics.

Lessons learned and justifications for choices made

Three MEGC units were allocated to the project: one on site, one being filled and one as a contingency. This enabled a continuous supply of hydrogen to site without disruption. GeoPura gave one-day notification for movements, which was sufficient for Reynolds Logistics to align resources. In hindsight, given the volume consumption patterns, the project could have operated without disruption with just two units.

The pre-delivery risk assessments were invaluable as these sites are not typical sites that Reynolds would visit. This practice will be embedded in processes for future construction projects.

Regulatory approvals/considerations

The vehicle and product movements were covered under standard ADR regulations, which are well developed in the UK and presented no challenges.

Figure 16 MEGC movements on site in Manchester

5. Demonstration Study

5.1. Overview and objectives

The aim of the demonstration study was to show that:

- Dual fuel excavators are comparable in their operational capability to diesel-only machines
- The hydrogen storage and dispensing facility can be deployed and operated safely and effectively on a construction site
- The modified fuelling regime is practicable and can be undertaken readily on the sites by the site personnel
- Machines on sites remote from the hydrogen dispensing compound can be successfully fuelled by a visiting hydrogen bowser.

The demonstration generated data to quantify emissions and productivity metrics identified by the consortium partners. The converted excavators:

- Conducted activities while running on dual fuel, enabling emissions and productivity data to be collected
- Conducted comparable activities while running on diesel only, allowing relevant baseline data to be collected.

Additionally, BAM site staff recorded site diaries which documented the work the machines did on site. Tasks included general excavation, material handling, and crushing concrete demolition waste generated on site.

Interviews with site staff who managed and controlled the construction activities provided us with first-hand accounts of the impact using hydrogen had on the site activities. Additionally, interviews with the machine operator provided valuable insight into the performance of the machine and how the refuelling was incorporated into the working day.

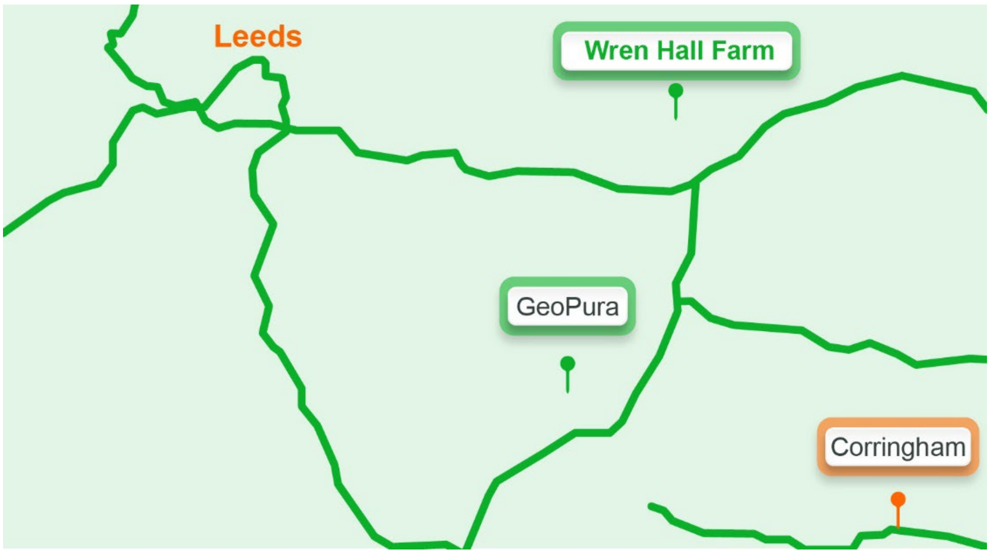
BAM and Skanska have operational projects across the UK with support from regional offices. In identifying suitable sites, several criteria were identified:

- GeoPura designed the site hydrogen storage and refuelling facility which required the site to accommodate a compound with approximate dimensions of 17m by 24m
- Additionally, access is required for delivery of the hydrogen using articulated HGVs with MEGC trailers and the ULEMCo hydrogen bowser
- When identifying the demonstration sites, a prime consideration was the location of the GeoPura hydrogen production facility in Doncaster and how it could feed the sites within a reasonable travel time. The initial search was conducted within a 50-mile radius from Doncaster. The area is well connected by the national road network.

Detailed discussions were held with the construction site teams. Documentation including visualisations, method statements and risk assessments were produced to enable effective communication of the scope of the site demonstration.

Shortlisted sites were Corringham (Skanska site subsequently not available within project timescale) and Eastern Green Link 2 (subsequently not available within project timescale).

Figure 17 Initial site selection



Final selected sites were Victoria North, Manchester, Brighouse Flood Alleviation Scheme and Transpennine Route Upgrade (TRU), Ravensthorpe.

Figure 18 Final chosen sites

5.2. Delivering the demonstration

During the site selection process, regular engagement with the construction site team ensured expectations were managed. Discussions covered the space that would be needed for the hydrogen storage, the type of excavators deployed and the specific work on site that they would deliver.

Our discussions included members from the clients' project teams who were supportive and keen to help the deployments and increase their knowledge of using hydrogen as a fuel in construction.

5.3. Main considerations and challenges

Using hydrogen on construction sites is novel. We developed a digital 3D model to better understand the constraints, inform the site teams and design the optimum layout of the equipment in the compound. Issues resolved through the 3D model include personnel working environment, component layout and vehicle paths.

Figure 19 Digital model used to design the optimum site layout

5.4. Hydrogen production

GeoPura produced hydrogen for the project using an electrolyser at their Croft Farm site. They compressed the hydrogen to 300Bar into MEGCs for transport. The hydrogen was Chemically Pure (CP) grade, with 99.999% purity, exceeding the requirements for the excavators during the trial.

Figure 20 GeoPura hydrogen production facility

5.5. Deployment to site

GeoPura HPU

The Victoria North site is effectively split into two distinct sites either side of the River Irk. The location selected for the hydrogen compound had a small site office and welfare facility powered by a diesel generator which was installed when the site was mobilised. It is this site accommodation that was connected to the electrical supply provided by the GeoPura HPU.

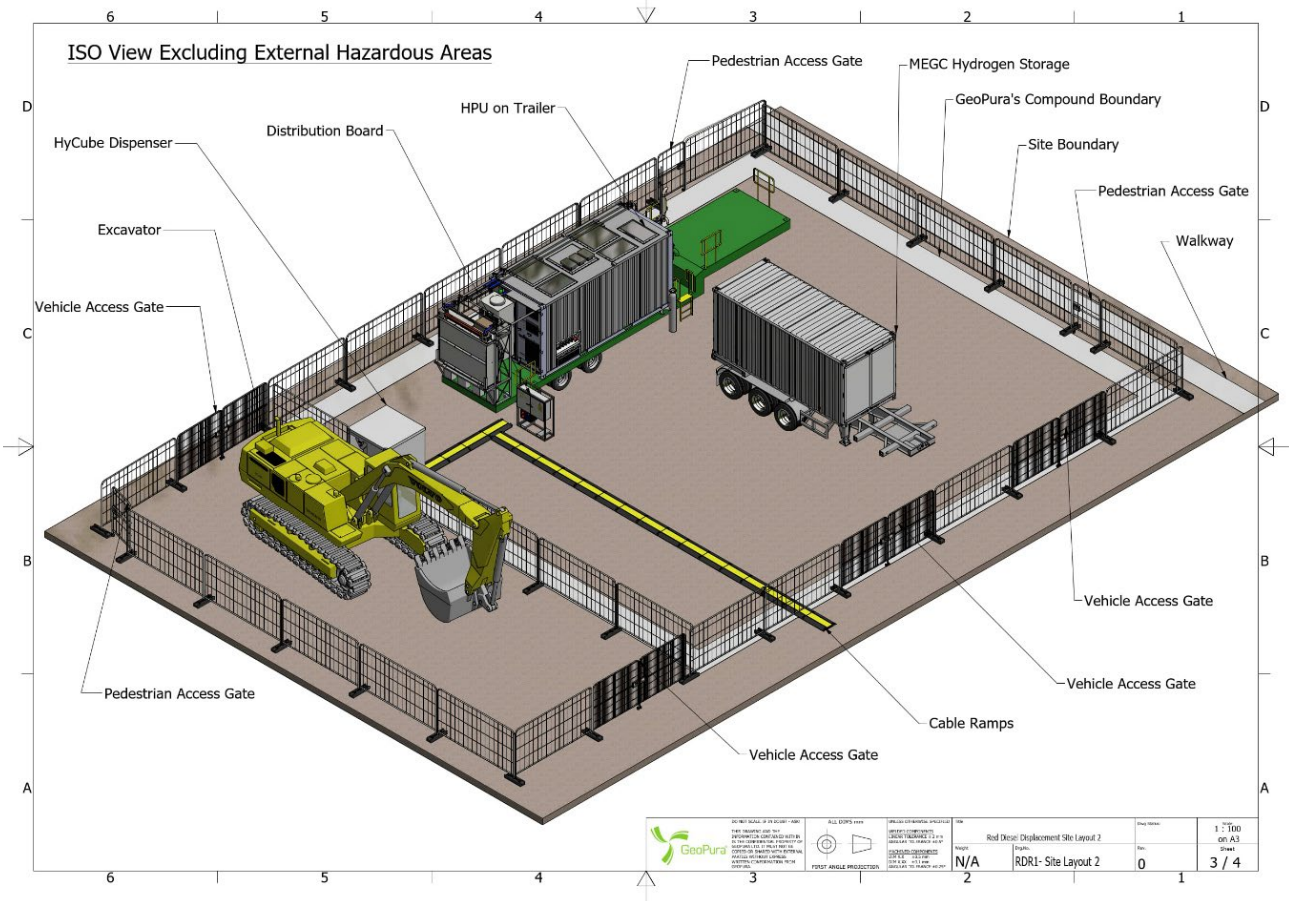
As a safeguard to ensure uninterruptible power to the site and to protect the site programme, a switch panel was provided which started the diesel generator in the unlikely event that the electrical supply from the HPU was interrupted. The HPU was deployed to site on 7 October 2024 and successfully began producing power on 8 October 2024. The site cabins were powered by the HPU once ducting had been installed to accommodate a cable from the HPU to the distribution board.

