Accelerate H_2

A hydrogen mobility strategy for the early 2020s

July 2020

UK H_2Mobility consortium

www.ukh2mobility.co.uk

Hydrogen's potential

The potential of hydrogen

Hydrogen can be used as a fuel to replace fossil-based fuels across the heat, industrial and transport sectors. Adoption of hydrogen will bring numerous benefits to the UK:

- public health improvements by reducing the harmful emissions from combustion of fossil fuels
- environmental benefits through reduction of CO2 emissions
- economic benefits are derived by reducing the cost of the UK importing energy
- employment benefits in high-end engineering and manufacturing jobs.

The mobility context

The UK has been working with a strategy for hydrogen based mobility devised in 2014 and covering the period 2015 to 2020. It is based on a first set of deployments (mainly for passenger cars) which has now proven the operational viability of hydrogen as a fuel but also exposed challenges which need to be addressed in any expansion phase.

Meanwhile, there has been significant progress worldwide in:

- deployment - there are over 140 fuel cell vehicles in the UK and, for example, over 5,000 fuel cell cars in California
- technology (London fuel cell bus fleets have vehicles with over 30,000 hours of operational fuel cell life)
- the diversity of vehicles which are available – ranging from two wheeled scooters through cars to articulated trucks, buses, trains and ships.

Given these developments, there is a need to update the approach to hydrogen mobility in the UK for the period beyond 2020.

This document is a proposal from the UKH_2Mobility coalition of leading industrialists in the sector to develop this approach.

A UK H_2Mobility strategy for the early 2020’s (1/2)

A strategy based on a diversity of vehicle types

Hydrogen appears to be the only viable option to deliver fully zero emissions and zero carbon emissions for the heavier vehicle types such as long distance trucks, non-electrified trains and ships. This is recognised by numerous reports, not least the Committee of Climate Change’s Net Zero report.

For smaller vehicles, battery vehicles will start to compete with hydrogen as a zero emission option. Battery and fuel cell technologies are likely to co-exist in these segments - even with today’s level of technology maturity hydrogen can be the preferred option in long distance bus and car applications (e.g. taxis) and will soon be able to offer an attractive option for longer range vans and delivery trucks.

The UK H_2Mobility consortium believe that cost reductions associated with economies of scale will allow hydrogen to become an increasingly competitive choice across all of the main mobility vehicle segments.

On this basis, this revised strategy is based on a diversity of vehicle types, with much of the initial demand for hydrogen coming from heavy duty vehicles such as buses and trains, whilst ensuring a good spread of refuelling infrastructure to support a growing fleet of passengers cars and vans.

The strategy is also based on a tight coupling between the rate of deployment of new refuelling stations alongside new sources of demand, which ensures good utilisation and hence good economics for the station investors.

A UK H_2Mobility strategy for the early 2020's (2/2)

A phased program is proposed which builds on the deployment which has occurred to date and progressively expands the level of ambition of deployment in 5 of the key vehicle segments (bus, train, truck, car and van). In so doing, the UK is prepared for a commercial expansion of clean vehicle deployment from 2025 onwards.

The aim of this approach is to allow each of the vehicle classes to mature their commercial offering so that, following the scheme, there is a commercially viable offer available for each of the vehicle types. Many of these vehicle types will be developed by UK companies (buses, trucks, trains) and UK component suppliers will be involved in all vehicles types.

The programme will lead to the deployment of over **6,000** fuel cell vehicles across 5 different vehicle classes (buses, trucks, cars, vans and trains). It will ensure that each of the segments achieves the economies of scale required to be considered competitive as a zero emission alternative to fossil equivalents.

It will also ensure a credible network of refuelling stations for the refuelling of an increasing fleet of fuel cell vehicles, helping to cement the UK as an attractive destination for new hydrogen vehicle activity.

A phased program to expand the hydrogen for mobility sector in the UK

Vision for the deployment of Hydrogen vehicles and infrastructure in the UK

Phase 3 – 4,000 new fuel cell vehicles will be deployed at volumes that will drive production costs down to a competitive level. 37 new HRS will be constructed with larger refuelling capacity to supply the increased demand from hydrogen mobility activities.

To 2025

Phase 2 – 600 new fuel cell vehicles will be deployed across a wide range of vehicle classes including trains, vans and trucks. 20 additional refuelling stations will be deployed which are able to meet the refuelling needs of these new vehicle types.

To 2023

Phase 1 (already committed programs) – will see projects such as JIVE 1 & 2 and OLEV's HTP delivering:

- 250 fuel cell passenger cars
- 100 fuel cell buses
- 20 hydrogen refuelling stations

2019 - 2020

Today

- ~120 FC vehicles have been deployed through one off competitions in a small range of transport modes.
- <20 HRS are deployed in clusters providing a basic national network

2025 vision

- >6,000 fuel cell vehicles operating across the UK.
- Fuel cell vehicles are available in majority of transport sectors with competitive ownership costs to fossil equivalents.
- A profitable network of over 80 HRS are deployed providing national coverage to fuel cell vehicle operators.
- Sector is positioned for rapid growth
- Substantial UK involvement throughout the vehicle, hydrogen station and component supply chain.

A renewed UK Government support programme

Achieving this program requires support. The proposal is to move to a program which pre-agrees support levels for vehicles and stations as they are deployed. A per vehicle subsidy scheme coupled with incentives for green hydrogen utilisation at the early stations will underpin the expansion.

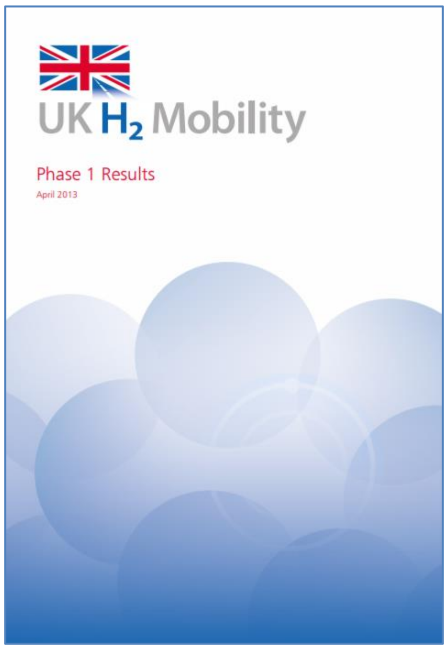
This support would be removed as volumes build up, thereby protecting the level of state investment required. In this document, the UKH$_2$Mobility industrial partners have set out the volumes at which each segment could be expected to have matured and the vehicles could commercially stand on their own without significant state support.

The public sector support required to achieve this will be circa **£190 million** over 5 years. The scheme will create **£840 million of private investment** in vehicles, stations and hydrogen production it will also contribute to the annual on-shoring of between **£14 and £22 million** per year of economic activity through the production of clean fuels in the UK.

This support program will enable UK based companies to develop a commercially viable hydrogen production and distribution system. It will also catalyse deployment of production facilities for vehicles and hydrogen equipment in the UK. This will position the UK to expand the deployment of this zero emission fuel on a sound commercial footing, from the late 2020s onwards.

This has huge potential for new economic activity for the UK. Securing even 10% of the UK's transport demand will lead to an on-shoring of over **£5.5 billion per year** of the UK's existing energy spend, an abatement of over **8.6 million tonnes of CO2e per year** and many billions of new economic opportunities for UK companies.

The UK H_2Mobility group of industrial players in hydrogen has provided much of the strategic analysis for hydrogen to date



UK H_2Mobility

UKH_2Mobility is a group of the leading industrialists in the UK with a commitment to the roll-out of hydrogen for mobility.

A number of Government organisations are also “Observer Partners” – OLEV, BEIS, Transport Scotland, Welsh Government, Greater London Authority.

The group prepared a report on a strategy for the roll-out of hydrogen mobility in the UK in 2014 and then helped to develop the national planning around hydrogen infrastructure roll-out.

This strategic planning was focussed on the period 2015 to 2020.

Since then, the group has expanded to incorporate a number of new vehicle types (buses, trains, boats). In addition, the hydrogen mobility landscape has inevitably evolved.

