Hydrogen in pipelines - pre-read in advance of workshop

E4tech elementenergy

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

↓

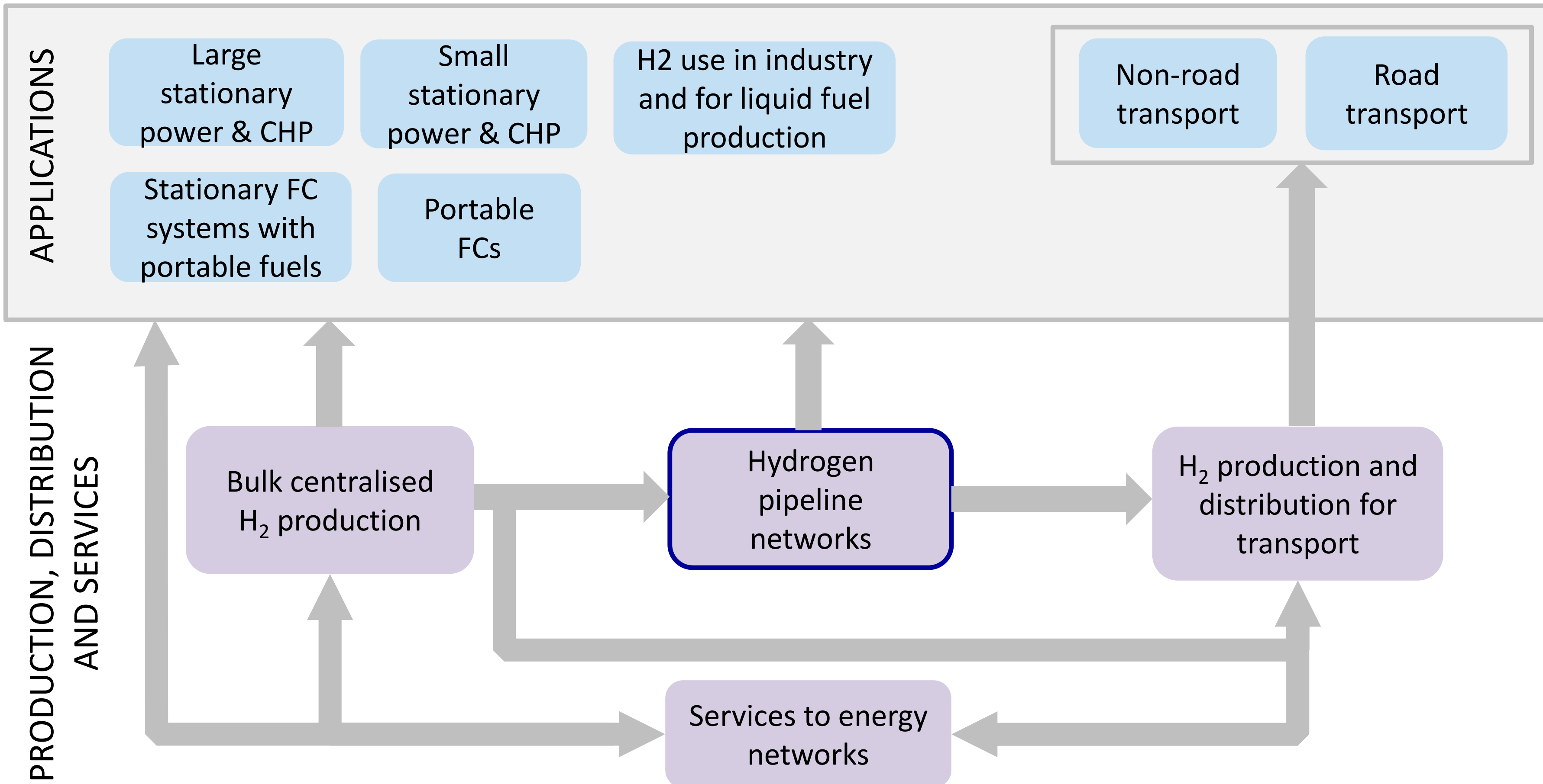
WP 5 – Understanding the overall national case

- 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

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



CROSS-CUTTING ISSUES: Underpinning research, skills, regulations, codes and standards

End-use roadmap

Supply chain roadmap

Today's workshop is to get your feedback on the draft mini-roadmap on hydrogen in industry and liquid fuel production

- 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**:
  - Is the level of ambition appropriate?
  - 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?

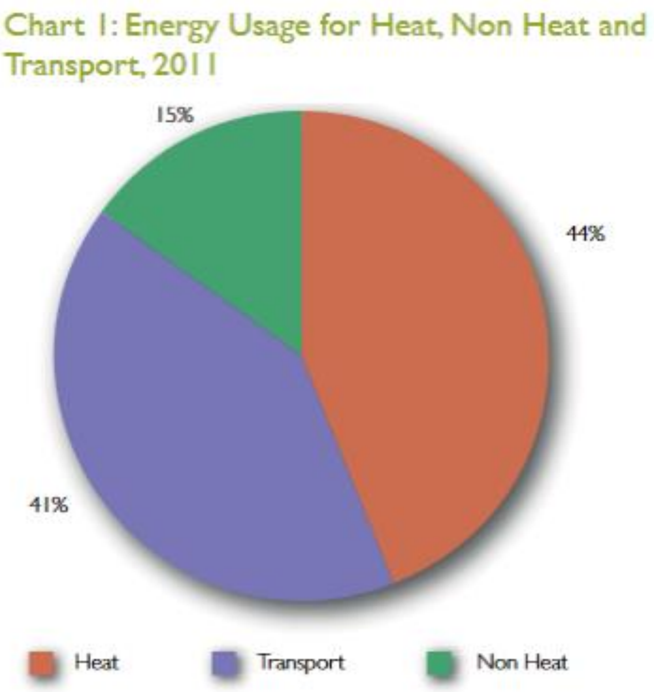
Market structure
e.g. ways to monetise value to grid of CHP could also apply to electrolysis

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

Hydrogen pipeline networks

Supplying hydrogen to buildings, industry and transport via pipelines could have lower costs than other options

