Mini roadmap outline – portable generators (<1 kW and 1-5 kW)

Introduction

This project aims to drive sustainable economic growth in the UK hydrogen and fuel cell industry in the period to 2025 and beyond

- **Public-private project** steered by Innovate UK, the Department of Energy and Climate Change (DECC), Transport Scotland, Scottish Government, Scottish Enterprise, Scottish Hydrogen and Fuel Cell Association (SHFCA), UK Hydrogen and Fuel Cell Association (UKHFCA), and the Knowledge Transfer Network (KTN)
- **Delivered by E4tech and Element Energy**, in consultation with the Steering Board and wider stakeholders
- Launched in January, due to be completed in early June
- Consists of **11 mini roadmaps**, on different sectors of hydrogen and fuel cell use, which will be brought together with an overall national case

WP 1 – kick-off workshop

Aligning on scope, timescale, governance

↓

WP 2 –Analysis of individual roadmaps

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WP 3 – Consultation

Workshops + bilateral discussions

↓

WP 4 – Revision of individual roadmaps

- Based on feedback and evidence received from consultation, revise individual roadmaps and benefits assessments

↓

WP 5 – Understanding the overall national case

- Understand interdependencies between roadmaps and critical decisions on each roadmap
- Agree on a prioritisation
- Assess required support
- Calculate national benefits

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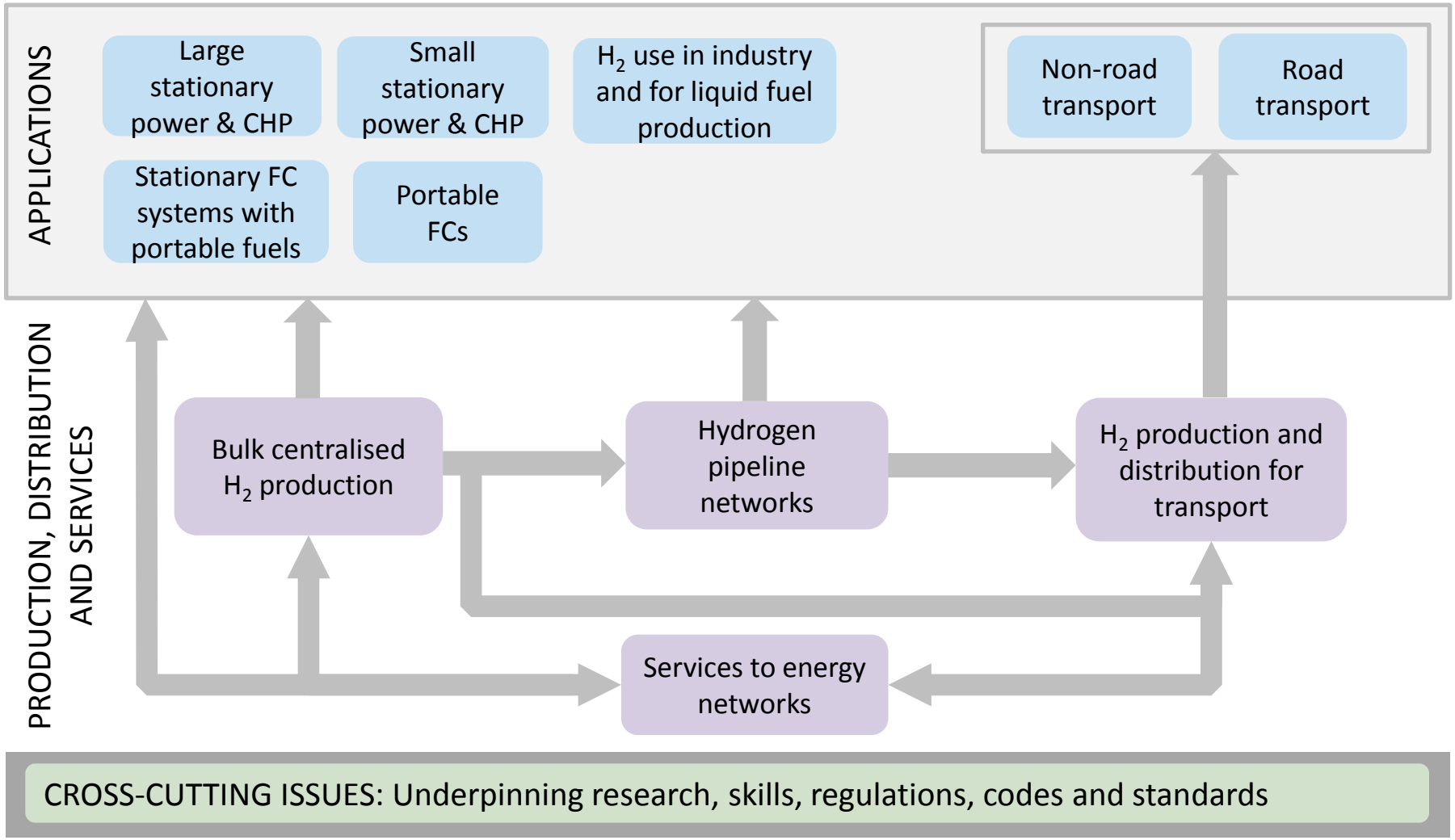
WP 6 - Draft and final reports