The UK H_2Mobility group has now aligned on a suggested strategy for the period beyond 2020

The purpose of this document

The group has come together to align on a suggested approach for hydrogen mobility in the UK in the early 2020s - aiming at the period 2020 to 2025

This document provides a summary of this suggested approach. The document has been prepared for UK and regional Governments to coincide with the spending review expected towards the end of 2019. The document can also be used to facilitate discussions with other external stakeholders to explain the preferred strategy of the group.

Level of detail and the nature of the request

This document is designed to suggest the principles of an approach for the early 2020s, which the industrial members of the group can support.

It outlines the conditions under which the partners feel it will be possible to create investible business cases between hydrogen suppliers and their vehicle customers.

The group recognises that this is a first set of proposals for the direction in the 2020s, which will need more detailed development.

There may also be areas where there would be merit in strengthening the evidence for policymakers.

The group looks forward to a continued dialogue about the details of the implementation of these ideas.

Rationale for the UK to engage early with hydrogen mobility

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Zero emission and carbon free driving

Hydrogen can be produced from ultra-low carbon sources:

- Electrolysis (using renewable electricity)
- Biomass gasification
- Fossil fuels (including carbon capture and storage)

When used in a fuel cell vehicle there are no harmful emissions, avoiding the impact on human health associated with poor quality air[1].

By 2030, hydrogen vehicles will offer an affordable option for the majority of vehicle types and their customers.

As a result, hydrogen vehicles will create a **viable pathway** to mobility with no local emissions and elimination of CO_2 emissions.

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Economic advantages for the UK

Hydrogen production in the UK increases economic activity in the UK and decreases reliance on foreign imports (a £1bn/year opportunity by 2030, growing exponentially as the sector expands).

Fuel cell vehicle manufacture relies on specialist engineering skills which suit the UK's manufacturing capability unlike the battery sector which is based on high cost raw materials and cheap mass manufacture.

The UK is already a leader in electrolyser manufacture and HRS deployment.

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Transitioning the UK's energy system

The transition to a fully decarbonised energy system benefits from the use of hydrogen (see e.g. CCC hydrogen report):

- Generation and storage of hydrogen offers a mechanism for storage of GWh of energy in an increasingly intermittent energy system
- As a fuel which can help solve the (very challenging) problem of decarbonising heat and industry
- At scale, hydrogen offers an affordable zero carbon fuel for mobility.
- Hydrogen also provides many opportunities for inter-linking different areas of the energy system (heat, transport and electricity), creating a more robust and flexible system.

[1]Public Health England attributes 26,000-36,000 early deaths to air pollution

Fuel cell vehicles are attracting significant attention from global vehicle manufacturers

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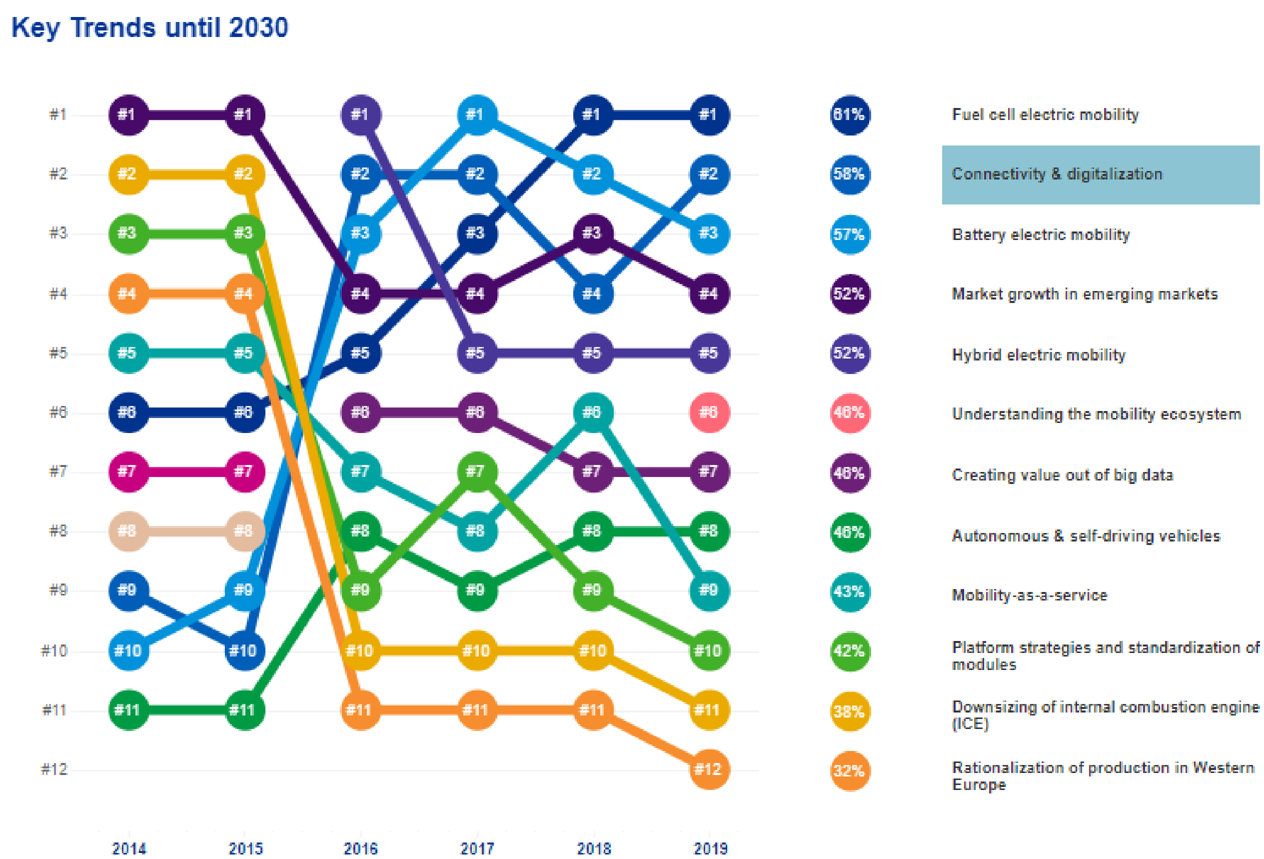


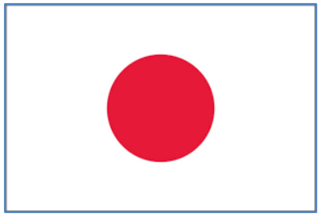
A survey by KPMG, in 2019, of global automotive executives has placed hydrogen fuel cell mobility as their top trend to 2030 for the past two years.

Note: the survey data shown excludes automotive dealers and non-major markets

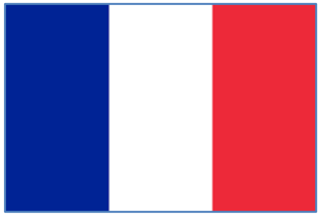
Other large markets are increasing their H2 activities and the UK risks losing the opportunity to benefit as an early mover

- China has set a target for 1 million fuel cell vehicles on the road by 2030. In 2018, it spent $12.4bn on supporting fuel cell vehicles to meet that target. The aim is to implement a similar scheme to the deployments which have transformed the electric vehicle market over the past 10 years[1].

- In 2018, the Japanese ministry of trade allocated $272 million to hydrogen research and subsidies, or 3.5% of its energy budget[2]. The Japanese state has made a public declaration that the 2020 Tokyo Olympics will be run on hydrogen mobility. Toyota plans to install capacity to annually produce 30,000 fuel cell stacks by 2020.



- Paris is home to the largest fleet of fuel cell taxis in the world thanks to generous European subsidies equating to over €20,000 per vehicle and has plans to expand it to over 500 by the end of 2020. The French minister for environment has released ambitious targets of 5,000 light vehicle deployments and 100 hydrogen refuelling stations by 2023. Renault and Peugeot are now working to introduce hydrogen fuelled vehicles as part of this coordinated French push.