- Decarbonising heat is an important part of meeting our climate targets. However, **decarbonising heat in buildings and industry is challenging**, for several reasons:
  - **Energy demand for heat is high, and varies considerably over the year.** These large peaks in demand are currently supplied by the gas network: if energy for heating was supplied via the electricity network then significant network reinforcement and storage would be needed
  - Most **technology options for low carbon heat** are expensive compared with natural gas (heat pumps, district heating, biomass, solar thermal) and require a change in technology and/or behaviour by the user
- There is interest in **converting the gas network to hydrogen, or blending smaller volumes of hydrogen into the gas network,** to provide a low carbon heating option that could be less disruptive for consumers, more familiar to them, and potentially cheaper than alternative low carbon options

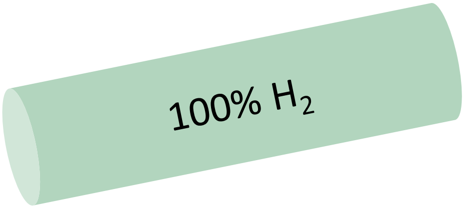


Source: The Future of Heating: Meeting the challenge, DECC, 2013

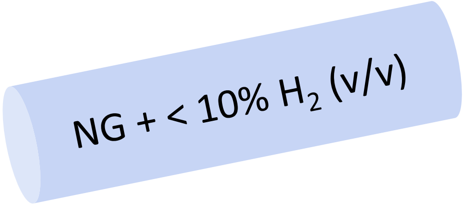
- Converting the gas network to hydrogen could also provide hydrogen for other users, such as the transport sector at lower cost than onsite production, or distribution from centralised production by road. This is discussed in the *Hydrogen production and distribution for road transport* roadmap

Here we are focusing on conversion of the gas grid to 100% hydrogen

- Here we are focusing on **conversion of the gas grid to 100% hydrogen** (H_2), and **use of H_2 in domestic and commercial** burners and boilers.
- Use of H_2 from the gas grid in other applications such as transport, industry and power generation is included in the other mini-roadmaps
- The reasons for this focus are:
  - There is a strong UK interest in decarbonisation of heat. Conversion of the gas grid to H_2 has very large long term GHG benefits
  - H_2 for heating has a large potential long term market in the UK and elsewhere
  - The UK has leading activities in assessing the feasibility of conversion

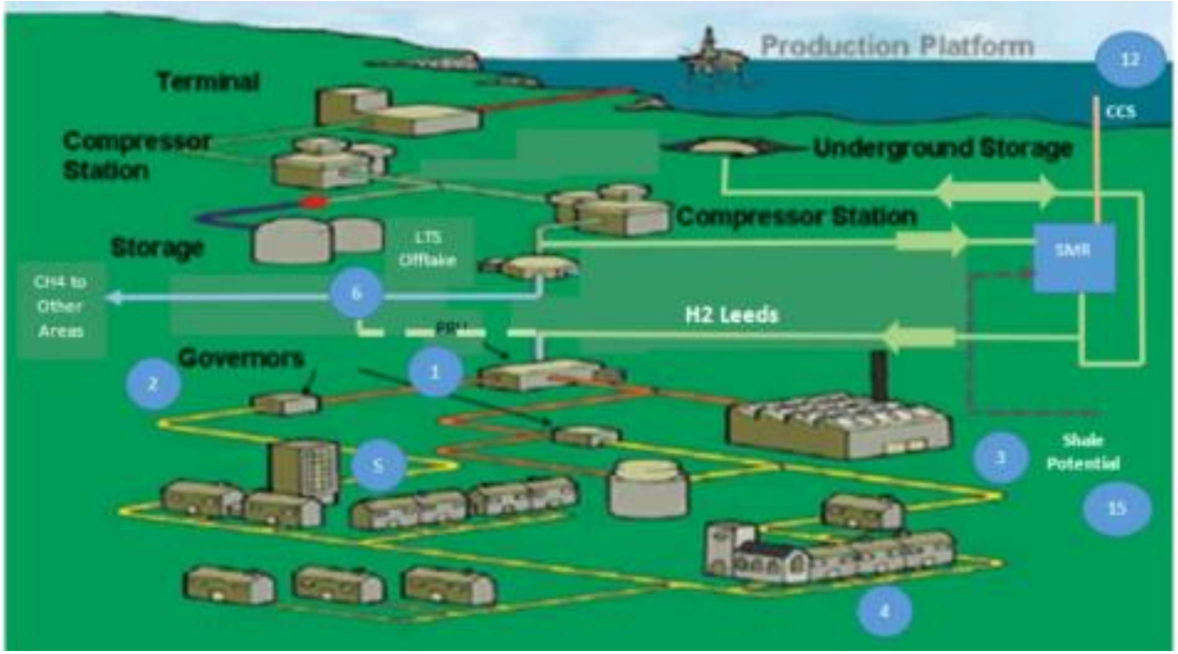


- **Blending H_2 into the gas grid in small percentages** (<10% v/v) is one option for H_2 produced from electrolysers providing services to the electricity network (see *Services to energy networks* roadmap). It is not an area of focus here as the GHG benefits of blending itself are small



The natural gas grid in a town could be converted to 100% hydrogen, supplying domestic, commercial, industrial and transport applications

- The existing natural gas low- and medium-pressure networks would supply 100% hydrogen to any application including domestic, commercial and industrial users and vehicle refuelling stations. These pipes are in the process of being replaced with plastic (PE) piping which can carry hydrogen.
- This would require boilers, appliances and meters in buildings to be converted. The hydrogen could also be used in fuel cell CHP in buildings or for district heating
- The gas transmission network would not be converted, as these steel pipes are not suitable for hydrogen. Hydrogen supply to the low- and medium-pressure networks and connection to storage sites would be via dedicated hydrogen pipelines, existing or new.



Picture: H21 Leeds Citygate, Dan Sadler, NGN
http://www.praseg.org.uk/docs/PRASEG%20EVENT%20NGN%20SLIDES%20dan%20sadler.pdf

FAQs: Hydrogen could carry as much energy as natural gas, and have similar levels of risk

How could hydrogen carry as much energy as natural gas?

