Small stationary power and CHP – pre-read material for workshop

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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

↓

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

↓

WP 6 - Draft and final reports

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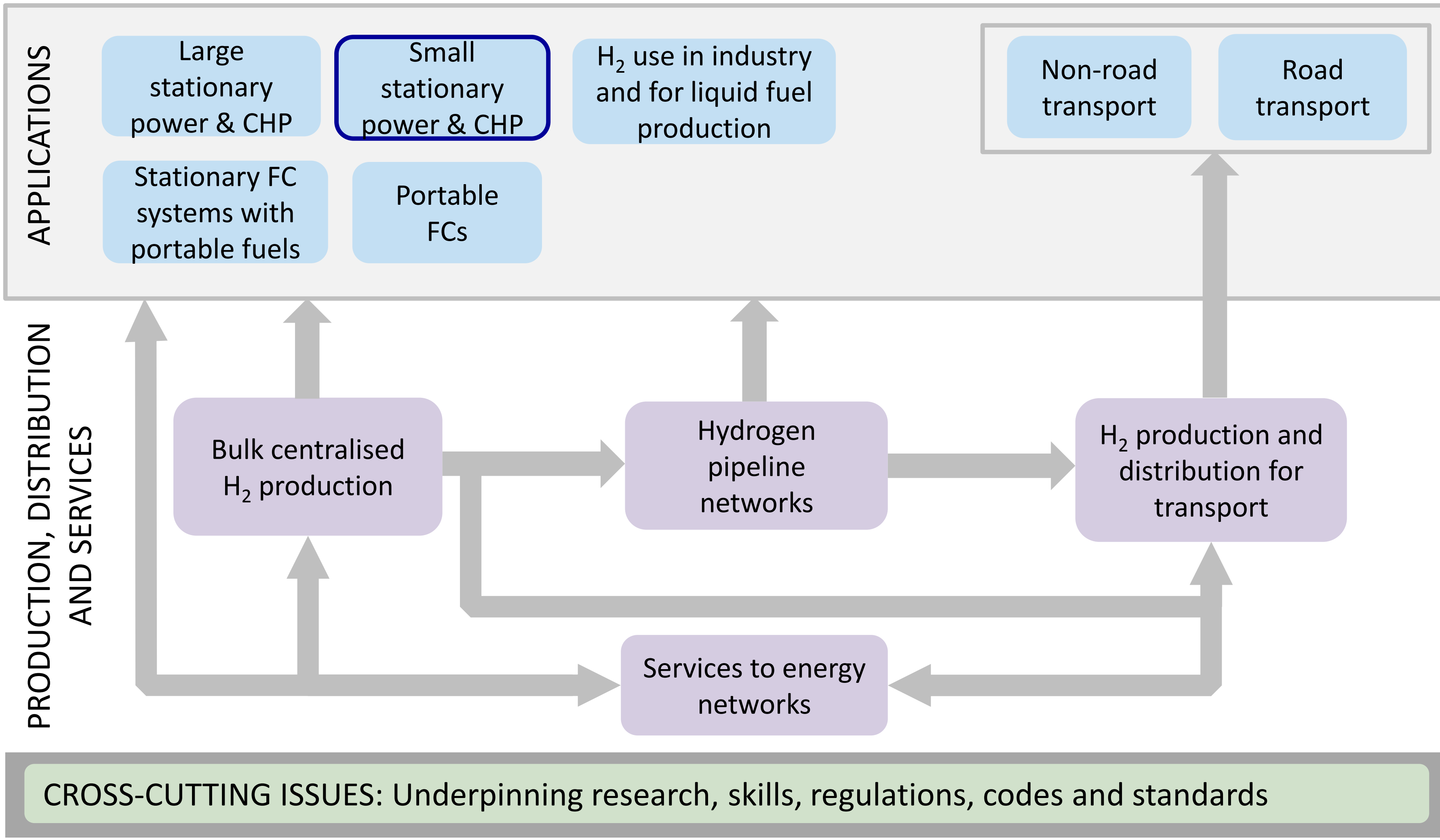
The 11 mini roadmaps cover uses of hydrogen and fuel cells, and production and distribution of hydrogen



Today's workshop is to get your feedback on the draft mini-roadmap on small stationary power and CHP

- 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 are interested in **your views on**:
  - Are the aims for 2025 appropriate? What level of deployment is feasible?
  - Are the important barriers included and are they well explained?
  - Will the actions proposed be enough to overcome the barriers? If not, what else is needed?
  - Who should be responsible for these actions? How much will they cost, and how long will they take?

- 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

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?

Small stationary power and CHP – draft roadmap

This roadmap describes small stationary fuel cells used for combined heat and power (CHP) and prime power applications

- There is a growing desire to reduce CO_2 emissions from the UK building stock, and a number of low carbon technologies (e.g. heat pumps, combined heat and power units) and policies (e.g. part L, code for sustainable homes) have been developed to reduce building energy intensity
- Stationary fuel cells operate at high electrical efficiencies close to the point of use., Efficiencies can be as high as the best combined cycle gas turbines (i.e. 55-60%) for some solid oxide options.
- When used for the cogeneration of heat and power (CHP), the overall efficiency exceeds 90% and will lead to a large CO_2 saving compared to a conventional home using heat from a gas boiler and electricity for the grid.
- Even if the grid were exclusively fuelled by efficient gas fired power stations, there would still be a considerable CO_2 saving, due to the ability to use waste heat and avoid the energy cost of electricity transmission and distribution.
- Fuel cell mCHP is one of a number of micro CHP options available. Of these, fuel cells have the highest overall electrical efficiency and are particularly suited for use in residential buildings due to their high electrical efficiency, low noise, vibration and pollution emissions. As a result, they have already achieved the highest global market share of all microCHP options
- Countries such as Japan and South Korea have already seen significant deployment of stationary fuel cell systems, but the European market is just beginning to develop
- MicroCHP systems can be highly responsive and therefore also involved in providing local or national grid support services, if deployed in sufficient numbers.