[1]https://www.ft.com/content/27ccfc90-fa49-11e8-af46-2022a0b02a6c

[2]METI, "2018 Summary of Resource/Energy Related Budget Request", August 2017, available at: www.meti.go.jp

Many mobility segments will rely on fuel cell vehicles to fully decarbonise and move to zero emissions

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Vehicle type	Market segment rational	Example vehicles under development
Cars – long range, heavy classes, rapid charging	Early H2 projects have revealed end users who require the long range and rapid charging of H2 vehicles (e.g. taxis, first responders)	
Buses – in zero emission zones	For large, heavy buses on long routes requiring zero emission (e.g. central London)	
Trains – on non-electrified branch lines	Electrification of regional lines is not economically feasible & battery trains do not have the energy density to meet many duty cycles	
Delivery vehicles – in urban centres with air quality issues	For longer duty (or high parasitic loads) vehicles delivering into low emission urban centres	
Trucks – long range	EU regulations restrict the size and weight of trucks which limits the duty cycles which could be met by battery electric vehicles	

Other segments including two wheelers and shipping are starting trials and show promise

A range of new fuel cell vehicle types and brands are coming

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2019	2020	2021	2022	2023	2024	2025

c.100 FCEV cars in the UK, mostly Toyota Mirai and Hyundai ix35

2nd gen Toyota Mirai begins production of ~30,000 stacks per year

Cars

Hyundai Nexo starts UK deployment with 15 vehicles

A range of other cars are being deployed worldwide, likely to come to the UK with the right support regime. Audi, BMW, Honda Daimler, PSA and many Chinese brands all have hydrogen plans in the early 2020s

56 buses deployed across London, B'ham & Aberdeen as part of the JIVE project

UK bus builders Wrightbus and Alexander Dennis actively developing FC buses for UK and export markets

>200 additional buses deployed in the UK due to H2 Bus Europe and other initiatives

Buses

18 single deck buses (Wrightbus and Van Hool) are running in London and Aberdeen

JIVE 2 will deploy 32 buses in Brighton & Dundee. Additional projects under development in Liverpool and across Scotland.

Demo projects / development

Early commercial

Mass market introduction

These new models and brands will increase the choice for hydrogen vehicle customers, but will only enter supportive markets

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2019	2020	2021	2022	2023	2024	2025

Several ULEMCO dual fuel hydrogen trucks used by Ocado

HV Systems H2Van enters UK deployment

Numerous Chinese initiatives to develop FC vans (e.g. SAIC), likely available in the UK in early 2020s

Vans

125
Symbio/Renault Kangoo's are operating across UK and France

787
Symbio/Renault Kangoo's planned for EU deployment

StreetScooter to produce over 400 Work L vans for DHL and Innogy in Germany

2 Coradia iLint trains are carrying passengers in north Germany

Alstom's Breeze trains deployed in the UK

Freight and other train types to be prototyped

c. 50 Breeze trains to be operating in the UK

Trains

Siemen's Mireo Plus H prototype to be completed

Demo projects / development

Early commercial

Mass market introduction

The trucking option is seen as particularly exciting, but we are still at the prototype phase

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2019	2020	2021	2022	2023	2024	2025

FCH JU project for 15 heavy duty trucks (with new European OEMs) deployed

ULEMCO dual fuel street sweepers deployed in Aberdeen

Scania deploy 4 fuel cell trucks for ASKO in Sweden.

REVIVE will test 15 Refuse collection trucks in 7 EU locations.

1600 Trucks project fully deployed in Switzerland

Trucks

Hyundai 1600 Trucks project in Switzerland begins deployment

Scania refuse truck deployed in Sweden

Nikola Tre enters European production

Demo projects / development

Early commercial

Mass market introduction

The option of using hydrogen in ships is also attracting increased attention, though work is still required on standards to allow widespread roll-out

Ferguson Marine Concept Hydrogen Ferry

The UK is host to some of the most pioneering work on hydrogen for shipping, for example the HySeas III project (jointly led by Shipyard, Ferguson Marine and the University of St Andrews) which aims to be the first sea-going ferry fuelled with hydrogen in 2020.

Other significant projects are occurring in Norway, where there is substantial use of ferries on the fjords and a zero emission requirement is forcing ferry operators to consider a move to hydrogen. Cruise ships are another promising early market where the customers place a value on low noise, emissions and vibrations.

At a larger scale, there are very few routes to the elimination of emissions from ships and hydrogen (and other fuels for fuel cells) are seen as some of the most promising options. This has led to new industrial partnerships between fuel cell manufacturers and ship drivetrains builders (e.g. Ballard with ABB and PowerCell with Siemens.

This document does not make explicit recommendations on hydrogen in the maritime sector.

Instead, it is recognised that the use of hydrogen in boats could be highly beneficial for the hydrogen sector.

This report recommends that the hydrogen maritime sector is supported alongside other mobility sectors, but recognizes that this support is distinct from that requested in this document.

For the overall benefits of hydrogen mobility to be achieved, an ambitious yet achievable program for 2020 to 2025 is required

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- The current OLEV support for hydrogen vehicles is based on a strategic plan for 2015 to 2020.
- As we approach 2020 a new plan is required.

Learnings from the current phase (2015-2020)

- The vehicles themselves have proven viable for customers.
- A group of first early adopters has emerged. These have a high mileage, a requirement for ultra-low emission, limited fuelling time, commercial fleet and geographically captive.
- However, roll-out has been slower than desired due to:
  - a) lack of infrastructure + delays in station roll-out
  - b) high vehicle purchase prices and slower than expected roll-out (e.g. from European OEMs)
  - c) station reliability issues
- Business case for back to base refuelling stations is easier to make than for public refuelling stations due to concentrating demand.
- Vehicle deployment in clusters appears to be the best way to develop the sector (as opposed to nationwide planning).
- High mileage users quickly use capacity up (particularly back-to-back capacity).
- Rapid acceleration in emerging markets (e.g. China) has absorbed resources, talent and focus.

Expectations/requirements for 2020 to 2025

- An increasing number of vehicle types and also models can be expected.
- A trend towards heavy duty vehicles using hydrogen (larger cars, vans, trucks and trains).
- The cost of the vehicles is expected to fall considerably with manufacturing scale.
- An increasing number of UK OEMs particularly for buses and trains.
- An increasing number of activities targeting hydrogen in other energy segments e.g. for heat or industry. These will lead to new regional clusters.
- For the hydrogen industry to prosper in the UK, one or more plausible refuelling station business cases need to emerge. This also applies to the existing stations, for whom operational sustainability still needs to be ensured.
- A clear focus is needed on early adopter passenger groups who choose hydrogen vehicles due to their superior attributes meeting their needs (e.g. for operational usability or to meet certain regulations).

These considerations inform the suggested strategy

Aims of the next phase

A next phase of development of the UK's hydrogen mobility sector is proposed, with the following aims by the end of the support program:

- To ensure that hydrogen mobility is **proven as a commercially viable zero emission option** in a number of key segments:
  - Car – targeting expansion in fleets requiring long range and/or rapid refuelling, with an expectation that during the period we will also see the beginnings of first sales to private customers
  - Bus - focussed on sales to cities requiring zero emission buses in their city centres
  - Vans - focussed on sales to cities requiring zero emission delivery vehicles
  - Trucks – freight movements requiring zero emissions, with a range/weight which rules out the battery option
  - Rail – for vehicles on non-electrified lines
- The purpose of the scheme is to ensure that at the end of the scheme, vehicles are commercially available in the market and can compete on an economically viable basis for early adopter fleets.
- The UK supply chain has matured for hydrogen production and dispensing so that hydrogen is available at or below the cost of taxed diesel (on a per km driven basis) for the target markets. The refuelling stations are designed to be compatible with the introduction of new vehicles types to the UK.
- The UK supply chain for vehicles and fuel cell vehicle parts is developing and major investment in production plants across the supply chain have been committed in the UK.
- A plausible (but not complete) nationwide network is emerging organically out of a series of early deployment clusters. The network can fuel both light duty and heavy duty vehicles.

Creating a supportive policy environment which allows the flourishing of this UK industry

- Achieving these aims for the next stage of the hydrogen mobility roll-out will require a supportive environment which attracts investment towards the UK as one of the places to make hydrogen for mobility happen.

- In a supportive environment vehicle manufacturers and infrastructure providers can make synchronised investments, build demand at refuelling stations and therefore create and invest in economically sustainable business models.

