



The JCB Hydrogen Fuelled Internal Combustion Engine

Fuelling the future of heavy plant
machinery and other diesel-powered
platforms



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Introduction



Introduction



The 4.8L inline-four hydrogen combustion engine (448 ABH2)— JCB's zero-carbon emissions solution for construction and agricultural equipment

Lord Bamford and JCB's wish to reduce emissions goes back around quarter of a century with its most modern diesel engines being designed to comply with the European Stage V regulations and these have already provided a 97% reduction in NO_x emissions since 1999 and a 98% reduction in particulates. In addition, JCB's drive to further reduce fuel consumption means that today's JCB engines use around half the fuel, on average, than those designed and built over a decade ago. This has saved circa 3.5 billion gallons of fuel – somewhere in the region of 53 million tons of CO₂.

JCB has been developing electric motors to meet customers' needs for zero-carbon products. Whilst battery electric is suitable for lighter machines which do less strenuous tasks for less hours, larger plant have a greater energy requirement. This would result in huge batteries, which would be heavy and take a great deal of time to charge, making them unsuitable for machines which work multiple shifts per day and do not have the luxury of downtime with which to recharge.

As part of its hydrogen development, inspired by the Company Chairman, Lord Bamford, JCB investigated the use of an ICE fuelled by hydrogen and in 2020 unveiled the 220X, the construction industry's first hydrogen-powered excavator.

For the time being, JCB has come to the conclusion that fuel cells are too expensive, too complicated and not robust enough for construction and agricultural equipment. In challenging the JCB engineering team to think differently using technology that is around us in a zero-carbon way, the JCB hydrogen engine was born.

The unique combustion properties of hydrogen enable the hydrogen engine to deliver the same power, the same torque, and the same efficiency that powers JCB machines today, but in a zero-carbon way. Hydrogen combustion engines also offer other significant benefits. By leveraging diesel engine technology and components, they do not require rare earth elements and critically, combustion technology is already well proven on construction and agricultural equipment. It is a technology which is cost effective, robust, reliable and well known throughout not just the construction and agricultural industry, but the whole world.

— JCB Chairman Lord Bamford



Background & Internal Structure



Company Timeline, origins & ethos



- Joseph Cyril Bamford, Agricultural Engineer and innovator
- 'Jamais content' was his mantra – JCB is still a company that is never content with its achievements...
- Sustainability is key to them, as they know it is to their customers and staff
- Emissions legislation and renewable fuels are the key area of research.
- World firsts are seized on as the opportunity to place the brand at the technical peak of developable heavy equipment.
- Combined with the company Chairman's infectious enthusiasm to propel JCB brand to instant recognition and headline position.
- From farm and army surplus beginnings, JCB have grown into a technical and marketing powerhouse, with important achievements through innovation.....



The Journey of JCB- Early years



1945 - military surplus makes tipping trailer



1947 - Major Loader, worlds first front-loader



1953 - Mark 1, Worlds first backhoe loader



1963 - JCB 3C- Design Classic with first backhoe slide



1971 - 110 Loading shovel

Design Council Award 1972

First Hydrostatic transmission



1977 - JCB 520
New Concept
Telescopic Handler
Production team-led innovation



1985 - JCB 3CX
Sitemaster.
100,000 backhoes produced



1988 - JCBGT
Chevrolet V8 Engine
100mph at British Grand Prix



1991 - Fastrac 125/145
World first high speed tractor



1993 - JCB 165 Robot
Innovation in boom lifting
Safest skid steer



Journey of JCB – The path towards hydrogen



2006 – JCB Dieselmax
World Land Speed
record for diesel, 350mph



2018 – JCB 19C-IE
First electric
mini excavator.



2019 –
JCB Worlds Fastest Tractor,
153 mph. Designed by
young JCB engineers



2020 – JCB 220X
Hydrogen fuel
cell excavator on test.



2020 – JCB Electric
Full range of electric
machines



2021 - JCB – Hydrogen
Engine prototype trailed in
JCB Backhoe.



2021 – JCB – Announces
£100M project to produce
hydrogen engines.



2021 – JCB Presented with
the RAC Dewar Trophy for
the development of the
hydrogen combustion
engine.



2022 – JCB Backhoe with
hydrogen combustion
Engine demonstrates
at Jubilee Pageant.

JCB is the world's third largest producer of construction equipment and has 22 factories around the world employing more than 15,000 people.



Future thinking and recognition



JCB PRESENTED WITH THE ROYAL
AUTOMOBILE CLUB'S DEWAR TROPHY FOR
THE COMPANY'S DEVELOPMENT OF A
HYDROGEN FUEL MOTOR

- The super-efficient hydrogen engine won one of the oldest and most prestigious awards in British automotive engineering honouring technical achievement.