The 11 mini roadmaps cover uses of hydrogen and fuel cells, and production and distribution of hydrogen



Today's workshop is to get your feedback on the draft mini-roadmap on portable generators

- The draft mini-roadmap shows **aims** for each application for 2025, **barriers** to achieving those aims, **actions** that need to be taken to overcome the barriers, and **benefits** of doing so

- Today we will discuss **your views on**:
  - *Accuracy* (~30 min). Have the important barriers and issues been clearly captured?
  - *Ambition* (~30 min). Are the aims for 2025 appropriate? What development or deployment ambition is reasonable?
  - *Action* (~60 min) Will the actions proposed be enough to overcome the barriers? If not, what else is needed? Is it reasonable to expect these actions?
  - Who should be responsible for these actions? How much will they cost, how long will they take, and who might pay?

- Note that today we are focusing on **actions to 2025**, not the long term vision for the hydrogen and fuel cell sector. The longer term vision will be articulated in the overall national roadmap

- We also want your views on cross cutting issues that could affect more than one mini-roadmap

We welcome your views on cross cutting issues that could affect all mini-roadmaps, today and subsequently

Underpinning research
e.g. What breakthroughs could change the outlook for several roadmaps?

Safety
e.g. What further work is needed?

Skills
e.g. Is education and training needed that spans several of these areas?

Financing
e.g. are there financing mechanisms that could help in several sectors?

Regional activities
e.g. Can pioneer regions be valuable in deploying several HFC technologies together?

Manufacturing and supply chain
e.g. joint design, production or procurement of certain components

Regulations, codes and standards
e.g. What further work is needed?

Marketing
e.g. how can one sector help another?

Market structure
e.g. ways to monetise value to grid of CHP could also apply to electrolysis

Joint initiatives between sectors
e.g. would these be useful?

Portable generators

The portable fuel cell sector starts with very small applications and encompasses anything that can be moved, even on a lorry

- The smallest applications (~10-100W) include laptops, cellphones and chargers, where few companies are participating and success will depend on global markets. Some very specialised – and small – market niches exist
- Portable generators <1kW compete favourably with batteries and ICEs and can help broaden familiarity and the supply base
- Portable generators 1-5kW can be used privately or in industry. Conventional gensets are often low cost, but noise and air pollution are drivers for new technologies.
- Larger gensets of 5kW+ might be used at open-air concerts, in national parks, in market stalls or in other on off-grid temporary applications such as construction sites. Noise and air pollution are again important considerations

Sources: Intelligent Energy, myFC, SFC energy, Kraftwerk, Tropical SA, Multiquip

Our chosen focus is in strategic applications with UK strength, or which reinforce other sectors

- Some 'portable power' applications have greater potential impact than others. Sectors such as consumer electronics are likely to be predominantly outside of the UK, and should in any case be primarily market-driven.
- In many applications, batteries are well established and extremely hard to displace. For some, however, increased autonomy and faster refuelling adds value and potentially opens up new market niches – this is a sweet spot for fuel cells.
- In some small applications a commercial case exists already; supporting and building on that can increase consumer familiarity with fuel cells and contribute to developing the sector overall.
- Larger portable fuel cells share technology features with other applications, such as stationary fuel cells. The potentially large numbers in the portable sector can help bringing cost down for certain components used in applications that have more significance for the UK industry

- The consumer electronics market has very high entry barriers and limited technology overlap with strategically important applications for the UK. This market was considered less relevant.
- **Portable generators**, ranging from ~**100 W to 5kW** feed into a relatively accessible niche and can reinforce other sectors with strategic importance for the UK fuel cell industry. We decided to focus on this segment of the portable market for the roadmap.