- There are **two main components for the policy request to create this supportive environment**:
  - Subsidy for vehicle purchase for the UK market introduction of FCEVs - Helping overcome the initial dis-economies of scale associated with introducing new vehicles by enabling vehicle purchase at an attractive total ownership cost
  - Subsidy for hydrogen fuel provision – using a mechanism such as the Renewable Transport Fuels Obligation (but designed to actively support hydrogen) which incentivises the kg of hydrogen sold to mobility

- In addition, there are sector specific requests (e.g. addressing the BSOG disparity for buses)

We envisage three phases of growth for the UK Hydrogen mobility sector

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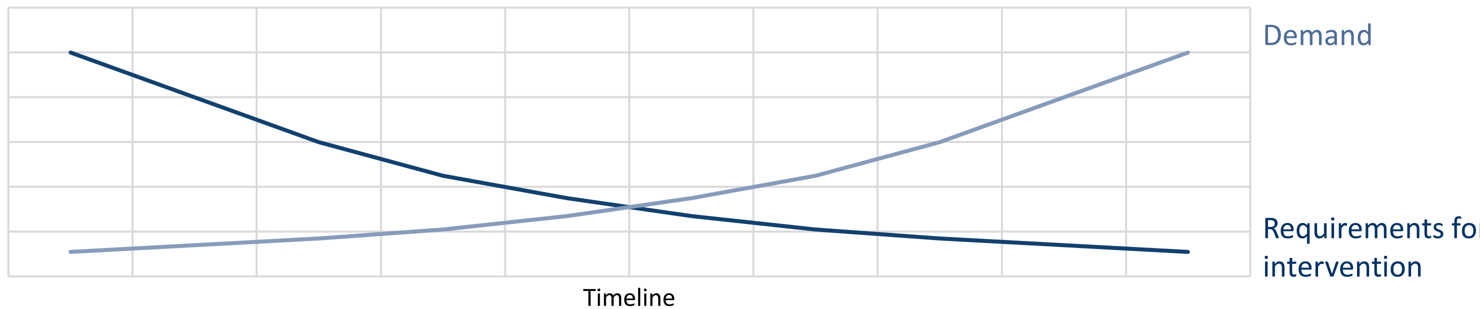
We envisage three phases of growth:

- Phase 1 - **Completing today's projects** (today to mid-2020) **-** in the period to mid 2020, a wide range of additional vehicles and stations will be deployed based on projects already underway and funded. **This phase is already underway** and is currently loss making but must be successfully implemented as part of this strategy.
- Phase 2 - **Cementing gains** (starting in 2020) - a second phase of expansion will cement these initial gains in the key early adopter clusters and introduce an increasing level of hydrogen demand mainly through heavy duty vehicles.
- Phase 3 - **Preparing for expansion** (starting only as specific vehicle types hit volume targets under Phase 2) – a third phase will then enable more rapid commercial expansion of the vehicle parc and associated stations

We envisage differentiated support by vehicle type and would expect the different vehicle types to transition between phases 2 and 3 at different rates according to the market success.

As the industry progresses through the phases of growth it will require reduced needs for government intervention

The graph shows the requirement for intervention vs the demand for hydrogen mobility



Phase 1 (today to mid 2020)	Phase 2 (from 2020)	Phase 3 (as vehicles mature)
Completing today's projects	**Cementing gains**	**Preparing for expansion**
• First refuelling clusters deployed (London, Aberdeen, other single station deployments) • Vehicles being used in day to day operations	• Secure current deployments/clusters • Make network work for the customers • Expand heavy duty sector which has UK content – this creates demand	• Reduced subsidy requirement • Demand led station expansion

Vehicle types move into a new regime only once the volume targets are met

A three category plan is designed to incentivise the success in hydrogen deployment…

We have developed a balanced plan for each of the vehicle sectors which is aimed at increasing the total UK hydrogen demand to 40 tonnes per day (the capacity of a mid-size methane reforming plant).

The model is based on three categories of deployment, divided according to the level of readiness of the vehicle technology.

		New vehicles deployed in each phase		
	Today (now deployed)	Today (contracted to mid-2020)	Phase 2 – Cementing gains	Phase 3 – preparing for expansion
Higher TRL vehicle types				
Cars and car derived vans	100	250	500	1500
Cars in large scale captive fleets	0	0	300	3000
Buses	20	100	200	300
Developing vehicle types				
Trains	0	0	20	40
Distribution trucks and vans	0	0	50	200
Trucks	0	0	20	100

- Despite the fact that cars and buses are more mature, the consortium believes that the mix of all vehicle technologies is an important part of a successful next phase of hydrogen mobility in the UK.
- As a result, a structure which aims to bring a number of vehicles in each segment is suggested. This will attract manufacturers of these vehicle types to bring UK-ready vehicles to the UK market.
- As noted above, there are vehicle types not included in this plan, for example maritime, two wheeler and other innovative vehicles as there is less certainty over the speed of roll-out of these vehicle types. In addition to the support above, we recommend that Government sets aside a fund to allow innovative proposals for a third category of new vehicle deployment in areas which can demonstrate their commercial potential.

Rationale for the size of the deployments – Cars (1/2)

Passenger cars

- The planned and existing deployments to 2020 are made up of:
  - ~50 cars deployed before HTP under a variety of schemes, using European funds (HyFIVE, H2ME)
  - ~250 cars deployed under the ongoing HTP 1 & 2 schemes and European funds (ZEFER, H2ME)
- The current planned rate of deployment (2019 and 2020) in the UK is approximately 150 vehicles per year (based on the OLEV HTP, H2ME and ZEFER commitments)

Basic ambition (general H2 vehicle sales)

- For Phase 2, a step up to 250 per year is a modest target given the stated aims of the global OEMs to increase production by an order of magnitude (see e.g. Toyota will install production capacity for 30,000 stacks by 2020 and Hyundai's aim to have 10,000's of cars per year at their plants)
- At this point, the combined 850 vehicle parc should be able to refuel at a total of 35 car compatible stations (according to the station planning), which means the loading per station is a manageable 24 cars/station
- Moving into Phase 3, it is reasonable to assume an increase in this level of deployment, but it is also clear that without a major expansion in the network, the target market is limited. By the end of Phase 3, a total parc of 2,350 cars will be using a network of 68 compatible stations – a comfortable average loading of 35 cars per station.

Rationale for the size of the deployments – City Scale Fleets (2/2)

Fleet sales

In addition to the general sales aspirations (which are modest), the car OEMs believe it will be possible to target specific user groups with a larger fleet-wide proposition for operators in cities with gated areas.

The ownership cost graph on the right illustrates the forecasted cost of ownership for a fuel cell vehicle operating in a high use case in the 2020 to 2025 period. A good example here is in taxi operation in London, involving double shifting of the vehicle (which is not viable using a battery vehicle).

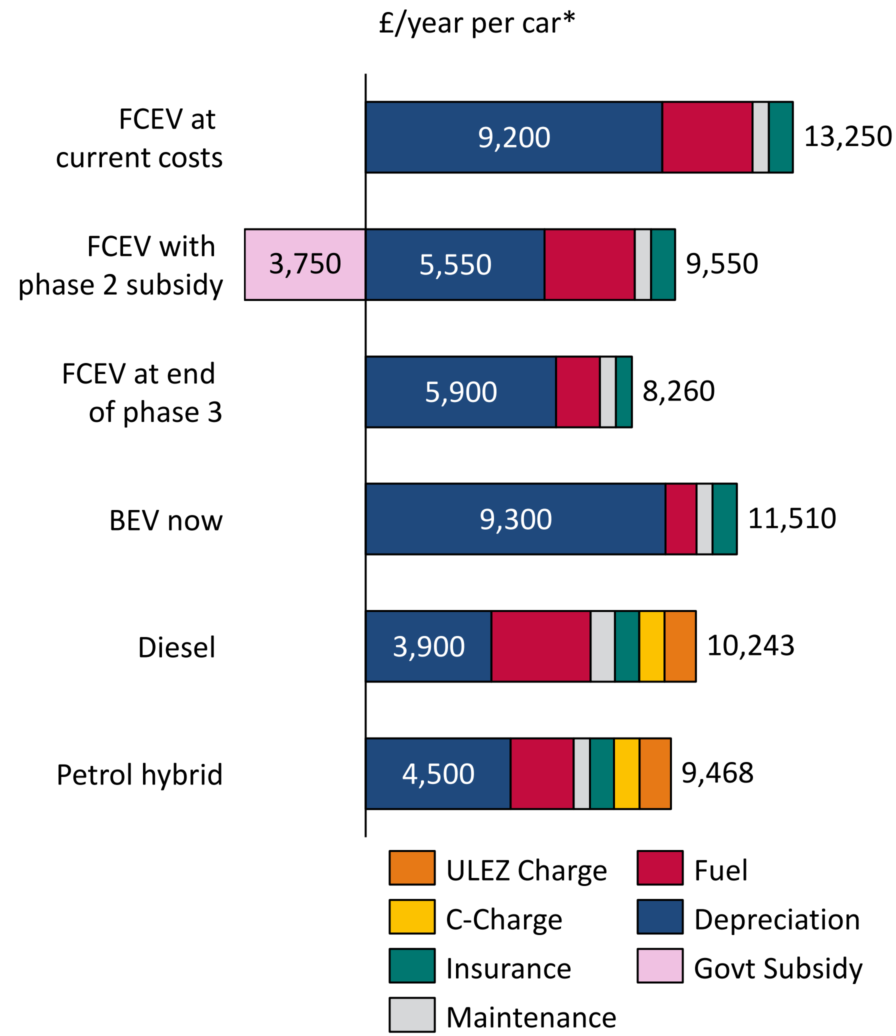
The vehicle OEMs will test a model where this type of fleet scale deployment is offered to cities (in partnership with infrastructure providers).