Refuelling compound

GeoPura designed and deployed a self-contained off-grid refuelling facility. The compound was on the construction site but clearly demarcated using secure fencing sited at the appropriate distance from the hydrogen equipment based on DSEAR guidance.

The BAM site at Victoria North was surveyed by GeoPura and Reynolds staff to assess its suitability. Once the compound area was identified and sized, BAM prepared the area with crushed concrete suitable for the weight of the vehicles and trailers delivering to site.

Figure 21 GeoPura refuelling compound design



Hydrogen dispenser

The hydrogen dispenser was designed for simplicity of use, aiming to make hydrogen dispensing a routine activity on future construction sites without needing specialised supplier input. During the trial, multiple plant operators received training on the refuelling process. After minimal familiarisation, they could complete refuelling without the hydrogen supplier's supervising engineer. Written and video instructions were also provided for reference.

Refuelling

The refuelling equipment was commissioned on 8 October 2024 and the first fill of the excavator took place on 9 October 2024. The following images show one of the CAT320 excavators being filled with Hydrogen at the Victoria North compound using the HyQube dispenser connected to a MEGC and powered by a GeoPura HPU.

Figure 22 Excavator re-fuelling by the machine operator

Subsequent refuelling was achieved at Brighouse and TRU using cascade filling with hydrogen stored in MCPs. Towards the end of the project, the mobile refueller, HyTANKa®, developed by ULEMCo was deployed to re-fuel the excavators at Victoria North and Brighouse.

Figure 23 GeoPura HyQube dispenser hose connected to an excavator

In late March 2025, the mobile refueller, HyTanka®, developed by ULEMCo was fully tested and certified for use and provided fuel for the modified excavators on the Victoria North and Brighouse construction sites.

Figure 24 ULEMCo HyTANKa® mobile refueller on site in Manchester

Figure 25 Refuelling the CAT machine with HyTANKa®

5.6. Lessons learned

The project team decided to use specialists from ULEMCo and GeoPura for refuelling, which led to some lost days of dual-fuel operation due to their limited availability. In future, machine operators will be trained and competent to conduct the hydrogen refuelling as required.

The excavators were defined as prototypes as defined in relevant regulations and standards. However, for commercial supply there is a need to identify a route which would allow this new technology approach - upgrading any make/type of existing machine with onboard hydrogen storage without modifying the base engine's control system or design – to meet assurance and safety compliance for customers. This currently seems challenging within existing regulatory structures.

For the project:

- The process followed with both plant hire companies and their safety compliance managers highlighted the design changes and the items a CE mark or equivalent would encompass:
    - Addition of high-pressure hydrogen storage using road-compliant systems (EC79/R134 standards)
    - Assessment of the design to consider the safe placement of the hydrogen storage packs on the machines
- The engine remains unmodified so its Type approval is not changed and stays a Stage 5 or 6 engine. (NB: the standards do not presently allow an OEM to get approval for a hydrogen dual fuel engine). The ULEMCo ECU does not interfere with the on-board diagnostics (OBD), ensuring emissions standards are met. Although the upgrade is not OEM approved, despite efforts to work with several OEMs to address this, ULEMCo provides a warranty matching the OEM's warranty to alleviate any customer concerns about potential impacts on the OEM warranty.

To achieve commercial usefulness and maximise carbon savings, the upgrade needs to apply to any make/engine and deliver carbon emission savings across all NRMM applications. This approach does not fit easily into conventional regulations. The cost of obtaining certified approvals for each engine or machine design is prohibitively expensive and unworkable without OEM support.

Ideally, a UKCA mark or similar certification could be defined that allowed for the general upgrade approach in NRMM. This would provide clarity on ensuring customer safety compliance requirements within existing standards. Once a clear route is established, ULEMCo would invest in creating a commercially certified product, particularly if market demand is confirmed.

6. Project Metrics

6.1. Technology Readiness Levels

Technology and commercial readiness levels of component parts summarised as follows:

End-to-end solution

Initial TRL: 5, target TRL: 7, achieved TRL: 7

Dual fuel conversion

Initial TRL: 4, target TRL: 7, achieved TRL: 7

Hydrogen shipping, storage and distribution on-site

Initial TRL: 4, target TRL: 7, achieved TRL 7

ULEMCo Bowser (HyTanka®)

Initial TRL: 4, target TRL: 7, achieved TRL: 7

Green hydrogen production and supply

Initial TRL: 6, target TRL: 8, achieved TRL 7 - Technology is available and improving; scale has been increased through the duration of the project.

6.2. Commercial Readiness Levels

End-to-end solution

Initial CRL:3a Target CRL: 3c Achieved CRL 3c – proven but complex commercial model with several parties required

Dual fuel conversion

Initial CRL:3a, target CRL: 3c, achieved CRL:3c – future conversions to be lower cost

Hydrogen shipping, storage and distribution on-site

Initial CRL:3a, target CRL: 3c, achieved CRL 3c – not commercially sustainable in construction

ULEMCo Bowser (HyTanka®)

Initial CRL 3a, target CRL: 3c, achieved CRL 3c – HyTanka has now been successfully deployed however there is currently only one of them available to use.

Green hydrogen production and supply

Initial CRL: 3a, target CRL: 3c, achieved CRL 3c - Technically possible but hydrogen cost remains as a barrier for adoption, price expected to drop as production increases.

6.3. Carbon emissions – based on metrics work (WP2 and WP6).

Emissions data

We captured and assessed key emissions metrics for hydrogen dual fuel excavators using real-time sensor instrumentation and data logging tools. These metrics provide both quantitative and qualitative insights into the environmental performance, operational feasibility, and potential challenges of using hydrogen-powered machinery in civil engineering applications.

A SEMTECH-LDV from Sensors, Inc was used to measure gaseous emissions. A flow tube was mounted on the exterior of the vehicle at the end of the tailpipe to measure total flow independently of the vehicle's systems.

The analyser measures CO, CO_2, NO and NO_2 gases and works in conjunction with a conditioning system to analyse conditioned sampled gases. The gas module incorporates Non-Dispersive Ultraviolet (NDUV) and Non-Dispersive Infrared (NDIR) benches.

Sensors Flame Ionization Detector (FID) measures Total Hydrocarbons (THC). The system is designed to minimise the loss of hydrocarbons prior to analysis by maintaining the required temperature using a heated filter, heated sample line and stainless-steel fittings which all have low gas absorption characteristics. Further details can be located at: https://sensors-inc.com/Products/SEMTECH/FID.

Span and zero calibrations of the gaseous measurement equipment were performed at the start and end of each cycle of tests to monitor and prevent analyser drift. The zero calibration was performed with pure nitrogen, followed by the span calibration against gas bottles of known concentrations supplied by Air Liquide.

The equipment had current certificates of calibration compliance for the linearity of the analyser and flow tube, from Sensors Inc. Due to practical and laboratory limitations, SOx and particulate matter (PM) were not included in the emissions scope.

Emissions Metrics Data Analysis

A field trial was conducted as part of the initial phase of the calibration process to evaluate the emissions performance and displacement potential of hydrogen-diesel dual fuel excavators on two machine types: CAT and Kobelco. This initial trial captured real-world data to assess diesel substitution rates, CO_2 savings, and the technical viability for wider deployment. Future savings are expected when the system is fully optimised following more extensive field operations.

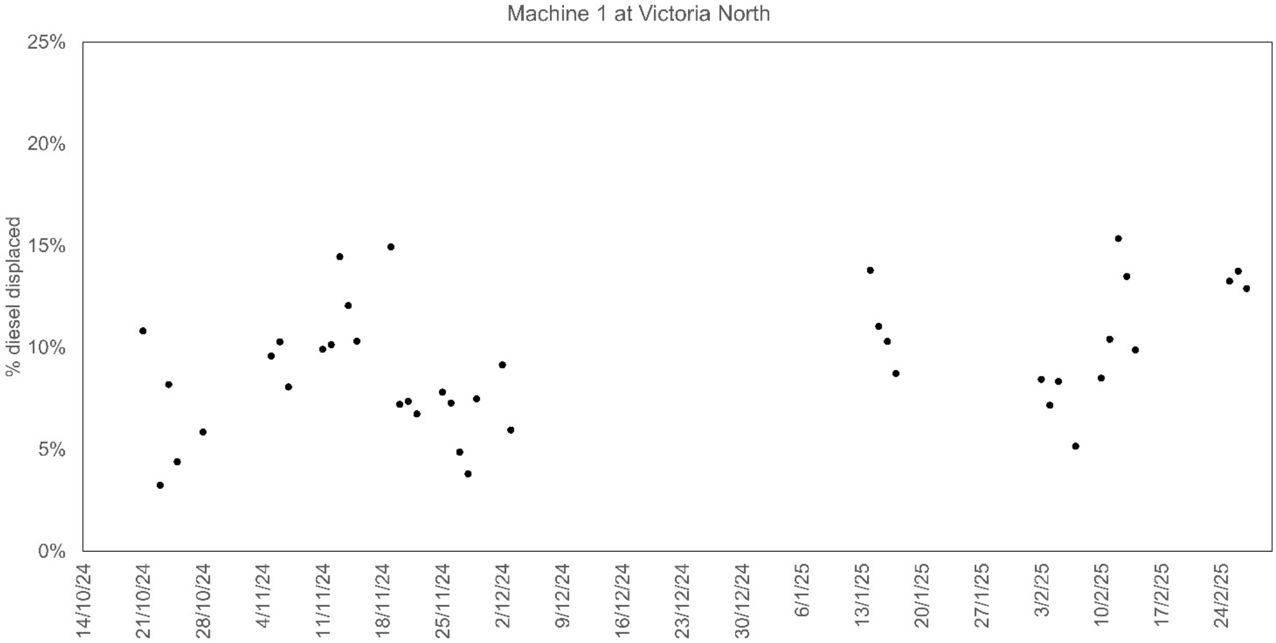
Overall data captured across the demonstration is in Appendix 6, with a summary below:

