



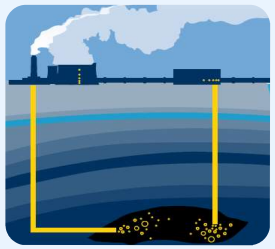



Development of trajectories for residential heat decarbonisation to inform the Sixth Carbon Budget

A study for the

Committee on Climate Change

Executive Summary

December 2020

elementenergy

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- Richard Bayliss, *Construction Industry Training Board*
- Andrew Culling, *Department for Business, Energy and Industrial Strategy*
- Richard Halsey, *Energy Systems Catapult*
- Ashley Malster, *Ofgem*
- Chris Nicholls, *Department for Business, Energy and Industrial Strategy*

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Introduction

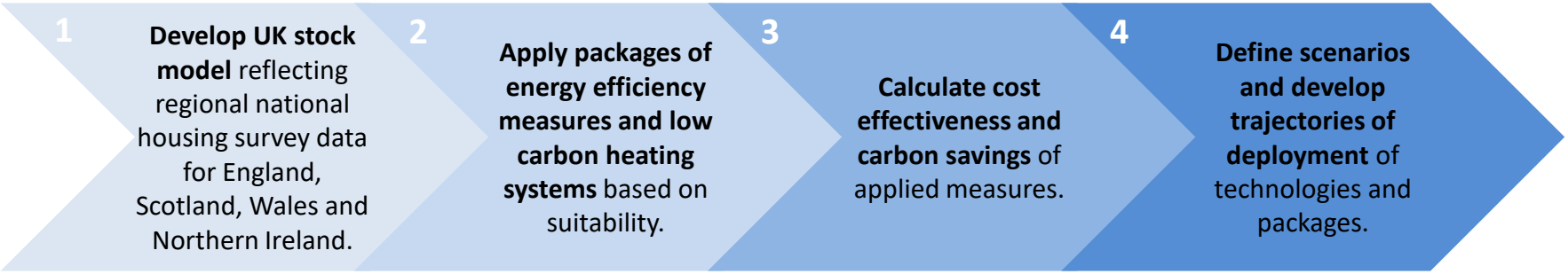
The Committee on Climate Change (CCC) have commissioned Element Energy to carry out research on evidence-based pathways and trajectories to achieve full decarbonisation of heat in buildings, to 2050. The resulting analysis will be used to inform the CCC's advice to Government on UK climate action, particularly relating to the 6th Carbon Budget (6CB) period between the years of 2033 and 2037.

Specific aims of the project were to:

1. Assess the most cost-effective and appropriate decarbonisation options for the entire UK housing stock.
2. Provide yearly profiles of measure deployment and costs for all homes to feed into the CCC's modelling to advise on the level of the Sixth Carbon Budget (6CB).

The focus of this analysis is on emissions from **space heating and hot water** demand in **existing buildings** across the UK stock. The CCC undertook separate analysis on heat in new homes, and emissions associated with cooking, lighting and appliance use.

Overview of approach



Overview of approach

- The ultimate aim of the research is to investigate viable pathways to reaching zero emissions from existing buildings in the UK in 2050, with a particular focus on the 6CB period (2033-37).
  - Decarbonisation is achieved via combinations of behaviour change, energy efficiency, and low carbon heating systems; measures are chosen to minimise costs and disruption for households and businesses.
- Starting with several 2050 mixes with varying balances of efficiency and fuel switching (with measure suitability considered), several futures are explored:

Exploratory Scenarios

Widespread Innovation: High innovation occurs in several carbon mitigation technologies and measures. Costs fall faster than central projections. This allows more widespread electrification, a more resource and energy efficient economy, and more cost-effective technologies to mitigate CO_2 emissions.

Widespread Engagement: People and businesses are willing to make more changes to their behaviour. This reduces the demand for the most high-carbon activities and increases the uptake of some climate mitigation measures.

Headwinds: People change their behaviour and new technologies develop, but there are no widespread behavioural shifts or innovations that significantly reduce the cost of low-carbon technologies ahead of current projections. This scenario is more reliant on the use of large hydrogen and Carbon Capture and Storage (CCS) infrastructure to achieve net zero.

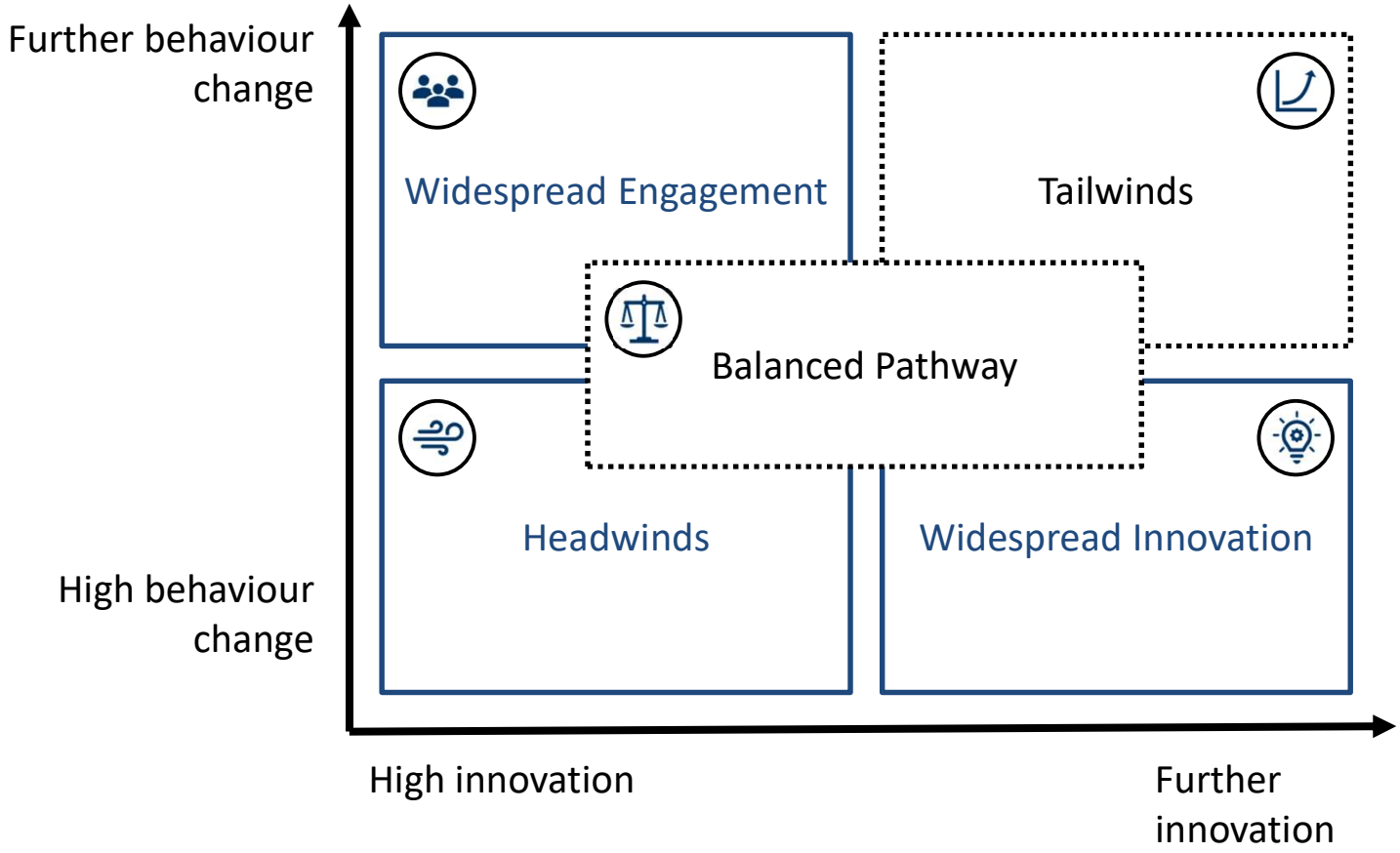
Central Scenarios

Balanced Net Zero Pathway: This scenario, also known as the Balanced Pathway, has a deployment trajectory which makes strong progress towards Net Zero and keeps open alternative states of the world. Reflects a 'fuel poverty first' approach for buildings.

Tailwinds: People pursue significant behaviour change; innovation and heavy infrastructure also succeed on all fronts. This scenario goes beyond the 6th Carbon Budget Pathway to achieve Net Zero before 2050.

Overview of approach – relative representations of scenarios

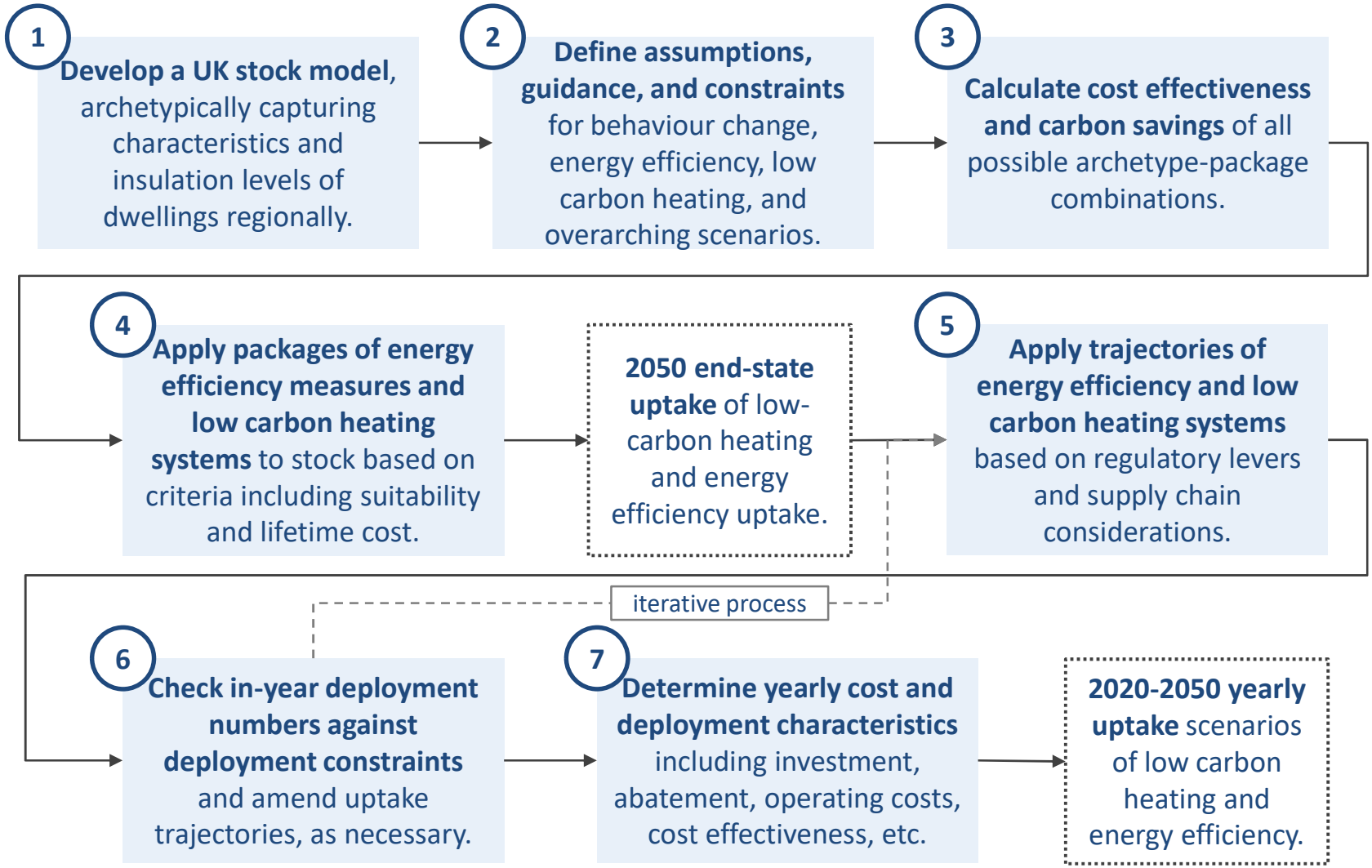
- The Balanced Pathway aims to keep options open through the 2020s.
- The Tailwinds scenario pursues behaviour change AND innovation AND heavy infrastructure and succeeds on all fronts.