Fuel cell systems of <2kWe suitable for installation in domestic properties either as boiler replacements or for stand alone heat and power generation

Fuel cell CHP in the 2-20kWe range are suitable for larger commercial applications and residential applications with shared services

Photos: renewable energy hub (top), e-architect (bottom)

The roadmap is focussed on microCHP applications for homes and larger systems for commercial and industrial buildings

- A filtering exercise concluded that this roadmap should focus on fuel cells operating in CHP mode.
- Two size ranges are considered:
  - microCHP <2kWe capacity, which is primarily aimed at domestic and small commercial buildings
  - Mini fuel cell CHP 2 – 20kWe capacity, which is aimed at residential blocks, commercial and small industrial buildings
- There is potentially a very large market for FC mCHP systems in residential settings in the UK, given the size of the existing domestic heating market (over 1m units per year)
- the UK has a potential market leader, Ceres, is a British company. Furthermore, FC CHP could be an opportunity for UK boiler and component manufacturers, who could incorporate their technology into this low carbon heating solution or incorporate fuel cells into their range of products
- However, the UK currently lags behind Germany and Japan in industrialisation of this technology
- Although it is a smaller market than the residential market, a number of UK companies are considering activity in the deployment of larger fuel cells with capacities of 2 – 20kW and there is less competitive pressure here
- The filtering process led to electricity only systems being excluded, as the economic and carbon case for their deployment is less clear. Hydrogen fuelled CHP systems were considered a technology which becomes relevant only once hydrogen use in pipelines is established, and the systems discussed here can be readily adapted to run on hydrogen, if an abundant supply of hydrogen becomes available

Ceres, a UK company, may have the potential to become a leader in small-scale CHP technology

Two fuel cell types are relevant for microCHP applications:

- **PEM** – currently the market leader (used by e.g. Panasonic, Toshiba), requires a fuel processor to convert methane to a hydrogen rich gas
- **SOFC** – gaining an increasing market share (e.g new systems from Aisin/Toyota), can partially reform methane internally, helping to reduce system complexity

Both systems can be fuelled by natural gas, but in the longer term could transition to hydrogen rich gas streams at low cost

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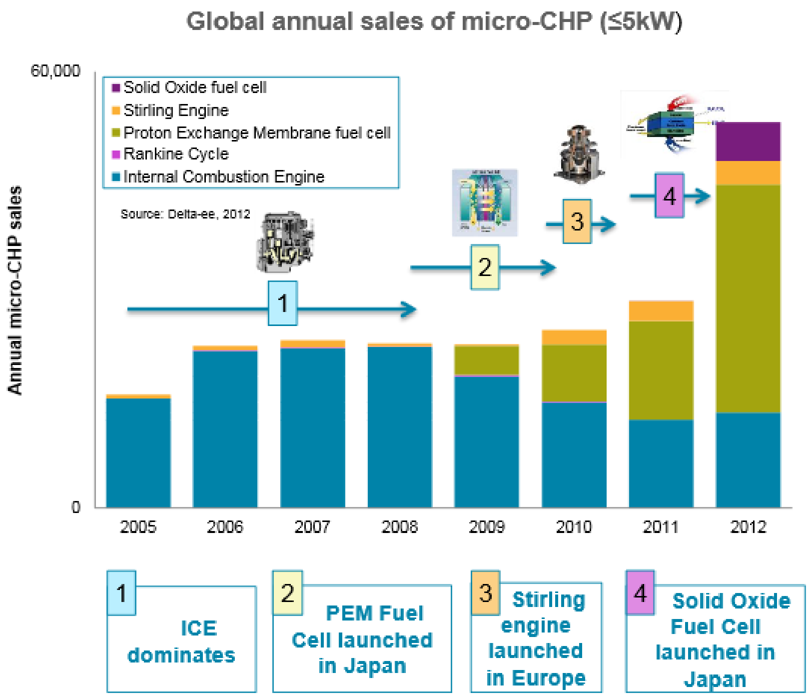
Fuel Cell CHP is a disruptive technology in the micro-CHP market driving rapid growth in Japan

- **Fuel Cell CHP (FC CHP) is a rapidly growing market**, capturing over 70% of the global mCHP market in 2014[1]
- The global leader in FC CHP is Japan, which started demonstrations in 2003, with a substantial subsidy program (ENE.FARM) started in 2009. The rationale for this program stems from Japan's desire to reduce dependence on foreign oil imports and also the potential to create a domestic manufacturing industry in these new technologies
- Cumulative deployment of FC CHPs exceeded 100,000 units in Japan in September 2014. **The leading manufacturers** (Toshiba, Panasonic) **are already producing 20,000 units/year** (PEM)
- **Other manufacturers are ramping up rapidly**, for example Aisin and Osaka Gas recently announced plans to increase production to 10,000/year (SOFC)
- Market **forecasts[1] have suggested that the global micro-CHP market will grow from 700 million GBP (2014) to 2.5 billion GBP (2019)**. mCHP is readily deployable throughout much of Europe, North America and Asia because any property connected to a gas grid has the required infrastructure to install a gas fuelled fuel cell



Source: Delta-ee (2012): www.delta-ee.com/images/downloads/pdfs/Delta-ee_mCHP_market_status_and_potential_Cogen_Czech_161012.pdf (s.8)

