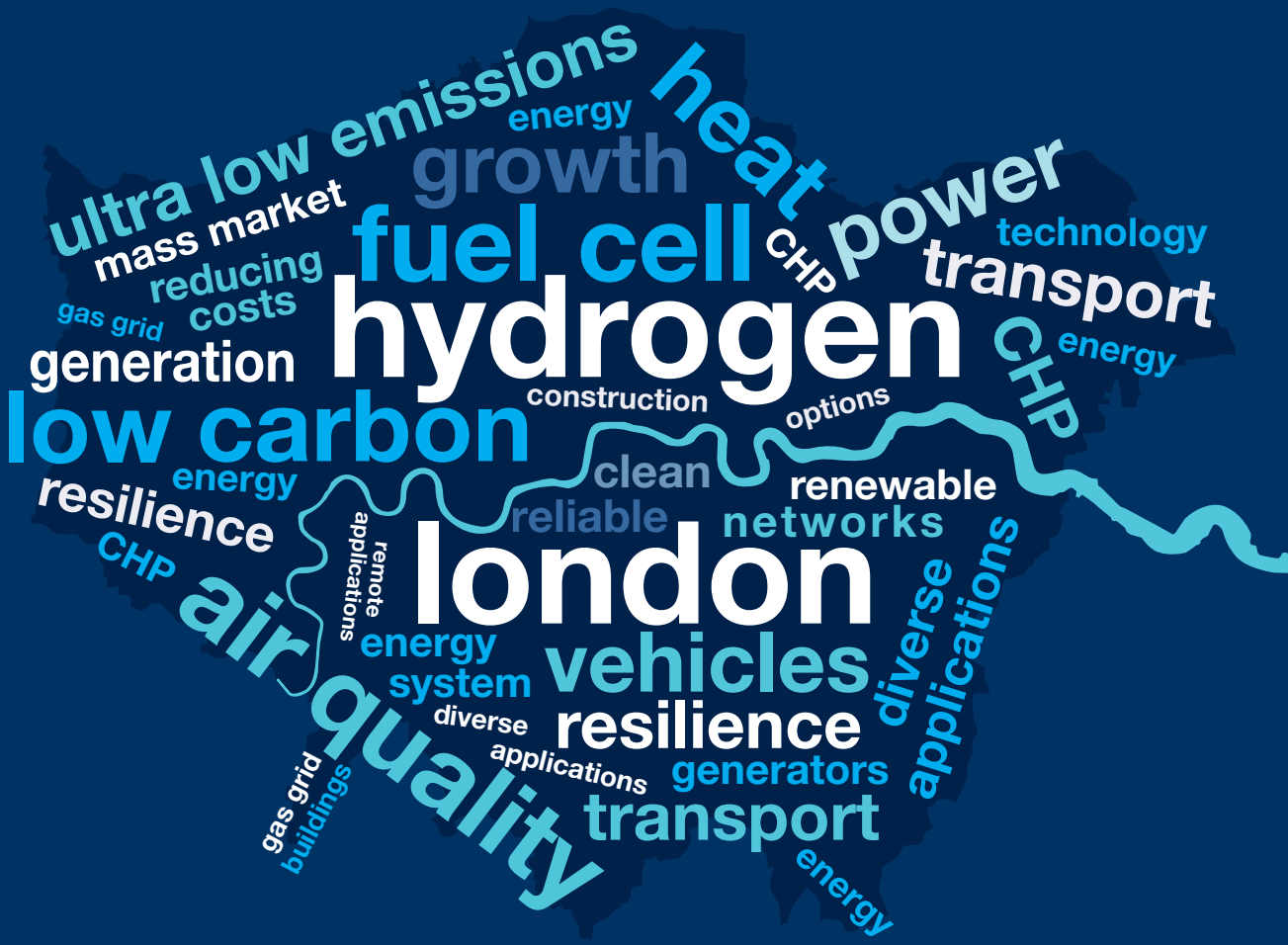
LONDON: a capital for hydrogen and fuel cell technologies



Executive summary

April 2016

SUPPORTED BY

MAYOR OF LONDON

HYDROGEN LONDON

HYDROGEN LONDON

Hydrogen and fuel cell technology has the potential to provide **solutions to London's most critical energy challenges** – enabling growth while improving quality of life and minimising environmental impacts.