JCB INVESTED £100 MILLION INTO A PROJECT TO
PRODUCE SUPER-EFFICIENT HYDROGEN
ENGINES

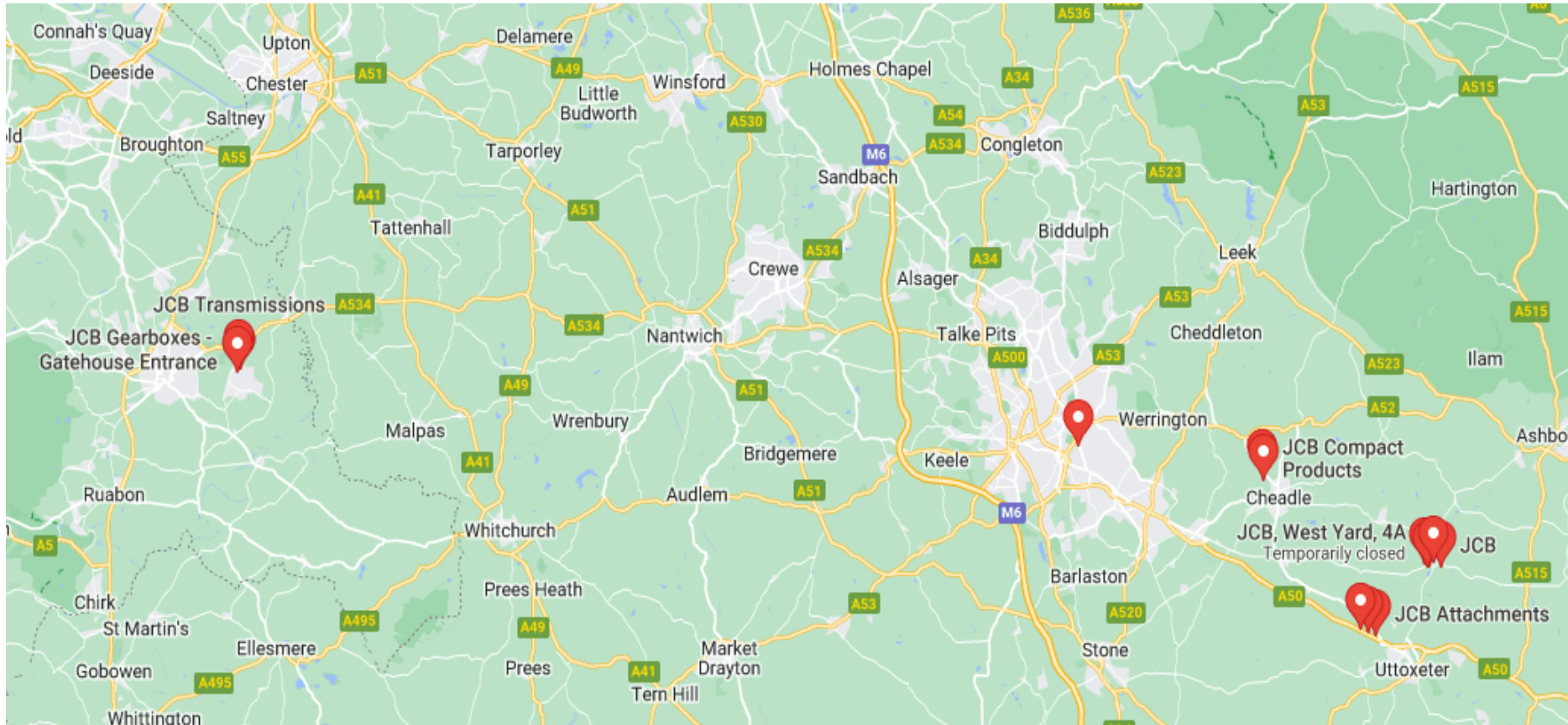
- JCB's emergence as a leader in zero-emission hydrogen technology comes as governments around the world unveil strategies to develop the infrastructure needed to support the use of hydrogen to drive down CO₂ emissions.



Expansion

From a single welder in a workshop to a Global engineering powerhouse with factories across the Midlands, into North Wales and Internationally.

22 factories in total along with a global dealership and servicing network.



Internal Structure

Board of Directors (Essentially a family run business)

- **Lord Anthony Paul Bamford - Son of Founder (100 shares)**
- **Joseph Cyril Edward (Jo) Bamford – Chairman (100 shares)**
- **Alice Camille Bamford (100 shares)**
- **Lady Carole Gray Bamford (100 shares)**
- **George Harry Anthony Bamford (100 shares)**
- **Steven Ernest Robert Ovens – Company Secretary (1 share)**
- **Michael Hargreaves – Legal Director (1 share)**
- **Transmissions & Engineering Services Netherlands (98 shares)**