- Currently, approximately 85% of all micro-CHP sales have occurred in Japan, with the remaining 15% in Europe. In Japan fuel cell CHP now accounts for over 95% of all sales

1: COGEN Europe / DELTA Energy & Environment: *The benefits of micro-CHP*, H2FCSUPERGEN: *THE ROLE OF HYDROGEN AND FUEL CELLS IN PROVIDING AFFORDABLE, SECURE LOW-CARBON HEAT*

Fuel Cell CHP is a disruptive technology in the micro-CHP market driving rapid growth in Japan

- **It is reasonable to expect that by 2025** (with global trends in support for commercialisation), **fuel cell mCHP could be a financially viable heating option for UK homes**
- The large scale deployment of fuel cell mCHP has a number of benefits:
  - **Primary energy savings of around 25% are possible with local cogeneration of heat and electricity** compared to separate boilers and power stations[1];
  - These **energy savings can directly result in energy bill savings of 25 – 34%**[1]; and equivalent CO_2 savings
  - Micro-CHP systems are relatively responsive and generate energy close to the point of use, they **can therefore support grid management and strengthen distribution systems**
  - **Longer term, these systems can make use of lower carbon gas** (or hydrogen in pipelines) increasing the CO_2 savings available
- **FC CHP specifically has a number of advantages over other micro-CHP technologies**:
  - **High efficiency compared to CHP engines.** Current electrical efficiencies have reached as high as 50% and total efficiencies 90%;
  - **Near elimination of pollutants** (e.g. NO_x) and particulates compared to engine technologies;
  - Fuel cell systems have rapid response times and can operate efficiently at reduced power, with significant potential for use within dynamic response and reserve services
  - Fuel cells are inherently scalable without losing efficiency, which means they are readily adaptable to this scale of application

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1: COGEN Europe / DELTA Energy & Environment: *The benefits of micro-CHP*

A relatively small number of European companies are positioned to participate in the domestic mCHP market, with three in the UK

UK companies active and other UK activity in the sector

- **CERES** Power, a leading UK fuel cells manufacturer, have developed micro-CHP units and in 2013 entered into a partnership with South Korean company KD Navien Co. Ltd. giving Ceres the opportunity to trial its units in Seoul and foster a future relationship[1]
- **Johnson Matthey** also operate within the value chain as a developer of fuel cell membrane assemblies.
- The business relies on partnerships with fuel cell developers to provide units to be integrated into buildings. **Logan Energy and Fuel Cell Systems** are integrators with an interest in the technology.
- The European market is dominated by heating manufacturers such as BAXI, Bosch, Vaillant and Viessmann. Other SME's such as SolidPOWER and Elcore have achieved some traction
- Globally the market leaders are Japanese (Toshiba, Panasonic (PEM), Aisin/Kyocera (SOFC)) – Panasonic have established a research facility in Wales

UK Latent potential

- **A number of UK manufacturers may participate in the FC mCHP market once it begins to mature:** potential latent players in the UK include boiler manufacturers, utilities and network operators
- There are inevitable supply chain benefits for microgeneration installers and maintenance personnel from increased mCHP activity

Measures to support the market

- UK FC developers and OEMs will need to prove their product if they are to compete for a share of this potentially large market **– fleet trials of UK products** to prove out the performance of UK built technology will be required. These could include either domestic or small commercial scale products, which have a significant UK component
- It is important that industry gains experience with real world deployment, this could be addressed by **support of field trials of all mCHP options,** including overseas products. However, there is little benefit to the UK from acting early in these trials without UK FC/OEM involvement. Hence, the support for this type of activity should wait for the technology to have clearly demonstrated potential market traction
- To justify investment in the UK a clear and **long term policy/regulatory** regime for the technology is needed
- Research priorities should focus on improved lifetime (reduced degradation) and manufacturing techniques to reduce cost at volume and improved electrical and overall efficiency
- Sponsorship of trials to understand the **potential of additional revenue streams from grid balancing** will be welcomed, once the technology achieves initial market traction

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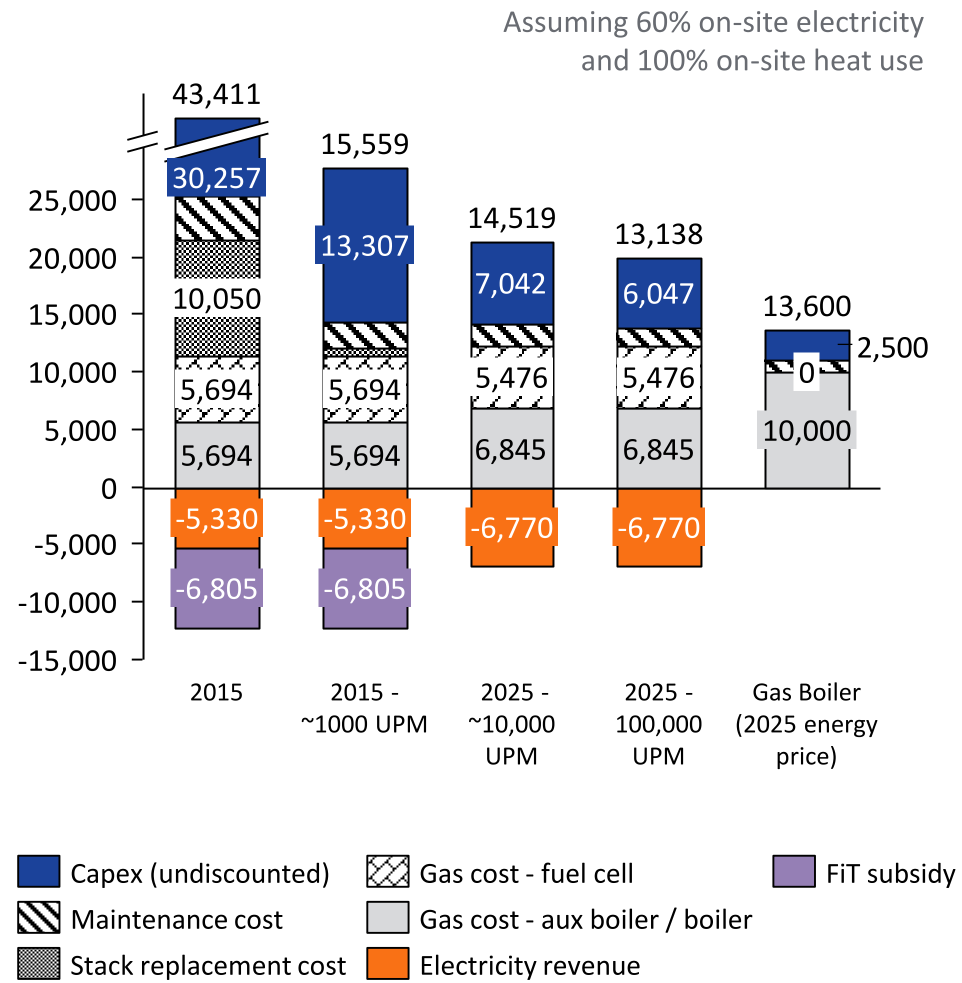
[1]Ceres Power
[2]Renewableenergyfocus.com