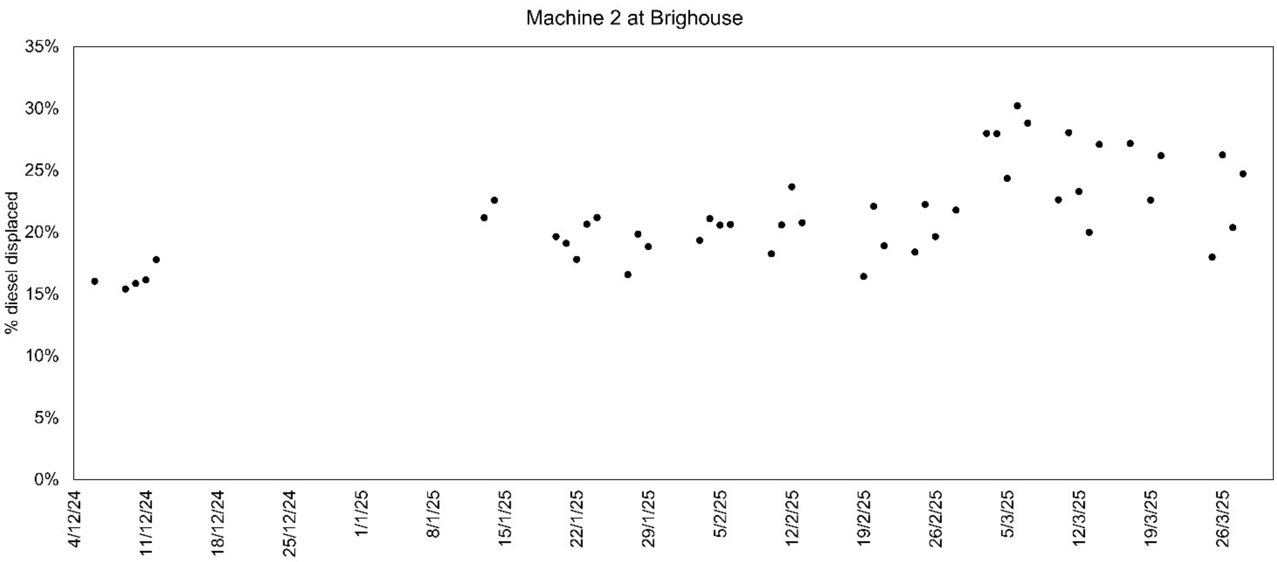
Figure 26 Summary of fuel consumption and Carbon Dioxide emission benefits

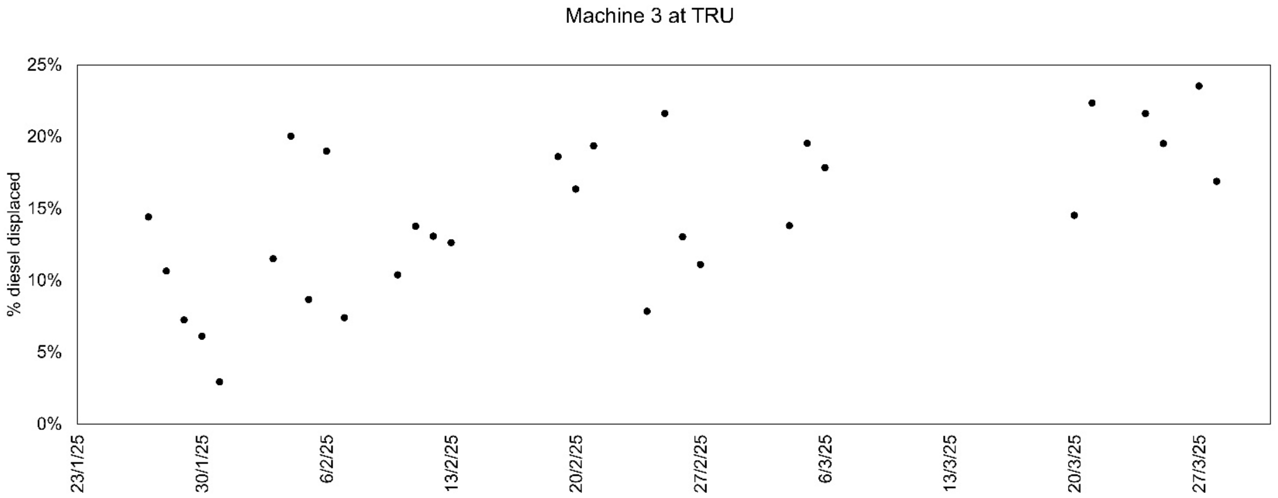
	Serial no.	Status	Dual fuel hours	H_2 consumed (kg)	Diesel consumed (L)	Dual fuel diesel consumed (L)	Diesel Saved (L)	CO_2 Saved (kg)	kg CO_2/Hr
CAT	EX25T330	Dual Fuel	140	35.7	1561	1304	117	314	2.3
	EX25T333	Dual Fuel	289	98.2	5239	3076	329	865	3.0
Kobelco	WB3005058	Dual Fuel	171	64.5	1809	1199	195	524	3.1
	WB03-00700	Dual Fuel	230	96.6	2508	1202	317	851	3.7
		Totals	821	291.0	11117	6781	952	2553	3.1

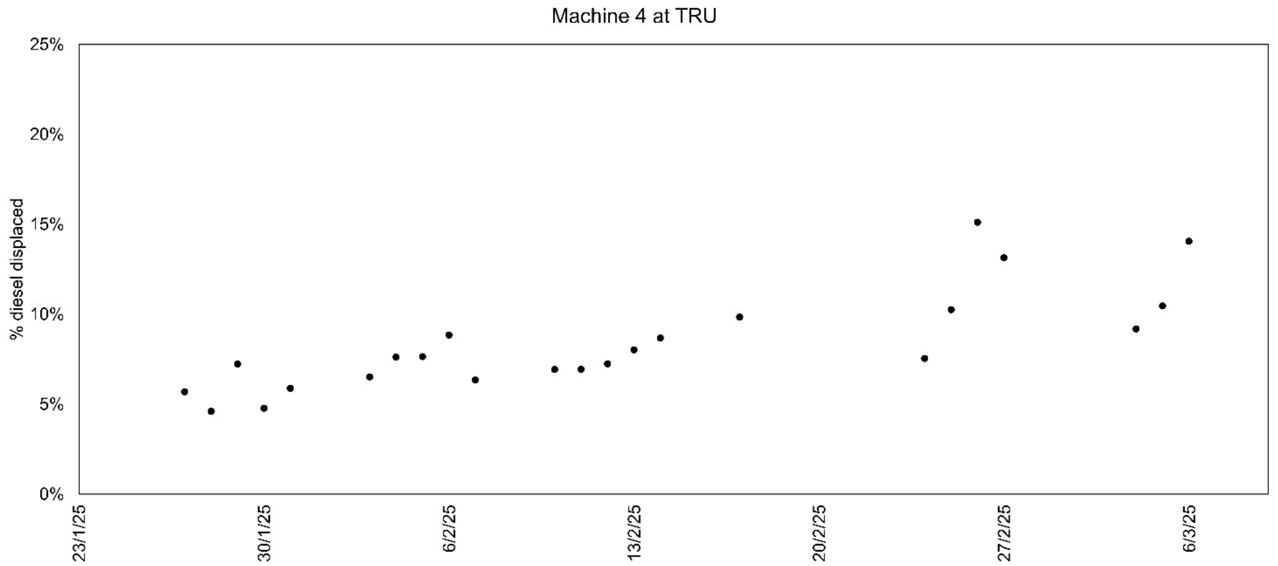
The following graphs show the generally increasing trend of diesel displacement for each of the four modified excavators deployed on the sites. Machine two shows the greatest increase in performance because a calibration upgrade was deployed to the machine during the latter stage of the deployment.

Figure 27 diesel displacement graphs









Across 821 dual-fuel operating hours, the demonstration including the initial field test consumed 291kg of hydrogen, displacing 952 litres of diesel and avoiding 2,553kg of CO_2 emissions. This equates to an average diesel displacement of 13.1% and a carbon saving of 3.1 kg CO_2 per hour across all four machines in the different operational environments and conditions. The abatement efficiency was calculated at 8.77kg CO_2 saved per kg of hydrogen consumed.

Individual machine performance varied, particularly between plant models, with the Kobelco excavators (WB3005058, WB03-00700) delivering better overall displacement rates than the two CAT (EX25T330, EX25T333) models, with WB03-00700 regularly achieving 25–30% diesel displacement rate towards the final stages of the demonstration, and once a second calibration/optimisation step had been completed. The two CAT machines achieved displacement rates of 8–10%, based on the initial calibration only. Applying the learning from the Kobelco machines, a second optimisation calibration would improve this significantly, and bring the rates closer together.

Further optimisation through software updates on both would push these final levels even further although it is expected that there will be variation between different types of machines, due to differences in equipment and engine configurations, and as the technical limits from combustion stability and duty cycle constraints are met. Based on ULEMCo's experience from other applications between 30-50% would be realistic.

The HPU displaced a diesel fuelled generator used to power a remote site office and welfare facility. It consumed 1,283kg of hydrogen during the trial. In comparing the performance of the HPU with diesel generators GeoPura have taken account of the relative efficiencies of the HPU and diesel generators:

- 1kg hydrogen contains ~33.3 kWh chemical energy. GeoPura HPUs are c.55% efficient.
- 1 litre of diesel contains ~10 kWh chemical energy. Diesel generators are c.31% efficient.
- Therefore, 1kg hydrogen used in the HPU produces the same energy as 5.9 litres diesel in a generator.