UK Management

- **Graeme McDonald CEO**
- **Marco Bersellini - Sales MD**

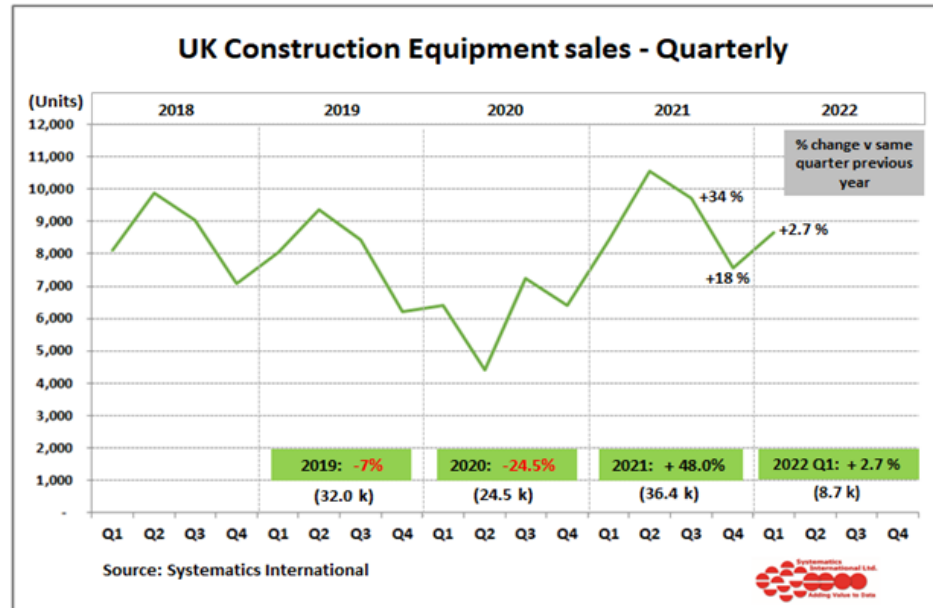
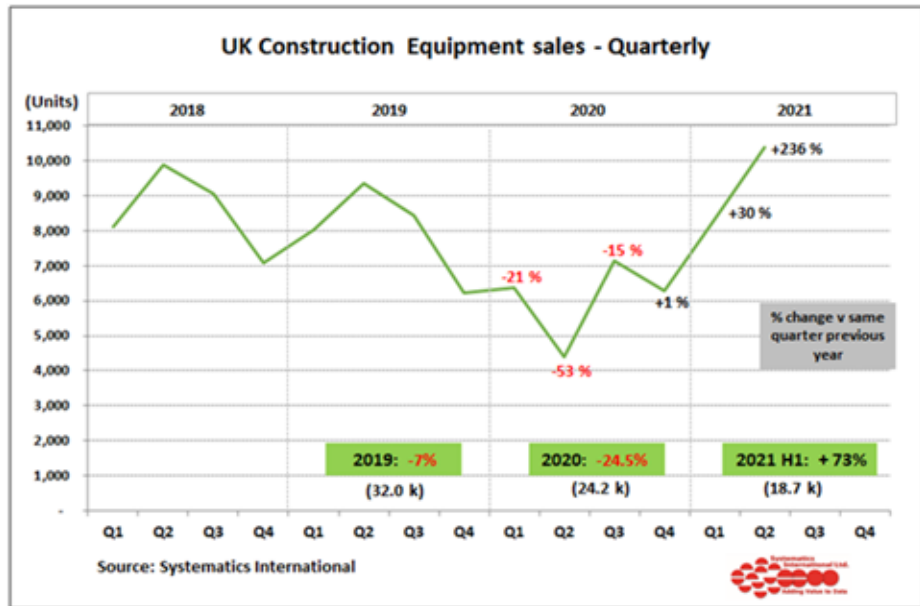