Analysis suggests that FC mCHP can be cost competitive when produced on scales of 5000 units per manufacturer

- This analysis is based on a household with a heat demand of 20,000 kWh per annum
- The analysis indicates that the CAPEX of the mCHP is currently the dominant cost component of ownership. Expected volume driven cost reductions[2] imply that the **unsubsidised Total Cost of Ownership will start to compete with a gas boiler at production levels of around 10,000 Units Per Manufacturer (UPM)**
- Hence, according to this model, **the European fuel cell mCHP industry will require some form of support up to the point where 10,000 UPM can be produced**
- This situation will be improved if higher electrical efficiency systems are developed (>50%)

Assumptions	<1000 UPM	>5000 UPM
Electrical output	1kWe	1kWe
Efficiency (electrical, thermal)	36%, 52%	42%, 53%
Side boiler efficiency	92%	
Feed in Tariff	14p/kWh (up to 30,000 units)	
Run hours	5000 per year	
CAPEX	See chart	
System / stack life(years)	10/4 initially, dropping to 14/14	

10 year ownership cost of a generic fuel cell - 20,000 kWh_{th} per annum[2] - £



1: Roland Berger: *Advancing Europe's energy systems: Stationary fuel cells in distributed generation,* as are replacement and maintenance costs
2: Electricity and gas prices based on central scenario of DECC: *Energy and emissions projections: Annex M*

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The 2-20kW Mini CHP for small commercial and industrial applications is a less crowded space

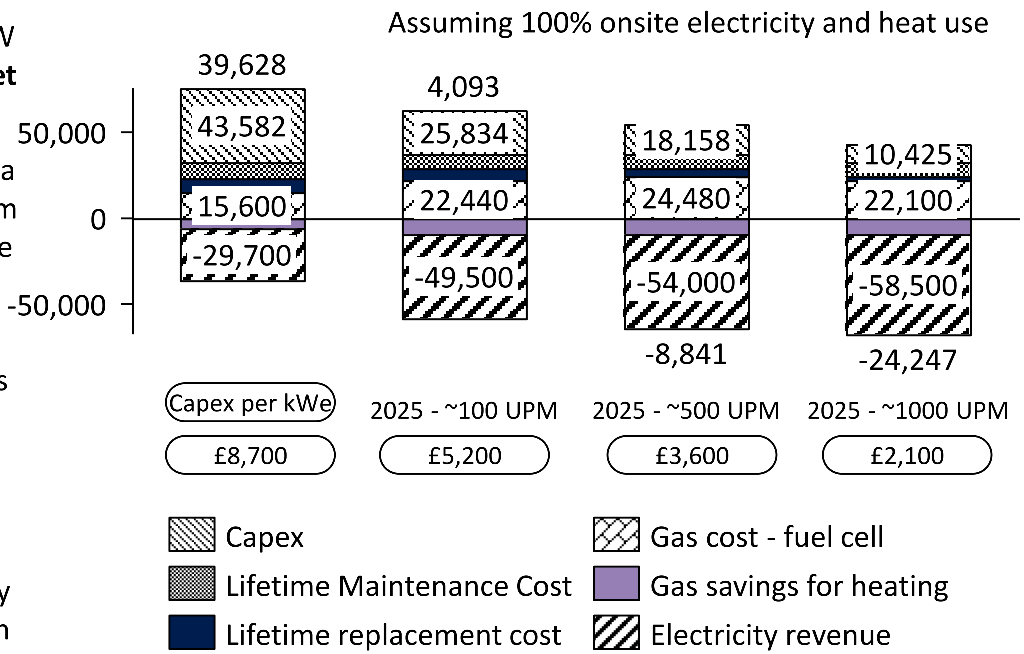
- **Few medium power fuel cells have been developed by the European industry** and it is yet to be seen how these technologies perform in these settings in any country[1]
- This is a much less crowded space the for micro-CHP and there is no equivalent program to ENEFARM operating around the world
- Similarly to micro CHP, mini CHP is applicable in any building with a gas grid connection, so the underlying infrastructure is already readily available in the UK and many other countries
- Mini-CHP has the potential to provide a source of heat and electricity for buildings, which is competitive with all alternatives, in buildings where heating systems are operated continuously through much of the day
- The market for these systems is considerably less well proven and more disparate than for micro-CHP but would include: **apartment buildings[1]**, commercial premises with long occupancy, small health facilities (e.g. care homes), 24 hour occupied buildings (fire/police stations) and small data centres
- In these applications, it is likely that the CHP product would be “stand-alone” which means it would be fitted into existing heating systems and would not include its own integrated gas boiler