Since being established by the Mayor's Office in 2002, Hydrogen London has been at the heart of London's hydrogen and fuel cell industry.

This group has played a central role in facilitating knowledge sharing, raising the profile of the sector, and initiating projects to demonstrate the potential for hydrogen and fuel cell technologies in London. The members of Hydrogen London include experts from government, the private sector and academia.

This document was prepared for Hydrogen London by Element Energy Ltd.

London's challenges: growth, access and liveability

Space-constrained growth

Emissions need to be cut dramatically despite London's population growth

Many low emission technologies are not space efficient

Energy network upgrades (gas, electricity) are expensive and can cause congestion

GROWTH

ENVIRONMENT

Cleaner air for London

Limited options for eliminating vehicle airborne emissions, particularly for large vehicles

Traditional options for decentralised generation produce local pollution – particularly energy from biomass/waste

Stronger, resilient energy networks

Increased energy security needed to support London's growing economy

Commercial buildings need secure electricity and heat: decentralised energy needed to avoid costly upgrades to the electricity grid

Avoiding climate change

Emissions reductions needed in all sectors – heating and transport particularly hard to address

Electrifying transport, heat and power in order to decarbonise increases pressure on the electricity grid, which is already strained

Hydrogen and fuel cells offer holistic solutions

Space-constrained growth

Fuel cells are one of the the most space-efficient ways to provide low carbon decentralised energy (easily integrated into buildings, vs solar & wind)

Zero-emission transport infrastructure with minimal land use

GROWTH ENVIRONMENT

Cleaner air for London

Hydrogen fuel cell technology: zero emissions at point of use

Hydrogen combustion: ultra low emissions

Stronger, resilient energy networks

Hydrogen can be produced affordably from a range of low carbon sources outside London and transported into the capital as a new clean way to import energy

Electrolysers producing hydrogen in London could help support an electricity system with increased renewable generation

Avoiding climate change

Low carbon hydrogen can be produced from local renewable sources and used to fuel heat, transport and power

Hydrogen can be used in the gas grid to progressively convert to zero carbon heat

Mass uptake will unlock increasing benefits for London

Broad energy system benefits unlocked when hydrogen is integrated throughout the energy economy

- Hydrogen supplied for heat & power through diverse supply routes (gas pipelines, onsite generation, freight delivery).
- Opportunity to meet London's growing energy demands without over-reliance on electricity networks.
- Low emission transport with minimal land use impacts.
- Inherently flexible generation from electricity and other low carbon sources.

As costs fall, emissions savings will accrue from hydrogen in transport and fuel cells for heat and power

- Vehicle commercialisation brings greater demand for hydrogen.
- Business models for hydrogen production and trading become established.
- Gas fuel cells for heat and power drive fuel cell cost savings.
- Reduced construction emissions through adoption of fuel cell generators.