An anticipated test scale of deployment will be 50-100 vehicles per cluster.

A successful deployment amongst fleet customers under Phase 2 would lead to rapid expansion for Phase 3. As a result, a further 3,000 vehicles are envisaged, subject to the success of Phase 2.

Note that these vehicle users have a higher hydrogen consumption than average vehicle users, which benefits the business case for hydrogen stations.

TCO for a D-segment taxi (4 year lifetime) – for assumptions see Annex



Rationale for the size of the deployments - Buses

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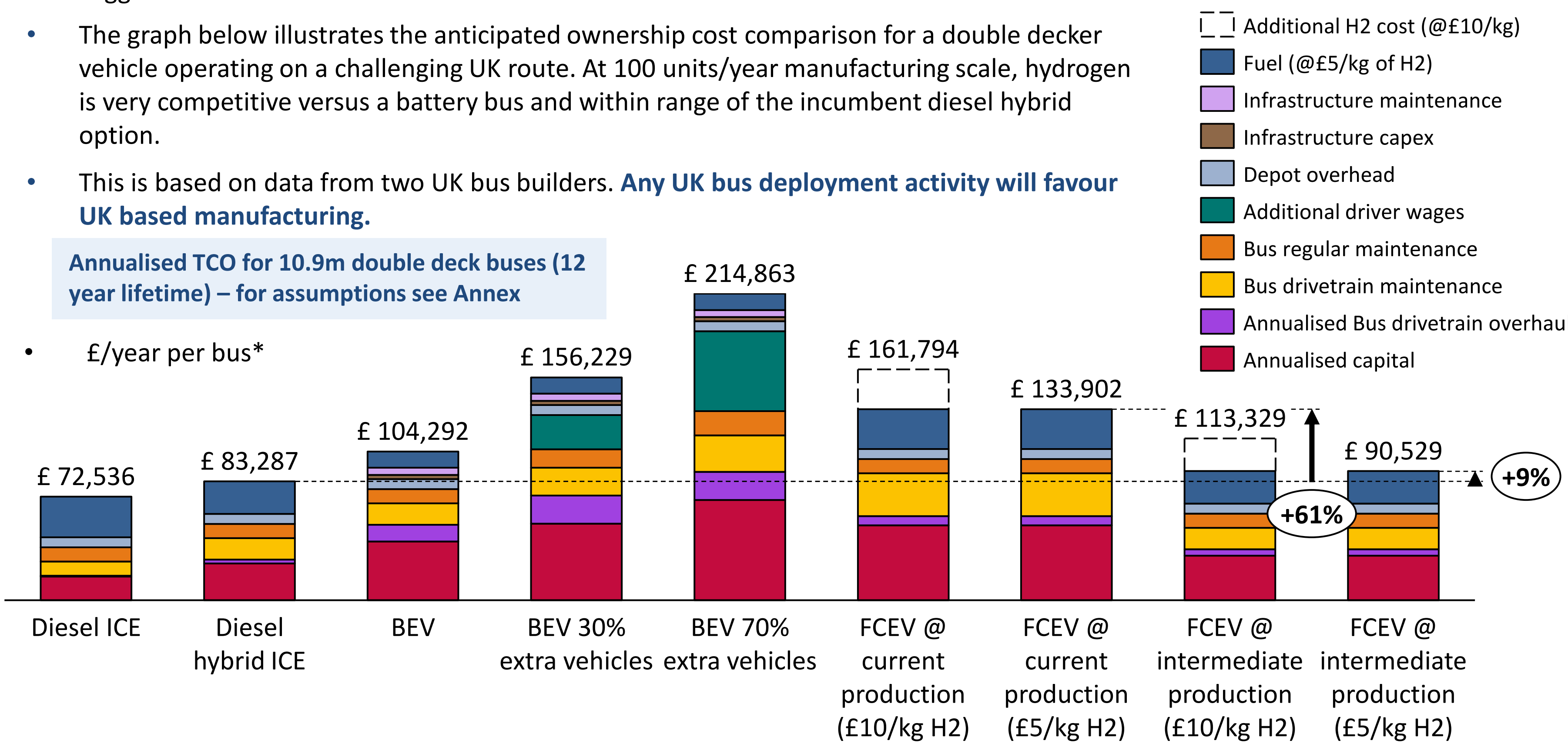
Buses

- There are 20 fuel cell buses on UK roads, though some of these are expected to reach the end of their life before 2020. Funding programs (JIVE and HTP) have committed a further 118 new buses to the UK. These buses are at various stages of contracting and there is some uncertainty over each project's delivery hence the estimate of 100 buses by 2020.
- For Phase 2 & 3, leading UK bus manufacturers are targeting production runs of 100 buses per year. The UK has a share of the H2Bus Europe project which could bring 200 buses to the UK market subsidised by Europe. This leads to the suggestion of 500 buses across Phase 2 & 3.
- The graph below illustrates the anticipated ownership cost comparison for a double decker vehicle operating on a challenging UK route. At 100 units/year manufacturing scale, hydrogen is very competitive versus a battery bus and within range of the incumbent diesel hybrid option.
- This is based on data from two UK bus builders. **Any UK bus deployment activity will favour UK based manufacturing.**

Annualised TCO for 10.9m double deck buses (12 year lifetime) – for assumptions see Annex



Rationale for the size of deployments – Vehicles at the prototype stage (1/2)

Vehicles at the prototype stage

For other vehicle types, specifically: trains, trucks and vans, there is less certainty. These vehicles are at the prototype stage of development, generally outside the UK. The business case for the move to hydrogen for mobility is strengthened by all of these vehicle types as they will create considerable demand for hydrogen and can appeal to a range of users for whom there is no other viable zero emission option.

The consortium believes the best mechanism to support these vehicle types and encourage UK compatible vehicles to come to the UK market is to signal a willingness to incentivise their introductions. The **rationale** for the numbers of vehicles to be incentivised is below:

Trains

- There are currently no fuel cell trains on the UK network and work is still required to gain type approval. Alstom, working with Eversholt, are in the process of securing first train trials in the UK. These projects target 5-10 train deployments and could occur by 2022. Other players (VivaRail, Porterbrook/Hitachi) are also developing hydrogen train offerings.
- Players in the trains sector believe that, with the success of these trials, it is reasonable to target a deployment of 40 vehicles by ~2025.

Trucks

- The fuel cell truck is very promising for hydrogen as it offers a large volume user that could underpin a nationwide network roll-out and justify investment in production assets. However, the trucking market is immature. Vehicles are at a prototype stage and the commercial introduction (particularly to the UK) is unclear.
- As a result, the rationale is to provide a supportive environment to encourage the first roll-out of trucks in the UK under Phase 2 (20 vehicles), followed by a first expansion phase under Phase 3 (100 vehicles).

Rationale for the size of deployments – Vehicles at the prototype stage (2/2)

Vans

- Delivery vans would also offer a useful model for early adopters who are heavily regulated and require clean vehicles for city delivery.
- At present, there is no commercial fuel cell van in the UK market, though a number of Chinese and European players are developing strategies to bring vehicles. There is also interest from a number of UK SMEs (Arcola, HV Systems) and activity for hydrogen in combustion engines in vans.
- As a result, the strategy is similar to trucks to allow a first roll-out during Phase 2 (50 vehicles), followed by expansion during Phase 3 (200 vehicles).