Overview of approach – summary of scenario definitions and drivers

Innovation area	Balanced Pathway	Tailwinds	Widespread Engagement	Headwinds	Widespread Innovation
Behaviour change	Moderate, with some pre-heating and feedback from smart meters.	High, with pre-heating, feedback from smart meters, multi-zone control, and heat as a service model.	High, with pre-heating, feedback from smart meters, and multi-zone control.	Moderate, with some pre-heating and feedback from smart meters.	High, with pre-heating, feedback from smart meters, multi-zone control, and heat as a service model.
Energy efficiency uptake	Moderate, with a focus on fuel poor homes.	Full economic potential.	Moderate-high, with a focus on fuel poor homes.	Lower uptake, with a focus on fuel poor homes.	Lower uptake using lower-end costs and deep retrofit packages, with a focus on fuel poor homes.
Low carbon heating uptake	Hybrid scenario, widely electrified with uptake of H_2 hybrid heat pumps. Heat networks electrified. Limited use of biofuels.	Hybrid scenario, widely electrified with hydrogen pockets around industrial clusters, and more ambitious lifetimes and cost reductions. Heat networks electrified. No biofuels.	Fully electrified (including heat networks). No biofuels.	High hydrogen uptake, with H_2 boilers in the north and H_2 hybrid heat pumps in the south. Heat networks use hydrogen peaking. Limited use of biofuels.	Hybrid scenario, including uptake of high temperature heat pumps and widespread use of flexible technology. More ambitious lifetimes and cost reductions. Heat networks electrified. No biofuels.

Overview of approach – modelling framework to generate scenarios



Summary of advancements relative to Net Zero work

- This work included several major advancements relative to the Net Zero work, including:
  - Trajectory modelling capability, which allowed detailed modelling of uptake trajectories for both energy efficiency measures and low carbon technologies.
  - Extensive updates to assumptions:
    - Heating demand baseline accounts for a warming climate and is more closely calibrated to real life consumption based on data from the National Energy Efficiency Data-Framework (NEED).
    - Fuel costs and emissions updated, with a refined representation of the effect of flexibility on electricity costs (five different electricity costs modelled, reflecting different profiles of use).
    - Incorporated latest evidence on energy efficiency: technical potential, cost data, including on hard to treat, and savings data from NEED.
    - Low carbon heat costs updated
    - Low carbon heat technology sizing updated (via updated load factors) based on latest evidence.
    - Yearly deployment constraints for heating technologies and energy efficiency measures accounted for in trajectory modelling.
    - Hydrogen trajectory aligned against trajectories developed in industry.
  - Wider range of technologies and technology variations modelled, including improved representation of Ground Source Heat Pumps and Solar Thermal.
  - High-level examination of relevant accompanying adaptation costs.
- As with the Net Zero analysis, hard to decarbonise attributes such as heritage value and space constraints were represented in the modelling. In some cases, representation was on a simplified basis relative to previous work (which focused specifically on hard to decarbonise homes), to accommodate greater levels of complexity elsewhere.

Overview of approach – behaviour change

- Behavioural measures are applied first in the modelling to reduce a household's energy demand (prior to energy efficiency or low carbon heating).
- Unless otherwise stated (e.g. pre-heating), behavioural measures applied in a scenario are applicable to the whole domestic stock.
- The process by which the behavioural measures, in the table below, were selected and applied is shown in the high-level process flow to the right.

1. **Conduct literature review of known behavioural measures** to develop a list of potential measures.
2. **Add additional novel behavioural measures** to the list, and check feasibility with relevant expert stakeholders.
3. **Select and model a few applicable measures** that are feasible for wide-scale uptake.
4. **Apply selected measures to scenarios** that align with the scenario narrative.

Innovation area	Balanced Pathway	Tailwinds	Widespread Engagement	Headwinds	Widespread Innovation
Pre-heating	25% of post-1952 homes.	50% of post-1952 homes	50% of post-1952 homes	25% of post 1952 homes.	50% of post-1952 homes
Heat as a service	No	Yes [a]	No	No	Yes [a]
Smart metering & control	Standard smart meter [b]	Smart meter with zonal control [c]	Smart meter with zonal control [c]	Standard smart meter [b]	Smart meter with zonal control [c]
Reduced water temperature	No	No	Yes, 50 degrees [d]	No	No
Low flow shower head	Yes				

[a] Heat as a service modelled using: 7.5% cost of capital, 5% increase in heat demand, 3% financial savings, 15% increase in heat pump efficiency.
[b] Heat demand reduction based on actions including turning thermostat down and changing operating times.
[c] Heat demand reduction based on implementation of automated multizone control and actions including turning thermostat down and changing operating times.
[d] 50 degrees only applicable in dwellings which uptake a HP; allowance for daily legionella cycle of 1hr duration included.

Overview of approach – energy efficiency

1. **Determine the cost (£) and demand savings (%/kWh)** per measure for different property types and sizes based on relevant studies
2. **Apply a savings uplift factor for partial closure of a measure's performance gap** based on a measure type's in-use factor
3. **Create three energy efficiency packages,** putting measures into low, medium, and high packages based on their cost effectiveness and levels of disruption
4. **Determine the annualised cost (£) and savings (£)** of each package for each archetype including capex and fuel savings.

2050 end-state energy efficiency packages based on suitability and lifetime cost

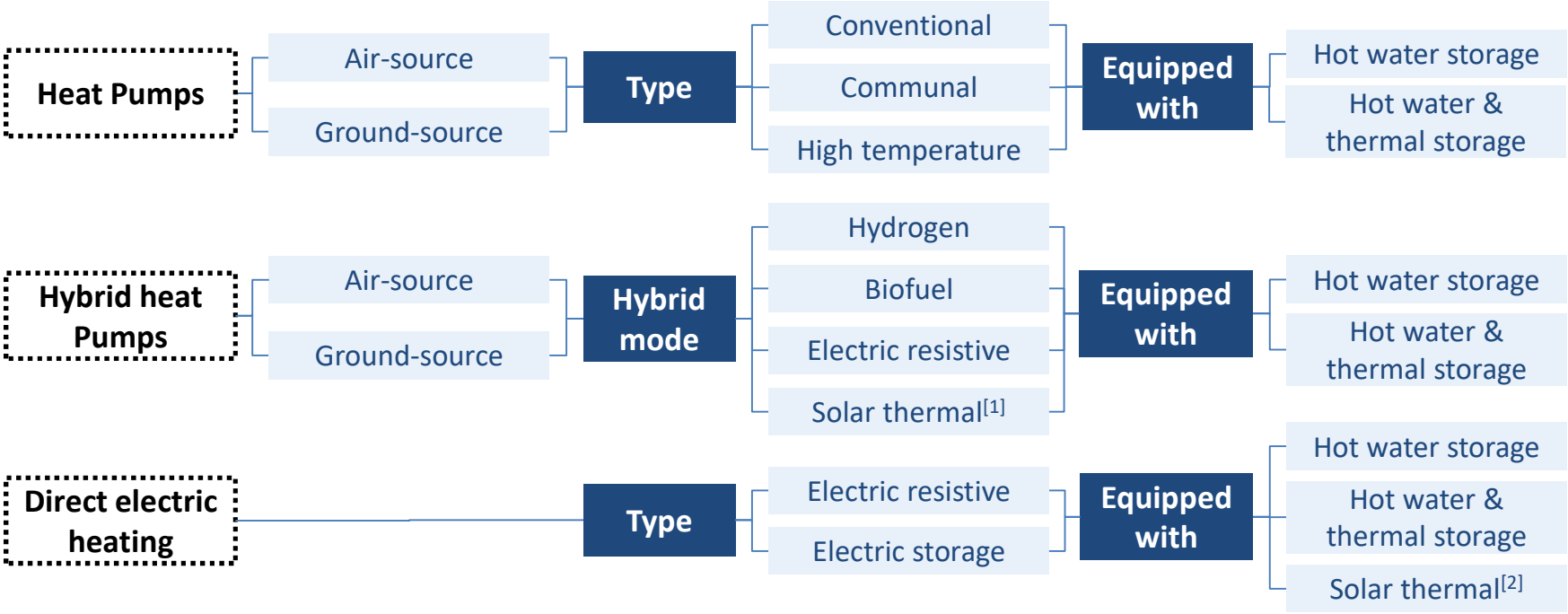
- Three main energy efficiency packages were modelled, each made up of different sets of building fabric and behavioural measures.
  - **Low:** Contains only the least cost, least disruptive measures.
  - **Medium:** Contains more measures than the low package, providing higher savings.
  - **High:** Contains all measures falling under economic potential, to achieve the higher energy demand savings at a higher cost.
- An additional, more extensive, 'deep retrofit' package was modelled particularly for the Widespread Innovation scenario. It is modelled as a whole-house, integrated retrofit approach which delivers an increased level of heat demand savings at higher cost.