Local benefits are already being achieved in applications across London

Local level impacts

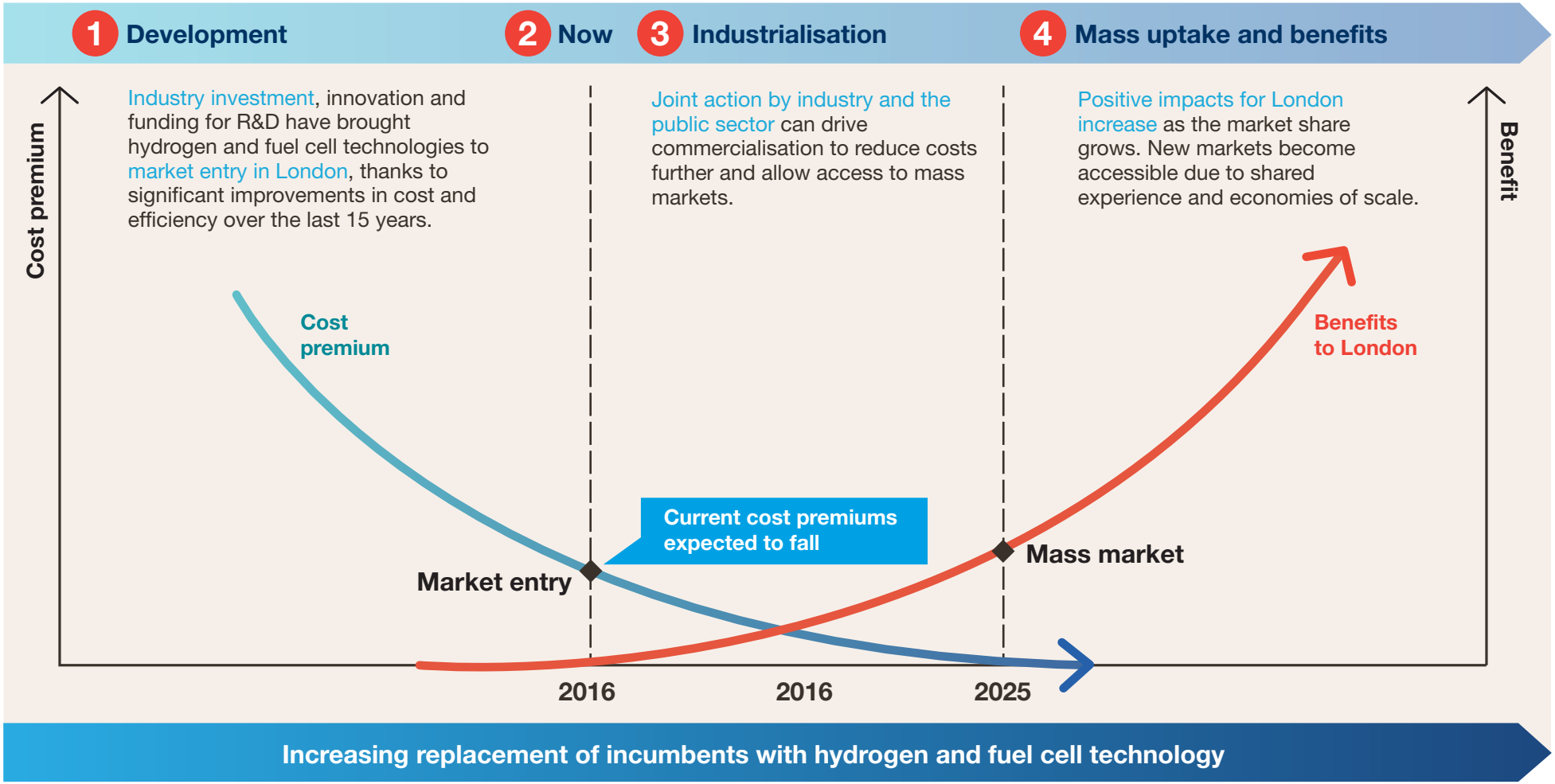
Early commercial opportunities

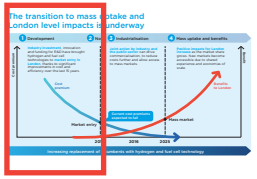
Significant impacts for London

Full range of commercial applications

Increasing scale of impacts

The transition to mass uptake and London level impacts is underway





1 London has helped mature the technology

The private sector has invested many tens of millions in hydrogen and fuel cells in London to date, resulting in a wide range of proven applications, demonstrating the market readiness of the technology

On a global level in 2014, **fuel cell sales exceeded $2.2 billion** (up from $1.3 billion in 2013)[1] and **over 100,000 fuel cells were shipped worldwide.**[2]

Transport

- Hydrogen cars, buses and delivery vans are now on the roads in London.
- Fuel cell cars can be commercially purchased or leased via OEM showrooms.

Public stations at Hendon and Heathrow; three more due to be installed in 2016

Fuel cell cars in operation with a range of public and private sector fleets

Fleet of hydrogen-diesel delivery vans (eligible for 100% congestion charge discount)

Fuel cell taxis introduced during 2012 Olympics and operated to late 2015

Fuel cell buses on a dedicated hydrogen route

Quadrant 3, Regent Street

TfL's Palestra Building

20 Fenchurch Street

Construction & specialised applications

- Unsubsidised, low power fuel cell units are in use in lighting towers, CCTV and road signs across London.
- Efficient, low emission heat & power for remote site cabins has been demonstrated using a fuel cell.