Fuel cells present a quiet and clean alternative to conventional backup generators

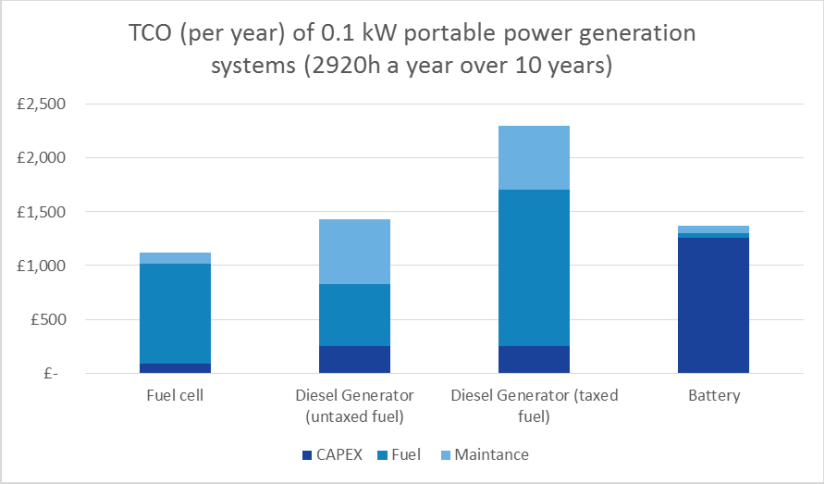
- This roadmap focuses on portable power generators below 5 kW. These devices are used to provide electricity for a limited time in locations where grid electricity is not easily available.
- Typical application spaces include construction sites (for welding or power tool use), military applications, stalls at markets and events, recreational vehicles and camping sites. The same systems are also well suited for low power applications with long duration or constant demand, such as lighting applications or traffic signalling applications.
- Polymer exchange membrane fuel cells dominate this segment. Direct methanol fuel cells are also used, primarily for sub-1 kW applications. Hydrogen and methanol are the two prevalent fuels in this sector.
- Fuel cells have near zero noise and pollutant emissions, an advantage over the incumbent gasoline and diesel generator technology. Fuel cells further offer higher efficiency and higher reliability. In particular, startup after long storage periods should be more reliable.
- Fuel cells can have longer runtimes than the battery systems also used in the low power off-grid segment, and can be easily refuelled.
- The current global yearly market for such portable fuel cells is about 3,000 – 4,000 units, with perhaps 100 in the UK.

Source: BOC

Source: Horizon fuel cell

For very small power applications with long duration, fuel cells can already be competitive

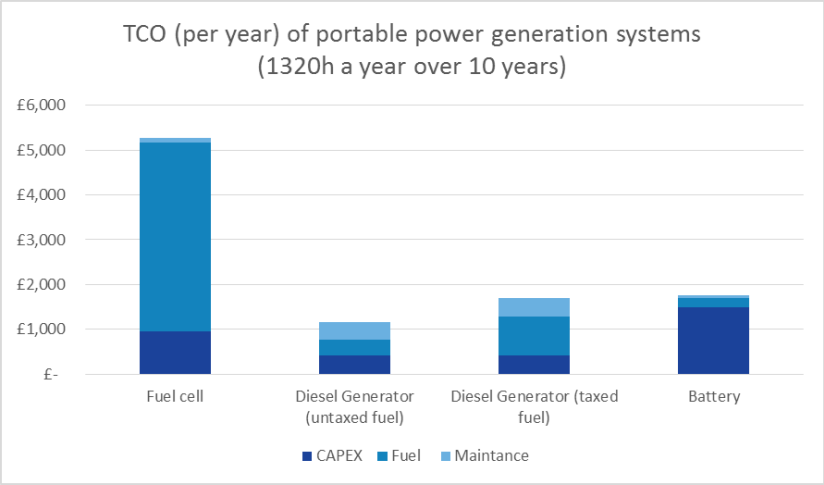
- For very small power brackets (~100 W), petrol and diesel generators are not available. For commercial use, the market starts at ~3 kW. To deliver such low power, these engines are oversized and run at very low efficiency. In practice they would be coupled to a resistance load to ensure they are delivering their minimal output (e.g. 500 W)
- Hydrogen delivered in suitable bottles for small fuel cell generators is expensive, but the low maintenance cost of fuel cells makes them competitive on TCO basis
- Batteries with high autonomy also have high CAPEX. Recharge logistics may also be a concern for remote applications



Parameter	Value
Average load	0.1 kW
Runtime per year	2920 h (8h a day year round)
Fuel cell	
Capacity	0.1 kW
Stack lifetime	10,000h
Cost per kW	£ 4,275
Efficiency	47%
Hydrogen cost per kg	£ 100
Maintenance per year	£ 100
Diesel generator	
Capacity	3 kW
Lifetime	10 years
Cost per kW	£ 825
Efficiency	10%
Diesel cost per litre	£ 0.40 (untaxed) £ 1 (taxed)
Maintenance per year	£ 600
Battery system (Li-ion)	
Capacity	7.2 kWh (72h autonomy)
Lifetime	10,000h
CAPEX	750 £/kWh
Cell replacement cost	500£/kWh
Efficiency	90%
Electricity cost per kWh	£ 0.13
Maintenance per year	£ 100