Measure	Cost Effectiveness (£/tCO2)	Low	Medium	High
Loft insulation, easy to treat (0-99 mm ETT)	-109	✔	✔	✔
Easy to treat cavity wall insulation (ETT CWI)	-82	✔	✔	✔
Loft insulation, hard to treat (0-99 mm HTT)	-39	✔	✔	✔
Hot water tank insulation	-34	✔	✔	✔
Loft insulation, easy to treat (100-199 mm ETT)	154	✔	✔	✔
Draught proofing (draught stripping)	176	✔	✔	✔
Suspended timber floor insulation	292		✔	✔
Hard to treat cavities wall insulation (HTT CWI)	293		✔	✔
Loft insulation, hard to treat (100-199 mm HTT)	473		✔	✔
Thin internal (solid) wall insulation	556		[1]	[1]
Internal (solid) wall insulation	661		✔	✔
Solid floor insulation	691			✔
External (solid) wall insulation	1039			✔
Double glazing (from single glazed)	2285			[2]
Double glazing (from double glazed pre 2002)	5935			
Triple glazing (from double glazed pre 2002)	4500			

[1] Thin internal (solid) wall insulation replaces standard internal (solid) wall insulation in the Widespread Innovation scenario.
[2] Glazing is present as part of the deep retrofit, which replaces the standard high package, in the Widespread Innovation scenario.

Overview of approach – low carbon heating

- 3 groups of low carbon heating technologies were modelled, with numerous configurations:



- **Hydrogen boilers** and **low carbon heat networks** were also modelled.
- Solar thermal was modelled in two different configurations, providing either (i) a portion of hot water demand, or (ii) a portion of hot water and space heating demand.
- Certain configurations were also split further, depending on the type of electricity used (e.g. flexibility of electricity demand of the technology configuration).

In total, **53** technology configurations were modelled. The list of suitable technologies and assumptions (e.g. costs, lifetimes), were varied between scenarios.

[1] Only air source heat pumps were modelled in the solar thermal hybrid configuration
[2] Includes configurations with added hot water storage and thermal storage

Overview of approach – trajectory development

- Deployment trajectories were developed based on an energy efficiency first approach, with the aim of readying the stock for uptake of low carbon heating technologies ahead of fossil fuel phase-out.
- The building stock was broken down by gas grid connection status (on- or off-grid), fuel poverty (fuel poor or not fuel poor) and tenure (local authority, private rented and owner occupied).[1]
- Each stock segment was then assigned a deployment trajectory representing a regulatory approach (on a UK-wide basis), based on levers for delivery which were deemed realistic:
  - A backstop approach (100% deployment by the backstop date) was used for energy efficiency deployment in the fuel poor, local authority, and private rented segments as those were considered easier to regulate (and in some cases already have government targets for energy efficiency).
  - For energy efficiency deployment in owner occupied homes, which were considered more difficult to regulate, an approach based on incentives for lenders and regulations at Point of Sale (PoS) was used.
  - For most low carbon heating technology deployment, an approach based on setting phase-out dates for fossil heating technologies was used, with the phase out date for off-grid homes set earlier than that for on-grid homes. This approach aims to work with replacement cycles and minimize scrappage costs.
  - For the deployment of hydrogen technologies and low carbon heat networks, trajectories were developed based on geographical conversion profiles e.g. hydrogen technologies being deployed in homes as they gain access to a converted gas grid.
- The regulatory approach used to develop deployment trajectories for this study is meant to be representative of a range of ambition that could be delivered in different ways.
- In total, an average of **28** [2] distinct trajectories were developed per scenario.

Early years (2020 – 2025): Trajectories primarily based on specific measure deployment constraints, developed via input from external stakeholders.

→

Later years: Trajectories modelled to reflect various policies, and to reflect four approaches.

- **Backstop dates**
- **Incentives and PoS regulations**
- **Phase-out dates**
- **Geographical conversion**

[1] Building stock was broken down further but only the 3 categories mentioned were used to define trajectories
[2] The exact number of curves per scenario varies based on the scenario definition

Overview of approach – key dates for trajectories

	Stock segment	Headwinds	Widespread Innovation	Widespread Engagement	Balanced Pathway	Tailwinds
Backstop date by which sufficient[1] energy efficiency required across all eligible homes	*Private rented sector:*	2030	2028	2027	2028	2027
	Social homes:	2030	2028	2027	2028	2027
	Fuel poor homes:	2030	2030	2030	2030	2030
Period over which incentives for lenders assumed to drive retrofits	*Owner occupiers (mortgagors):*	2025 - 2035	2025 - 2035	2025 - 2030	2025 - 2033	2025 - 2030
Date by which regulations at trigger points are implemented	*Owner occupiers (outright owners):*	2030	2030	2025	2028	2025
Date by which all new heating systems must be low carbon	*Off gas grid:*	2028	2028	2026	2028	2026
	On gas grid:	2035[2]	2035	2030	2033	2030
% of all homes assumed energy efficient by on gas grid regulation date[3]		90%	89%	76%	77%	76%

[1] 'Sufficient' defined as the level of energy efficiency uptake in the scenario i.e. 100% uptake is achieved by the backstop date. [2] Full region-by-region conversion from 2030. [3] Will remain a function both of deployment pace and level of energy efficiency in scenarios.

Key features of the Balanced Pathway scenario [1/2]

- The Balanced Pathway scenario is the basis for the CCC's 6th Carbon Budget recommendation.
- It presents a scenario which, up to the 6CB period, makes strong progress towards Net Zero while keeping open alternative pathways to that goal, and reflects a 'fuel poverty first' approach for buildings.
- The key features of the Balanced Pathway scenario are as follows:
  - Early deployment of energy efficiency, with the aims of:
    - gaining the fuel bill reduction benefits and wider benefits of low regrets measures, and
    - ensuring that sufficient energy efficiency is deployed to make the building stock suitable for low carbon heating over the timescales required.
  - Hyready boilers mandated from the mid-2020s (modelled as 2026), minimising potential scrappage costs in the case of widespread hydrogen rollout[1].
  - Strong growth in deployment of heat pumps during the 2020s:
    - to send a clear signal to the market and incentivise supply chains to mobilise and deliver at scale.
    - to keep options open and ensure that the scenario remains compatible with full electrification up to the mid-2030s. With the aim of full electrification and the assumed fossil fuel phase out dates (see previous slide), supply chains must progress in the 2030s such that they are able to supply between 1 and 2 million heat pumps a year by 2035.
    - to deliver additional benefits, including driving down near-term emissions, increasing consumer familiarity and driving down costs through learning by doing.
  - Hydrogen trials through the 2020s to enable decisions on the future of the gas grid in the mid 2020s.

[1] 2026 was chosen as a modelling assumption. Further work by the CCC has brought the policy recommendation in this area forward to 2025.

Key features of the Balanced Pathway scenario [2/2]

- The scenario is intended to remain flexible with regards to the level of deployment of certain technologies and the precise technology mix in 2050:
  - There is optionality to deploy low carbon heating, including HPs, faster than shown in the Balanced Pathway scenario without leading to unfeasible demands on the supply chain, so that if the deployment of certain key technologies such as solid wall insulation or other measures falls short, those technologies can make up the 'gap' to achieve the 6CB.
  - The extent and timing of hydrogen conversion is uncertain and further evidence is needed before a decision can be made on the role for hydrogen – the level of deployment in the Balanced Pathway scenario is only one possible approach to meeting the 6CB and the actual level of deployment could be higher or lower to achieve a similar outcome in carbon emissions terms.
  - The mix of heat pump types (ASHP vs. GSHP, full electric vs. hybrid, individual vs. communal), is intended to be illustrative, and the actual mix could vary materially without substantially impacting the level of the 6CB or the date of achieving Net Zero. It has only been possible to consider a subset of relevant factors in determining technology mixes (and on this basis the mix of heat pump types).

Findings – emissions abatement by scenario

	Direct emissions abatement[1]				Total emissions abatement[1]			
	2035	2035	2050	2050	2035	2035	2050	2050[2]
Scenario	$MtCO_2e$	%	$MtCO_2e$	%	$MtCO_2e$	%	$MtCO_2e$	%
Balanced Pathway	25.8	43%	59.9	100%	24.3	41%	59.2	99%
Tailwinds	36.4	61%	59.9	100%	34.1	57%	59.4	99%
Widespread Engagement	32.1	54%	59.9	100%	30.5	51%	59.4	99%
Headwinds	24.4	41%	59.9	100%	23.5	39%	58.4	97%
Widespread Innovation	32.9	55%	59.9	100%	32.3	54%	59.8	100%

- The Balanced Pathway scenario represents 41% total yearly emissions abatement by 2035 at lowest cost, driven by:
  - deployment of 8 million heat pumps in existing homes (across stock segments), and
  - deployment of 11.9 million energy efficiency packages in existing homes across the private rented and local authority sectors in addition to all fuel poor homes (including owner-occupied fuel poor).
- Total emissions abatement in 2050 varies slightly between scenarios due to the addition of indirect emissions associated with hydrogen and biofuel use.
  - The effect is most pronounced in Headwinds, which has the highest use of both hydrogen and biofuels.
- Direct emissions abatement in 2035 varies by scenario from a low of 41% (Headwinds) to a high of 61% (Tailwinds).
- The pace of decarbonisation in the Balanced Pathway remains close to Headwinds. This reflects both the intent to advise on a budget level which remains compatible with widespread hydrogen conversion, and an ambitious pace of hydrogen conversion in Headwinds, led by industrial decarbonisation.

[1] Percentages represent yearly emissions abated as a % of baseline emissions in the specified year. [2] Total emissions abatement in 2050 varies slightly between scenarios due to the addition of indirect emissions associated with hydrogen and biofuel use.

Findings – summary of costs by scenario [1/2]

Scenario	Average cost effectiveness (£/tCO_2)	Average abatement cost (£bn/y)	Total abatement costs (£bn)		Total net investment costs (£bn)[1]		Total net opex costs (£bn)		Total net costs (£bn)
			To 2035	To 2050	To 2035	To 2050	To 2035	To 2050	To 2050
Balanced Pathway	229	6.3	34.2	190	117	256	-11.1	-37.4	218
Tailwinds	303	9.8	70.5	295	155	259	-15.3	-48.4	211
Widespread Engagement	230	7.2	44.8	217	158	302	-18.2	-69.9	232
Headwinds	267	7.0	30.3	211	94.3	182	-6.4	40.7	223
Widespread Innovation	341	9.5	82.7	286	167	252	-13.2	-54.3	198

- Total abatement costs to 2050 in the Balanced Pathway scenario are the lowest across scenarios, at £190 billion, whereas the highest costs are £295 billion in the Tailwinds scenario. Factors leading to the Balanced Pathway having the lowest cost include:
  - Other scenarios forcing in additional energy efficiency measures (further beyond those deemed cost-effective[2] by the model), such as in Widespread Engagement and Tailwinds.
  - Other scenarios deploying expensive low carbon heating technologies, such as high capex high temperature heat pumps in Widespread Innovation or high opex hydrogen boilers and hybrid H_2 heat pumps in Headwinds.
- Total net investment costs to 2050 in the Balanced Pathway are £256 billion (representing an average of £9,000 per home) and range from £182 billion in Headwinds (£6,400 per home) to £302 billion in Tailwinds (£10,700 per home).
- The Balanced Pathway scenario has the lowest average cost effectiveness, at £229/tCO_2, while the Widespread Innovation scenario has the highest, at £341/tCO_2.
  - Average cost effectiveness is influenced both by total abatement costs and the total cumulative emissions abated. A scenario which reaches Net Zero earlier (e.g. Tailwinds) abates more emissions cumulatively (i.e. has higher yearly abatement for a longer period), so has a lower average cost effectiveness than a scenario with similar total abatement costs e.g. Widespread Innovation.