Market Analysis



Market Analysis

UK



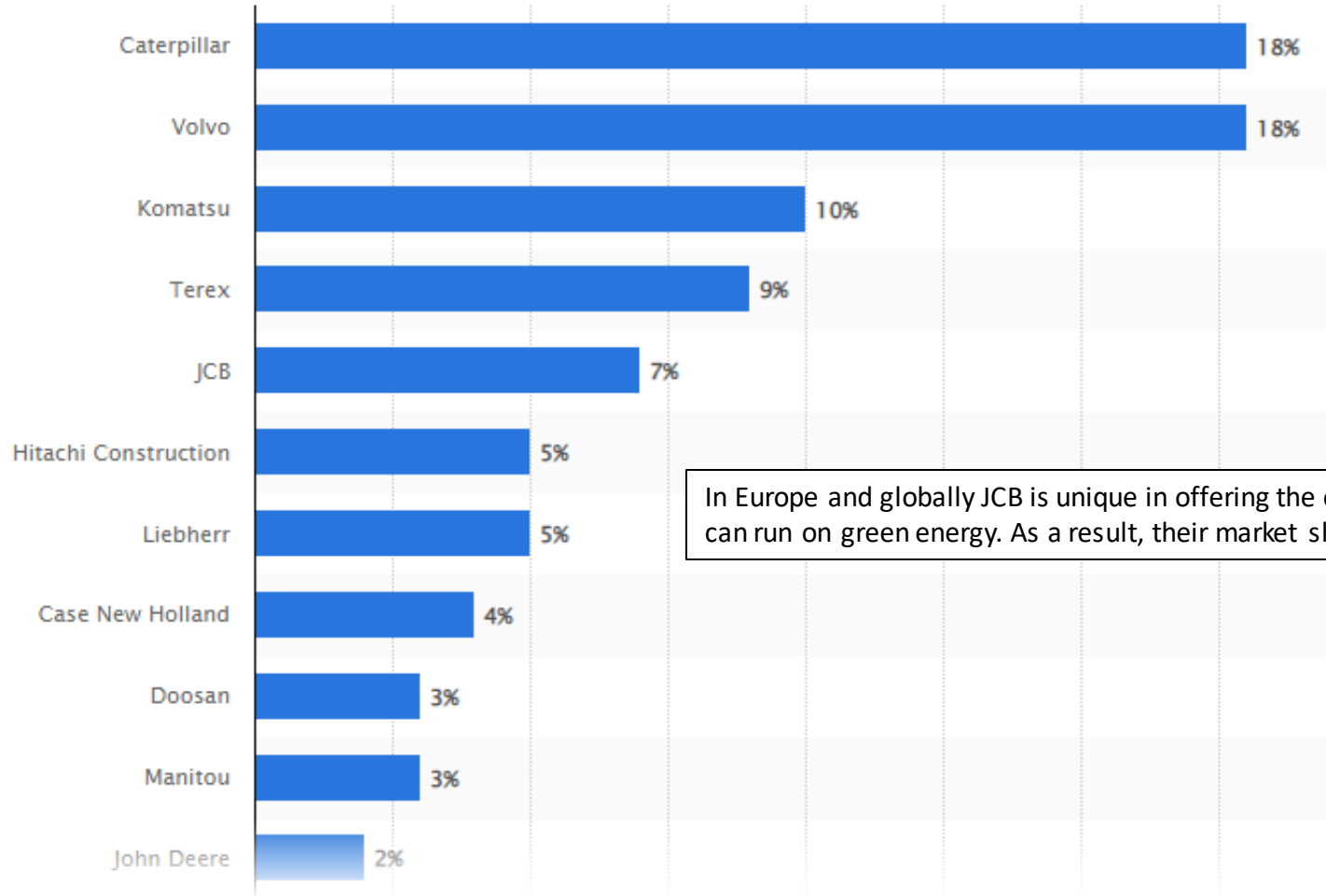
An upturn in UK sales is predicted for Years 2022 and 2023, with JCB offering the only viable plant that can run on green energy, their market share will only rise.

In Europe and globally JCB is unique in offering the only viable plant that can run on green energy. As a result, their market share will only rise.