1: Roland Berger: *Advancing Europe’s energy systems: Stationary fuel cells in distributed generation*

In commercial sectors larger stacks could give a net profit when they are manufactured on scales of 500 units per manufacturer

- An analysis based on the total cost of ownership of a 5kW stack[1] suggests **a mini-CHP installation could return a net profit when produced at scales of ~500 UPM** (in 2025)
- This analysis assumes that the CHP is installed alongside a natural gas fired boiler – hence revenues are derived from sale of electricity and savings of gas that would otherwise have been used in the boiler
- This lower required market size for breakeven suggests that the fuel cell may penetrate more easily and with less marketing effort per unit installed than for domestic mCHP. Given that there are fewer companies targeting the space and that the UK has two companies active in this area, it could be an attractive market entry point
- Note that the market relies on a) high electrical efficiency and b) locations with high continuous heat demand, even during the summer c) high continuous electricity demand so that electricity produced is consumed on site – these properties exist, but identifying demand in this fragmented market will be challenging and routes to market are less clear cut than for the domestic segment

Lifetime cost of ownership[2] - £



Assumptions	
Efficiency (electrical, thermal)	(50%, 37%) increasing to (60%, 38%)
CHP output (electrical)	5kWe
Run hours	6000 per year
System life	10 years initially increasing to 14
Stack replacements	One stake replacement over lifetime

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1: Based on Roland Berger: *Advancing Europe's energy systems: Stationary fuel cells in distributed generation.* Maintenance and replacement costs are also based on this
2: Electricity and gas prices based on central scenario of DECC: *Energy and emissions projections: Annex M*

There are a number of barriers to the uptake of fuel cell microCHP in the UK (1/2)

A need for real world experience

- For UK mCHP manufacturers, a significant barrier to entering this market is the lack of high profile trials for their technology. German (Callux/ene.field/PACE) and Japanese (ENEFARM) manufacturers have entered structured progress to deploy their units. Companies (Ceres in particular) will need to prove the technology in a fleet trials of 10's of units in order to create confidence in the technology from OEM's and investors
- There is **very limited field data available** in the UK to inform the commercialisation of FC CHP, as well as policy decisions on the subject
  - Organisation of field trials involving 100s of units (such as the ene.field trial[1]) would provide valuable experience for UK early movers, as well as raising awareness of the technology
- Assuming the technology becomes attractive to consumers, there is a need to ensure there are sufficient **trained installers of FC mCHP in the UK.** A deficit of trained installers will not only increase the cost and inconvenience of installation, but will also decrease the uptake of mCHP, because many domestic users are recommended heating systems by their installer
  - This could be resolved by supporting the training of a new generation of installers, or by developing relationships between FC mCHP suppliers and experienced installers

FC mCHP will enter a market crowded with up-and-coming and mature technologies

- High satisfaction with incumbent technologies and lack of user awareness of mCHP mean that it is unlikely that customers will choose to switch heating systems. Moreover, many purchases of heating systems are distressed, where new heating systems are unlikely to be bought in an emergency
- Policy incentives for the uptake of mCHP may not be as encouraging as for other low carbon technologies
  - CHP has a Feed in Tariff (FiT) of 13.61p/kWh, limited to 2kW installations or less, and capped at 30,000 units nationally. Analysis above suggests that at current mCHP costs, this is unlikely to be large enough to change purchasing decisions (i.e. early commercial markets will occur elsewhere until European volumes increase allowing lower costs and hence penetration of the UK market). CHP doesn't benefit from the RHI, while other heating technologies such as air and ground source heat pumps, are supported

[1]http://enefield.eu/

There are a number of barriers to the uptake of fuel cell microCHP in the UK (2/2)