Diesel generators remain cheapest for professional applications

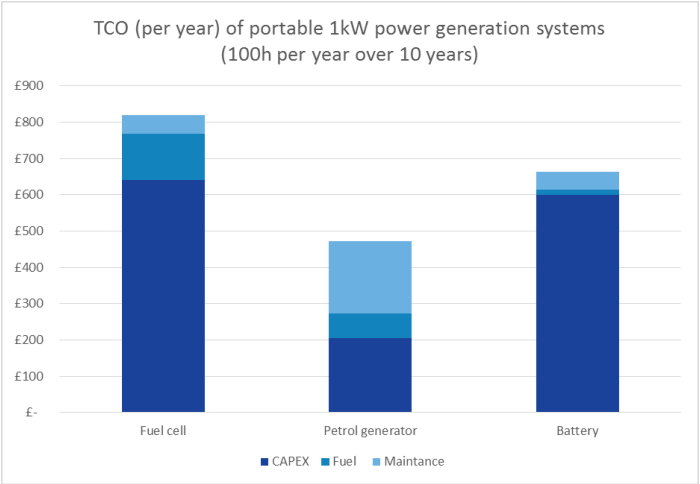
- Fuel cell generators can be compared with slightly oversized diesel generators. The latter are needed to meet starting currents, and professional grade gensets are not readily available in small sizes
- For high utilisation portable power generation (e.g. on a construction site), fuel cells are currently outperformed by diesel generators both on CAPEX and on OPEX, as hydrogen is costly in small quantities.
- Batteries look attractive on a TCO basis, but are likely to face logistical constraints due to long charging times
- Air quality and noise remain important drivers for fuel cells



Parameter	Value
Average load	1 kW
Runtime per year	1320 h (6h a day on 220 days)
Fuel cell	
Capacity	1.5 kW
Stack lifetime	10,000h
Cost per kW	£ 4,275[1]
Efficiency	47%[1]
Hydrogen cost per kg	£ 50
Maintenance per year	£ 100
Diesel generator	
Capacity	5 kW
Lifetime	10 years
Cost per kW	£ 825
Efficiency	15%
Diesel cost per litre	£ 0.40 (untaxed) £ 1 (taxed)
Maintenance per year	£ 400
Battery system (Li-ion)	
Capacity	12 kWh (12h autonomy)
Lifetime	10,000h
CAPEX	750 £/kWh
Cell replacement cost	500£/kWh
Efficiency	90%[1]
Electricity cost per kWh	£ 0.13
Maintenance per year	£ 100

Petrol generators are the cheapest option for recreational applications

- Compared to professional grade equipment, petrol generators for private use are available in smaller sizes (e.g. 2.5 kW). Consumer products are likely to run on taxed fuel, while professional generators can run on untaxed diesel.
- CAPEX plays a relatively important role for low utilisation applications, hurting the economic case of fuel cells in comparison to petrol generators
- Consideration such as noise levels and pollutant emissions may again be more relevant than TCO in this market



Parameter	Value
Average load	1 kW
Runtime per year	100 h (5h a day on 20 days)
Fuel cell	
Capacity	1.5 kW
Stack lifetime	10,000h
Cost per kW	£ 4,275[1]
Efficiency	47%[1]
Hydrogen cost per kg	£ 50
Maintenance per year	£ 100
Diesel generator	
Capacity	2.5 kW
Lifetime	10 years
Cost per kW	£ 825
Efficiency	15%
Petrol cost per litre	£ 1
Maintenance per year	£ 400
Battery system (Li-ion)	
Capacity	12 kWh (12h autonomy)
Lifetime	10,000h
CAPEX	750 £/kWh
Cell replacement cost	500£/kWh
Efficiency	90%[1]
Electricity cost per kWh	£ 0.13
Maintenance per year	£ 100

Fuel cells can develop a foothold in niche markets

- First commercial products have already appeared on the market, and are being sold in low thousands globally. With increasing technical product maturity and increased customer familiarity with fuel cell technologies, portable fuel cells are likely to ramp up deployment in niche markets where they are particularly attractive.
- The first addressable markets are the market segments that are premium tolerant from a price point of view and those where low emissions and quiet operation are an important differentiator. Applications with high runtimes are also favourable for fuel cells, as, with their high efficiency compared to gasoline and diesel generators, they have a competitive advantage on operating cost.
- Fuel cells could extend markets in areas where generators cannot be used (e.g. because of air or noise pollution in urban areas, national parks or indoor locations) and batteries cannot provide power for sufficiently long intervals
- The current yearly market for portable generators (mainly gasoline powered) is ~35,000 units in the UK and approximately one million units globally. The fuel cell market in this segment is nascent, with a few thousand units produced yearly, mainly for the European market.
- Cumulative possible fuel cell deployment by 2025:
  - UK: 10,000 units
  - Global: ~300,000 units