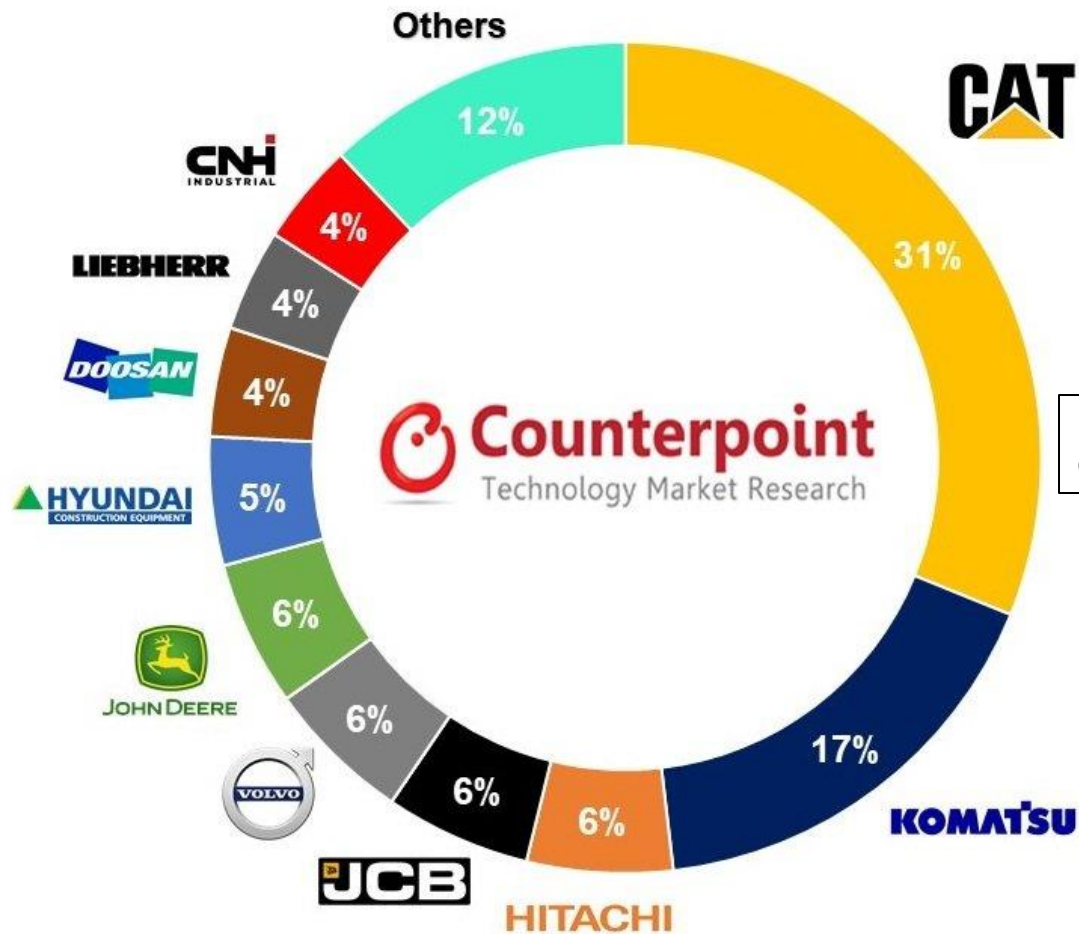
Market Analysis

Europe



Market Analysis

Global



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Technology Drivers



Management of Innovation Developments in terms of Satell's Typology

Has the innovation and development been technology dependent and if so, what technologies?

"Technology-led company" (Roper, 2016)

- The company ethos and mission, primarily centred around using engineering technology to meet the needs of the customer whilst minimising the carbon footprint of, not only JCB but its customers and partner companies through the whole Hydrogen supply to use network.
- JCB operates a wide range of business divisions, all of which rely on innovative strategies and technology for growth and expansion. This could be something as complex and advanced as the Internal Combustion Engine and Transmissions or something more simplistic, such as the data gathering, with its operator monitoring system that allows them and the owners to monitor the usage and performance of the plant

Breakthrough Innovation

Developing the new engine using established base and sump, but advanced, self-developed head, turbo, and fuelling.

Basic Research

Introduced many innovations to site plant
Developed electric and hydrogen fuel cell for smaller plant
Chairman gave JCB Powertrains 2 years to develop a hydrogen ICE in-house - achieved
Mechanical powertrain and propulsion innovation - DieselMax, JCBGT etc.

Sustaining Innovation

Ensuring the technology of hydrogen generation is developed by investing heavily in market leaders-ITM
Engine base means that existing mechanical skills in service universally, in all sectors, can be used with the new ICE - Evs are a radically new and many people are untrained and lacking the skillset plus recharging can make sites inaccessible?

Disruptive Innovation

The promotion of hydrogen ICE to disrupt the EV and hybrid 'single-mindedness'
Innovating the 'means of production' - ITM, and the means of delivery - the site delivery truck - sidesteps barriers from other interests.



Management of Innovation Developments in terms of Satell's Typology

Examples of technology-dependent innovations at Octopus Energy and how they would be framed on the Innovation Matrix

Breakthrough Innovation – access to resources. Laser focus. Understanding of customer needs. Appropriate technical capabilities.

Sustaining Innovation – close customer involvement. Nurture a culture of 'freedom'. Regular incremental improvements/fixes/features to the existing products.

Basic Research – cost effective option. Scientific papers and conferences

Disruptive Innovation – simple solution to your customers' problem. Radical new use and/or functionality.

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Considerations & Summary



Considerations

JCB not only foresaw the requirement for a reliable and powerful ICE, but the company also had the foresight to sustain its innovation through:

- Investing in Hydrogen producing companies in order to procure a plentiful resource for its product.
- Entering into relevant partnerships within the growing Hydrogen field.
- Seeking out better, cleaner ways of producing a hydrogen supply.
- Investing in the supply infrastructure required to service the refuelling needs of its customers in the field. (Refuelling truck)
- Exploring new applications of its Hydrogen ICE technology within the diesel type markets. (Mercedes platform test bed)



JCB Innovation Matrix (Satell, 2018)



Problem Definition

Not Well Defined Well Defined

Breakthrough Innovation Developing the new engine using established base and sump, but advanced, self-developed head, turbo, and fuelling.	Sustaining Innovation - Ensuring the technology of hydrogen generation is developed by investing heavily in market leaders-ITM - Engine base means that existing mechanical skills in service universally, in all sectors, can be used with the new ICE – Evs are a radically new and untrained/inaccessible? skillset
Basic Research - Introduced many innovations to site plant - Developed electric and hydrogen fuel cell for smaller plant - Chairman gave JCB Powertrains 2 years to develop a hydrogen ICE in-house – achieved - Mechanical powertrain and propulsion innovation – DieselMax, JCBGT,	Disruptive Innovation - The promotion of hydrogen ICE to disrupt the EV and hybrid 'single-mindedness' - Innovating the 'means of production' – ITM, and the means of delivery – the site delivery truck – sidesteps barriers from other interests.