Lighting towers e.g. for construction

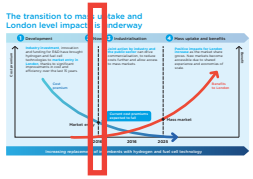
Remote site heat & power

Fuel cell & solar powered lighting for construction at the Olympic park

Heat & power

- London is the European capital for fuel cell combined heat and power (CHP), with the largest installed capacity of any European city.
- Gas fuel cell CHP has been installed without subsidy to meet new build planning guidelines.
- In other cities such as Seoul, hydrogen and hydrogen-ready fuel cells are starting to be used for megawatt-scale CHP, showing the potential for London.

References: 1- Fuel cell technologies market report 2014, Fuel Cell and Hydrogen Energy Association, DoE 2015
2 - 4th Energy Wave Fuel Cell 2015 annual review



2 Londoners are enjoying using the technology today

◀ Fuel cell buses

Fuel cell buses in London have covered over **1.1 million kilometres**

"I think this is a great bus, very quiet, very comfortable to drive, people are loving it"
(TfL Bus driver)

Fuel cell taxis ▶

Fuel cell taxis have covered **101,000 zero emission kilometres** in central London

"This is the quietest and most responsive vehicle I've driven since I started driving a taxi nearly 40 years ago. After a day's driving you do not feel fatigued by the constant drone that you normally get from a diesel taxi"
(Taxi driver)

Hydrogen-diesel vans ▼

"The hydrogen technology powering Commercial's vans currently offers best-in-class carbon emissions without significantly affecting range or payload requirements. Being able to offer a hydrogen-powered delivery service …is a key differentiator in the stationery market place."
(Simone Hindmarch-Bye, Director of Commercial Group)

Fuel cell cars ▶

Toyota Mirai

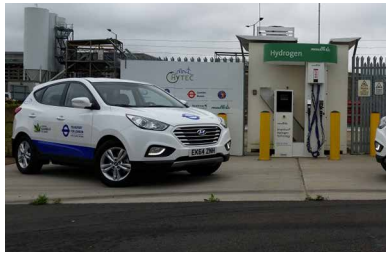
"Passenger feedback is always positive because it's so quiet, it's really comfortable. My son calls it the muscle car because of the way it just takes off. It's really fantastic to drive"
(Theo Etrue-Ellis, Mirai driver for Green Tomato Cars)

Fuel cell combined heat & power ▼

"Installing the UK's biggest in-house hydrogen fuel cell and signing up to the 10:10 commitment reinforces TfL's commitment to cutting carbon and improving our energy efficiency."
(Andrew Stanton, TfL's Head of Sustainable Buildings)

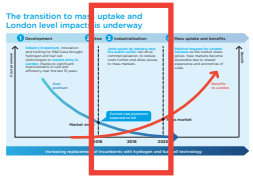
▼ Ecolite-TH2 fuel cell lighting tower

"The use of the Ecolite-TH2 lighting unit on our project has significantly enhanced our mission to protect the environment by reducing our carbon emissions and noise impact of work on Network Rail's lineside neighbours." (Geraldine Simak, Environmental Manager for Costain)