First UK companies are entering the market – others have the capabilities to follow

- **BOC**, the largest provider of industrial gas in the UK, currently offers a fuel cell for portable generation in the segment addressed by this roadmap. Their **HYMERA** fuel cell generator is a 150 W system, currently mainly used for low power and long duration applications such as security cameras, traffic lights, movable lighting systems and alarm systems. BOC does not manufacture the fuel cell itself, but integrates it into a ready to use product with communication capabilities and easy refuelling capabilities with BOC's proprietary hydrogen cylinders.
- BOC also has key capabilities and infrastructure for the refuelling logistics of portable fuel cell units. This aspect is both essential for the operability of portable fuel cells and potentially a high margin component of the portable fuel cell business.
- Other UK companies, such as **Intelligent Energy** and **CERES** have capabilities that would allow them to develop commercial products in the segment, should they see a solid value proposition in entering this market. **UPS Systems** also supplies fuel cells developed by others.
- Other UK based companies, such as **Johnson Matthey Fuel Cells,** have the capabilities to contribute to the supply chain of such fuel cells, for instance through the provision of MEAs. They already do this for some players.
- Portable fuel cells also align well with the research interests of numerous **UK research institutions**, such as Imperial College, UCL, and the universities of Loughborough, Southampton, Surrey and Cambridge

Fuel cell capex is high but with competitive fuel costs they could become competitive on total cost of ownership

- Capital costs are currently the most important barrier to the wide spread deployment of fuel cells in the portable sector. Fuel cells systems in this segment currently cost ~4,000 £/kW, with an additional 2,000 £/kg for hydrogen storage. Gasoline and diesel generator systems, on the other hand, range between 200 – 600 £/kW for mass market devices to 1,500 – 2,000 £/kW for high reliability professional systems in the 5 kW range. Professional grade internal combustion generators in the more common range of 20 kW cost as little as 600 £/kWh. As large parts of the portable generation market are taken up by units with low utilisation (e.g. backup or recreational use), capital cost represents the most important decision factor for many customers.
- On a total cost of ownership basis, the high efficiency levels and low maintenance requirements of fuel cells can make them attractive, with high utilisation. However, hydrogen as a fuel for portable fuel cells may be delivered in non standard bottles, which currently drives up the price. Prices of up to 100 £/kg of hydrogen can outweigh the higher efficiency of fuel cells in comparison with internal combustion generators, though this could drop with greater uptake.

Actions

- Capital costs of fuel cells can be reduced through scale-up of manufacturing. This requires greater demand, and the development of early markets, such as premium tolerant customers (e.g. high end recreational segment, military) or applications that require zero pollutant or noise emissions (e.g. operation in cities with bad air quality, close to hospitals or schools etc.). Public funding or policy might help kick-start those markets through deployment by local authorities etc, or procurement in pollution-sensitive areas such as parks.
- The hydrogen supply chain for these applications needs to mature to lead to lower fuel costs. This can be achieved through scaling up deployment of such fuel cells and through synergy effects with other segments (e.g. stationary fuel cells with portable fuels)

Portable generation is a mature market with high entry barriers

- **Lack of familiarity with technology**: incumbents are simple ICEs, familiar to users in all sectors. Despite their drawbacks (low efficiency, high noise and pollutant emissions), there is no strong drive for new technology options in most markets. Risk-averse customers may be hesitant to buy fuel cells, as they do not yet have a long track record, especially in adverse environmental conditions (construction sites, military applications).
- **Supply chain dominated by few big players**: About half a dozen companies currently compete in the portable generator market. They often not only build and integrate the internal combustion engines, but also dominate the distribution chain. It is hard for new players, and especially new technologies, to enter the market.
- **The variety of competing fuel cell technologies** (PEMFC, SOFC, DMFC) adds uncertainty for potential customers. This makes the space appear complex and adds uncertainty, as customers may fear backing a technology that could lose out against similar technology options

Actions

- Potential customers need to be familiarised with the technology, perhaps through industry workshops. Fuel cell manufacturers need to reduce customer risk through sound service and maintenance contracts. Pilot projects may help developing an understanding for the capabilities of the technologies.
- Initial niche markets need to be identified / created and used to showcase the technology. As portable generators are rarely safety-critical, and easily replaceable in case of failure, they represent a good initial market to prove technology readiness
- Technology suitability may be addressed through warranties, removing some consumer anxiety, or through clearer articulation of system benefits rather than technology-specific ones. A structured dialogue between fuel cell providers (or solution providers) and potential customers could help the fuel cell industry to understand customer needs and customers to identify opportunities.