- The calorific value of hydrogen (the energy per unit volume) is about a third that of natural gas. However, its density (the mass per unit volume) is about an eighth that of natural gas. This means that hydrogen moves faster through a pipe for the same pressure drop. This means that an existing low pressure or medium pressure gas pipeline could carry about 80% of the energy when carrying hydrogen compared to when carrying natural gas, assuming the same pressure drop.
- However, there are some enhancements to the network that will occur under a natural gas to hydrogen conversions which would remove the majority of the capacity constraint. These include the opportunity to increase the pressure in the low pressure network to meet its maximum operating pressure of 75mbar.

Is it safe to use hydrogen in buildings?

- Whilst more work is required, initial studies such as Hyhouse indicate that hydrogen in building causes a comparable risk to natural gas. Town gas, which was 50% hydrogen was extensively used across the UK for the first 150 years of the gas industry, with a good fire and explosion safety record. Recent tests have shown that if hydrogen leaked inside a building, the concentration of hydrogen in the building would be higher than that for natural gas. However, it is likely that damage from a hydrogen explosion would be comparable to that from a natural gas explosion, as hydrogen has a lower energy content.
- Further testing work is needed on hydrogen’s behaviour in buildings in different situations. Overall, hydrogen can be treated as another in the group of flammable gases, including natural gas & LPG, which are already supplied to buildings, with similar levels of risk.

By 2025, preparation could be completed to allow a small number of towns to convert from natural gas to hydrogen soon afterwards

- Conversion of the low and medium-pressure gas network to hydrogen would be done on a town-by-town basis, with coordinated conversion of the network and appliances.
- The overall process is similar to the successful conversion of the UK gas networks from town gas to natural gas in the 1970s in Great Britain and in the last decade in the Isle of Man. At the peak, 10,000 appliances were converted each day.
- By 2025, preparation could be completed to allow two or three cities to convert from natural gas to hydrogen soon afterwards. Preparatory work on two or three cities would enable different challenges to be identified, and costs compared
- Conversion of these towns and cities would enable:
  - Lower GHG emissions from domestic, commercial and industrial sectors
  - More widespread availability of hydrogen for transport and portable applications, at lower cost than hydrogen transported by other means, enabling faster roll out and so faster GHG and air quality benefits
  - Reduced NOx emissions if catalytic burners are used rather than combustion
- The first conversions should be planned with a wider rollout in mind for the longer term, to enable the optimal system design, but would not imply a locked-in path to conversion of the whole gas grid: it would be possible for natural gas and hydrogen grids to co-exist in different regions, and to co-exist with other low carbon heating options.

The preparation tasks needed include technical and engineering activities, as well as changes to policy and regulation

- The **H21 Leeds Citygate** project is considering what it would take for Leeds to be converted to hydrogen. The forthcoming report on the project will set out the tasks required for this preparation. In addition, a programme of enabling work has been identified alongside this project, with specifications for work packages of 57 projects covering the strategic, technical/engineering, regulatory, governance and consumer tasks needed.
- The first step would be to establish a programme for the conversion, to run and coordinate the engineering tasks required.
- Based on previous reports and interviews, the **technical/engineering tasks** are likely to include:
  - Engineering studies, trials and changes – network conversion, domestic, commercial and industrial use, including
    - gas network modelling to identify where changes to the networks are needed
    - Ensuring that the ongoing **Iron Mains Risk Reduction Programme (IMRRP)** which is replacing most existing iron pipes within 30m of buildings with polyethylene pipes (which can carry hydrogen) for safety reasons proceeds with potential hydrogen conversion in mind
  - A robust plan for conversion of each network
  - Selection, siting and construction of hydrogen production plants, storage and transmission pipelines
  - Availability of appliances that can use 100% hydrogen in domestic and commercial buildings, both new appliances and conversion of existing ones, and feasibility of use in industry
  - Survey of properties to assess conversion needs
- In the **longer term**, conversion of further towns and cities will require work on links between their networks, and expansion of the hydrogen transmission system

This would rely on progress on areas covered by several other roadmaps

- Conversion of the natural gas distribution network to hydrogen would require **progress in several areas covered by other roadmaps**
  - Large scale low carbon hydrogen production
  - Bulk hydrogen storage – to allow for inter-seasonal storage and production plant downtime
  - Readiness of industry in these towns to switch to hydrogen, or identification of alternatives
- Note that progress in **fuel cell** development and deployment would increase the range of uses for hydrogen from the gas network, but is not a prerequisite for gas network conversion, as hydrogen could be used in boilers and burners
- Note also that the ability to **blend smaller percentages of hydrogen in the gas grid** (e.g. <10% by volume) is not a competing option with gas grid conversion: this could be done in regions that had not yet been converted to hydrogen. However, if blending was at high enough levels to require appliance modification, there may be limited value in incurring these costs if a conversion to 100% hydrogen was envisaged in the near future.

Several recent projects have assessed the feasibility of gas network conversion in the UK, in addition to strong UK research

H21 Leeds Citygate (ongoing)

This is a feasibility study for converting Leeds city region from natural gas to hydrogen, led by Northern Gas Networks. Additionally, the project team have produced a roadmap detailing tasks required for conversion, including specifications for 16 work packages comprising 57 projects covering the strategic, technical/engineering, regulatory, governance and consumer aspects of the work. The report is due at the end of Q2 2016.

HyHouse (2015)

This project, conducted by Kiwa Gastec for DECC, investigated the risks likely from the release of H_2 or H_2/natural gas mixtures into a 3-bed house. The project consisted of low rate gas leak simulations, with concentrations of the gases measured throughout the house, plus high rate releases to simulate a leaking vehicle or gas main. Overall, the risks of a significant fire and explosion and so the impact on the health of a householder following a significant leak of either H_2, natural gas or a mixture were found to be similar, with further work needed on release into enclosed spaces such as cupboards.

Delivery of Alternative Heat Solutions to a Typical Town in the UK (ongoing)

DECC-funded study and site work conducted by Ramboll to investigate and compare hydrogen, hybrid heat pumps, electric heat pumps and heat networks to replace the use of natural gas in a UK town. Options will be compared for their installed and operating costs at distribution level along with legal/regulatory and environmental barriers.