[1] See footnote on next slide. [2] Cost-effectiveness is defined as the cost of a measure per unit of emissions abated, in £ per tonne of CO_2e. The costs do not account for wider social benefits such as improved health.

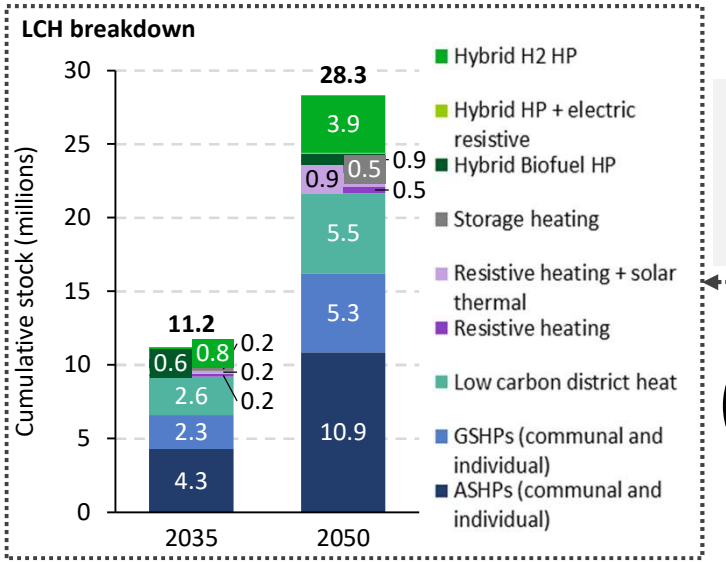
Findings – summary of costs by scenario [2/2]

			Total abatement costs (£bn)		Total net investment costs (£bn)[1]		Total net opex costs (£bn)		Total net costs (£bn)
Scenario	Average cost effectiveness (£/tCO_2)	Average abatement cost (£bn/y)	To 2035	To 2050	To 2035	To 2050	To 2035	To 2050	To 2050
Balanced Pathway	229	6.3	34.2	190	117	256	-11.1	-37.4	218
Tailwinds	303	9.8	70.5	295	155	259	-15.3	-48.4	211
Widespread Engagement	230	7.2	44.8	217	158	302	-18.2	-69.9	232
Headwinds	267	7.0	30.3	211	94.3	182	-6.4	40.7	223
Widespread Innovation	341	9.5	82.7	286	167	252	-13.2	-54.3	198

- Investment costs only account for in-year, undiscounted capex, and therefore are unaffected by the cost of capital. Abatement costs, on the other hand, incorporate annualised capex discounted by the cost of capital in addition to opex and fuel costs discounted by the discount rate. The two figures are therefore not directly comparable.
  - The cost of capital used for Widespread Innovation and Tailwinds (7.5%) is higher than that used for the other scenarios (3.5%) overpowering more ambitious assumptions on cost reductions and leading to higher abatement costs in the former two scenarios (see slide).
  - Comparing total costs (investment + opex) with abatement costs shows a consistent pattern of net costs being higher than abatement costs for scenarios using the lower cost of capital.

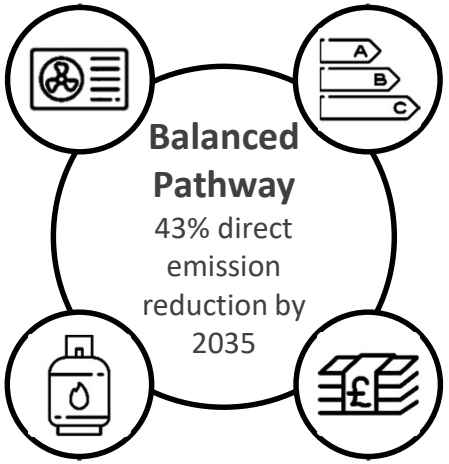
[1] Investment costs in this modelling are expected to be overestimated to some degree, due to assuming renewal costs for all household conversion items including radiators. An adjustment has been made to remove these additional renewal costs in the CCC's final Balanced Pathway.

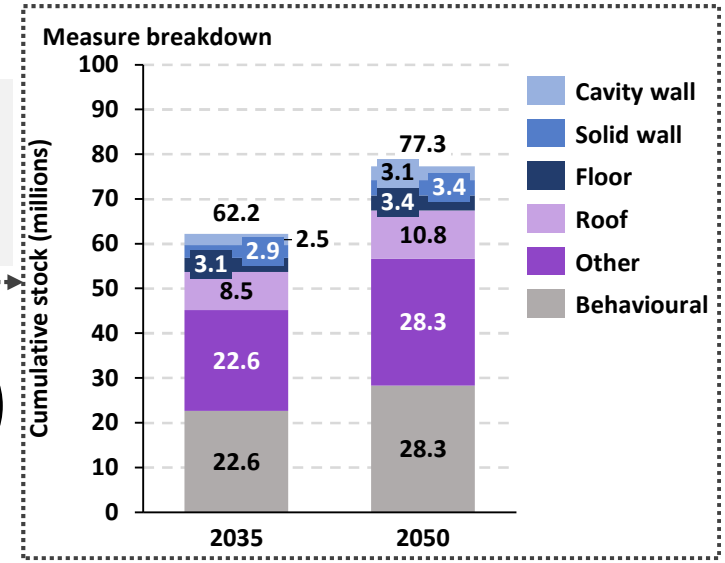
Findings – Balanced Pathway scenario overview

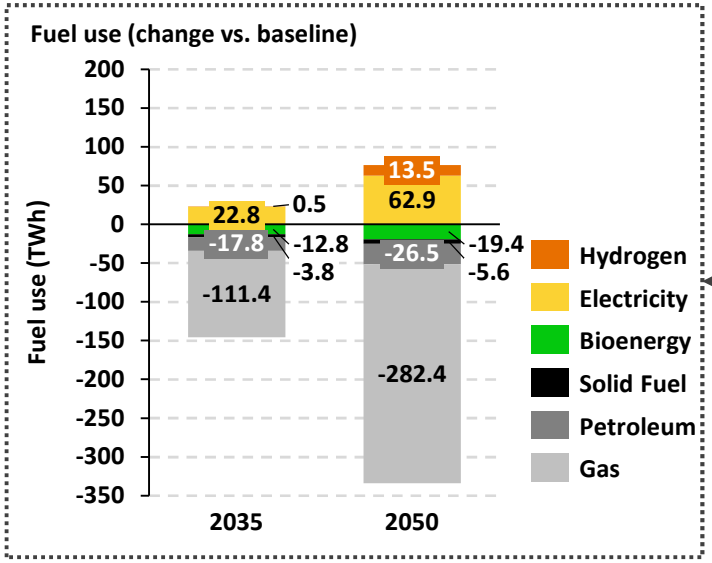


LCH & EE Key Numbers

- Average £/tCO_2e: 229
- Heat pumps (all kinds): 21m
- Homes with HS: 1.4m
- All practicable cavities & lofts insulated. 3.4m solid walls.

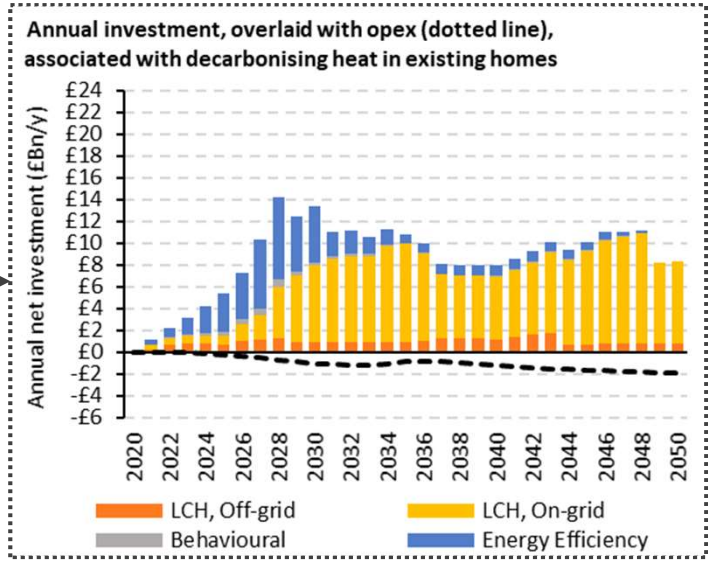






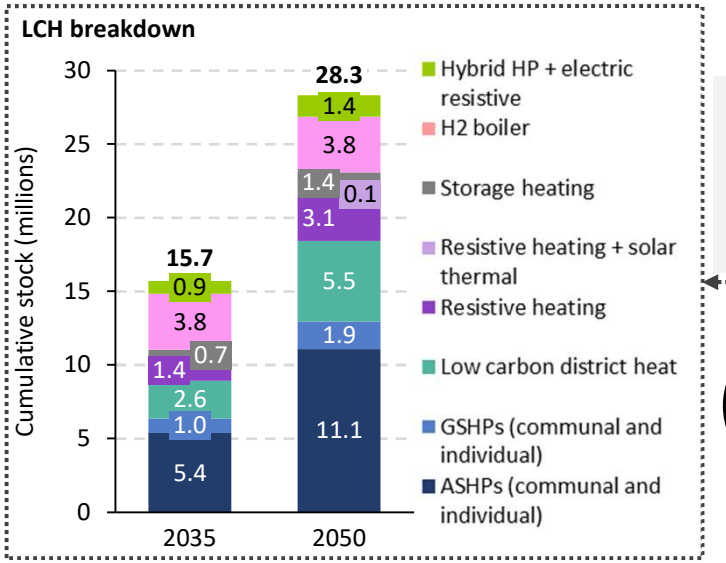
Fuel Use & Investment Key Numbers

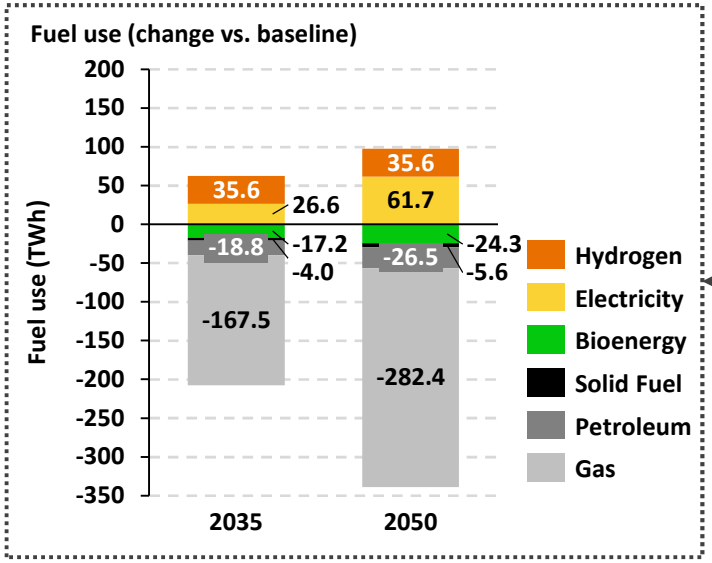
- Net investment: £256bn.
- Electricity demand: 86 TWh
- Average yearly abatement cost[1]: £6.3bn/yr.