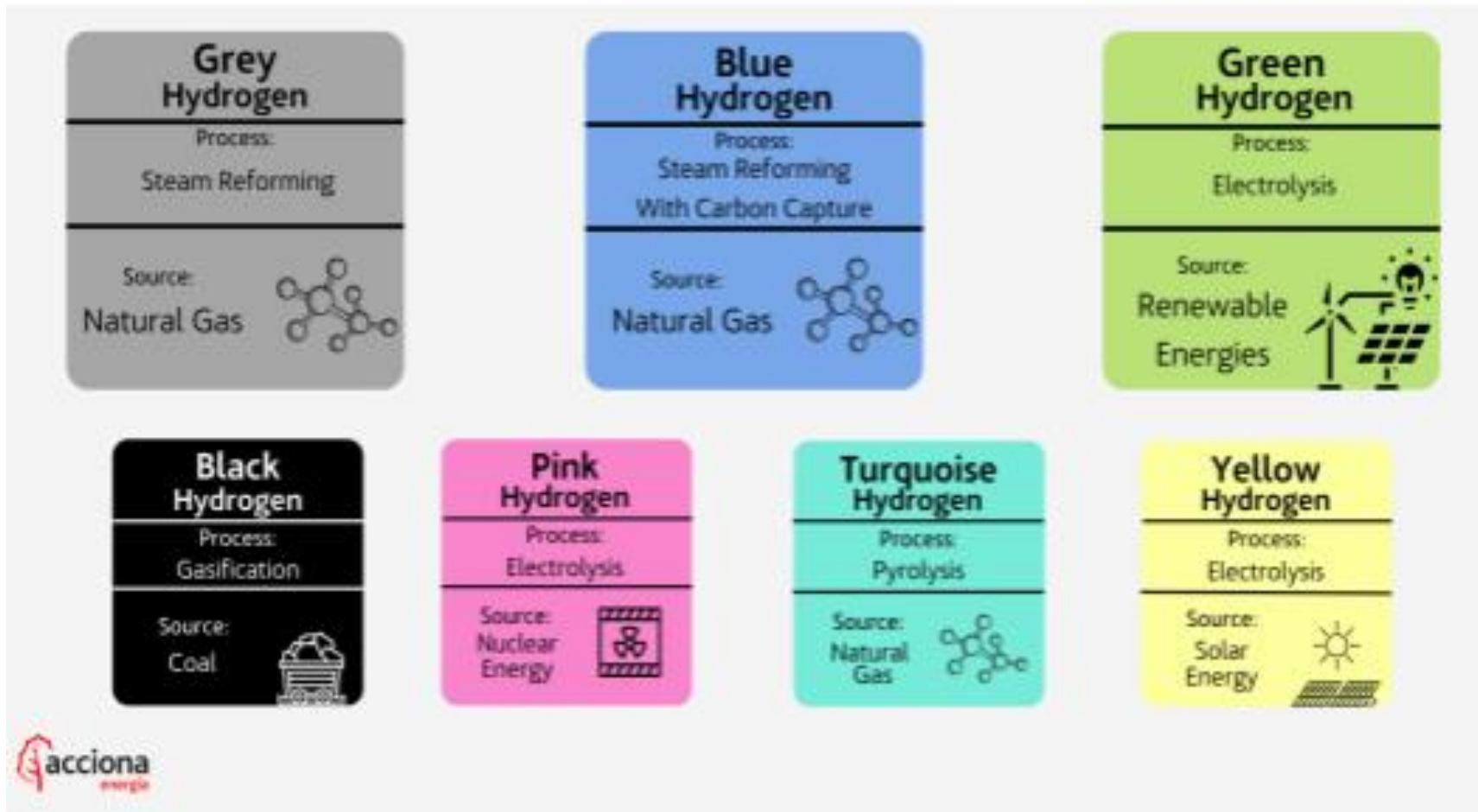
Not Well Defined

Well Defined

Domain Definition

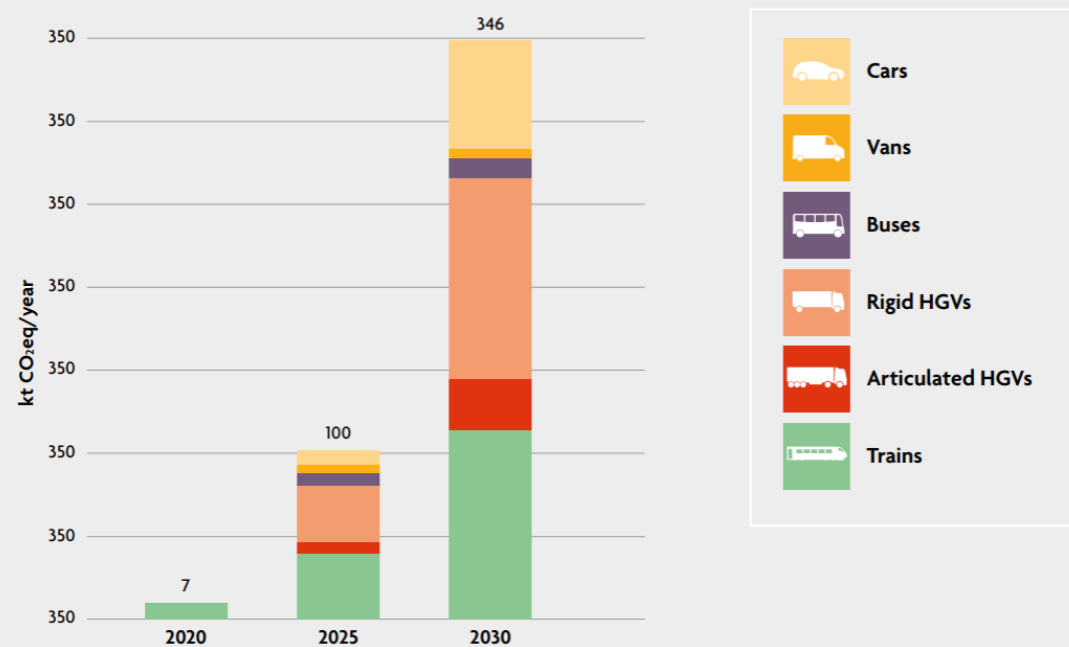


Hydrogen types and sources



Recognition of the need for Hydrogen Networks

Figure 1: Potential CO2 reduction from hydrogen vehicles in the North West to 2030



Source: Cadent (2019) HyMotion: Network-supplied hydrogen unlocks low carbon transport opportunities, June 2019

North West Hydrogen Alliance

A Hydrogen Mobility Roadmap
May 2020



NWHydrogenAlliance.co.uk

Partners

Cadent
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PROGRESSIVE
ENERGY



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BOC
A Member of The Linde Group

HALTON
BOROUGH COUNCIL

SNC-LAVALIN

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MACDONALD

OTTO
SIMON

THYSON
TECHNOLOGY

University of
Chester

Thornston
Science Park

COSTAIN

incovyn
An INEOS company



Recognition of the need for Hydrogen Networks

BayoTech
ON-SITE HYDROGEN

Hydrogen from RNG

Why and How?



BayoTech Summary

- Hydrogen technology is ready now