Other vehicle types and innovation – a flexible fund

- In addition to the vehicles described above, there are vehicle types not explicitly included, in particular, marine vessels and also two wheeler scooters. There is also a potential for innovation which is not currently foreseen will alter today's 2019 perspective.
- As a result, we would also recommend keeping an open fund to allow new entrant vehicles with appropriate cost dynamics to mature. This could be competitive or spent on a discretionary basis as vehicle options pass the threshold for commercial viability.

These deployments will increase the demand for hydrogen to over 40 tonnes per day

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- This creates the following demand:

	Daily demand (kg/day)			
	Today (to mid-2020)	Phase 2 – Cementing gains	Phase 3 – preparing for expansion	Total demand – all phases by type
Higher TRL vehicle types				
Cars and car derived vans	250	500	1,500	**2,250**
Cars in large scale captive fleets	-	600	6,000	**6,600**
Buses	2,000	4,000	6,000	**12,000**
Developing vehicle types				
Trains	-	6,000	12,000	**18,000**
Distribution trucks and vans	-	250	1,000	**1,250**
Trucks	-	200	1,000	**1,200**
Demand per day (per phase)	**2,250**	**11,550**	**27,500**	
Cumulative demand (kg/day)	**2,250**	**13,800**	**41,300**	

- A demand of 40 tonnes per day is equivalent to a medium scale reformer, or a 130MW scale electrolyser

The distribution of demand is heavily skewed to the heavy duty vehicle types

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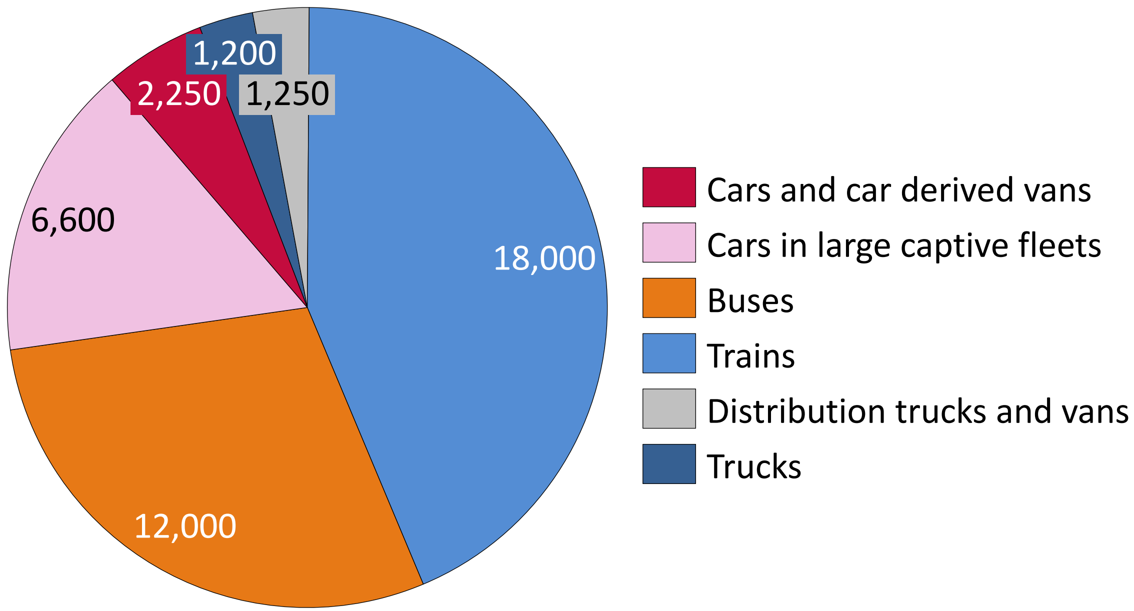
Distribution of demand in kg/day (end of support phase)



Demand assumptions	kg/day per vehicle
Cars and car derived vans	1
Cars in large captive fleets	2
Buses	20
Trains	300
Distribution trucks and vans	5
Trucks	10

This will require additional investment in refuelling stations and production equipment

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Learnings from the current subsidy phases

- Deploy highly reliable and robust stations.
- Build stations to meet secured demand where possible (e.g. a bus project)
- Ideally, these can be used to serve both the heavy duty demands and the smaller vehicle needs, thereby creating a national network.
- An indicative scenario for the number of stations to meet this demand, whilst ensuring ~75% loading by the end of the third phase, is shown below.

	Cumulative number of stations		
	Today (to mid-2020)	Phase 2 – Cementing gains	Phase 3 – preparing for expansion
Stations (car)	17	23	40
Stations (bus + truck)	4	8	12
Stations (HD + car)	4	12	28
Stations (train)	0	2	4
Total capacity	**4,900**	**24,100**	**53,500**
Capacity utilisation	**46%**	**57%**	**77%**

	Indicative capacity assumption to mid 2020 (kg/day)	Indicative capacity assumption in phase 2 &3 (kg/day)
Stations (car)	100	200
Stations (bus + truck)	400	1000
Stations (HD + car)	400	1000
Stations (train)	-	3000

- We envisage these stations being concentrated in **regional clusters**, which should have a strong regional rationale for hydrogen engagement (air quality issues or industrial potential)

The need for continued subsidy intervention in the hydrogen sector

Hydrogen vehicle adopters face considerable barriers which prevent uptake.

- Economics – today's low volume economics are prohibitive for most users (see below)
- Lack of fuelling infrastructure – which means vehicle owners are taking a risk around the future development of the fuel when adopting a hydrogen vehicle
- Unfamiliarity – this is not a familiar fuel or fuelling process
- Support for other alternative fuelled vehicles – which creates confusion about the most appropriate option and also the option which will eventually succeed in each market segment
- Hassle – there is an inevitable hassle associated with a switch to a new fuel in terms of training drivers, planning in case of downtime and adapting to new fuelling procedures

These factors all contribute to a challenge of taking up hydrogen vehicles early (and hence delay uptake).

These have to be set against the brand value associated with an early move to adopt a new fuel and also the regulatory and performance benefits of the fuel cell option.

Generally, the pitch to end users which has proven viable to date has been to use state help to offer a vehicle with the **same ownership cost as a fossil fuelled option today**. Then the hassle of a switch to a new fuel is expected to be compensated by the green/operational benefits.

This has been the approach for example in selling buses and taxis to the early adopter groups which have taken up vehicles in the UK (e.g. First Group in Aberdeen or Green Tomato taxis in London).

This is the **basis of the subsidy request in this document**.

The consortium believes a move to a market based support scheme is now required

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The table compares the Pros and Cons of two subsidy approaches

Competition-based subsidy		Subsidy based on vehicles deployed and hydrogen turnover	
Pros	Cons	Pros	Cons
• Subsidy mechanism is already in place and delivering results • No need to create a new program	• Low incentive to move to a more commercial regime • Competition system creates uncertainty for all investors • Does not cover any operating cost of the assets	• Provides certainty to all investors • Degression incentivises first movers • Only incentivises deployment success • More realistic incentive structure • Will push the industry towards market-based mechanisms as opposed to capital subsidy reliance	• Requires larger effort on the part of HMG to create a new regime • Locks in 2020 logic (may need a review mechanism)

- **The UKH_2Mobility consortium has reached the conclusion that it strongly favours the shift to a confirmed subsidy per vehicle or unit of hydrogen sold**

We envisage differentiated subsidies for each vehicle type and phase

The subsidy levels below are based on achieving TCO parity for the most promising early adopter customers. Assumptions behind these subsidy levels are provided in the annex.