HS: Heat Storage. [1] Abatement costs incorporate annualised capex discounted by the cost of capital in addition to opex and fuel costs discounted by the discount rate.

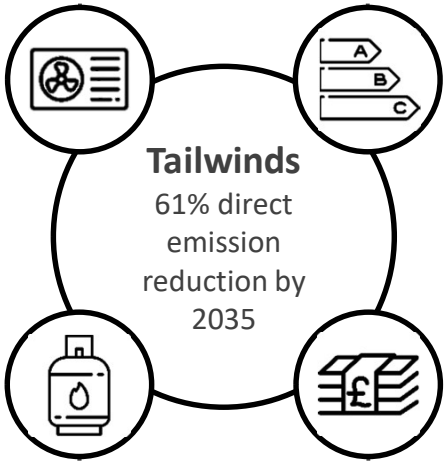
Findings – Tailwinds scenario overview





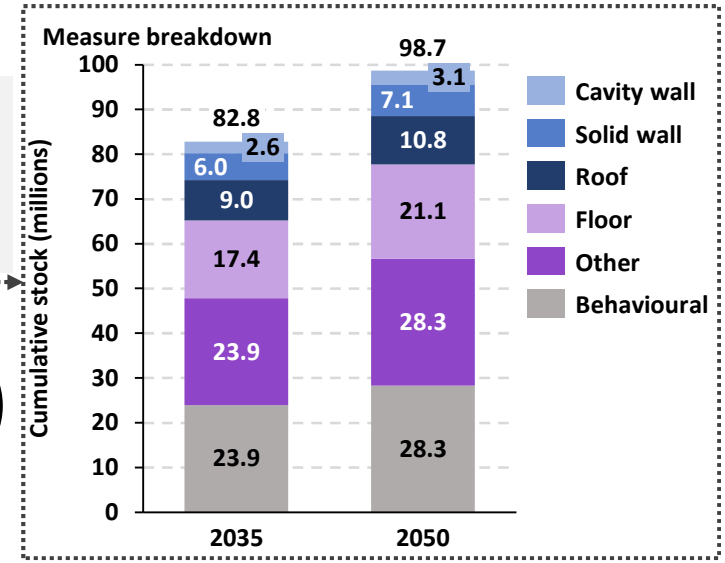
LCH & EE Key Numbers

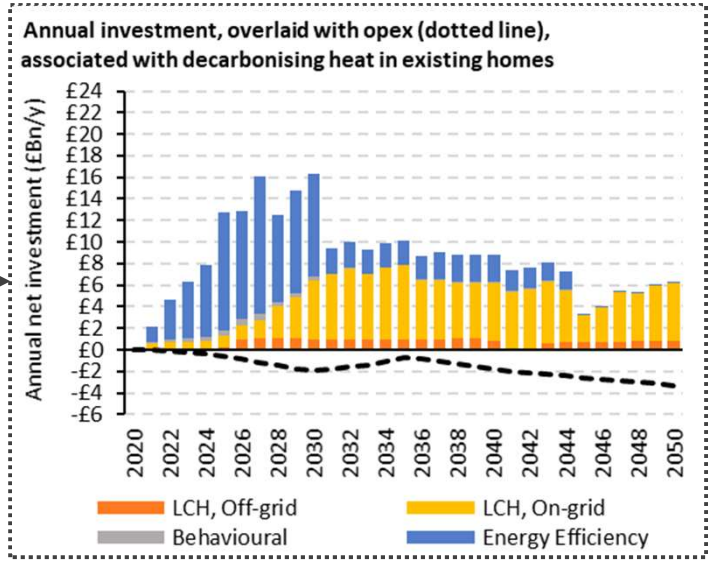
- Average £/tCO_2e: 303
- Heat pumps (all kinds): 14m
- Homes with HS: 5.9m
- Full economic potential deployed for fabric efficiency.



Fuel Use & Investment Key Numbers

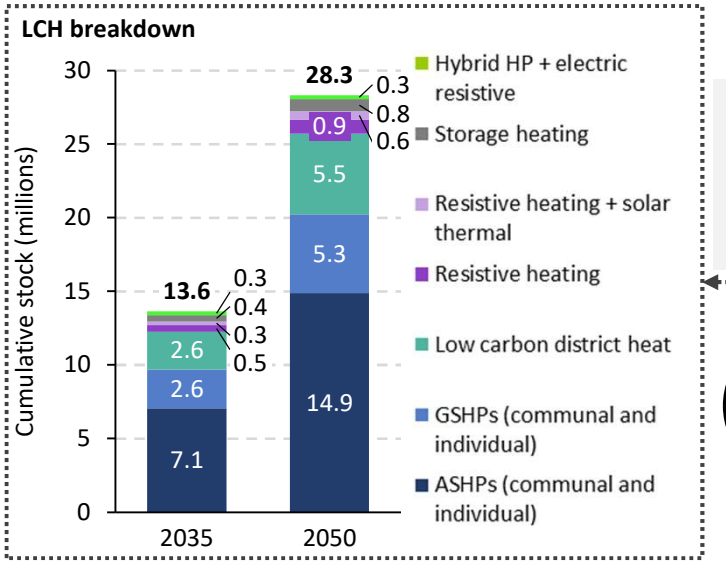
- Net investment: £259bn.
- Electricity demand: 84 TWh
- Average yearly abatement cost[1]: £9.8bn/yr.

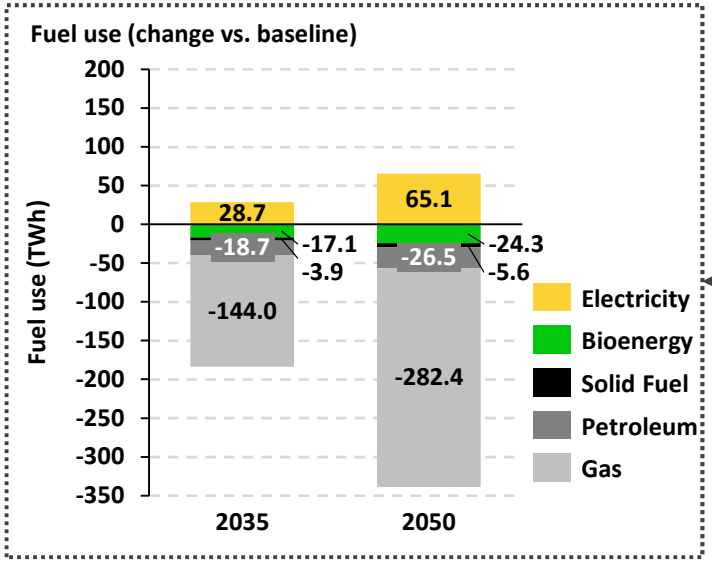




HS: Heat Storage. [1] See footnote on "Findings – Balanced Pathway scenario overview" slide.

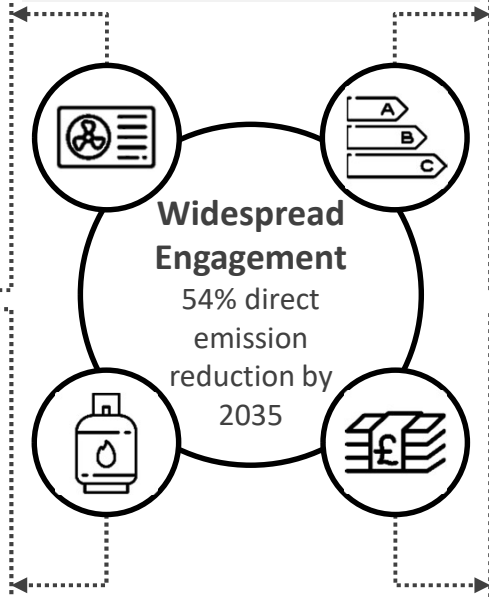
Findings – Widespread Engagement scenario overview





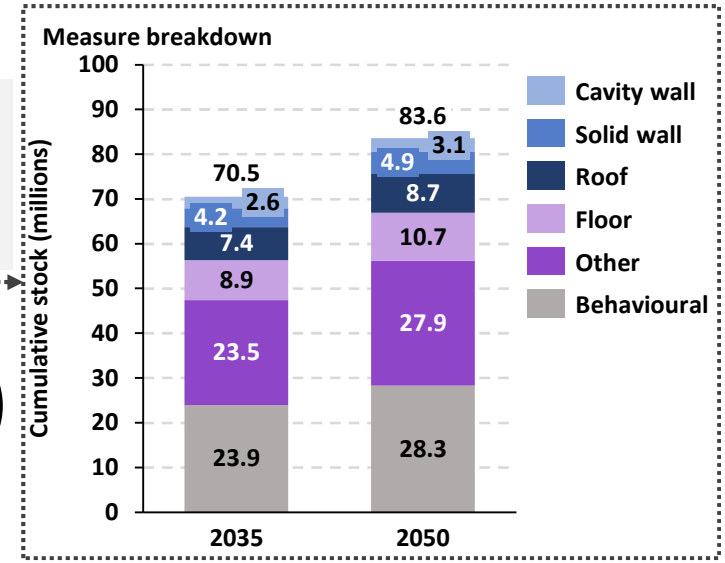
LCH & EE Key Numbers

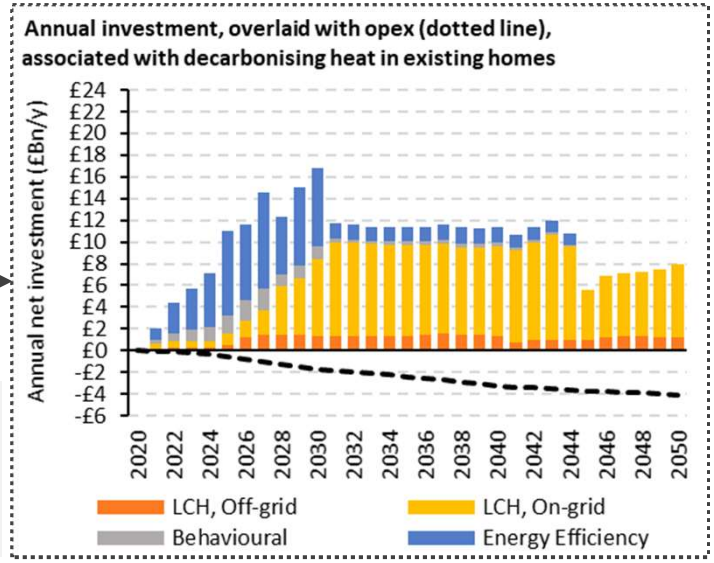
- Average £/tCO_2e: 230
- Heat pumps (all kinds): 21m
- Homes with HS: 4m
- All practicable cavities insulated. 4.9m solid walls.