Hydrogen scenarios to 2050 (2015)

This project, by E4tech, UCL and Kiwa Gastec for the Committee on Climate Change developed scenarios including gas grid conversion to hydrogen, informed by modelling using the UKTM energy systems model, and Kiwa Gastec's practical experience, considering technology developments, and energy systems implications, as well as policy needs

UK academic research strengths

Research at UCL has assessed the potential for and energy system impacts of conversion of the gas grid to 100% hydrogen, including through modelling using the UK TIMES energy system model (UKTM) and through assessment of the process of conversion from town gas to natural gas

Hydrogen appliances (ongoing)

Kiwa Gastec and E4tech are assessing the potential for development of domestic and commercial hydrogen appliances, and potential barriers to developing a supply chain for these products in the UK

H21 Leeds Citygate http://www.smarternetworks.org/Project.aspx?ProjectID=1630
Hyhouse Final report Kiwa Gastec 2015 http://sse.com/media/383190/HyHouse_FinalReport.pdf
E4tech, UCL and Kiwa Gastec for the CCC: 'Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target' 2015

Gas grid conversion would rely on a strong policy driver for decarbonisation of heating

- There is currently **no strong policy driver for widespread decarbonisation of heating**.
  - Conversion of the gas grid will not occur without policy support, as hydrogen is more expensive than natural gas in operation, and additionally there are costs and disruption of the conversion of the grid and appliances. Similarly, it is unlikely that the alternative low carbon heating options will have significant uptake without a policy driver.
  - Relatively short term, specific policy, such as that aimed at reducing the cost of hydrogen for the heat sector or increasing the cost of alternatives, would be unlikely to drive conversion alone, given the large scale of the change needed and the locked-in nature of the change.

Actions:

- A high level policy on heat decarbonisation is needed , that enables a strategic direction to be set for the UK. The most appropriate solution is likely to vary between local areas (hydrogen, heat pumps, district heating etc.). As a result, policy that requires decarbonisation rather than specific options is needed: the next steps would be identification of the best option for each then planning for roll-out. Local authorities would need to be strongly involved in driving and facilitating the changes, but would need support to identify the best option. The policy would need to align with policy on hydrogen in other sectors, with a coherent vision. The policy would need to be recognised by Ofgem in the next price review (2021 to 2029), otherwise, gas DNOs networks will delay any action until the 2030s.
- Selection of the best low carbon heating options could be supported be tools such as the EnergyPath Networks tool developed for the ETI Smart Systems and Heat programme, designed to help local authorities to plan cost-effective local energy systems. This does not currently include hydrogen.
- Once a decision was made to switch, consistent and robust support from national and local government would be needed to make sure that the confidence of the DNO and public was maintained throughout the process.

E4tech, UCL and Kiwa Gastec for the CCC: 'Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target' 2015
EnergyPath Networks tool http://www.eti.co.uk/project/energypath/

Conversion relies on large supplies of low carbon hydrogen, which relies on a successful CCS project, and a policy framework for CCS

- Conversion of the gas grid to hydrogen results in a hydrogen demand significantly larger than those of other sectors. This means that it will not be feasible unless bulk low carbon hydrogen supply options are available, in particular, SMR with CCS.
- Lack of success with CCS would imply a need to move to other low carbon hydrogen production options, such as large scale electrolysis, or biomass gasification and reforming, which could be have higher costs, and would affect the comparison with other heat decarbonisation options. Some stakeholders have strong doubts that the gas grid would be converted to hydrogen without SMR+CCS, due to the availability of renewable electricity and electricity network infrastructure that would be required.
- Further widespread conversion of cities to hydrogen would mean very large requirements for primary energy, CCS infrastructure and storage capacity, and hydrogen storage capacity, which have not yet been investigated in detail

Actions:

- A review of progress in CCS will be required in around 2020 to determine whether it is feasible to progress with plans for conversion. A clear policy to support CCS and enable the first projects will be needed by this time. This will determine whether SMR with CCS is likely to be a viable pathway for hydrogen in the long term, and whether it will be available in time for the first conversions, or very soon after (it may be acceptable to convert to hydrogen using unabated SMR if there is reasonable certainty that CCS will be included very soon afterwards) .
- In the near term, hydrogen production should be included in a CCS demonstration before 2025, using pre-combustion decarbonisation, to inform this decision (LCICG, 2014). Adding the volumes of CO_2 captured from hydrogen production at a large scale could help to increase the viability of early CCS projects.
- Assess what the implications of roll out to more cities would be in terms of primary energy demand, CCS infrastructure and capacity, and hydrogen storage potential

Support is needed for preparation for conversion: particularly trials of network conversion and end-use

- Currently, innovative activities in this area are supported through several programmes, but these are not appropriate for large scale project roll-out, as they are relatively small and focused on saving money for consumers today
  - The Ofgem Gas Network Innovation Competition (NIC), which allows gas network companies to compete for funding for development and demonstration of new technologies, operating and commercial arrangements.
  - The Gas Network Innovation Allowance (NIA) - a set allowance DNOs receive as part of their price control allowance, suitable for "smaller technical, commercial, or operational projects directly related to the licensees network that have the potential to deliver financial benefits to the licensee and its customers; and/or to fund the preparation of submissions to the Network Innovation Competition". The H21 Leeds Citygate project was funded through this mechanism
  - DECC-funded projects such as those on alternative heating towns, and hydrogen appliances

Actions:

- As explained previously, there are many tasks needed in the enabling programme for conversion. Depending on the level of funding required for these tasks, there will be a need for **increased levels of support or new mechanisms for support** beyond those listed above, starting now and ongoing until 2025. This will need to fund different types of activity (project teams, studies, trials, coordination activities) involving different actors (one or more DNOs, technical services, networks) and taking into account benefits in different areas (gas network improvement, reduced electricity grid impacts, enabling low carbon transport, CO_2 and air quality benefits). Taking early action to assess the benefits of grid conversion and implementation of demonstration projects could greatly reduce long-term costs and increase the likely success of conversions.
- **Continuation of the IMRRP** - Completion of the programme is needed to ensure that gas pipelines are hydrogen-compatible in the first cities, and in other cities to be converted in the future. This is likely to continue in any case, but it is worth noting that it is needed for hydrogen conversions to take place

Dodds, P. E. and Hawkes, A. (Eds.) (2014) *The role of hydrogen and fuel cells in providing affordable, secure low-carbon heat.* H2FC SUPERGEN, London, UK.