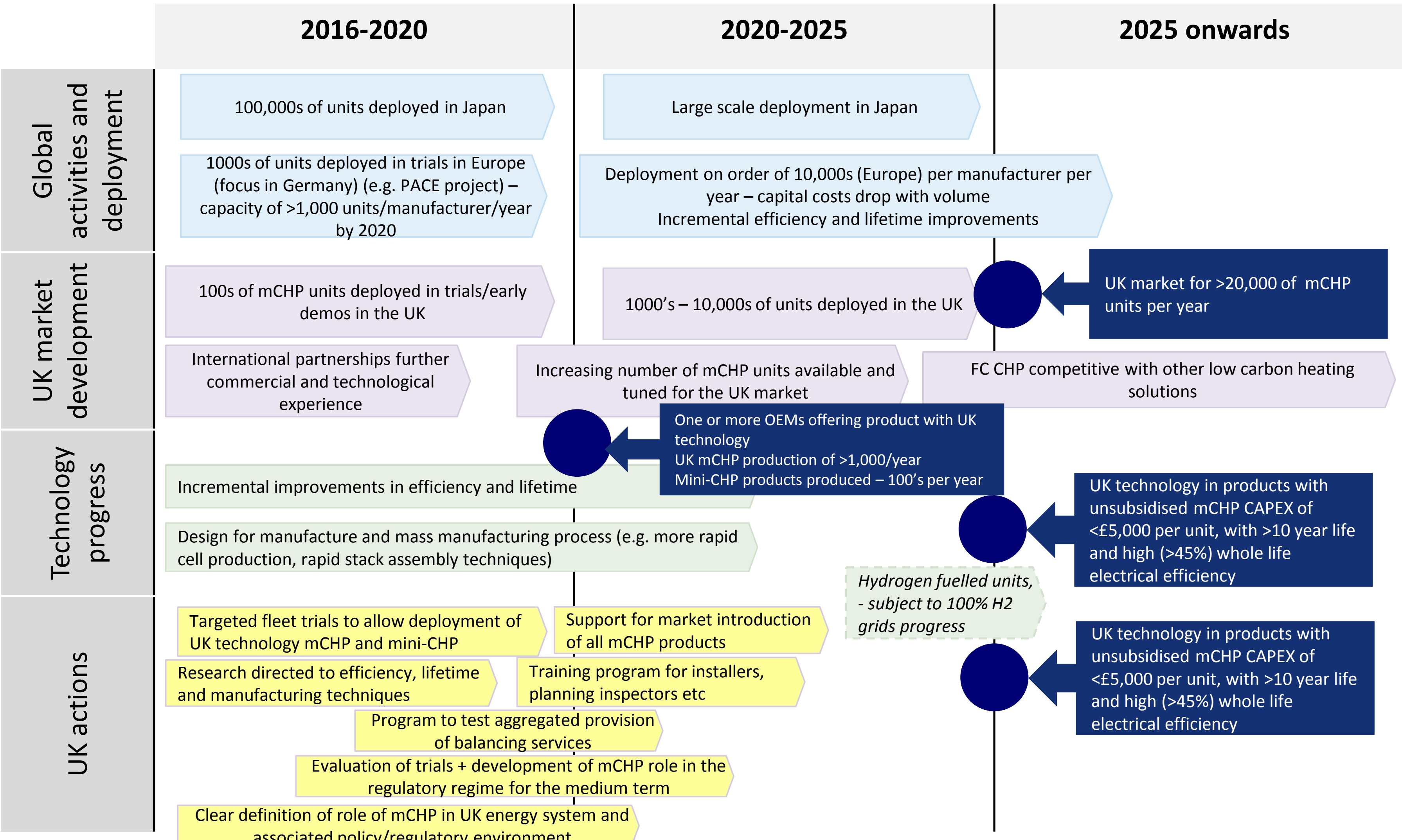
Fuel cell mCHP technologies have attributes which limit their appeal across the UK housing stock

- mCHP units have comparatively high volumes compared to boilers and typically are installed outside the home or in a basement. This may reduce their appeal to many UK consumers, who are used to small wall hanging boilers
- To work efficiently, fuel cell mCHP systems require storage of heat - the UK boiler market has shifted towards combi-boilers and many hot water tanks have been removed (or no space has been left for them in new housing stock)
- Fuel cell CHP systems typically have low flow and return temperatures, which are not compatible with the older UK building stock, which makes use of small radiators and higher temperatures
- At present the best product for the UK market is not established – should these CHP units be sold as stand alone systems integrated to existing heating systems or integrated with a boiler to provide a boiler replacement? Overall, further work is required to better optimise the fit of fuel cell mCHP with the UK building stock, developing a flexible product family that is appealing across the range of UK homes

There is a lack of clarity regarding the energy system benefits of mCHP

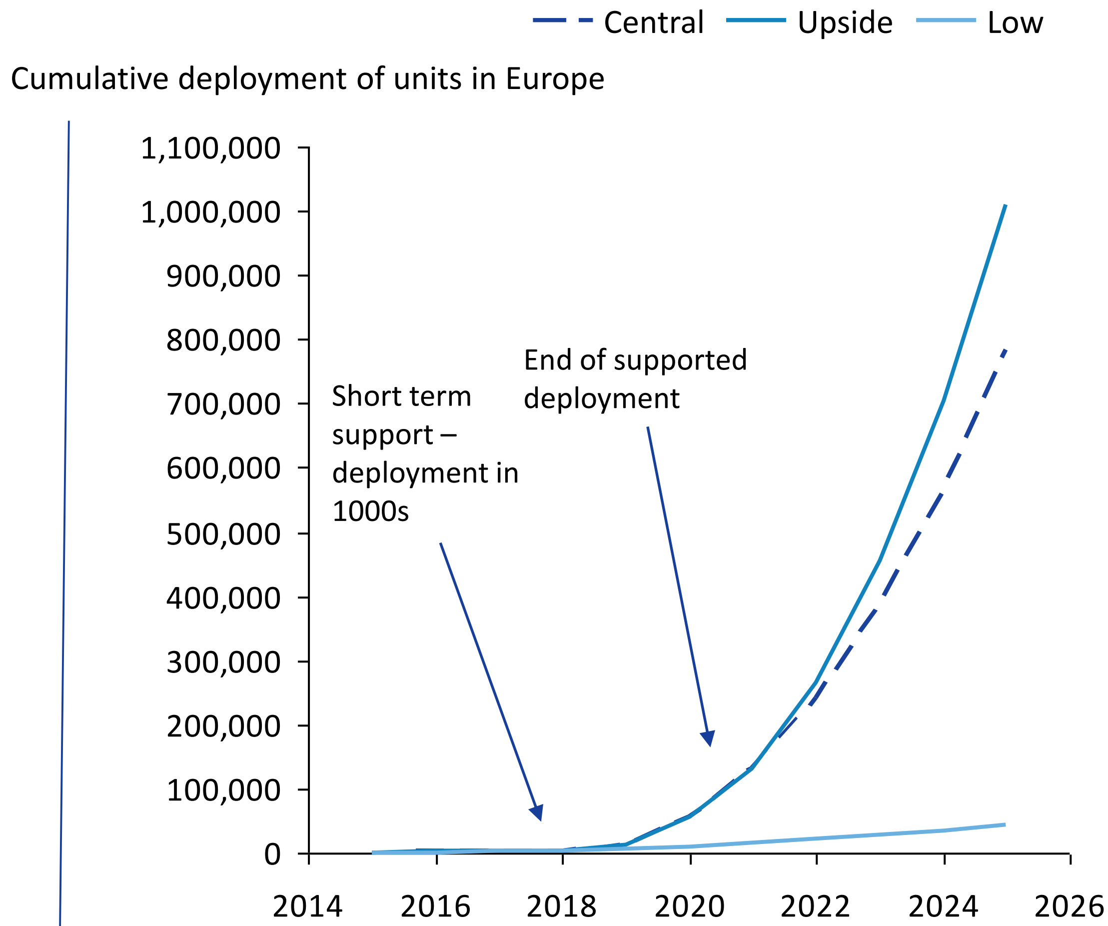
- Domestic CHP is not fully accepted as a mainstream option for decarbonisation. As a result, the policy environment is not stable and long term – this harms the ability to make investment in the technology and prepare for market uptake
- Domestic CHP has potential to be used in a number of grid balancing services. However, domestic response services are yet to be commercially proven:
  - For domestic balancing services to be realised, an aggregation structure needs to be developed that will pass benefits on to customers - mCHP will need to compete against other domestic heating technologies competing to provide the same services
- Emissions reductions of mCHP relative to its competitors will depend on the degree of decarbonisation of the electricity and gas supplies
  - As the electricity supply becomes increasingly clean, the relative emissions saving potential of mCHP compared to electric systems will drop. This could be mitigated by the diversification of the gas supply which has potential to increase the emissions savings of mCHP. Longer term, if low carbon hydrogen becomes available in pipelines in towns (see pipelines roadmap), mCHP would be an attractive option to generate distributed low carbon electricity. This would also be possible at a relatively low cost as mCHP systems using fuel cells would require more limited balance of systems (this applies to all fuel cell types – PEM and SOFC)