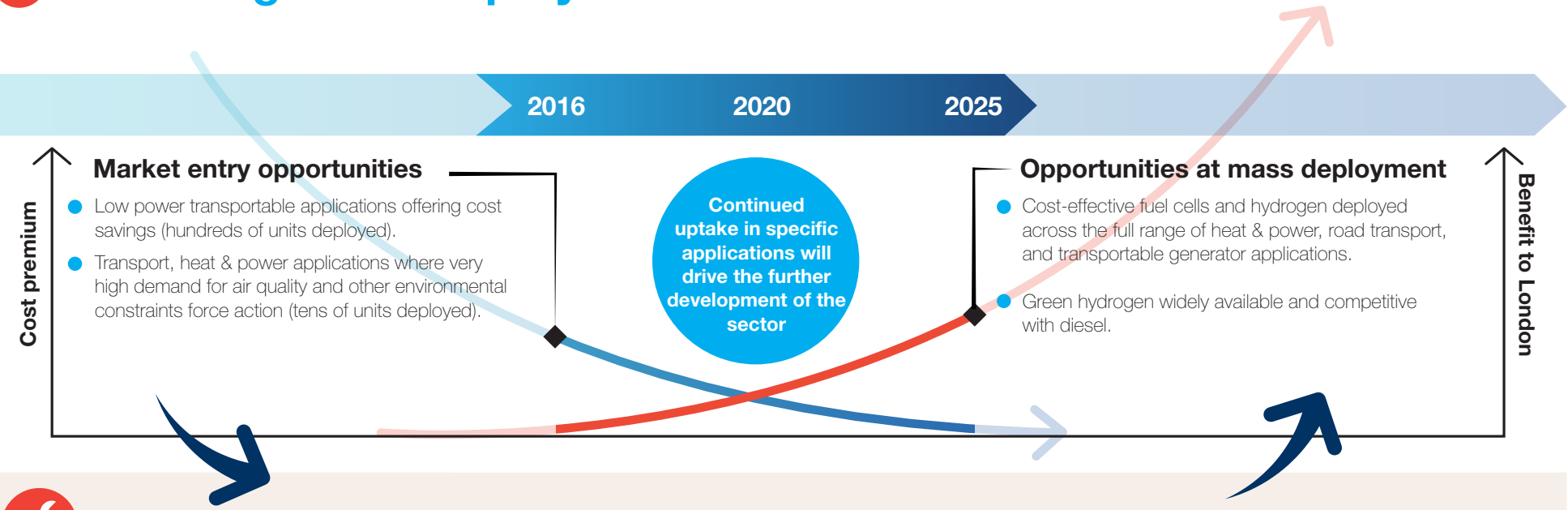


◀ Hydrogen stations

"Refuelling with Hydrogen is as easy and as quick as a petrol or diesel car… topping up with Hydrogen gives you another 220 miles in less than 5 minutes."
(Luke Tan, FCEV driver)



3 Achieving mass deployment in London

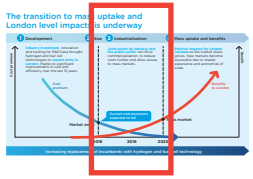


London's toolkit to drive commercialisation

Develop a 4 year action plan, including:

- Help facilitate early product deployment projects.
- Use the London Plan to ensure that policy is inclusive and references the potential of hydrogen and fuel cells to help meet London's targets.
- Support Greater London Authority family organisations in adopting more hydrogen and fuel cell technologies.
- Encourage other public and private users to be early adopters, using London's influence and networks.

Heat & Power	• Enforce air quality regulations for distributed generation via the planning system. • Promote the reliability and air quality benefits of fuel cells for power (and heat).
Road transport	• Use the Ultra Low Emission Zone to stimulate zero-emission vehicle uptake. • Conduct high profile trials for new segments (e.g. heavy vehicles); joint procurement to reduce costs (e.g. fuel cell buses). • Increase demand around existing stations and work with industry on strategic deployment of new stations.
Transportable generators	• Use the Low Emission Zone for non-road mobile machinery to introduce new regulations for generators e.g. mandate zero emissions for remote, low power applications; incentivise zero emission options for larger generators.



3 Hydrogen and fuel cells in other world-leading cities

Achievements to date (early 2016)

Tokyo

- Tens of hydrogen stations, hundreds of fuel cell vehicles
- Local subsidies for microCHP have led to many tens of thousands of units deployed, driving cost reductions

Future plans

- Target: 6,000 fuel cell vehicles and 35 hydrogen stations by 2020
- 10,000 fuel cell vehicles and 80 hydrogen stations by 2025
- 2.5 million microCHP units in Japan by 2030

California (Los Angeles, San Francisco, San Jose)

- Ten hydrogen stations, hundreds of fuel cell vehicles, trials of hydrogen hybrid trucks
- Fuel cells have access to state combined heat & power incentive scheme; over 100 MW of stationary fuel cells installed

- Zero Emission Vehicle Program – sales targets for battery electric vehicles and fuel cell vehicles signed into law: >50,000 fuel cell vehicles expected by 2020
- Up to 100 hydrogen stations to be built by 2024