Fuel Use & Investment Key Numbers

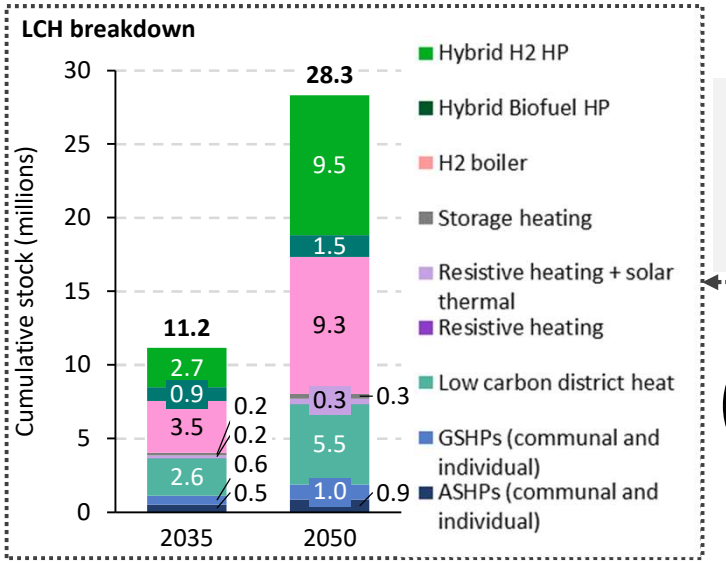
- Net investment: £302bn.
- Electricity demand: 88 TWh
- Average yearly abatement cost[1]: £7.2bn/yr.

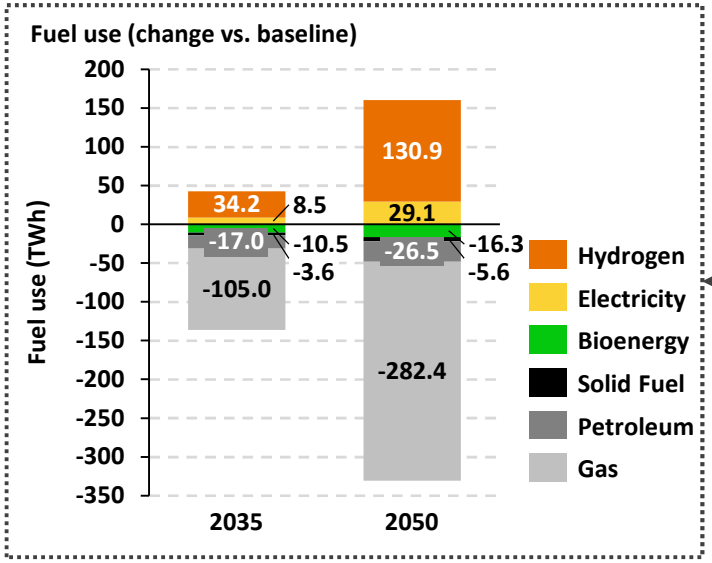




HS: Heat Storage. [1] See footnote on "Findings – Balanced Pathway scenario overview" slide.

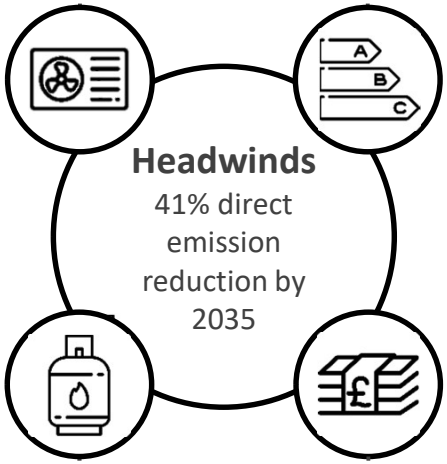
Findings – Headwinds scenario overview





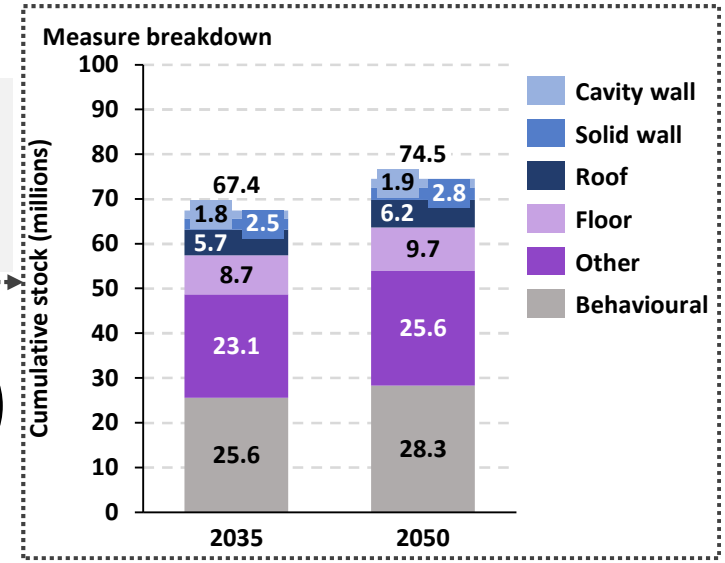
LCH & EE Key Numbers

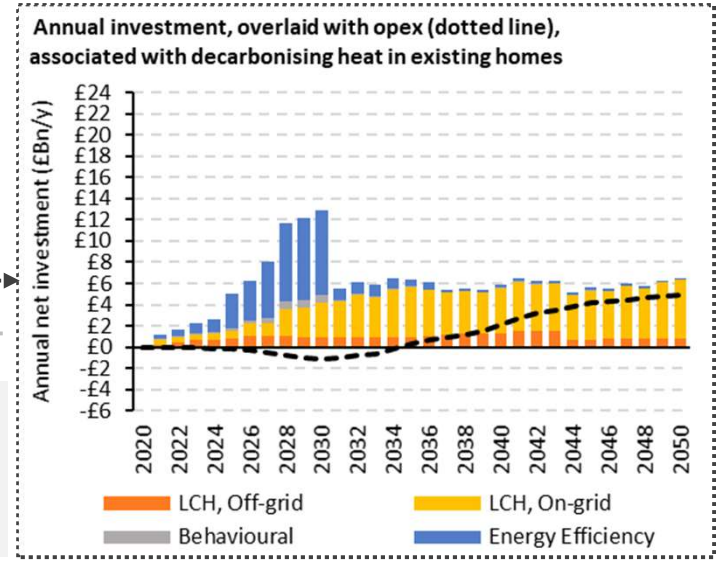
- Average £/tCO_2e: 267
- Heat pumps (all kinds): 13m
- Homes with HS: 0.4m
- Lower energy efficiency uptake[1].



Fuel Use & Investment Key Numbers

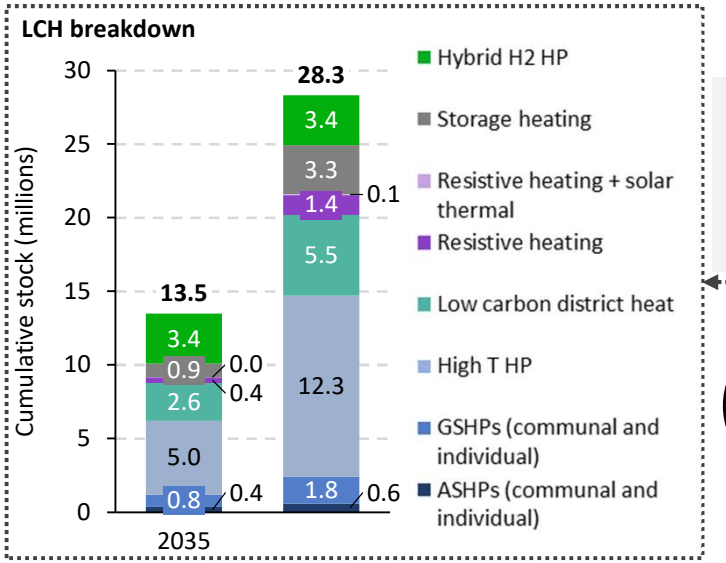
- Net investment: £182bn.
- Electricity demand: 52 TWh
- Average yearly abatement cost[2]: £7.0bn/yr.





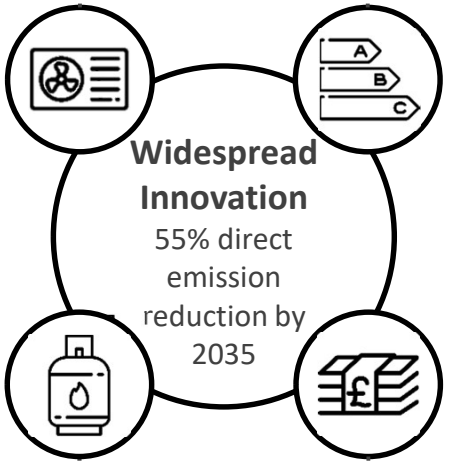
HS: Heat Storage. [1] Model allowed to determine 'cost effective' level (not reflecting wider benefits) for non-fuel poor homes but reflecting higher bound assumptions on hydrogen costs. [2] See footnote on "Findings – Balanced Pathway scenario overview" slide.