Diesel Counterfactual

A diesel counterfactual model was developed using standard operating data and equipment performance maps. This model enabled a direct emissions comparison and confirmed that hydrogen substitution significantly reduces lifecycle CO_2 emissions. If extrapolated across a fleet of 1,000 machines operating 1,800 hours annually, the CO_2 saving potential exceeds 5,600 tonnes per year, equivalent to taking over 1,200 cars off the road.

A comprehensive assessment of the hydrogen supply chain and decarbonisation strategies in construction sites was conducted. This included production, transport, storage, and site-level refuelling logistics. Findings confirmed the viability of hydrogen deployment through modular storage and mobile delivery options. Integration with existing site workflows was achieved with minimal disruption, although cost, availability, and refuelling frequency remain critical factors for large-scale deployment.

The transition to hydrogen-based operation was further supported by process mapping and performance validation of dual fuel excavators, underscoring the logistical feasibility and reliability of this approach in operational environments.

Air quality improvements were inferred from lower NO_x and THC emissions, as evidenced by sensor data and literature benchmarks for hydrogen co-combustion. Additionally, field observations indicated notable reductions in engine noise, enhancing worker safety and community relations, particularly in urban or residential project zones.

Economic viability remains a key challenge. Hydrogen costs during the demonstration were £58.50/kg, making fuel expenditure significantly higher than diesel. However, anticipated price drops, alongside carbon pricing and ESG-driven procurement requirements, may shift this balance in favour of dual fuel systems. Moreover, the ability to retrofit existing plant offers substantial capital savings over full equipment replacement.

The dual-fuel hydrogen retrofit approach demonstrated better environmental performance, achieving over 2.5 tonnes of CO_2 reduction in pilot deployment. The operational data supports the technical feasibility of hydrogen use in the construction sector, particularly when combined with localised supply models and existing site practices. With continued investment in hydrogen infrastructure, policy incentives, and broader contractor engagement, this solution presents a scalable and effective route for decarbonising non-road mobile machinery in line with UK Net Zero goals.

Figure 28 Emission testing at Flannery Operator Skills Hub

Productivity data

The productivity metrics for hydrogen-powered excavators were assessed on three construction sites. These metrics were essential for evaluating the efficiency, performance, and productivity of hydrogen excavators. By continuously monitoring and optimising these indicators, operators could improve excavation operations while gaining insights into efficiency, cost-effectiveness, and overall performance of the plant.

Fuel consumption comparisons were also analysed, using energy equivalence between kilograms of hydrogen and litres of diesel. While hydrogen-powered plant demonstrated higher efficiency at operating power, they require substantial fuel storage to match diesel autonomy. An excavator requires 12kg of hydrogen to achieve equivalent operational range, though this is not expected to be a limitation.

Ad hoc interviews with plant operatives provided essential information on the plant daily operations. The main initial concern was related to downtime due to refuelling of the hydrogen tanks. However, it has been demonstrated in practice that the process requires around 10 minutes every other day and is comparable to the time to refuel the plant with diesel. Thus, the refuelling process has a limited impact in the overall productivity. Also, the operation of the hybrid plant is very similar to conventional diesel-powered plant, requiring little training to operate in hybrid or diesel-only modes.

Site diaries provided essential qualitative data to contextualise productivity results, an example is available in Appendix 6. A standardised site diary form was created and adopted on three construction sites, to capture relevant information of the plant operations daily. These diaries documented daily work activities, weather conditions, site terrain, plant downtime and duty cycles, offering valuable insights that complemented the sensor data. The structured site diary approach allows for transparent tracking of key activities and downtime events, forming a foundation for ongoing performance monitoring.

Productivity Metrics Data Analysis

Productivity metrics – including machine efficiency, work cycles, and uptime – were assessed. Site-specific factors such as work intensity, environmental conditions, and fuel logistics were also examined to determine the practicality of hydrogen adoption in construction. This information is also captured in the site diaries for context. The collected data indicated that when operating under similar conditions, hydrogen-powered excavators can match the performance of diesel-operated plants.

A qualitative analysis of the data captured in the site diaries was performed. There were 104 work entries extracted from the site diaries in three locations. The data consolidation focused on daily key work activities and corresponding downtime periods to identify operational trends, productivity patterns, and potential areas of improvement. A summary of the data captured in the site diaries is presented below:

Metric	Data
Total Work Entries	104
Entries with Downtime*	42
Entries without Downtime	62
Total Estimated Downtime Hours	53.33
Average Downtime per Entry (hrs)	0.51
Most Frequent Activity	Stockpiling Material

*Downtime refers to any activity that requires the machine to stop operating for a period.

Throughout the reporting period, 42 entries reported some form of downtime while 62 entries recorded no downtime events. The total estimated downtime across all entries reached approximately 53.3 hours, representing an average downtime of 0.51 hours per recorded activity log. These figures suggest that while downtime occurrences were not constant, they were frequent enough to account for around half an hour of inactivity on average for every work entry submitted.

The most recurring operational activities involved stockpiling material, fuel management, machine logistics such as loading and unloading, and day-to-day movement of materials around the site, often linked to soil and clay repositioning or dump truck loading. This indicates that the nature of work was predominantly earth-moving and material handling, with frequent reference to support tasks around hydrogen plant operations, stockpile management, and general equipment usage.

Downtime entries reveal a few identifiable operational constraints. Isolated full-day downtimes were recorded, likely representing safety precautions, technical inspections or machine stand-downs. Partial downtimes typically ranged between one to two hours, often coinciding with regulatory maintenance activities or temporary malfunctions, such as hydrogen system checks, regulator fittings, or precautionary checks following machine performance concerns. The presence of 'all day' entries and non-operational hydrogen generator notes indicate both planned and reactive stoppages linked to the dual-fuel technology integration on site.

Overall, while most workdays experienced effective deployment of machinery with limited stoppages, downtime still presents opportunities for operational optimisation. Specifically, interventions around hydrogen equipment reliability, pre-emptive maintenance scheduling and improved task sequencing could contribute to further reducing unproductive periods. The dataset confirms that although the hydrogen-powered excavation trials generally performed as intended, integration challenges inherent to emerging fuel technologies continue to introduce some variability into daily productivity.

Training and certification

Construction organisations collect data from incident reporting that occurs on their sites. They then review this data to identify areas where there are high instances of accidents and how to prevent these accidents occurring in the future. The process is ongoing so that the impact of any changes or developments in the levels of incidents occurring can be identified. This will be another method of promoting assurance and required training in terms of Health & Safety.

Within the UK construction industry, Construction Skills Certification Scheme (CSCS) is used. CSCS cards provide evidence that individuals working on a construction site have the appropriate training and qualifications to do their job effectively and safely. Although it is not a legal requirement for workers on a construction site to have a CSCS card, most major contractors in the UK require workers to hold a valid CSCS card.

If hydrogen use on a construction site increases, it would be beneficial if either CSCS or CPCS (Construction Plant Competence Scheme) cards introduced an additional training module to address the health and safety risks of hydrogen use on a construction site. This would promote the safe use of hydrogen on construction sites and provide guidance to the construction industry.

If hydrogen is stored as a gas under pressure there is a possibility that it could explode if heated. In fact, wherever hydrogen is stored in this form explosive atmospheres may occur. Therefore, it is recommended to use ATEX-approved equipment which has undergone rigorous testing as outlined by European Union ATEX directives.

The converted plant was manufactured so that the operation of the plant was as similar as possible to the operation of a pure diesel plant. This ensured that the plant operators did not have to receive significant additional training to successfully operate the plant and were familiar with its internal layout.

Figure 29 ULEMCo representative supervising excavator filling

Other barriers to mainstream use

Taking the viewpoint of a plant hire company looking at commercially offering the diesel/hydrogen dual fuel solution, considering the lessons learned from the ELEMENT1 project there are three key barriers to adoption:

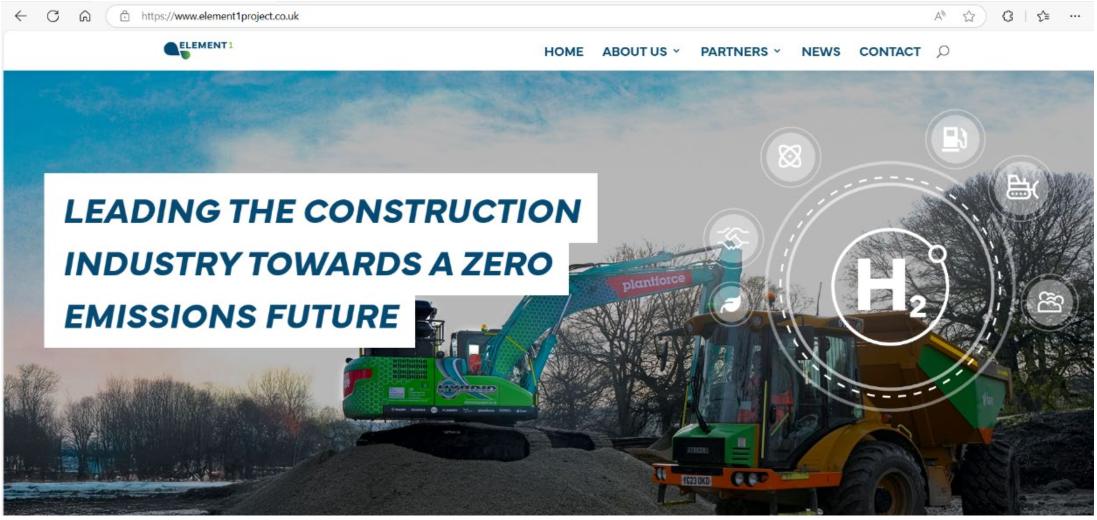
- Green hydrogen supply at a commercially viable cost
- The fuel and carbon savings seen during the demonstration process are comparable to an electric/diesel hybrid excavator in comparison to conventional diesel (between 20-30%), which is available at a considerably lower investment cost. However, the prospect of installing the dual fuel solution to a hybrid excavator offers a more attractive solution
- Clarification is needed regarding the certification of the dual fuel prototypes for commercial hire use (i.e. CE marking). During the ELEMENT1 project's demonstration process, the dual fuel machines were classified as prototypes, so did not require CE marking or engine type approval. For commercial use after the project, Government regulatory bodies and standards agencies must provide clear requirements.