London

- 3 hydrogen stations, with more planned for 2016
- 8 fuel cell buses, 15 fuel cell vehicles from global OEMs, 10 hydrogen-diesel vans
- 3 large-scale fuel cell combined heat & power plants (largest number in one European city – combined total of c.1MW)
- Hundreds of unsubsidised portable power units sold

NOW:
opportunity for London to define clear goals and remain a leading world city for these technologies

New York

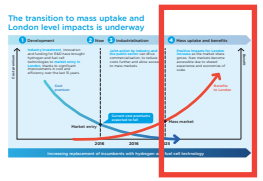
- 15 MW of fuel cells for heat & power
- State grant and loan programmes; tax incentives and renewable portfolio standards

- Targeted 543–724 MW of fuel cells for heat and power by 2025
- State incentive programmes are planned for fuel cell transport as well as heat & power

Copenhagen

- Tens of fuel cell vehicles, 3 hydrogen stations (9 in total in Denmark)
- 50–100 fuel cell microCHP in homes across Denmark

- The city aims to be carbon neutral by 2025
- Targeted 185 hydrogen stations in Denmark by 2025



4 Delivering major positive impacts across London

Benefits to London will accrue over time as the market share of hydrogen and fuel cell technologies increases

2025

Growth

Strong hydrogen skill-base and increased employment in London

Environment

Hydrogen and fuel cells bring local air quality improvements by displacing diesel in thousands of cars, hundreds of buses, and thousands of transportable generators, and displacing gas combustion in hundreds of fuel cell CHP installations

Resilience

Locally produced hydrogen widely available and competitive with diesel, bringing energy resilience

Benefits accrue

2050

Growth

Jobs and economic growth for London as a result of local fuel production and specialised maintenance skills

Environment

Hydrogen vehicles deliver 15–50% reduction in transport CO_2 (vs 1990)

Zero carbon from heat and power, including hydrogen supplied via gas grids, and hydrogen fuel cell CHP taking a significant market share

Clean air across London; fuel cells a key contributor (e.g. construction emissions vastly reduced through use of fuel cell generators)

Resilience

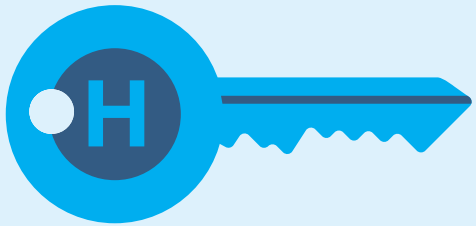
Hydrogen as a competitively priced, locally produced, low carbon fuel

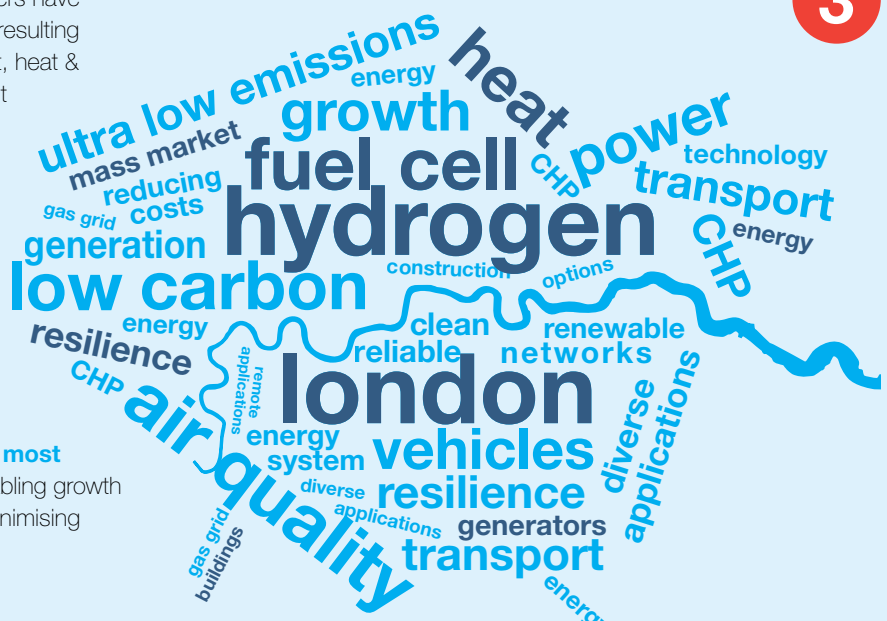
Increasing replacement of incumbents with hydrogen and fuel cell technology