Whilst further work is needed on the costs of conversion and H_2 supply, this is not the primary barrier to the first conversions

- The costs of conversion and operation of hydrogen supply via the gas grid are not the primary barrier to the preparation needed to 2025. Whilst feasibility work carried out in this time will identify how costs can be minimised, this is not an area where significant innovation in technologies is needed to bring down costs to enable deployment.
- Conversion costs will include the costs of the required feasibility studies, changes to the network itself, and coordination of the roll-out. Costs are being established as part of the H21 and Hydrogen town projects. Cost of conversion of domestic dwellings have been estimated at £3500 for new appliances and a meter (Kiwa Gastec estimate from E4tech, 2015), with reductions possible through economies of replication in large towns, down to £230-490/house for modification (Dodds and Demoullin, 2013)
- The major market for hydrogen supplied via the gas grid will be heat. Costs of heating using hydrogen will be higher than the natural gas incumbent. This is because the main options for low carbon hydrogen production are SMR+CCS using natural gas as an input, and large scale electrolysis, which is likely to remain higher cost than SMR+CCS, even with cost reductions projected through technology development. Fixed operational costs should be the same as natural gas (e.g. inspections, maintenance).
- However, the costs of all alternative low carbon heating options, including heat pumps and district heating, will be higher than the incumbent. It important to continue to compare the costs and benefits of this option with other low carbon heating alternatives for each region.
- Further information on the costs of conversion to hydrogen is an important output of the H21 Leeds Citygate project and the DECC hydrogen town study, which will also provide comparison with the costs of alternatives
- The way in which these low carbon heating options are financed will affect how much of these costs are passed on to heat consumers and other end users, as discussed on the following slide

Dodds and Demoullin 'Conversion of the UK gas system to transport hydrogen' International Journal of Hydrogen Energy 38 (2013) 7189 -7200
E4tech, UCL and Kiwa Gastec for the CCC: 'Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target' 2015

The way in which conversion and supply are financed will affect costs to the consumer, and requirements for policy support

- If gas DNOs were allowed to finance these changes under Ofgem's framework for price control (RIIO (Revenue=Incentives+ Innovation+Outputs)). In this case, the costs of hydrogen production plants, changes to infrastructure and to appliances could be amortised over 45 years, and also could be distributed across all customers, rather than only those in the areas first converted to hydrogen. This would significantly reduce the impact on consumers. Price control periods are currently 8 years, with the next starting in 2021.
- As roll out to future cities would necessarily be relatively slow, the costs to DNOs would be spread out over the whole transition, which would be at least 15 years. Given that the IMRP will have been completed by this time, and so spending on this have declined, some interviewees estimate that the impact on bills may not be large.

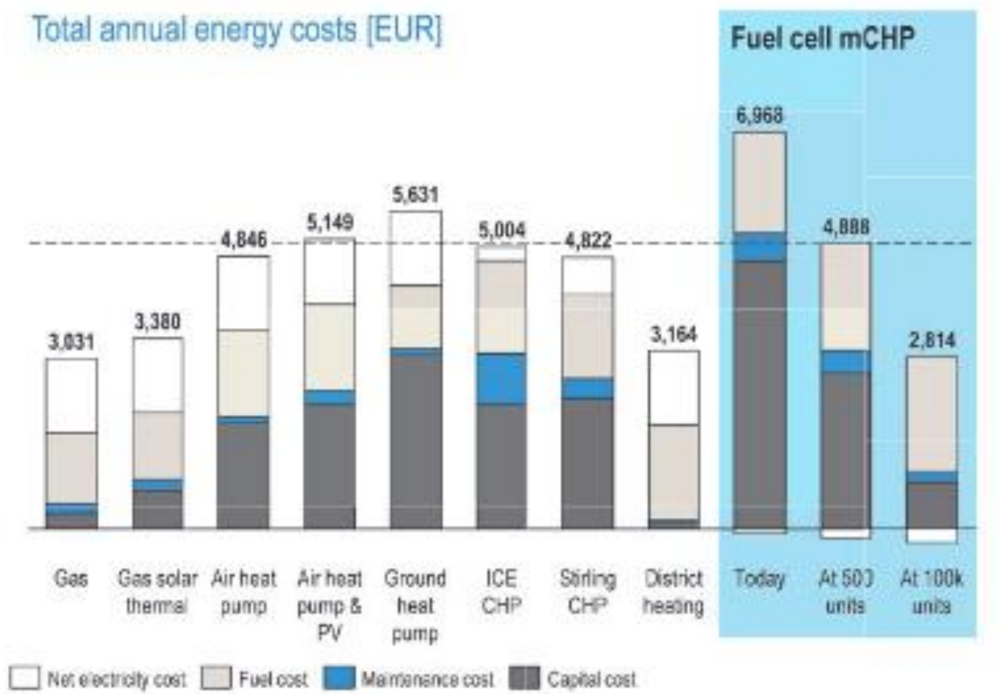
Actions:

- Continued feasibility and cost **assessment of low carbon heating options** including gas grid conversion
- Gas DNO discussion with Ofgem on how cost of initial conversions could fit with **price control** (e.g. whether costs would need to be specified by 2021, or could be agreed later) and how future conversion could be financed. Note that Ofgem are only likely to support network business plans for enabling work and/or conversion if there is a clear policy steer from DECC
- If a cost gap remains, public support to reduce the cost of hydrogen would be justified on the grounds of lower GHG emissions than natural gas. This could be done by **policy support for low-carbon hydrogen production**, for example in a similar manner to support for biogas under the Renewable Heat Incentive. Support could be varied according to the lifecycle GHG emissions of the hydrogen production, as is being discussed in DECC's Green Hydrogen Policy group. Support would need to recognise the value of hydrogen in providing inter-seasonal heat storage capacity as well as the differential costs between natural gas and hydrogen. Note that UKHFCA have previously advocated support for hydrogen production at 7.3 p/kWh, based on biogas feed-in rates under the RHI, but this level may not be required depending on the financing options used, and may not be appropriate for 100% gas grid conversion

E4tech, UCL and Kiwa Gastec for the CCC: 'Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target' 2015
'A FiT across sectors for UK hydrogen & fuel cells', AMEC representing UKHFCA, 2013