7. Secondary Project Benefits

7.1. Dissemination activities and media coverage

The project captured stills and video footage at key points during the project and these have been used to help disseminate the project work to a wide audience. Additionally, we created a project website which is regularly updated with key achievements: www.element1project.co.uk. The website will continue to remain live for a period after the project's completion to serve as a source of information and knowledge dissemination.

Figure 30 Project website home page, www.element1project.co.uk



In March 2024, the project hosted a roundtable event at BAM's London office. A selection of representatives from the project, DESNZ and construction clients gathered to discuss some key issues facing the increased use of hydrogen as a fuel in the construction industry.

Figure 31 ELEMENT1 round table event 25 March 2024

7.2. IP generation

ULEMCo

The project has largely involved the transfer of Intellectual Property (IP), including know-how, that ULEMCo has developed in road transport applications including, but not limited to:

- Patented IP in leak detection embedded into the ULEMCo H2ICED® hydrogen dual fuel engine control unit (ECU)
- Engineering designs and knowledge of integrating high pressure hydrogen on-board storage technology for vehicle applications
- The HMI, monitoring and diagnostics technologies incorporated in the upgrade process
- The application of FMEA and FEA assessments of failure mode and risk of applying hydrogen technology on machines
- Extensive knowledge and IP in the ability to calibrate engines to work on hydrogen dual fuel; optimising the hydrogen displacement rate on any make of engine, within the scope of meeting air-quality emission standards; and matching operational requirements such as power output, without knock or other related parameters or engine performance.

The project has enabled specific IP and knowledge in the two models of excavators:

- Engineering designs for the addition of retrofitted, onboard hydrogen storage solutions
- Specific engine calibrations for the two models
- Experience of applying the guidance for the manufacturing standards for NRMM as it relates to the hydrogen dual fuel upgrade
- Performance data on the engine testing
- PEMS based emissions data from the initial tests
- ECU software strategy developments and changes that can help future optimisations.

The project included ULEMCo building and testing their first mobile solution for hydrogen refuelling, namely the diesel bowser equivalent, HyTANKa®:

- Engineering designs for the integrated vehicle solution
- The integrated control system for safe operation and refuelling
- A novel integrated approach to maximising the delivery of mobile hydrogen fuel directly into a vehicle or machine
- A novel approach to filling hydrogen fuel into a MEGC using onboard compression and boosting
- ADR certification for the design and integrated vehicle.

GeoPura

- Off-grid hydrogen refuelling powered entirely by hydrogen for the first time
- Improvements in cascade refuelling efficiency using MCPs
- Development of commercially viable hydrogen vehicle refuelling
- Delivering hydrogen to fuel cell generator and refuelling unit using the same hydrogen source
- Efficient swaps of hydrogen supply vessels – MEGCs and MCPs
- Supporting multiple sites with hydrogen refuelling at the same time
- Low pressure, low volume cascade refuelling using specialty refuelling hoses.

7.3. Jobs created and activities improving

GeoPura can directly credit the ELEMENT1 project with the addition of three full-time employees (FTE) to the organisation. These are an R&D Engineer, Fuel Production Engineer and Field Service Engineer.

During the project, GeoPura also secured its inaugural debt funding round, securing £22 million to fund renewable fuel infrastructure and support the clean energy transition. This followed a £56 million investment round that will help accelerate the UK's adoption of green hydrogen by expanding production capacity, growing the specialist workforce in the UK, and increasing the deployment of GeoPura's power generation technology.

During the project, ULEMCo added three FTE to their team, growing from 22 to 25 people, in that time. The company's turnover in FYE September 2024 grew by 16%, a record since their foundation in 2014, and received private equity investment of £5m in the year to support scale up and further growth plans.

Sector skills and experience

- ULEMCo's upskilled experience in applying the NRMM machines standards (ISO12100) General principles of safety of machinery to H2ICED® upgrades
- ULEMCo's experience of the different duty cycle energy use and how this impacts hydrogen optimisation
- ULEMCo's staff member Sean O'Kane passed his ADR certificate
- ULEMCo and GeoPura staff CSCS Level 1 health safety and awareness cards
- Regulatory, training and certification issues (from WP2).

7.4. New partnerships

As a direct result of the ELEMENT1 project, new business to business relationships have been created. An example is the relationship between BAM and GeoPura where several high-level meetings have taken place and opportunities to work together identified.

ULEMCo has, because of the project, engaged Reynolds Logistics on a commercial basis to support them in the logistics for their own mobile refuelling stations (procured during the project) and for future use of HyTANKa®.

ULEMCo has had, and will continue to have, business to business meetings with Plantforce and Flannery about the wider commercialisation of the hydrogen dual fuel upgrades on the existing machine types and future off- road machinery.

ULEMCo, BRE, Plantforce and BAM are preparing a bid for Innovate UK funding to build upon the work of ELEMENT1. All partners continue to explore collaborative R&D projects for the application of hydrogen technology approaches in the construction sector.

7.5. Supply chain development

Through delivering ELEMENT1, those partners who had existing business to business relationships have intensified them and a greater number of personal relationships have been created.

ULEMCo has extended their supply chain into the component and equipment suppliers needed for HyTANKa®, particularly the booster (Haskel), the vehicle hydraulic supplier and the sub-frame trailer manufacturer. The latter two are UK-owned and UK-based businesses.

7.6. Project Management

Project structuring and scheduling

The core engagement of the project partners was through the weekly Friday team meetings where progress and issues were discussed in the wider group. To supplement this, other technical and commercial meetings were held as required with appropriate attendees.

Key members from each organisation were identified at an early stage and they provided continued and consistent representation at the project meetings.

Key risks and mitigations

An early challenge faced by the project team was the withdrawal of one of the partners in the initial quarter. However, a thorough process of evaluating the potential gap in delivery resources including reviewing potential new partners concluded with the existing scope remaining intact and being delivered by the remaining eight consortium partners. The project team initiated a risk register at application stage which was maintained during the delivery of the project and regularly reviewed by the team.

The following are some key risks to project delivery and how they were mitigated:

Risk ID 128

- Description: technical failure of bowser
- Impact: delay in deployment of bowser
- Mitigation: alternative fuel supply approach using MCPs

The delay in the bowser assembly and testing had a significant negative impact on the deployment of the dual fuel excavators on site at TRU and Brighouse. The project team met to discuss what could be done to mitigate this, and it was suggested that an alternative fuel delivery and storage solution could be implemented in the interim using hydrogen in Multi Cylinder Pallets (MCPs).

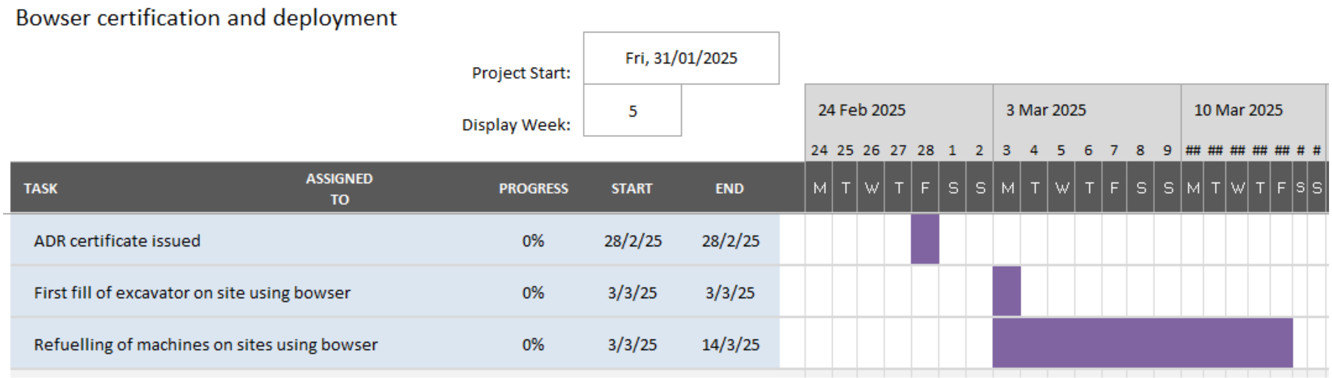
Figure 32 Hydrogen MCPs deployed at Brighouse mitigating bowser delay

Risk ID 124

- Description: vehicle registration process at North West Trucks
- Impact: HyTanka required for up to two weeks for registration, delayed deployment
- Mitigation: inspections and certification scheduled to provide visibility

The inspection and certification of a modified HGV to carry hydrogen on the public highway requires a series of inspections by external bodies which need to be booked in advance. The successful completion of these checks was essential before the deployment of the HyTanka® on the public highway as a mobile refuelling solution. The timing and duration of these tasks has been detailed below:

Figure 33 Bowser inspections and certifications



Risk ID 106

- Description: availability of the site at Wren Hall for hydrogen compound is delayed
- Impact: delayed site deployment
- Mitigation: assess an alternative deployment site for the compound - Victoria North,

Site at Wren Hall forms part of the EGL2 construction project. Start date of the construction project was close to the original planned site demo date for ELEMENT1 and it was decided that due to the risk of access not being available on time that an alternative site would be used. The alternative construction sites selected were already operational and therefore the space and interaction required at the specified date could be provided with certainty.

Lessons learned

In the initial stages of the project delivery, there was significant uncertainty and impact on the project caused when one of the original project partners identified at application stage decided to leave the consortium. In hindsight, we now recognise that the hydrogen sector is dynamic and there is an element of business fragility which was not identified in the financial checks that were conducted by the lead partner. However, this issue was resolved successfully following a market engagement exercise and the subsequent decision taken to deliver the full scope with the remaining partners.