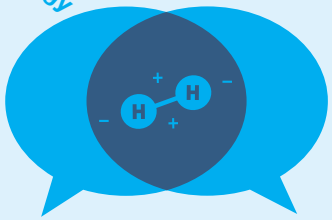
A call for leadership to address London's challenges

1 **London is already recognised as a major global platform** implementing and showcasing the capabilities of hydrogen and fuel cells. Hydrogen London members have used London as a proving ground, resulting in sustainable solutions for transport, heat & power that are ready to be rolled out across the city.

2 The technology has the potential to provide **solutions to London's most critical energy challenges** – enabling growth while improving quality of life and minimising environmental impacts.







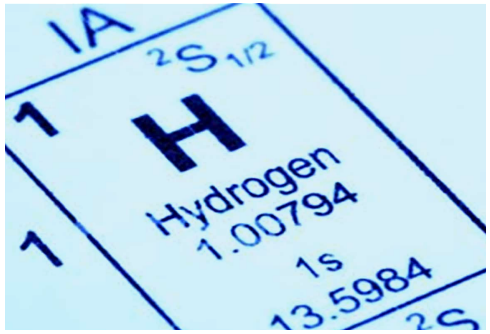
3 To realise this vision, the Hydrogen London industry partners invite the Mayor of London and the Greater London Authority to work alongside them to take the **decisive strategic actions needed to deliver successful technology outcomes for London** into the next decade and beyond.

- **Develop** an updated hydrogen action plan for London with Hydrogen London partners.
- **Support the inclusion** of hydrogen and fuel cells within the London Plan and other strategic documents, recognising their potential impact on London's challenges.
- **Make London a leading city** by encouraging early adoption of hydrogen and fuel cell vehicles across the GLA family fleets.
- **Encourage** others in London to engage with the technology, using the GLA's influence, networks and ability to organise partners within London.

Glossary

Hydrogen

- Hydrogen is a very common element. It does not occur naturally as a gas on Earth and is generally combined with other elements (e.g. carbon (as in hydrocarbons) or oxygen (to form water)).
- While it is not a primary source of energy, hydrogen is an energy carrier and can therefore be used as a fuel. Transporting hydrogen (e.g. via gas networks) in order to move energy to its point of use provides an alternative to using electricity networks.
- Pure hydrogen can be obtained from hydrocarbons via the application of heat (reforming), by passing electrical current through water (electrolysis), and from a number of other processes.
- There are a number of low carbon routes to produce hydrogen, including electrolysis using renewable electricity and reformation of biogas.
- Hydrogen has been used as an industrial gas for decades, which means methods to safely and efficiently produce, distribute, store and use hydrogen are mature.
- The versatility of hydrogen as a fuel makes it a good candidate to replace fossil fuels in a range of applications – it can be combusted in an engine or used in an electrochemical device (fuel cell) to generate electricity.
- Whether burnt or used to produce electricity, hydrogen fuel provides ultra low emissions (carbon and other) at the point of use.



Hydrogen storage (compressed gas)

Fuel cells

- Fuel cells are electrochemical devices that generate electricity (and water) from oxygen and hydrogen. Being based on a chemical process instead of combustion, fuel cells can operate at high efficiency and have ultra low / zero harmful emissions such as NOx and particulates.
- Various types of fuel cells exist, each with their own characteristics (power density, fuel flexibility, cost, lifetime, etc.).
- Fuel cells can therefore be used in applications with a wide range of energy and power requirements, from consumer electronics charging, to powering vehicles, to providing heat, cooling and electricity for buildings.

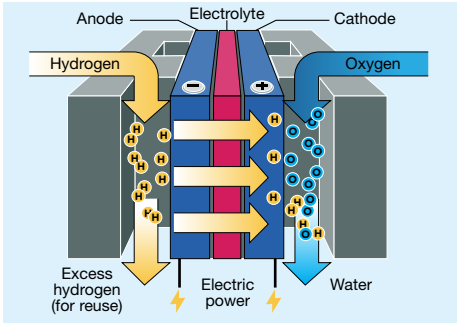


Diagram of a typical fuel cell