Even if hydrogen supplied via the gas grid was more expensive than gas, this could be cheaper than other low carbon alternatives

- The graph below shows the cost of energy provision for a 1/2 family dwelling (FCHJU, 2015). This shows that using gas for heating is the cheapest option, followed by district heating. With increased production volume, fuel cell microCHP has the potential to become competitive with these options
- The relevance here is that even if hydrogen supplied via the gas grid was more expensive than gas, hydrogen used in existing equipment could still be a considerably cheaper option than heat pumps and non FC CHP in the future



Economic benchmarking of a fuel cell mCHP in a renovated German 1/2 family dwelling

Roland Berger for the FCHJU, 2015 Advancing Europe's energy systems: Stationary fuel cells in distributed generation

Conversion will require a tightly managed and coordinated process

- The conversion itself will require a **tightly managed and coordinated process**. Successful transitions will rely on the local gas distribution network operator (DNO) working with the local authority and providers of hydrogen equipment. The DNO would convert the network and provide conversion or supply of appliances, and work with the local authority to plan the switch and provide information to the public. This depends on a consensus decision to make the switch, and a significant degree of coordinated activity
- If conversion to hydrogen is to be an available options for cities and regions in the future, the **success of the first conversions is crucial**: technical or logistical difficulties in conversion, or a poor reaction from the public to the conversion could delay or prevent future conversions.
- Coordination activity could also include facilitating construction of **hydrogen transmission pipelines**: whilst pipelines already exist and are in use today, there are concerns from some stakeholders that wayleaves for new transmission pipelines could take decades, and would be much more difficult than for gas pipelines. Further work is needed to establish what the barriers are in this area, and what actions could overcome these.

Actions

- Coordination between cities and DNOs working on the first conversions could help to support the first transitions. However, **coordination and support from a national body** is needed to ensure and assess the success of early conversions and may be more effective in transferring information and skills for later conversions. This body could also develop a **roadmap for more widespread roll out**, based on assessing the costs from the first conversions, potential for their reduction over time and with experience, and the best way to phase future roll out given local plans, skills availability and development of infrastructure for hydrogen production and transmission, and CCS. If future rollout is not considered at the time of the first conversions, the overall systems design is likely to be sub-optimal

E4tech, UCL and Kiwa Gastec for the CCC: 'Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target' 2015
Dodds, P. E. and Hawkes, A. (Eds.) (2014) *The role of hydrogen and fuel cells in providing affordable, secure low-carbon heat.* H2FC SUPERGEN, London, UK.

Information provision is crucial for consumers and related sectors

- Consumers need to understand the benefits, costs and safety issues associated with hydrogen. This is particularly important as the switch away from natural gas will be compulsory in the areas converted, although consumers could choose to switch to alternative heating sources
- Metering and billing arrangements will also need to be agreed

Actions

- Communicating the safety of domestic hydrogen is needed through co-ordinated efforts by companies and industry bodies, backed up by evidence gained through testing programmes. This could be done in a similar way to the switch to digital television, where a dedicated organisation was set up to manage the switch and provide information to consumers, funded by the television networks.
- If communicated to consumers, blending of smaller amounts of hydrogen in the gas grid could help consumers to become familiar with the idea of gas networks carrying hydrogen
- Use of hydrogen in other applications visible to consumers (e.g. portable applications, vehicles) could help to increase familiarity with hydrogen as a fuel
- Progress updates to other sectors are important – communication to other hydrogen using-sectors of the expected progress of conversion, to aid planning of infrastructure e.g. refuelling stations

E4tech, UCL and Kiwa Gastec for the CCC: 'Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target' 2015
Dodds, P. E. and Hawkes, A. (Eds.) (2014) *The role of hydrogen and fuel cells in providing affordable, secure low-carbon heat.* H2FC SUPERGEN, London, UK.

Hydrogen appliances for domestic and commercial use have been developed, but are not yet widely available…

- Several boiler makers have already produced H_2 boilers at a variety of scales. Some H_2 boilers are already on the market ranging from a few kW to those burning H_2 in industry at several MW. Numbers sold are very small, probably less than 100 (Kiwa Gastec)
- Appliances will be developed and manufactured by both UK and non-UK companies. The UK has several boiler and stove manufacturers, with activities in the UK even if they are part of larger groups. Several boiler maintain R&D facilities in the UK (e.g. Ideal Boilers, Keston and Worcester Bosch). Pure Energy Centre has a catalytic H_2 boiler product, and Almaas Technologies are working on H_2 burners for cooking
- Note that the speed and cost of conversion will be minimised if H_2 boilers can easily replace current natural gas boilers, through using the same backplate, which is manufacturer-specific. This means that multiple developers will need to develop H_2 products
- The main barriers to development of appliances are being identified through a DECC-funded project, through interviews and workshops with manufacturers. Manufacturers considered that roll out of a sufficient number appliances to convert a city by the mid 2020s was a reasonable scenario. Barriers identified so far are:
  - Manufacturers need confidence that conversion will happen as planned to invest in RD&D and training
  - Need to understand market needs (e.g. appliance sizing) to enable design of widely applicable products
  - Concerns over the nature of competition between suppliers for initial contracts
  - Concerns over bottlenecks in the supply of components as all developers within the UK would have to work with the same gas valve, seal, control and burner manufacturers.
  - High demand and competition for R&D capacity and skills
  - High risks of RD&D, requiring financial support. Need to confirm long term performance before mass roll-out
  - Lack of specific IGEM standards for hydrogen appliances – although IGEM are now reviewing this
  - Increased challenge for commercial (as opposed to domestic) appliances as the market is smaller
- To develop and launch a range (i.e. including both development and initial production set-up costs) for a range of hydrogen products from several UK manufacturers is likely to be in the range £10m to £50m over 5 years

E4tech, UCL and Kiwa Gastec for the CCC: 'Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target' 2015
Kiwa Gastec and E4tech for DECC Hydrogen appliances project workshop reports and draft report

… as a result, several actions are needed to enable a wide range of appliances to be available by 2025

Actions:

- A strong policy framework and planning (see other slides) is needed to give manufacturers confidence that the market will exist, so that they start to develop, test and certify appliances. The DECC hydrogen appliances project draft report estimates that incorporating a product line of 100,000 units could take up to 5 years with the first 1,000 units ready within 2-3 years from project start
- Coordination activity to give information to the appliance industry to communicate market needs:
  - Assessment of opportunities for appliances now that could **facilitate the transition** e.g. changes to gas appliances now to make them easier to switch to using hydrogen later, use of gas heat pumps.
  - Potential for additional support for **low NOx appliances** such as catalytic hydrogen boilers, that are currently pre-commercial, for example specifications for NOx levels in appliances, or support for lower NOx appliances
  - Although there has been demonstration of domestic appliances using hydrogen, and a suitable regulatory framework exists, **guidance and installation-specific documentation** for their use in the UK is needed
- A **hydrogen appliance testing hub** could give manufacturers access to hydrogen and a certification body
- Manufacturers consider that **support for RD&D** will be needed once policy is in place to bring down unit costs
- Previous reports have indicated a current lack of knowledge about the existing gas appliance stock, with estimates that thoroughly mapping UK appliances would require a large workforce. An alternative approach would be **ongoing data collection on appliances** now, through registration of new installations by gas appliance installers, and collection of data from existing appliances on servicing. This would involve potentially commercial sensitivities between manufacturers and personal privacy issues, and some stakeholders believe that the data would be of poor quality and difficult to manage, given the complexity of model types of gas appliance. Nevertheless, recent experience of house by house gas appliance testing by SGN in Oban, Scotland related to a change in natural gas composition saw only a very few objections by householders, which could mean that these barriers are not large in practice.

Dodds, P. E. and Hawkes, A. (Eds.) (2014) *The role of hydrogen and fuel cells in providing affordable, secure low-carbon heat.* H2FC SUPERGEN, London, UK.

In standards and safety, further work is needed on standards development and trials

Actions:

- There are no specific standards for hydrogen distribution, which would be required to ensure that appropriate, safe and consistent practices were followed across the first and subsequent conversions, and clarify liabilities or responsibilities of the various parties. The Institute of Gas Engineers and Managers (IGEM) should be encouraged to sponsor appropriate research and then write the necessary standards.
- Standards for hydrogen handling and use in buildings are already under development, but are lacking in some areas. Further work testing real systems is needed to underpin the further development and evolution of these standards and the relationship between them.
- Hydrogen will need to be odorised to help detection of leaks. Some odorants poison fuel cells and so would need to be removed for some uses. A non sulphur based odorant compatible with fuel cells has been developed in Japan, but public perception and recognition of the smell are important issues
- An existing or new body should be appointed to ensure standards are put in place at the right time. A new body – or a larger mandate for an existing one such as IGEM – to consider hydrogen energy standards holistically and ensure appropriate implementation or revision of existing industrial and other regulations could help to streamline and rationalise the process and the standards themselves. This could also be done by the coordination body discussed earlier
- Note that standards already exist to cover dedicated hydrogen pipelines.
- International cooperation - work is ongoing internationally, such as the European HySafe project (IEA, 2015), and these programmes can be built upon locally. Wider international collaboration will also be important, for example with North America and Asia, as components and complete technologies are international, and because of the important learning and skills transfers possible.

E4tech, UCL and Kiwa Gastec for the CCC: 'Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target' 2015
Dodds, P. E. and Hawkes, A. (Eds.) (2014) *The role of hydrogen and fuel cells in providing affordable, secure low-carbon heat.* H2FC SUPERGEN, London, UK.

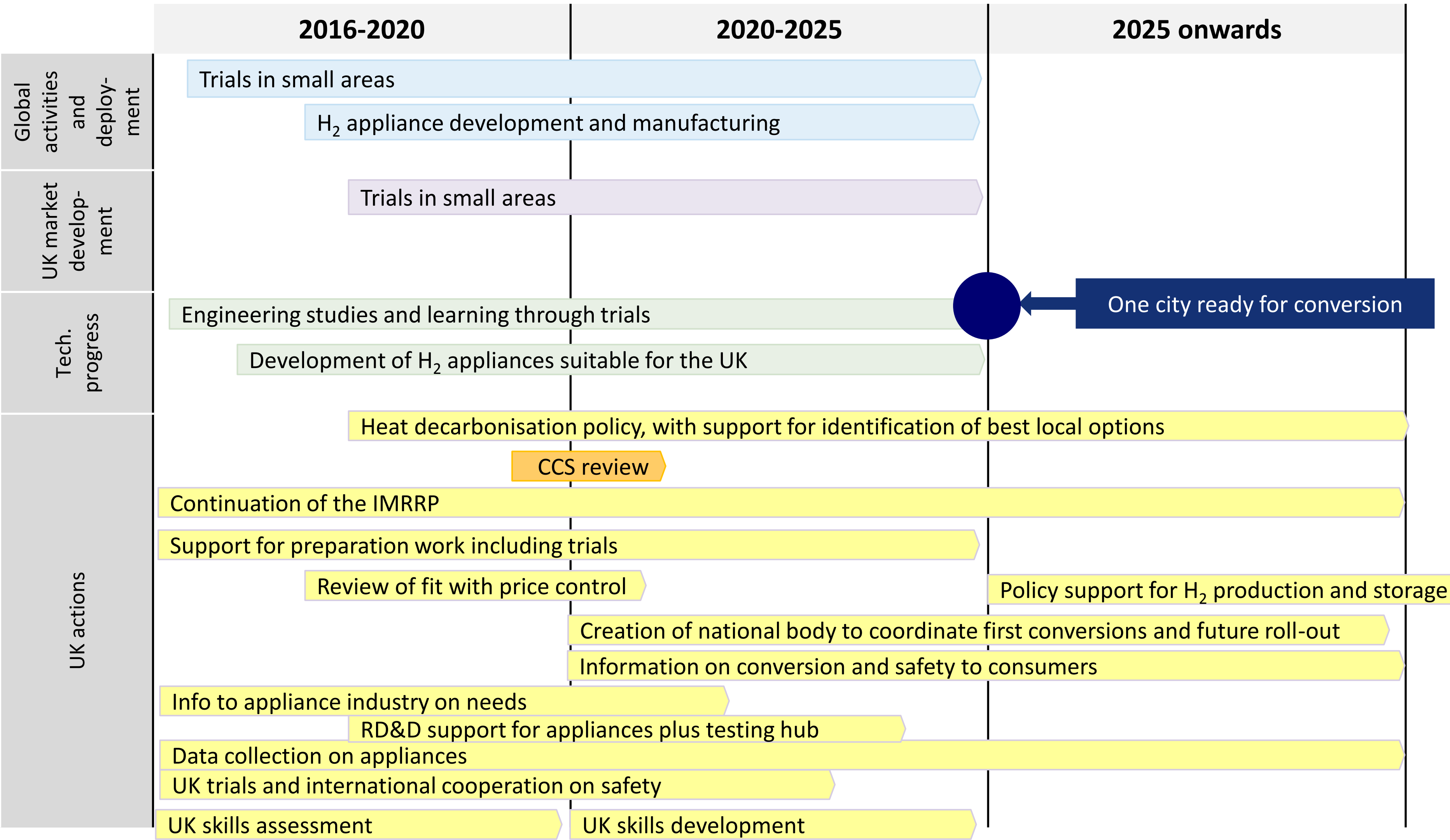
Skills development is needed in all areas to produce new appliances and enable conversion