Overview of the deployment timeline, technology progress and possible actions for supporting this application



Most of the barriers identified for this application can be resolved before 2020 even for modest deployment levels

- Large scale trails are currently underway or planned in Europe. Along with ene.field, Germany are planning a Technology Implementation Program[1] that aims at deployment of over 130,000 mCHP units by 2021
- Beyond 2021 the central scenario assumes that sales will reach levels suggested by ROI models for costs based on production scales of the order of 5,000 units per manufacturer per year. These sales are assumed to be unsubsidised since with the TCO suggested at this level mCHP should be competitive
- A total of 10 large-scale manufacturers are expected in the long term[3], and production rates are based on cost reductions driven by volume per large-scale manufacturer
- Based on this model, we can expect around 100,000 units to be deployed by 2020 and 800,000 units to be deployed in Europe by 2025[4]
- The lower bound depicts a failure to achieve market traction



Assumptions: in the long term there are 10 companies operating in the mCHP sector (based on 2); the addressable market up to 2025 is principally inside Germany and the UK (with some penetration into Italy and Poland – based on 1); deployment in the central and upside scenario is driven by supported projects until 2021, when high volume manufacturing has been established

[1] Vaillant Group: *How to commercialise microchp fuel cells in Europe?*

[2] Roland Berger: *Advancing Europe's Energy Systems: stationary fuel cells in distributed generation*

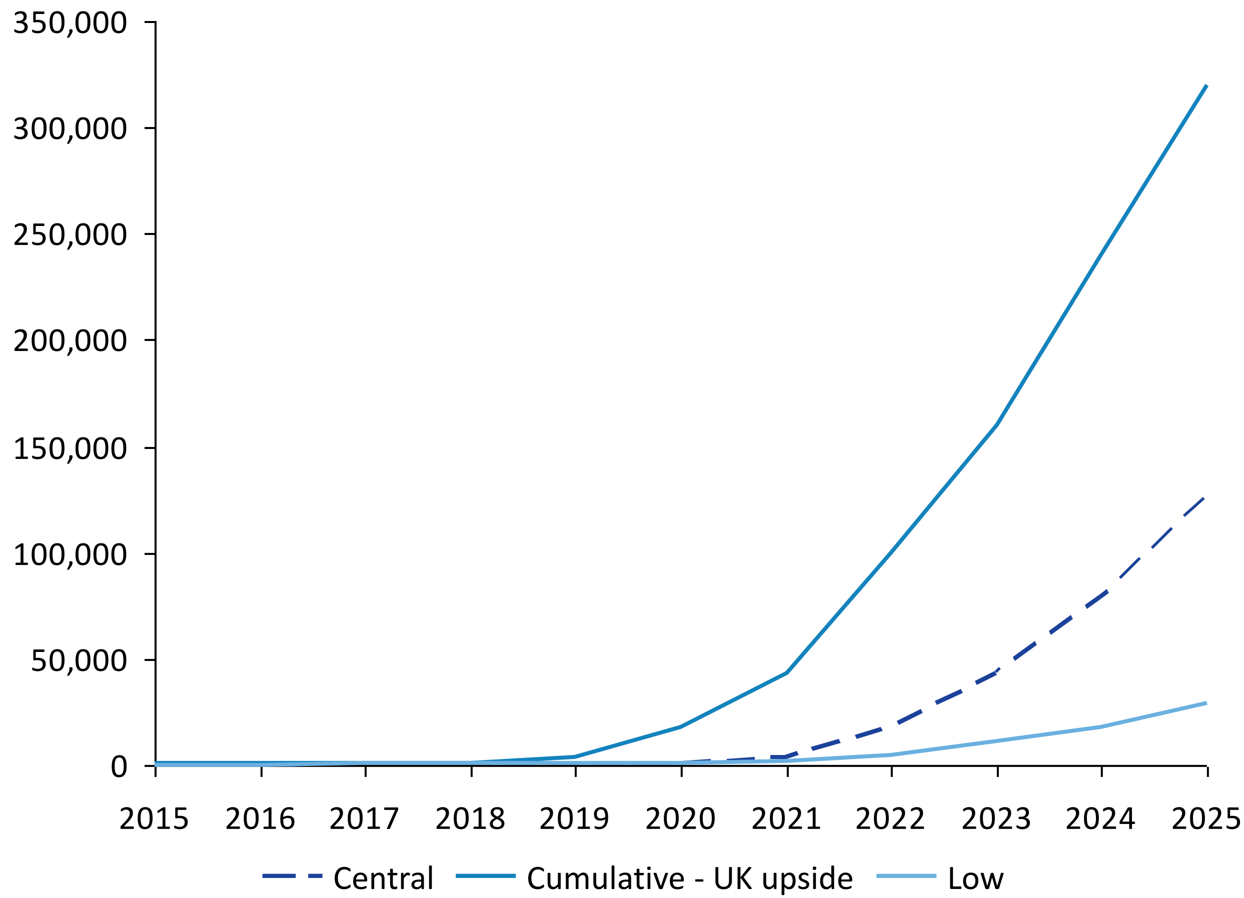
[3] Cogen: *Micro-CHP potential analysis European level report*