Fuel supply chains for fuel cells need further development

- **Lack of familiarity with hydrogen and methanol for fuel cells :** Current technologies use either petrol or diesel, widely available and used fuels. Potential costumer may be unfamiliar or uncomfortable with gaseous fuels, and hydrogen in particular, as they have concerns or limited knowledge about safety. Methanol, a liquid fuel, may be more familiar to consumers, but is less well-known than gasoline or diesel. Any need for a reformer would increase the fuel cell cost and complexity.
- **Concerns about fuel availability: T**he fuel for conventional professional generators is often supplied through the same route as the fuel for other machinery (e.g. on construction sites). The widespread availability of gasoline and diesel is appreciated in the consumer market, in particular for backup applications. Hydrogen or methanol would require a new logistic chain and infrastructure, potentially a significant additional cost or complexity burden.

Actions

- Familiarity can be addressed through information campaigns on fuels, and reinforced through showcases of the technology in operation. This could be through the wider presence of fuel cell vehicles (e.g. buses) or options for consumers to experience portable fuel cells directly (e.g. through rental facilities)
- Building up a hydrogen supply chain for this application should fit into the wider context of developing hydrogen infrastructure. With increasing numbers of fuel cells, hydrogen can be provided more easily.
- Standardised hydrogen bottles for portable systems could facilitate supply from different providers in the long run. However, proprietary hydrogen delivery systems may be necessary for companies to sell the fuel cell system at an attractive price while earning a satisfactory margin on the fuel, offsetting the capex disadvantage of fuel cells and taking advantage of high operating efficiency.

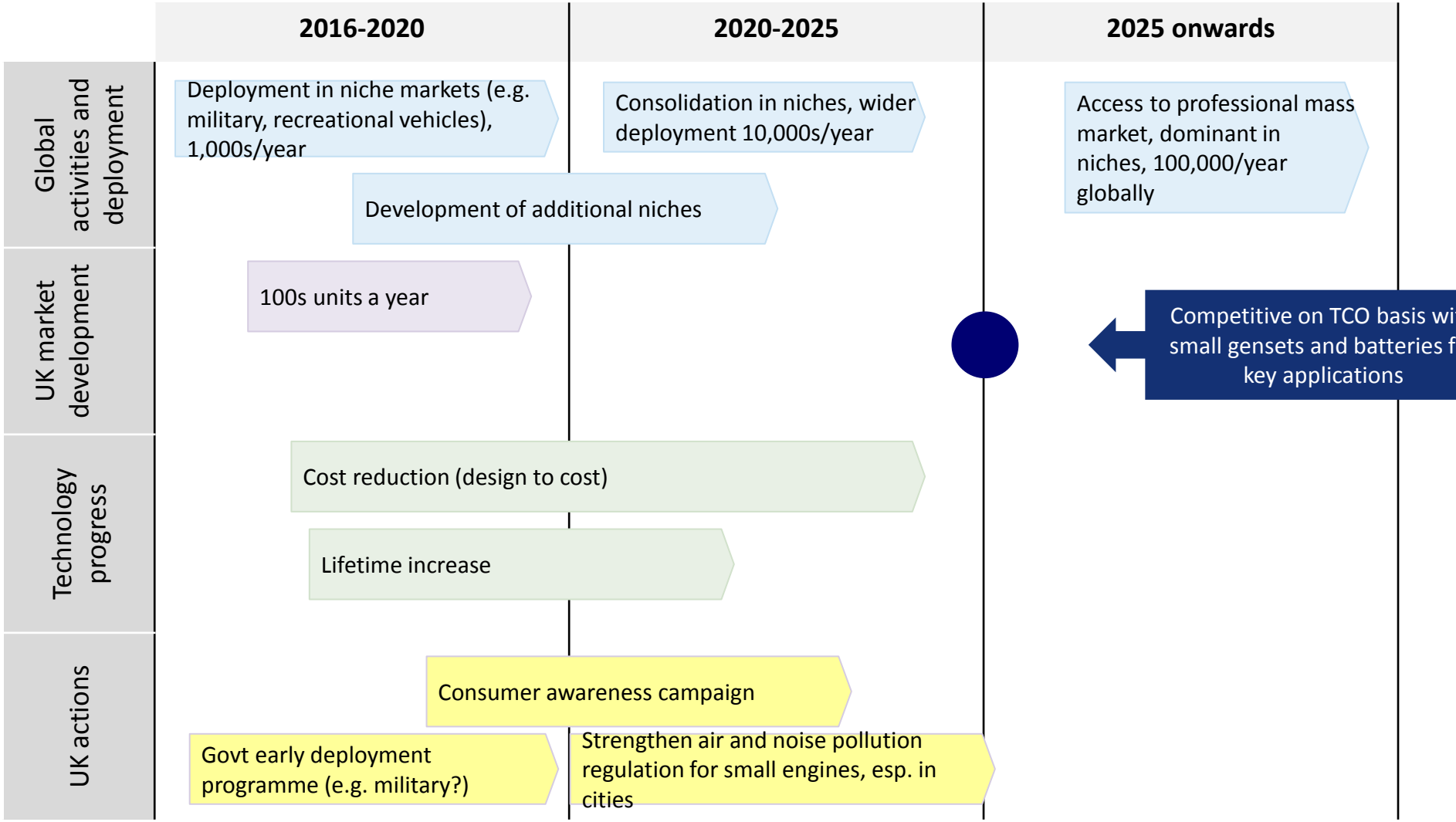
Air quality and noise regulation could drive fuel cell uptake but are unlikely to be a game changer