Subsidy request	Subsidy required per vehicle today (000s £)	Proposed Phase 2 subsidy per vehicle (000s £)	Proposed Phase 3 subsidy per vehicle (000s £)	Sector specific policy requests
Cars and car derived vans	25	15	5	• Gated zones (e.g. ULEZ) and supportive local policies for cities • Public procurement approaches favouring hydrogen • Continued plug-in car grant support
Cars in large captive fleets	25	15	7.5	• Supportive local government programs to introduce large captive fleets
Buses	350	120	50	• Ensure BSOG parity for ZE busses • Zero emission bus policies
Trains*	-	1,000	500	• DfT require zero emission trains on non-electrified routes • Due to the nature of the rail sector's commercial structure, equivalence of subsidy may be achieved indirectly in support of train operation
Distribution trucks and vans	-	30	10	• Zero emission zones and supportive local policies for cities
Trucks**	-	150	50	• Zero emission zones and supportive local policies for cities

*subsidy is per train including locomotive and carriages

**the consortium recognises a lower degree of certainty around the figures for trucks

The approximate request for vehicle uptake support is ~£130M over Phases 2 and 3

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If each of the phases uses all of the subsidy allowance, this would lead to the following subsidy request:

Vehicle subsidy request	Cumulative subsidy to date (approx) (million £)	Subsidy for Phase 2 (million £)	Subsidy for Phase 3 (million £)
Cars and car derived vans	7.5	7.5	7.5
Cars in large captive fleets	-	4.5	22
Buses	35	24	15
Trains	-	20	20
Distribution trucks and vans	-	1.5	2
Trucks	-	3	5
TOTAL subsidy per phase	**42.5**	**60.5**	**72**

Note that the majority of the vehicle subsidy received to date has come from the European Union FCH JU program, supplemented with grants from OLEV under the Hydrogen Transport Program.

On the hydrogen production and distribution side, the aim is to use a subsidy per kg used to incentivise private investment

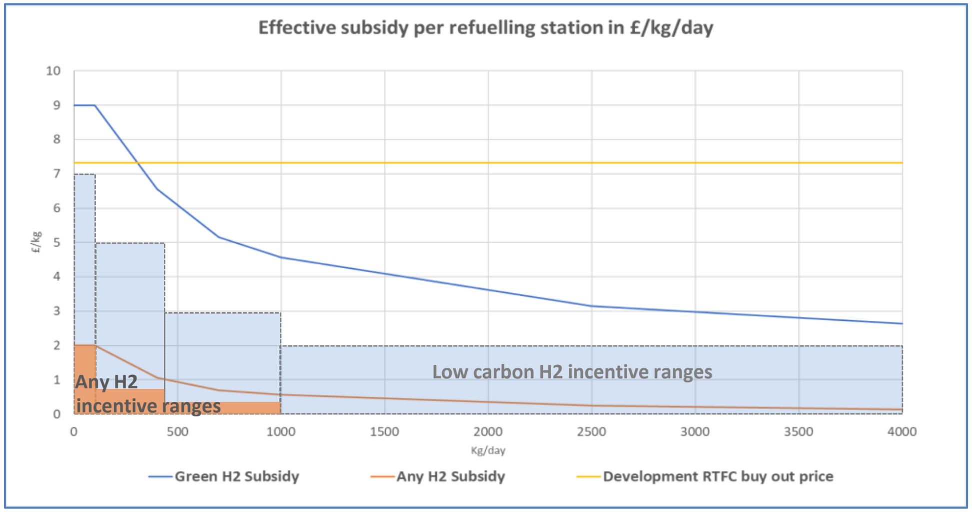
The RTFO implementation with respect to hydrogen has been very challenging for the sector.

However, this support scheme has illustrated how a well designed subsidy per kg sold could incentivise private investment in infrastructure. Similar, volume-based subsides have been applied to electricity, biofuels and red diesel which could be repeated for a hydrogen specific support scheme.

Our request consists of a base subsidy for any H2 which starts at £2/kg and steps to zero as the volume sold per station reaches 1000 kg/day. In addition, there would be a low-carbon H2 uplift subsidy starting at £7/kg and stepping to £1.5/kg for volumes above 4000 kg/day. The low-carbon uplift for hydrogen certified using the using a UK specific mechanism to certify the green hydrogen.

The proposed subsidy mechanism will create strong incentives for the development of UK refuelling infrastructure while having a lower cumulative cost than the Development RTFC buy out price for hydrogen which is shown below for comparison.

	Guaranteed incentives over 10 years (£/kg/day)	
	All H2	Low-carbon uplift
First 100kg of demand	2	7
Demands from 100-400kg/day	0.75	5
Demands from 400-1,000kg/day	0.25	3
Demands from 1,000 - 4000kg/day	0	2
Demands over 4000kg/day	0	1.5



Note: Subsidies would only be made available to the stations built under Phase 2 and 3

The cumulative cost of this subsidy is lower than that required for the development RTFO

An intervention of this type would allow stations to offer hydrogen at parity with taxed diesel on a km equivalence basis.

The cost of the intervention can be estimated as an upper bound assuming all of the stations built in Phase 2 & 3 achieve 75% utilisation. In practice, the demand would be distributed unevenly and a fraction of the stations would have a larger demand (and hence a lower intervention rate). Also, the stations would need time to reach full capacity. These are **therefore UPPER BOUND estimates**:

Cost per station	Annual subsidy per station		Total subsidy over 10 years if planned Phase 2 & 3 HRS are deployed	
	If all "any H2" (000s £)	If all "green H2" (000s £)	If all "any H2" (million £)	If all "green H2" (million £)
Stations (car)	87	433	12.6	50.2
Stations (bus + truck)	187	1,373	11.2	71.2
Stations (HD + car)	187	1,373	29.9	189.8
Stations (train)	210	2,582	6.3	71.2
TOTALS			**60.0**	**382.4**

These totals are a small fraction of the total development RTFO subsidy scheme which at a market price of £6/kg would cost ~£550 million.

The advantage of this policy is that a) it only incentivises success and b) it confers an early adopter advantage to investors who make an initial investment in the UK's hydrogen infrastructure.

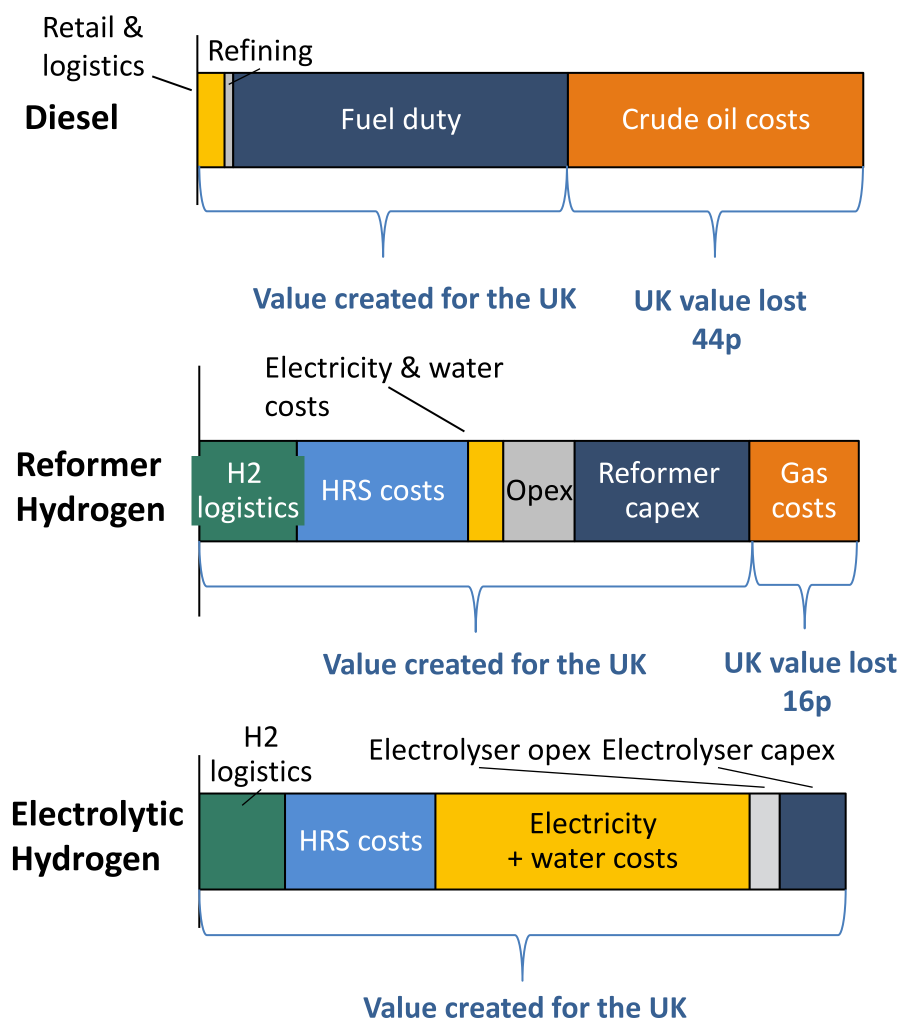
An increase in hydrogen demand will increase the value generated for the UK economy on each kilometre travelled

The value of ‘on-shoring’ UK fuel

- Replacing diesel with hydrogen fuel means that fuel production will occur within the UK and so the value from that activity is brought ‘on-shore’
- Each UK pound spent on diesel loses 44p to over seas-oil extraction & production costs. This number still applies even if oil is produced from UK reserves as it is a fungible asset which could be sold abroad.
- For fossil-produced hydrogen the value lost per pound to over-seas gas costs is reduced to ~16p
- Renewably generated Hydrogen can have its whole value chain located on UK shores and so could return 100% of the money invested to the UK.