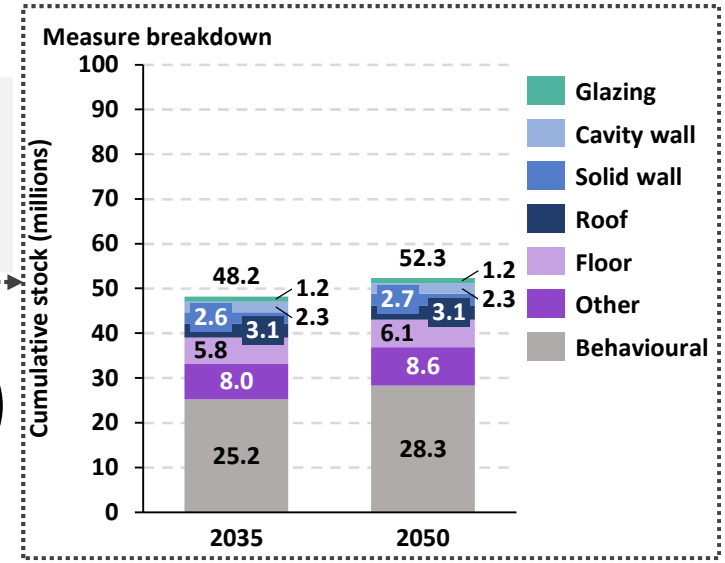
Findings – Widespread Innovation scenario overview

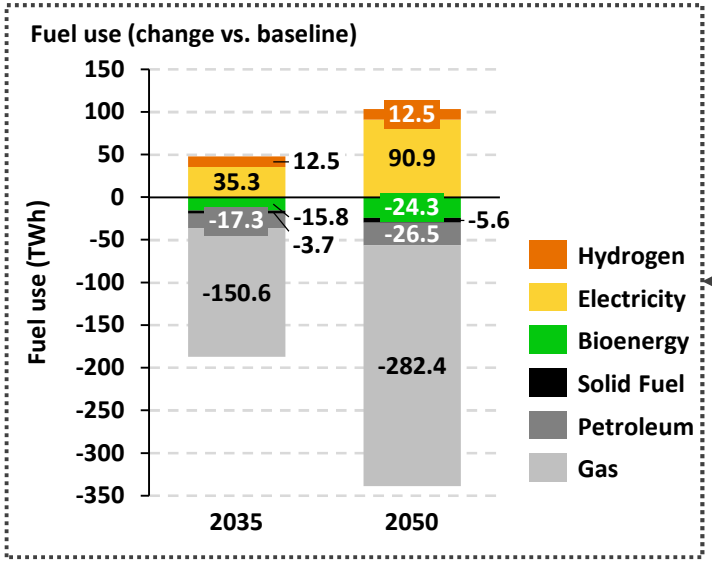


LCH & EE Key Numbers

- Average £/tCO_2e: 341
- Heat pumps (all kinds): 18m
- Homes with HS: 14.2m
- Lower efficiency uptake, with some deep retrofits[1].

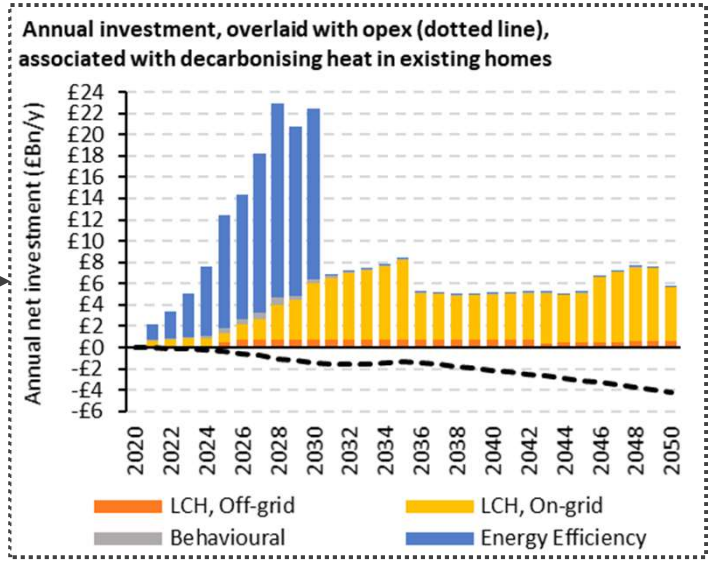






Fuel Use & Investment Key Numbers

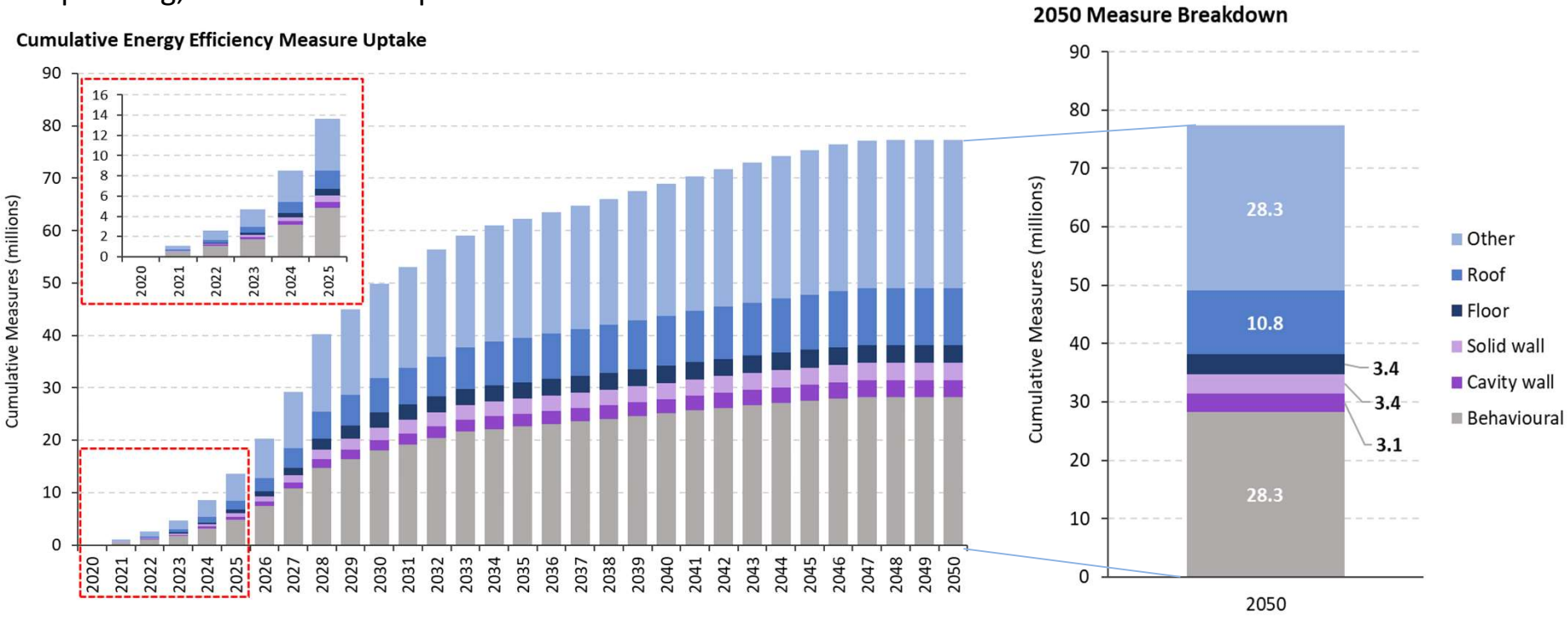
- Net investment: £252bn.
- Electricity demand: 114 TWh
- Average yearly abatement cost[2]: £9.5bn/yr.



[1] Model allowed to determine 'cost effective' level (not reflecting wider benefits) for non-fuel poor homes. All high packages (e.g. in fuel poor homes) modelled as deep retrofits. [2] See footnote on "Findings – Balanced Pathway scenario overview" slide.

Findings – Balanced Pathway energy efficiency uptake trajectory

- As the scenarios are based on an "energy efficiency first" approach; uptake of energy efficiency ramps up rapidly from current levels in the early years.
  - 64% of energy efficiency deployment in Balanced Pathway happens in the first 10 years (i.e. to 2030).
  - Urgent ramp-up is needed relative to deployment levels today to achieve the scenario's targets.
- The Balanced Pathway scenario represents a level of energy efficiency uptake which focuses on maximising uptake of low cost, low disruption measures such as loft insulation, cavity wall insulation and draught proofing, with moderate uptake of solid wall insulation.



Findings – Energy efficiency uptake ranges across scenarios [1/2]

	Number of measures deployed (millions)						Total heat demand (TWh/y)			
Scenario	Loft	Cavity wall	Solid wall	Floor	Other	Behavioural	2017	2050	Energy demand savings (TWh/y)	Reduction in heat demand as a result of EE
Balanced Pathway	10.8	3.1	3.4	3.4	28.3	28.3	313	276	37	12%
Tailwinds	10.8	3.1	7.1	21.1	28.3			245	68	22%
Headwinds	9.7	2.8	1.9	6.2	25.6			278	35	11%
Widespread Engagement	10.7	3.1	4.9	8.7	27.9			263	50	16%
Widespread Innovation	6.1	2.7	1.2	2.3	8.6			274	39	12%

- Energy efficiency levels are driven by different factors in each scenario:
  - **Balanced Pathway:** inclusion of all practicable loft and cavity insulation (i.e. all economic potential[1]), in addition to solid walls where the package they are taken up with had a cost effectiveness <£600/t.
  - **Tailwinds:** inclusion of full economic potential for all energy efficiency measures.
  - **Headwinds:** model permitted to optimise for the lowest lifetime cost EE + LCH combination, given high H_2 prices, with no wider benefits costed for non-fuel poor homes. This is the only scenario with 'cost-effective' uptake at standard prices.
  - **Widespread Engagement:** deployment of at least a medium energy efficiency package in all households.
  - **Widespread Innovation:** model permitted to optimise for the lowest lifetime cost using lower-end costs, with no wider benefits costed for non-fuel poor homes; deep retrofits replace standard high packages.

- Solid walls in fuel poor homes are insulated across scenarios (implemented via the high energy efficiency package).
  - Given the high uncertainty over the achievable performance of solid wall insulation in particular, a broad range of uptake levels was modelled across the scenarios, with Tailwinds representing full economic potential.

[1] Generally, measures where costs came in above £700/tCO_2e for a typical home excluded from economical potential. A typical home was assumed to be a medium semi-detached home. Scaffolding and design costs were not included in calculations of economic potential.