- Although supply and use of hydrogen has similar levels of risk to other flammable gases, such as natural gas and LPG, its characteristics are different, requiring training for engineers, gas-safe workers and safety personnel.
- Roll-out of hydrogen to whole towns and cities will require trained and registered hydrogen-safe workers, converting both gas mains and building appliances. Emergency responders must also be suitably equipped to deal with the different hazards associated with hydrogen technologies.
- There is a need for gas engineering skills in end-use appliances and gas distribution network management. The H2FC Supergen white paper reported that there is only one MSc dedicated to gas engineering in the UK and the number of domestic students was reported to be small, with gas industry stakeholders interviewed noted a potential shortfall in gas engineers may be emerging.

Actions:

- Skills assessment needed to meet the rollout programme set out, managed by a coordinating body or an existing body such as IGEM, plus additional training and education courses needed to meet any gaps.

Roadmap: actions summary



Progress by 2025 depends on the amount of work that can be done on feasibility, and affects deployment after 2025

Low scenario
A successful trial of a small hydrogen network in a new housing development, potentially near to a industrial hydrogen user to share hydrogen production facilities, or in an area previously off the gas grid.
Could be done even if CCS progress is slow or unclear

Central scenario
Preparation work completed for conversion of one town to hydrogen, supported by trials as in the Low scenario

High scenario
Preparation work completed for conversion of 2-3 towns to hydrogen, supported by trials as in the Low and Medium scenarios

Discussion: what actions are needed to drive each level of activity?

Scenario	Actions	Activity in 2025
High	**Additional actions compared with Central Scenario** • More robust heat decarbonisation policy • Greater level of support for preparation work including trials	Preparation work completed for conversion of 2-3 towns to hydrogen, supported by trials as in the Low and Medium scenarios
Central	• Heat decarbonisation policy • Support for preparation work including trials • CCS review • IRRMP continuation • Review of fit with price control • Policy support for H_2 production and storage • National coordination body • Info to appliance industry on needs • RD&D support on appliances plus testing hub • Data collection on appliances • Skills assessment and development	Preparation work completed for conversion of one town to hydrogen, supported by trials as in the Low scenario
Low	**Actions still needed** • Support for preparation work including trials (lower level)	Trial in small area

Actions needed in any deployment scenario

- Information for consumers
- Safety trials

E4tech elementenergy

Converting a city would bring significant GHG benefits, and build UK capability that could be exploited worldwide

- The H21 Project and Alternative heating solutions for a town projects will quantify the benefits of conversion of towns and cities to hydrogen.
- As a **rough initial estimate**, the GHG savings from converting Leeds to hydrogen would be around 1.8MtCO_2/year from displacing natural gas in domestic heating and a further 0.4 MtCO2/year from displacing natural gas in low temperature industrial and commercial applications
- **Additional environmental benefits include:**
  - GHG and air quality benefits from increased use of hydrogen in transport and portable applications
  - Indoor NOx reduction from catalytic boilers and burners compared with those based on combustion
- There would also be significant potential for **job creation and opportunities for UK companies globally**
  - A large workforce would be needed to convert and replace appliances, and well as the teams needed to plan conversions, and would provide a boost to the economy of Yorkshire and the North East, where first conversions are mostly likely.
  - This activity would make the UK world leading in gas grid conversion to hydrogen, which would create the opportunity for UK companies to sell consultancy and engineering services to other countries. Although there is no strong interest elsewhere now, potential countries would be those with high heating demands and plastic pipes, such as Canada, Germany and Denmark

GHG estimate: E4tech estimate based on DECC Total sub-national final energy consumption, 2013 and DECC 2014 data: Industrial final energy consumption by end use https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/energy-consumption-in-the-uk.

Assumes hydrogen produced by SMR with CCS. Unabated SMR from natural gas (299-349g/$kWh_{H2\ HHV}$) in LBST & Hinicio for FCHJU: Study on Hydrogen from Renewable Resources in the EU (2015) with an added 10% efficiency penalty for CCS and 90% CO_2 capture rate

Links to other roadmaps

Dependencies

- Hydrogen production – in particular SMR with CCS
- Energy system services – inter-seasonal hydrogen storage would be required. As an example, in order to meet peak heat demands, modelling using UKTM model for the CCC assumed that the SMR design capacity was 30% higher than the average annual output, and that salt cavern storage with a capacity of 25 days of average annual hydrogen consumption was required in each converted gas network
- Industry – ability to use hydrogen in low and high temperature applications
- Fuel cell development, particularly domestic and commercial scale CHP could bring benefits here, but is not crucial for hydrogen conversion

Beneficial effects

- Transport deployment – less need for decentralised production, and so lower cost of hydrogen provision
- Portable deployment
- Very widespread skills development in handling hydrogen
- Widespread decarbonisation of heat by 2050 would mean that emissions reductions in other sectors could be lower, whilst still meeting the UK's GHG target. This would affect the technologies used in those sectors, and the speed at which they would need to be rolled out. This means that there would be less need for more expensive atmospheric CO_2 sequestration through biomass with CCS. Widespread adoption of hydrogen would also mean little electrification of heat and transport