- *Note that as both Natural gas and diesel are tradeable we argue here that any UK produced oil or gas could still be sold on the international market if it not consumed in the UK, hence the net effect of avoiding UK consumption of either fuel is to improve the UK’s balance of payments by the value of that oil or gas.*

Breakdown of cost of fuel sources per £ spent on fuel



The volumes of hydrogen consumed in the subsidy period could create significant financial value for the UK economy

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Why value is created by 'on-shoring'

- Each unit of hydrogen consumed displaces a unit of diesel demand.
- By taking the difference between the UK value created for each pound spent on diesel vs each pound spent on hydrogen, we can estimate the value which would be added to the UK economy through the on-shoring of fuel production.
- The annual value on-shored, at the end of phase 3, by switching to hydrogen ranges between **£14.1 and £22.1 Million** if all the hydrogen was either reformer or renewably derived.
- If 10% of the UK fleet were switched to hydrogen it would lead to an on-shoring of **£5.6 billion** per year.

Range of values brought 'on-shore'

Value on-shored table	End of Phase 2 (per year)	End of Phase 3 (per year)
Annual Hydrogen demand* (tonnes)	4,200	10,000
Annual Expenditure on Hydrogen (£ million)	29.5	50.2
Value brought 'on-shore' by switching from diesel to reformer hydrogen (£ million)	8.3	**14.1**
Value brought 'on-shore' by switching from diesel to renewable hydrogen (£ million)	13.0	**22.1**

*Assumptions:

1. Hydrogen has cost parity per km with diesel
2. The daily H2 demand increases linearly over 5 years to the value at the end of each phase (slide 15)
3. H2 cost in Phase 2 is £7/kg and in Phase 3 it is £5/kg

This intervention would unlock private investment across 3 sectors

Private investment in refuelling stations

HRS type	Indicative station capex (£ million)	Stations deployed in phase 2 & 3	Private capital invested (£ million)
Car (200kg/day)	1.5	23	34.5
Bus + Truck (1000kg/day)	3	8	24
Heavy duty + car (1000kg/day)	3	24	72
Train (3000kg/day)	6	4	24
Total		59	**154.5**

Private investment in Hydrogen production

Hydrogen demand	Phase 2	Phase 3
Average Hydrogen demand (tonnes/year)	2,100	5,000
Total H2 demand in the phase* (tonnes)	10,500	25,100
Private investment in dispensed hydrogen (£/kg)	3.5	3.5
Private investment in the phase (£ million)	**36.8**	**87.8**

The subsidy will unlock large volumes private investment across 3 parts of the hydrogen value stream

1. **£154 Million** invested in Hydrogen refuelling stations over the 2 subsidy phases
2. **£125 Million** invested in Hydrogen production and logistics
3. **£559 Million** invested in Hydrogen vehicle assets (shown in the next slide)

*assuming each phase lasts for 5 years

The subsidy is likely to create more than a nine times private sector investment ratio

Private sector investment ratio

- The total private investment across the three sectors during both subsidy phases could be **£838 million** from an upper bound of government investment of **£132 million** a >**x6** private sector investment leverage ratio

- This would lead directly to UK business (at the end of Phase 3) with:

i. Annual turnover of over **£50m/year in fuel supply**

ii. A yearly purchase of over **£104m/year sale of vehicles**, the majority of which will be manufactured in the UK

iii. Positioned for substantial growth (see next slide)

Private investment in Hydrogen Transport

Transport mode	Indicative asset capex (£ 000s)	Number of vehicles deployed by end of phase 3	Total capex registered (£ million)
Cars and car derived vans	50	2,000	100
Cars in large captive fleets	50	3,300	165
Buses	375	500	187
Trains	3,700	60	222
Distribution trucks and vans	70	250	17
Trucks	200	120	24
Total capital expense	-	-	692
Subsidy input from government	-	-	132
Total private investment	**-**	**-**	**559**

This will create valuable UK business with major capacity for expansion

But perhaps more importantly, the sector will be **poised for dramatic growth** without significant government intervention:

- UK manufacturing throughout the vehicle supply base (heavy duty vehicles, components which need UK expertise)
- UK manufacturing throughout the electrolyser and hydrogen mobility value chain
- New UK hydrogen supply companies with skills for export
- A sector with the skills base to expand as demand for vehicles picks up
- An early national hydrogen network allowing basic coverage and the start of more mainstream adoption
- Vehicle priced at the point where they are a mainstream option for customers

This creates **economic opportunities of many billion pounds per year.**

Commitments from industrial partners

- This two phase program would **be endorsed publicly by the UKH_2Mobility members**
- The partners would:
  - Publicly endorse the aspirations in the plan (at a senior level)
  - Commit to the following activities through the UKH_2Mobility group:
    - Regular review of the strategy against the observed results
    - Open sharing of data from the market's reaction to the hydrogen proposition
    - To make resources available to achieve their elements of the strategy
    - Demand aggregation – to work to bring committed end users into the consortium. In particular to:
      - Explore exercises to use aggregated UK demand to bring vehicles to the UK
      - Ensure hydrogen is included on key public sector procurement frameworks

The double decker bus TCOs analysis rests on the following key assumptions

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Parameter	Diesel ICE	Diesel hybrid ICE	Battery electric	FCEV	FCEV at 100s of buses/yr/OEM
Bus capex (000s £/bus)	200	310	495	630	375
Bus drivetrain overhaul capex (000's £/bus)	5.9	33	140	78	54
Depreciation period (years)	12	12	12	12	12
Annual Mileage (000s km/year)	60	60	60	60	60
Bus drivetrain maintenance (000s £/yr/bus)	10	15	10	15	15
Bus regular maintenance (000s £/yr/bus)	10	10	10	10	10
Fuel consumption (l, kWh, kg/100km)	43.0	34.4	190	9.3	7.6
Driver salary (000s £/yr/bus)	40	40	40	40	40

Note: The cost of capital is not included

Source: Based on EE discussion paper, Commercialisation of hydrogen fuel cell buses, 2017, and bilateral discussions with bus manufacturers

The FCEV taxi TCOs rests on the following key assumptions

Parameter	FCEV at current costs	FCEV with phase 2 subsidy	FCEV at end of phase 3	BEV	Diesel	Petrol hybrid
Capex (000s £/car)	55**	55**	35	55.6*	23.3	27
Govt vehicle subsidy value (000s £/car)	-	15	-	-	-	-
Congestion charge £/day	-	-	-	-	11.5	11.5
Ultra low emission zone charge £/day	-	-	-	-	12.5	12.5
Depreciation period (years)	4	4	4	4	4	4
Residual value (% of Capex)	33%	33%	33%	33%	33%	33%
Annual Mileage (000s km/year)	40	40	40	40	40	40
Fuel consumption (kg, kWh, l/100km)	1	1	0.7	16	7	4.7
Fuel cost (£/kg, kWh,l)	7	7	5	0.15	1.1	1.0
Insurance (£/yr/car)	500	500	500	500	750	500
Regular maintenance (£/yr/car)	750	750	500	750	750	750
Driver salary (000s £/yr/vehicle)	40	40	40	40	40	40

Zero emission vehicles are exempt from the congestion charge and future ULEZ charges

Note: The cost of capital is not included.

*https://www.levc.com/technology/tx-price-specification/

** Based on Totota Mirai costs