- It is the best link between Biomethane and zero emission vehicles
- Pipeline supply for Biomethane – onsite production
- Biomethane to hydrogen is viable and effective
- It is the only way to create carbon negative hydrogen
- Captured fleets provide the perfect setting for RNG to hydrogen facilities
- BayoTech can deploy these systems today for low cost, low carbon hydrogen

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Capacity: 200 kg to 1,000 kg per day
(84,660 to 423,190 scf per day)

*5- and 10-ton units planned for 2021



Recognition of the need for Hydrogen Networks

What's already happening in the North West?



Liverpool City Region Combined Authority and partners Arcola and BOC are rolling out 20 hydrogen buses on routes into central Liverpool.



Alstom in Widnes is ready to deploy its new Breeze trains and is working with Northern Rail to identify routes that are suitable for conversion to hydrogen.



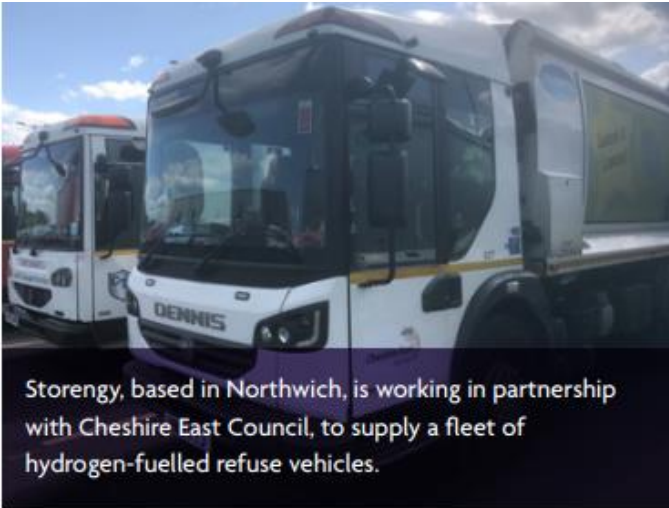
Storengy, based in Northwich, is working in partnership with Cheshire East Council, to supply a fleet of hydrogen-fuelled refuse vehicles.