- **Pollutant emission regulation is limited for small generators:** While spark ignition engines are regulated for any size, diesel generators below 19 kW are not regulated through European Directives, which define emission limits in the UK. The next stage of restrictions for Non Road Mobile Machinery (NRMM), including generators may be more stringent, and affect small diesel engines, but is unlikely to be prohibitive. London's low emissions zone for NRMM also does not affect engines below 19 kW
- **Uncertainty about future air quality and noise regulation**: Air quality and noise limits are likely to become more stringent, but it is uncertain if this will require new technology deployment, such as fuel cells. Low emission zones in cities are likely to emerge more widely, but the effect on small machinery remains unclear.
- **EU noise emission limits are under revision:** The European Commission is considering a revision of the directive on noise emissions of machinery. While this could put further pressure on generator manufacturer to reduce the noise emissions of their products, it is unlikely to force a big shift from internal combustion engines

Actions

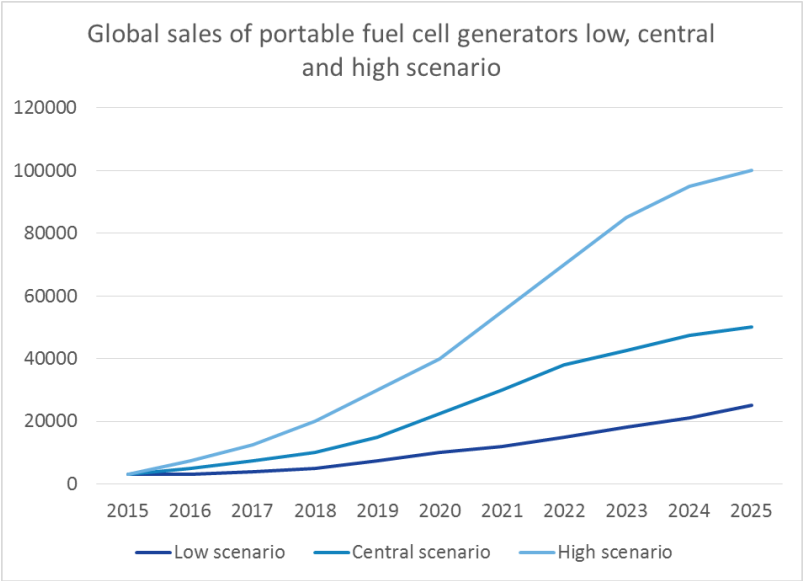
- **Clear signals form policy makers could drive deployment**: strengthened emission limits in sensitive areas could force equipment suppliers to provide alternatives to internal combustion engines. Those being considered for vehicles in London's super low emission zone could be proposed for small equipment such as generators, and lead to the deployment of technologies technically ready for the market but requiring greater demand to be competitive against incumbent technologies.
- **Proving the technology is available:** Fuel cell producers need to deploy their products in early markets to prove alternative technologies with very low emissions are technically ready, and that they present a viable alternative to conventional technologies.