[4] This is corroborated by near term projections from H2FCSUPERGEN: *The Role of Hydrogen and Fuel Cells in Providing Affordable Secure Low-Carbon Heat*

With appropriate support, it is anticipated that 250,000 FC mCHPs could be deployed in the UK by 2025

- Assuming success in the German TIP program and support for UK manufactures, up to approximately 40,000 FC mCHPs could be deployed in the UK by 2023
- Based on cost reductions driven by volume, it is anticipated that FC mCHPs could exhibit increasing uptake, and future cost reductions could drive the uptake of small FC CHP units upwards. Under these assumptions, **up to around 120,000 FC mCHPs could be deployed by 2025**

Cumulative deployment of units in the UK



Deployment exercise slide for workshops

Scenario	Actions	Deployment numbers (or other)		
		2015	2020	2025
High	**Additional actions needed** • Dedicated support programme for mass market deployment in the UK – "no regrets" program involving a well designed subsidy for energy production is suggested • Programmes testing aggregated grid balancing services and allowing incorporation of revenues in offer to customers • Clear gas grid decarbonisation program		1,000's	~300,000
Central	• Fleet trials to allow the deployment of UK developed mini and micro CHP units – to prove market readiness • Extent support to allow >2kW mini CHP • Industrialisation support aimed at allowing scale-up of UK technologies to market • Training for installers and other personnel • Continuation of FIT at current level • Ensure fair treatment of mCHP for new homes • Technology awareness campaign within the key routes to market – new homes, heating installers, utilities (following field trials)	Tens	100's	100,000
Low	**Low scenario would likely occur with:** • Removal of current FIT • Failure of UK technology developers		700	29,000

Fuel Cell mCHP could have a value of up to £100 million for the UK economy by 2025

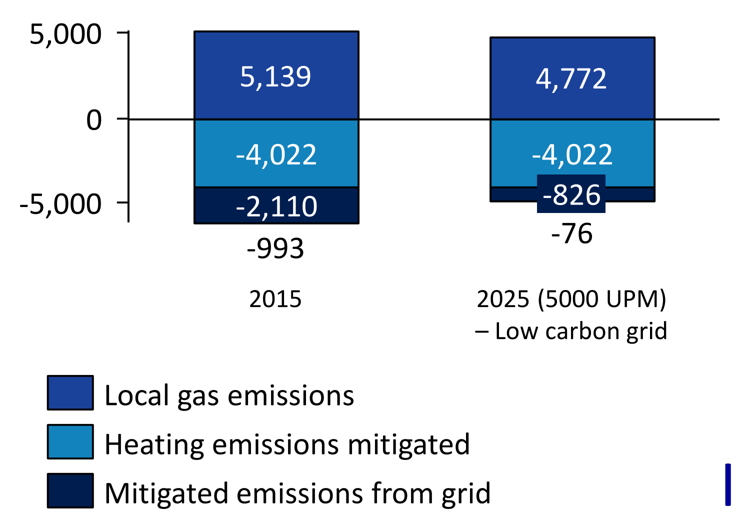
UK Market Size

	Cumulative by 2025	Notes
Global addressable market	Low millions of units	Assumes UK domestic market could account for 4% of global market
Global addressable market value	Up to £9 billion	
UK Share of Tradeable Global Market	Up to 4%	Assuming a medium competitive advantage by 2025
Potential value for UK economy (GVA)	Up to ~ £ 0.15 billion (of which ~ 20% from UK market)	Assuming 50% of sales displace existing economic activity
Potential UK job creation	1000 - 2000	

Greenhouse gas reductions

- Currently, there are significant CO_2 savings possible with CHP units (~1 tonne per year from a 1kWe unit, based on the system analysed on slide thirteen compared to generation with a boiler of 92% efficiency and electricity imported from the grid).
- As the carbon intensity of the electricity grid decreases, this improvement drops. If the grid can be decarbonised to the levels estimated in DECC's *Updated energy and emissions projections: 2015*, the emissions intensity of the electricity grid could drop from 422 g CO_2e/kWh to 165 gCO_2e/kWh, which could substantially reduce the relative emissions savings of a CHP unit (see right). Hence, the longer term case for mCHP relies on a decarbonisation of the gas grid via hydrogen or bio-methane.

Annual CO_2 Savings for a 1kWe FC CHP – kg CO_2 per annum



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