The project consortium is large with eight partners having a wide range of skills, specialisms and organisation size. There were also several established personal and business relationships within the consortium which along with the diversity proved to be a successful combination. Delivering a project such as this is only possible through an equitable share of project external funding, without this funding model, important work to advance industrial capability does not happen.

8. Commercialisation Plans

8.1. Scalability; construction

There are circa 25,000 - 30,000 items of operated diesel-fuelled plant (5t and greater) in the UK. Key machine types are excavators - small, large and wheeled (>50%), bulldozers (12%), dumpers and Articulated Dump Trucks (ADTs) (26%), telehandlers and others (CPA, 2021).

Construction plant is mostly owned by hire companies. Contractors hire equipment, either fuelled or with a separate fuel supply arrangement. Leading plant hire companies replace assets every 5-7 years. Residual value/depreciation is a key factor (and barrier to adoption of new technology) in financial models.

OEMs are developing zero emission plant. We understand that commercially available hydrogen powered plant, of some types/ranges, may be available within 2-5 years. The purchase of these will need to fit within the carefully managed asset replacement programmes (timing and access to capital) that the plant-hire companies found their financial models on.

Conversion of the existing diesel-powered fleet to dual fuel would facilitate the transition to net zero, enabling existing plant to remain in use while refuelling infrastructure and zero-emission alternatives are phased in over time.

Under ELEMENT1, we have considered timelines for this transition. A 10-year timeline for the transition of site construction plant from the use of 100% diesel to 100% hydrogen as a fuel has been proposed. This assumes a phased conversion of the existing fleet to dual fuel and subsequently to 100% hydrogen and electric-powered.

The 10-year timeline indicates that circa 20,000 machines will need to be converted to dual fuel by the mid to late 2030s (with a maximum of about 2,000 machines converted per annum).

Priority machines are currently assumed to be 12-24 tonne excavators (circa 25-30% of plant on site). The sector would require approximately 203.1Mkg hydrogen annually if the UK fleet were powered by 100% H_2.

The cost of upgrading equipment to dual fuel is largely dependent on the cost in the supply chain of high-pressure hydrogen storage components and the labour for assembly and installation. With economies of scale, and increased competition for supply of components, it is anticipated that the costs for an upgrade will add between 20-30% onto the original equipment cost. As learning is generated about the daily use rates, optimisation of the hydrogen displacement rates aligned with refuelling strategies, this allows for calculations of the value money trade-off between carbon saving and capital cost.

8.2. Hydrogen supply and timelines (from WP1)

The UK's commitment to expanding its hydrogen production capacity is highlighted by initiatives like GeoPura's HyMarnham Power project and the broader Hydrogen Allocation Round 1 (HAR1) incentivisation scheme.

HyMarnham Power, a joint venture between GeoPura and JG Pears, is transforming the former High Marnham coal-fired power station into a clean energy hub, featuring a 15MW green hydrogen production facility. This project is among the 11 selected in HAR1, collectively adding 125 MW of electrolytic hydrogen production capacity across the UK.

Successful deployments, such as the ELEMENT1 project in construction, highlight real-world applications of hydrogen and provide confidence in its commercial viability. By demonstrating real world applications and proving the technology, ELEMENT1 proves both the demand for hydrogen solutions and the potential for further investment.

These developments not only advance the UK's net-zero ambitions but also drive economic growth, supporting private sector investment and job creation. However, realising hydrogen’s full potential will require ongoing policy support, cost reductions, and infrastructure expansion.

8.3. Scalability; other sectors

ULEMCo’s commercialisation plan for the outputs of the project (the demonstration of the applicability of their core technology hydrogen dual fuel into off road machinery and the HyTANKa®) are as follows:

Short term:

- Support future trials that Plantforce and Flannery wish to lead, in terms of technical support and options for hydrogen supply
- Invest in the ECU developments and apply the calibration improvements identified to increase hydrogen use (and therefore real-world CO_2 savings)
- Create a marketing plan for formal launch of H2ICED® NRM in the NRMM sector
- Resolve regulatory options for upgrade approach
- Commission the full functionality of HyTANKa® and identify a partner for demonstration of this, and the powertrain hydrogen dual fuel upgrade
- Complete a design review to apply learning for version 2 HyTanka® and find routes to fund the build of the improved version.

Determine pricing and specification for commercial launch within six months, including an agreed finance package for customers.

Medium term:

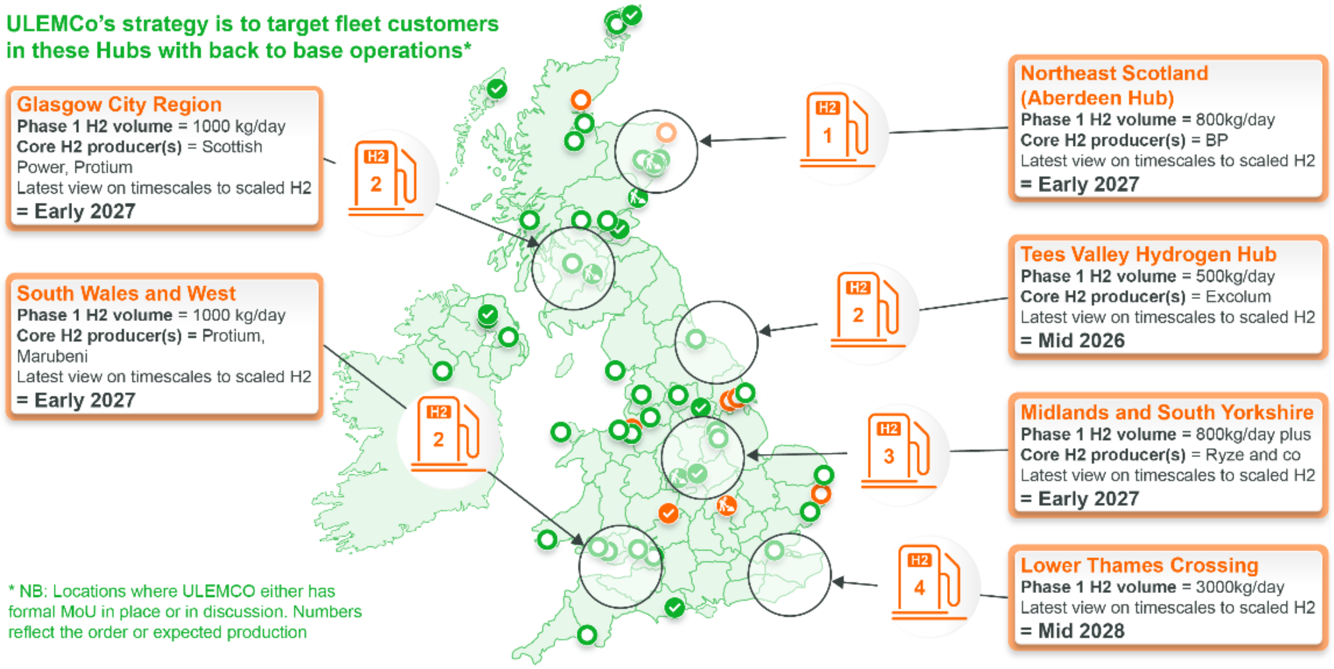
- Build a customer base within the hire company and hydrogen supply chains
- For other construction machine types, particular ADT and other heavy-duty equipment
- For other off road machinery applications including agriculture, forestry and quarries
- For HyTANKa® on other chassis (particularly off-road like a Unimog) and or detachable trailer format.

Long term:

- Develop full hydrogen internal combustion engine (ICE) and or fuel cell (FC) solutions for upcycling.

ULEMCo's business plan aims to proactively target the development of hydrogen hubs to 2030 in the UK as follows:

Figure 34 Proposed hydrogen transport hub map (as of March 2025)



Based on the principle that ULEMCo's hydrogen partner relationships will help create demand, hydrogen will be delivered at a price comparable to diesel.

Figure 35 ULEMCo modelling on hydrogen pricing using local supply hubs

NB: A suggested hydrogen price of £10/kg could result in this model being commercially sustainable.

Also, ULEMCo customers own fleets in the following sectors (including construction):

Figure 36 Specialist fleet operators in local geographic hub locations

The strategy is then to focus on Specialist Vehicle Fleet Operators

Within 50-100 miles area of scaled production

1. The Local and County Councils
2. Commercial Waste Collection
3. Utility Co's (Gas, Water, National Grid, IT / Comms)
4. Construction and Engineering Firms
5. Airport / Port and Rail Depots
6. Logistics Hubs
7. Supermarket and Retail depots
8. Major Manufacturing site, industrial and development cluster
9. Other public service fleet (NHS Trust, Ambulance, Police and Fire Service, Forestry Commission, Inland Water)
10. Major Public works
11. Local H2 and Net Zero stakeholder Groups

9. Conclusions and next steps

9.1. Outcomes against objectives

- The ELEMENT1 project team has proven an end-to-end hydrogen fuel solution for the construction industry is technically possible
- The team successfully demonstrated the solution on three construction sites
- A significant proportion of diesel fuel was displaced by hydrogen – a maximum of 30% with anticipated further improvements achievable with follow-on development work.

9.2. Other observations

OEMs are exploring the use of hydrogen as a fuel both through fuel cells and combustion engine solutions.

Hydrogen as a fuel for construction plant is being explored by OEMs including Hyundai, JCB, LIEBHERR, Volvo, Hitachi and Manitou, through either fuel cell or internal combustion engine technology. Most are currently at prototype status, the exception being JCB with their internal combustion engine product which is due to be introduced soon. Cummins also have a hydrogen combustion engine which is likely to be adopted by some manufacturers.

Societal pressure to decarbonise continues to increase as individuals adopt lower carbon personal transport solutions such as electric vehicles (buses, vans, cars) and notice the associated improvements in air quality. However, it is important to consider commercial constraints, as these solutions often have higher initial capital costs.