A range of actions at different times would help build a market



Even small market shares in the large portable power generation market can drive fuel cell deployment scale-up

- In the **low scenario**, Fuel cells remain niche premium products in some specific areas (e.g. recreational vehicles) but fail to gain significant market shares in larger markets, and remain at 2.5% of the global portable generator market. Fuel cell cost remains high as uptake is slow in other sectors, too
- In the **central scenario**, fuel cells enter price-tolerant markets in the recreational and professional sectors (e.g. market stalls, event and construction sites in noise sensitive areas) and gain market shares of 5% in the overall portable generator market by 2025. Technology advances in other sectors, such as telecoms backup, drive fuel cell costs down
- In the **high scenario**, fuel cells become a major contender in certain premium tolerant sectors and enter the high end consumer market (10% market share overall in 2025). A large scale uptake of fuel cells in the same size range in other sectors (e.g. telecom backup) helps reduce cost



Deployment depends in part on specific actions

Scenario	Actions	Deployment numbers (units sold per year)		
		2015	2020	2025
High	**Additional actions** • Introduce strong local air and noise pollution effectively banning ICE generators in certain areas creating a strong market pull • Develop hydrogen supply chain to considerably increase hydrogen fuel availability	UK: <100 Global: ~3,000	UK: 1,500 Global: 50,000	UK >3,000 Global: 100,000
Central	• Introduce local air and noise pollution regulation provide some incentive to move to zero emission generators • Fuel cell industry improves products to achieve their cost reduction targets • Public procurement through local authorities and military	UK: <100 Global: ~3,000	UK: 1,000 Global: 25,000	UK: 2,000 Global: 50,000
Low	**Actions still needed** • FC manufacturers achieve cost reductions and lifetime increases through better product design	UK: <100 Global: ~3,000	UK: <300 Global: 10,000	UK: <900 Global: 25,000

The UK benefit in 2025 could be significant

	Cumulative by 2025	Notes
Global market	~ 275k units	
Global market value	~ £4.3 billion	
UK Share of Tradeable Global Market	Up to 7%	Higher shares for fuel cell system, lower shares for operation
Potential value for UK economy (GVA)	~ £15 million	
Potential UK job creation	~ 80	

- The GVA analysis includes fuel cell and fuel system cost, as well as maintenance and fuel cost.
- The overall premium tolerant share of the generator market is estimates to about 5% of the global market for generators below 10 kW.
- Core UK competency is likely to remain in research, development and design of fuel cell systems, as well as operating models. Little manufacturing is considered likely to occur in the UK, outside some components.

Portable fuel cells are unlikely to become a large UK based industry, but can be a significant step to wider fuel cell deployment

- Some of the possible applications of portable generators do not require high proven reliability of the devices, allowing consumers to make less conservative technology choices than in other potential markets for fuel cells. The portable generator market could hence develop into a proving ground for fuel cell technologies, where they can showcase their reliability and performance. This could be a stepping stone for the UK fuel cell and hydrogen industry overall.
- While the contribution of portable generators to the UK greenhouse gas emissions is minimal, fuel cell generators could develop into an important option to reduce the noise and air quality impact of portable electricity generation. This would have a particularly positive effect in cities with air quality issues (e.g. London) and in noise sensitive areas, such as national parks, and areas surrounding schools or hospitals.
- If successful in the market place, portable fuel cells are likely to be manufactured in large numbers. The corresponding mass production facilities are unlikely to be located in the UK, meaning that the impact of this segment on the UK manufacturing sector is likely to remain limited, though components such as MEAs may still come from the UK. Currently marketed products are already largely manufactured in Asia.
- Added value for UK companies in the portable fuel cell segment can also come from system integration, i.e. integrating fuel cells and hydrogen storage system into a fully functional portable generation system. A large part of the value of portable fuel cells is likely to remain within fuel provision, rental, servicing etc. Large UK companies such as BOC and small ones such as UPS Systems are well placed to develop this area.

Portable fuel cells can help scaling up the industry, if other aspects follow suit

- The large market potential of portable fuel cells in terms of units makes them a potential stepping stone for other segments, such as **back up generation**. As the reliability requirements for portable fuel cells, especially in the recreational sector, are less stringent as in other potential markets for fuel cells, portable fuel cells can help building the confidence in the technology that more demanding consumers require.
- Fuel cells are likely initially to be marketed as an environmentally friendly alternative to conventional generators. While the greenhouse gas impact of portable generators is not the driving factor for uptake, using fossil hydrogen can be a reputational risk. The development of **clean hydrogen sources** is hence an important factor for portable fuel cells in the future.
- An increased presence of **fuel cells and hydrogen in transport** could lead to synergies in refuelling, especially for industrial customers, who are unlikely to make major investments in a refuelling infrastructure exclusive to small generators.
- More widely, the further inclusion of **hydrogen in infrastructure (e.g. the gas grid)** would simplify refuelling and increase customer familiarity with hydrogen as a fuel.