Recognition of the need for Hydrogen Networks



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ULEMCo in Aintree has converted a range of vehicles (including trucks, refuse vehicles and ferries) to hydrogen or dual-fuel hydrogen/diesel.

Cadent launched its HyMotion report in June 2019, which evidenced the benefits of supplying hydrogen using pipeline networks.³ Cadent is seeking partners for demonstration projects that provide learning on the distribution of hydrogen for mobility via networks. Such demonstrations will include showing that, by including relatively simple 'upgrading' equipment, pipeline networks can deliver hydrogen to the purity specifications required by fuel cells.

Assuming moderate uptake of hydrogen vehicles in 2030, supported by hydrogen from HyNet (the UK's leading hydrogen and carbon capture project located in the North West, led by Progressive Energy) available from 2025, as shown in Figure 1, over 0.3 million tonnes of CO₂ emissions could be avoided, a total which would likely grow significantly in the subsequent years.

An Overview of Combined resources and infrastructure



VALEBOND CONSULTANTS LIMITED



THE WHOLE SOLUTION

Ryze transport hydrogen, manage distribution networks, supply hydrogen and hydrogen infrastructure.



Future thinking and recognition



Graeme Macdonald, CEO, JCB

The company currently recruits around 150 people a year. Graduates from the JCB Academy - which is open to 13-18-year-olds - can choose between starting JCB apprenticeships and going to university when they come to leave the school. They may go on to work with JCB or at other manufacturing or engineering companies in the Midlands or beyond.

The company supports communities in other areas of the globe too, with several charitable trusts focussing on education and children's welfare. It also has a relationship with the NSPCC. Macdonald says: "I think the trendy name is corporate social responsibility, but we've been doing it for many, many years. It's very well embedded in the JCB DNA."

For JCB, the future is bright as well as yellow. "In an ever-evolving industry, our relationship has stretched over decades," says Macdonald. "Our strategy over the next two to three years will be to grow market share, and we do that by investment in great new products, manufacturing capability and distribution. We can't do that alone."

As the company continues to grow, Macdonald is sure that their partners will support it all the way. "The great thing about our partners is that because we've had such a longstanding relationship, they really have a deep understanding not only of JCB, but of our industry. "They can provide great innovative solutions such as trade financing for this specific industry, and they really understand the mechanics of how that operates. And that makes growing our business so much easier."

“ We have a phrase – ‘innovation is our life blood’ – and we live it and breathe it every day ”

Graeme Macdonald
CEO, JCB



Sustaining the future of the engineering and business expertise



T-LEVELS >>>

THE JCB ACADEMY

Changing lives by developing the engineers and business leaders of the future

ACADEMY

PARENTS

EMPLOYERS

DESTINATIONS

APPLY Y9 & Y10

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nationalgrid

ULTRA

Hitachi Energy

CAPULA

LOWE

Midlands Partnership University
NHS Foundation Trust



Student
Learning



Student Learning

Simon Shuker

On the face of it, "build us a new hydrogen engine" is a large task.

Having Satell's matrix allows a guide through the interlinked strands of innovation needed to fulfill this task and sustain it in a market.

The breadth of innovation constantly progressed by JCB - mechanical, powertrain, fuel type and engineering, opens up the opportunities which can then be seen to sit within Satell's classifications.

From the basic research necessary to build a novel mechanical system, or a novel fuel engine, to the Sustaining Innovation of making sure the new engineering is not too radical that the adoption is cost-prohibitive.

In the same way the disruptive innovation of building your own fuel supply truck and becoming majority shareholder in the market leader in UK hydrogen electrolyzers, securing a practical source of fuel, and network of fueling stations for users. JCB's new hydrogen innovation, removing some major blockers that could be placed against their success.

The business and management strategy at JCB revolves around the innovation they thrive on and succeed with.

As their employee said, "...Innovation is in our DNA at JCB".

Simon Shuker

Gerard Logan

"I learned that Satell's matrix can be used to map innovation around:

1. Whether or not a problem is clearly defined:

In this case I believe it was clearly defined -
The global move away from fossil fuels, added to the fact that heavy plant could not be powered efficiently as wholly EVs, necessitated an alternative. Hydrogen is generally made from "dirty" processes so green alternatives were required. With the ability to provide the fuel source in rural and remote areas where needed also.

2. The market in which the issues exist (The Hydrogen ICE could be applied to many sectors, but the innovation was applied to the heavy plant sector in the first instance before being rolled out to others)

3. The strategy and where to solve these problems (the right investor, the right people, the right skill sets).

4. Maintaining the innovation through investment in putting in place a supply infrastructure & associated technologies, further sustaining through supply & tech acquisitions, along with operational excellence and customer care.

Looking at the case of JCB and the Hydrogen ICE, they have achieved both disruptive and breakthrough innovations."

Gerard Logan



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Thank You for your
attention

We are now open to
questions