9.3. Policy/regulatory issues and recommendations

Government-funded construction projects will drive plant decarbonisation. For example, Lower Thames Crossing has already made public their plans to use hydrogen to fuel a significant proportion of construction plant. By the time this project is in the construction phase, there will be significantly more production capacity of hydrogen in the UK stimulated by the UK Government Hydrogen Allocation Rounds (HAR).

9.4. Lessons learned

- This project scope was only possible with external funding provided by DESNZ, whilst each party had the desire to develop and grow their capability it was only made possible through a funded collaborative R&D project
- The consortium size was large with 8 partners however it worked well making good use of the diversity of skills and experience – two Tier 1 contractors, two plant hire companies, three hydrogen sector specialist and a Research and Technical Organisation
- Early engagement with construction site teams is essential to ensure their buy-in is obtained due to the novel nature of using hydrogen within the construction industry
- Engagement with BAM's insurers was a very positive exercise providing an opportunity to increase their awareness of the topic of hydrogen as a fuel and how it is likely to become more prevalent in the construction industry.
- As with many R&D projects the scaling of the solution post-project is a challenge – it is technically feasible but the cost of hydrogen remains prohibitive currently (expected to fall when production is increased)
- Further Government investment is required before hydrogen as a fuel in construction plant is mainstream – we have deployed four modified excavators and different fuel storage and dispensing solutions for a relatively short period of time.

9.5 Next steps

ELEMENT1 work increased diesel displacement from 15% to 30%. With the inclusion of hardware-based AI strategies we believe we can obtain a further 30% increase in the mass of H_2 consumed at a given speed load. These strategies will include:

- Adaptive learning techniques to monitor engine NO_x emissions when running in diesel mode and then use these parameters to adjust the hydrogen quantities in real time to ensure maximum diesel is displaced without detriment to the vehicle tailpipe NO_x.
- Using real time sound inputs from the engine to allow H_2 to be injected until we reach either harsh combustion (in some cases Knock) or the NO_x limit.
- Allowing hydrogen to be injected at full load without increasing the engine torque, but still reducing the quantity of diesel used.

The ELEMENT1 project has created future opportunities for further development work and raised awareness of the potential benefits and accessibility of hydrogen as a fuel in the construction industry.

Funding applications

- BRE, supported by BAM, have led a funding application submitted to the Energy Networks Association to develop solutions for ‘Zero Emission Excavations’ and have been successful in the reaching the next stage of the competition.
- ULEMCo have submitted a funding bid to the Advanced Propulsion Centre which includes several consortium members and seeks to build upon the work of ELEMENT1.

Dissemination

The project website Element 1 - Join the movement for positive change continues to be live beyond the project duration to provide a platform to share information and to receive enquiries.

The team continues to engage in dissemination events such as the DESNZ supported Clean Hydrogen End Use webinar on 27 March 2025 which reached over 200 people across 35 countries. ULEMCo presented HyTANKa at the Hydrogen Energy Association conference in Westminster on 5 June 2025 attracting significant attention.

Recognition

BCIA FINALIST
BRITISH CONSTRUCTION & INFRASTRUCTURE AWARDS 2025

Figure 37 HyTANKa on display in Westminster at event after project end

10. References

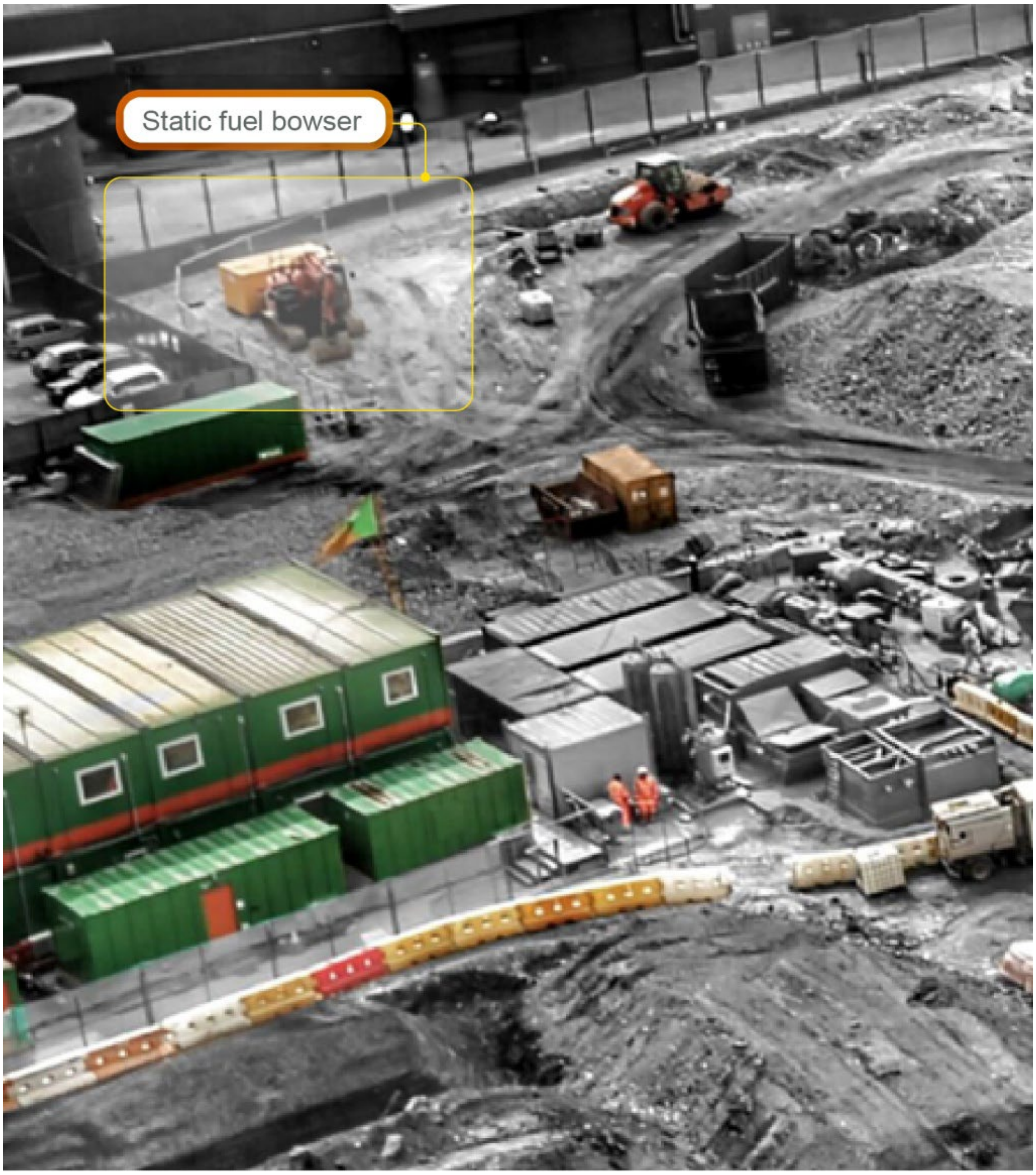
- Construction Plant-hire Association (CPA). (2021) The Economic Contribution of the UK Construction Plant-hire Sector. London: CPA. Retrieved from https://www.cpa.uk.net/downloads/643/CPA_Report_WEB.pdf
- Construction Skills Certification Scheme (CSCS). Learn More About CSCS. Retrieved from https://www.cscs.uk.com
- European Union. ATEX Directives – ATEX Product Certification. Retrieved from https://www.getac.com
- Health and Safety Executive (HSE). (2015). The Control of Major Accident Hazards Regulations 2015: Guidance on Regulations (L111). Retrieved from https://www.hse.gov.uk/pubns/books/l111.htm
- Office for National Statistics (ONS). (2024, June 5). UK Environmental Accounts: 2024. Retrieved from https://www.ons.gov.uk
- Sensors, Inc. (n.d.). SEMTECH-FID – Flame Ionisation Detector. Retrieved from https://sensors-inc.com/Products/SEMTECH/FID
- Sensors, Inc. (n.d.). SEMTECH-LDV – Portable Emissions Measurement System.
- UK Government. Hydrogen Allocation Round 1 (HAR1) Incentivisation Scheme. Department for Energy Security and Net Zero.
- UK Government. Hydrogen Allocation Rounds (HAR). Department for Energy Security and Net Zero.
- UK Statutory Instruments. (2009). The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009 and Dangerous Substances and Explosive Atmospheres Regulations (DSEAR).

11. Appendices

1. Diesel use on site
2. Plant conversion (ULEMCo)
3. Hydrogen storage and distribution on-site (WP4)
4. Hydrogen production and supply (WP3)
5. Site demonstration
6. Metrics
7. Dissemination

Appendix 1 - Diesel use on site

Use of diesel on construction sites – the following images show diesel fuel storage and delivery on a typical construction site.


Static fuel bowser

Appendix 2 - Plant conversion

The following pages provide additional information on the plant conversion to dual fuel.

The machines were surveyed to determine the space available for equipment modifications, recognising the need to maintain access for maintenance and inspections.

Figure 38 Initial plant survey

Figure 39 Tank installation on CAT320

Figure 40 Tank installation on Kobelco SK210

Figure 41 Emissions testing at Flannery Operator Skills Hub

Appendix 3 - Hydrogen storage and distribution on-site (WP4)

The first deployment at Victoria North, Manchester has an off-grid hydrogen dispenser powered by one of GeoPura's Hydrogen Power Units (HPU). Bulk hydrogen is delivered to site by Reynolds using one of their MEGCs.

Figure 42 MEGC swap at Victoria North, Manchester

Figure 43 On site hydrogen dispenser

Due to the delay in the readiness of the mobile refueller, the project implemented an interim fuel storage and dispensing solution using MCPs at Brighouse and Ravensthorpe. GeoPura supplied the MCPs, which they offloaded and delivered to the controlled access hydrogen storage compound.

Figure 44 MCP delivery at Brighouse

Figure 45 Hydrogen storage at Brighouse

Appendix 4 - Hydrogen production and supply (WP3)

Supplying Low-Carbon Hydrogen to Power a Cleaner Future

As a leading innovator in low-carbon hydrogen production, GeoPura is at the forefront of driving the hydrogen economy forward. Our cutting-edge Hydrogen Power Units (HPUs) are already delivering zero-emission power across industries, replacing traditional diesel generators and helping businesses meet their sustainability goals. To support the growing demand for green hydrogen, we are scaling our production capacity and offering our excess hydrogen to the market—making it easier for organisations to secure reliable

- Low carbon hydrogen available today
- Delivery or collection
- Competitively priced
- Flexible volumes supplied
- High purity fuel cell grade hydrogen

Expanding Green Hydrogen Production Capacity

GeoPura currently operates multiple hydrogen production sites across the Midlands and South Yorkshire, including industrial-scale electrolysers commissioned in Spring 2022:

Croft Farm, Doncaster, UK
Low Marnham, Nottinghamshire, UK

We are expanding our operations with **HyMarnham Power,** a new 14MW facility set to go live in 2025, with plans for additional capacity in the future. This growth positions us as a key player in meeting the increasing demand for clean hydrogen, and we are eager to collaborate with partners to help them transition to a low-carbon energy source.

Hydrogen That Meets the Highest Standards

Our green hydrogen production meets the stringent GHG Emission Intensity Threshold[1] of the UK Low Carbon Hydrogen Standard (LCHS), ensuring that you receive a reliable, sustainable fuel that aligns with your net-zero objectives. This high-purity, fuel-cell-grade hydrogen is ideal for various applications, including industrial processes, energy storage, and mobility. Hydrogen purity tested to the stringent ISO14687:2019 Type 1, Grade D standard.

Comprehensive Hydrogen Storage and Distribution

At GeoPura, we don't just produce hydrogen—we also ensure seamless storage and delivery. We have invested significantly in scalable infrastructure to meet the needs of our partners:

150 MCPs (forkliftable storage containers) for flexible on-site hydrogen storage

A fleet of **80 MEGC tube trailers** available to enable bulk transportation

Whether you need hydrogen delivered or prefer to collect it using your own storage solutions, we offer flexible supply options to suit your operations.

Offtake Agreements to Support Your Sustainability Journey

By partnering with GeoPura, you gain access to more than just hydrogen. With our 'Offtake in a Box' solution, we provide priority access to our Hydrogen Power Units (HPUs), enabling you to stimulate demand and increase offtake with zero-emission energy applications.

1 Having a Final GHG Emission Intensity that is less than or equal to the GHG Emission Intensity Threshold of 20 grams of carbon dioxide equivalent per megajoule of Hydrogen Product, using Lower Heating Values (20.0 gCO_2e/MJLHV Hydrogen Product).

Appendix 5 - Site demonstration

The following pages provide additional information on the site deployments at Victoria North Manchester, Brighouse and TRU Ravensthorpe.

Figure 46 Second set-up location at Victoria North, Manchester

Figure 47 HyTanka® dispensing hydrogen on site in Manchester

Figure 48 Kobelco SK210 working at Brighouse

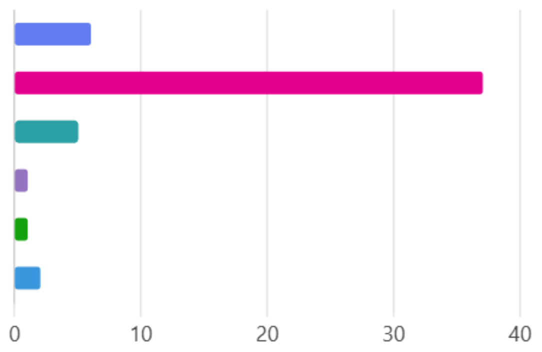
Figure 49 CAT and Kobelco machines working at TRU Ravensthorpe

Appendix 6 - Metrics

Figure 50 Examples of summarised data captured in the site diary

5. Weather conditions - Afternoon

Sunny	6
Overcast	37
Rain	5
Wind	1
Rain + wind	1
Other	2



10. Key work activities - Daily tasks

More details

52
Responses

Latest Responses

"Mixing site won material with lime, stockpiling, Geopura finished stripping h... "
"Mixing wite won material with lime & stockpiling"
"mxing site won material, loading wagons"
...

12. Downtime - Work stopped due to (REASON). Insert exact times above as it is crucial to assess productivity.

50
Responses

Latest Responses

"N"
"N"
"n"
...

14 respondents (28%) answered Machine for this question.

Appendix 7 - Dissemination

I3P feedback on round table event

Infrastructure Industry Innovation Partnership (i3P)
2,137 followers
1d •

This week i3P were kindly invited by BAM UK & Ireland to their R&D round table event to discuss hydrogen fuel in the construction industry.

Convened by Colin Evison, Innovation Technical Lead at BAM UK & Ireland, guests included clients, contractors, consultants, plant providers, fuel manufacturers and government. The core discussion topic was how we can work together to create the conditions for hydrogen powered plant to become more commonly used on construction sites.

It was heartening to hear our policy makers talk about the cross-government commitment to net zero, and that they are making funding available to support the transition. Combined with strong shareholder interest and the public net zero commitments organisations have made, conditions are favourable for this transition to happen.

Key insights from the discussions included:

💡 Focus on the plant that is difficult to electrify
💡 1st develop component technologies
💡 2nd demonstrate how these can be integrated into systems
💡 Engage the regulators early – they are learning too
💡 Overcoming transport and storage issues will be a big enabler
💡 Business models will need to change – consider 'energy as a service'
💡 Carbon pathfinder projects grow understanding and confidence.
💡 Avoid the temptation to have numerous trials of the same technologies.

Discussion points included - breaking the supply demand stalemate, the role of anchor clients in creating demand stability, and where new opportunities may emerge with the hydrogen economy. Example opportunities included using the oxygen generated at water treatment plants and using spare nuclear energy capacity to create hydrogen to store for later use.

In our net zero future electricity is expected to be the fuel of choice, with more of a mix of other fuels on sites than at present. Contracts will need to balance technical and commercial choices to keep the industry moving forward at the pace our planet needs.

#hydrogen #climatechange #unleashingInnovation #climatesolutions #cleanenergy #netzero #netzeroinnovationportfolio #NZIP

CPA Bulletin August 2024

decarbonisation but also maximises the value of current investments.

It offers a cost-effective pathway to reduce emissions and extends the lifespan of existing machinery, thereby supporting sustainability goals.

The HEA is strongly advocating for the inclusion of retrofit solutions in regulatory frameworks, communicating the successful retrofitting projects in the UK and across the EU, which have demonstrated that safety and efficiency can be maintained with proper standards and protocols.

Drawing on Experience

Valuable lessons can be drawn from both the Netherlands and Norway. The Netherlands has implemented a Subsidy for Clean and Zero Emission Construction Equipment (SSEB), which offers distinct funding streams for purchasing, retrofitting, and experimental innovation.

Similarly, the Norwegian Government provides subsidies for the purchase of electric NRMM, covering up to 40% of the additional cost compared to diesel alternatives. Implementing a similar incentive scheme for hydrogen could be crucial in realising its potential to decarbonise NRMM.

Future Prospects and Collaboration

The potential of hydrogen in the construction sector extends beyond machinery. Hydrogen can play a significant role in decarbonising various aspects of construction, from powering equipment to providing heat and electricity for building sites.

Collaboration across the industry, from manufacturers to end-users, is essential to harness this potential fully.

In Summary

Hydrogen offers a path to significant emissions reductions and operational efficiencies in the construction sector.

The transition to a hydrogen-powered future in construction and plant machinery is not just a possibility; steps are already being made to ensure that the benefits offered by hydrogen in this sector are realised, providing operators with practical decarbonisation solutions.

The HEA is advocating for policies that support this transition and is working with a range of stakeholders to build a cleaner, more sustainable future for the construction industry.

With the right regulatory framework and industry collaboration, the potential for hydrogen to revolutionise construction and plant machinery is immense.

We're dedicated to leading this charge, ensuring that hydrogen becomes a cornerstone of the UK's journey to Net Zero.

Case Study:

Members of the Hydrogen Energy Association - Reynolds Logistics, ULEMCo, and Geopura - are collaborating in a cross-industry consortium led by BAM, known as Element 1.

This project is developing hydrogen as a supplement to reduce diesel usage on construction sites and is funded by a £4,872,653 grant from the Department for Energy Security and Net Zero.

The project unites expertise from various sectors: construction (BAM and Skanska), plant hire (Flannery and Plantforce), the hydrogen sector (ULEMCo, GeoPura, Reynolds Logistics), and the research and technical organisation BRE.

Element 1 aims to enhance hydrogen manufacturing and supply chain efficiency through off-site and on-site production, off-grid compression, and innovative storage and distribution solutions.

The system is designed to accelerate the replacement of diesel on construction sites by using engines capable of operating with 30-50% hydrogen, significantly reducing diesel consumption. This approach allows for the continued use of existing machinery, minimising the carbon footprint associated with scrapping equipment before the end of its useful life.

Spanning two years, the aim is to offer practical solutions demonstrated on active construction sites, reducing the construction industry's dependence on fossil fuels.

By bringing together various contractors and suppliers from across the sector, the Element 1 project is set to drive advancements in hydrogen manufacturing and supply chain efficiency.

This publication is available from: www.gov.uk/government/publications/red-diesel-replacement-competition-successful-projects/red-diesel-replacement-competition-phase-2-successful-projects

Any enquiries regarding this publication should be sent to us at: RDR@beis.gov.uk

If you need a version of this document in a more accessible format, please email alt.formats@energysecurity.gov.uk. Please tell us what format you need. It will help us if you say what assistive technology you use.