Findings – Energy efficiency uptake ranges across scenarios [2/2]

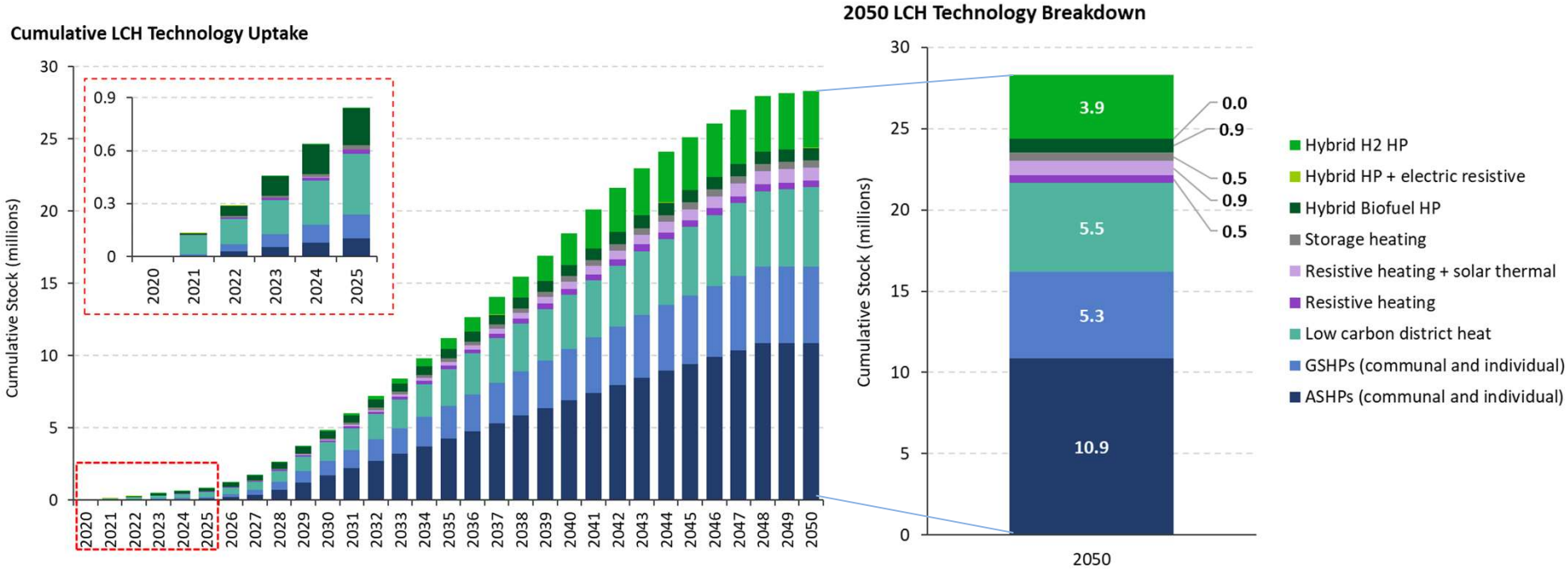
	Number of measures deployed (millions)						Total heat demand (TWh/y)			
Scenario	Loft	Cavity wall	Solid wall	Floor	Other	Behavioural	2017	2050	Energy demand savings (TWh/y)	Reduction in heat demand as a result of EE
Balanced Pathway	10.8	3.1	3.4	3.4	28.3	28.3	313	276	37	12%
Tailwinds	10.8	3.1	7.1	21.1	28.3			245	68	22%
Headwinds	9.7	2.8	1.9	6.2	25.6			278	35	11%
Widespread Engagement	10.7	3.1	4.9	8.7	27.9			263	50	16%
Widespread Innovation	6.1	2.7	1.2	2.3	8.6			274	39	12%

- The overall heat demand reduction has significant variation across homes:
  - A proportion of homes do not get any additional energy efficiency measures. This applies to homes where there is existing insulation or where additional measures would not be cost effective. The number of such homes varies from 0% in the Balanced Pathway and Tailwinds to 69% in Widespread Innovation.
  - In the Balanced Pathway scenario, a typical household which installs cavity wall insulation, loft insulation, and floor insulation sees heat demand savings of 30%.
  - A home getting a deep retrofit (applicable in Widespread Innovation) sees heat demand savings of 57%.

- Energy efficiency and behavioural packages in the Balanced scenario deliver a 12% reduction in heat demand to 2050, with a 22% reduction being delivered in our Tailwinds scenario.
  - The lower stock-level heat demand savings relative to the Net Zero analysis reflect a number of factors, including updated technical and economic potential (leading to lower deployment), and updated cost and savings assumptions (leading to lower cost effectiveness).

Findings – Balanced Pathway low carbon heat uptake trajectory

- Rapid ramp up of energy efficiency deployment prepares the stock for low carbon heating uptake, which also deploys rapidly in the early years.
- 3.3 million heat pumps are deployed in existing homes by 2030 and 8 million by 2035 in the Balanced Pathway scenario.
- Deployment of hybrid[1] H_2 heat pumps ensures consistency with scenarios in the industry sector, with hydrogen grid conversion potentially occurring all the way to 2050 (see slide). Hybrids are deployed steadily to 2050 to ensure they are only deployed in areas which will be converted to H_2.



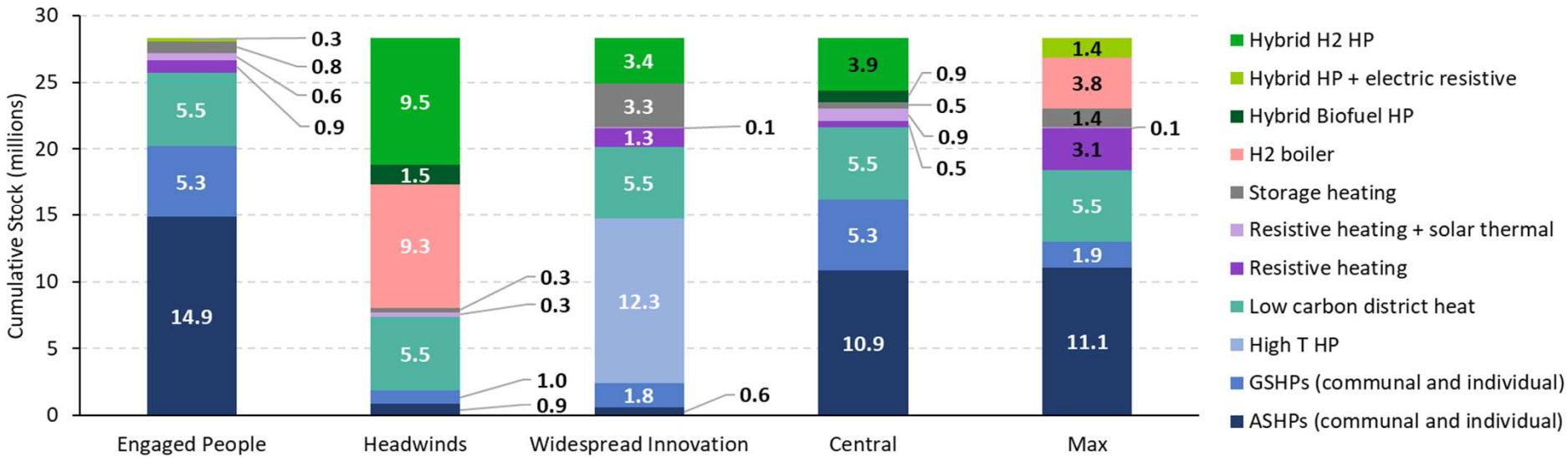
[1] While both ASHP and GSHP hybrids were tested in the modelling, ASHP hybrids were found to be more cost-effective and are therefore the variant deployed for all hybrid configurations.

Findings – 2050 low carbon heat uptake across scenarios

- The graph below shows the different end-state technology mixes in each scenario, illustrating how Net Zero can be achieved via various technology routes.
- Common themes across the scenarios include:
  - 5.5 million homes are connected to low carbon heat networks.
  - A high number (over 10 million) of heat pumps are taken up – of various types, including hybrids – even in a hydrogen-heavy scenario (Headwinds).
- Deployment of technologies with additional heat storage varies from 0.4 million in Headwinds to 14.2 million in Widespread Innovation.

Scenario	Number of technologies deployed with additional thermal storage[1] (millions)
Balanced Pathway	1.4
Tailwinds	5.9
Headwinds	0.4
Widespread Engagement	4.0
Widespread Innovation	14.2

2050 LCH Technology Breakdown

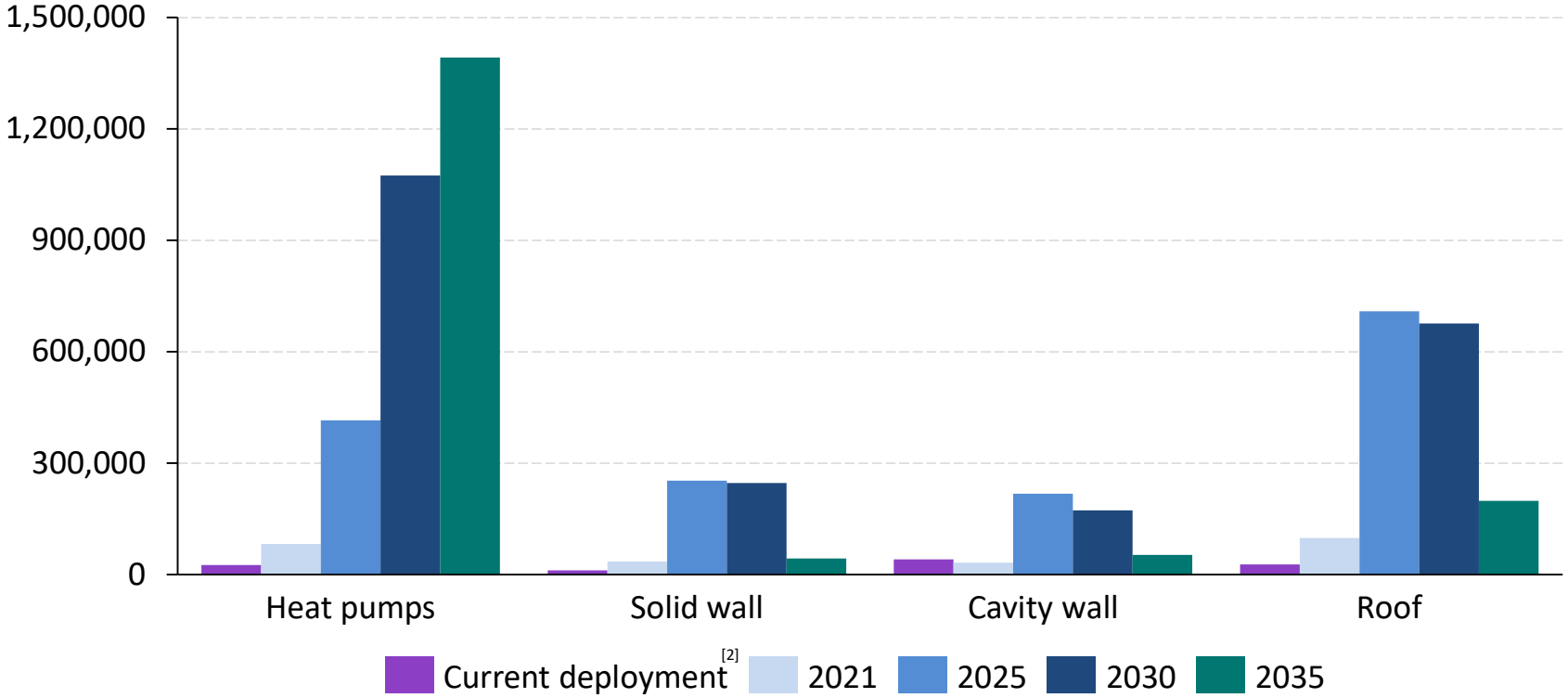


[1] Thermal storage is assumed to be delivered via a heat battery, but could equally be delivered via an electrical battery. The level of deployment of thermal storage affects the number of homes able to access cheaper electricity as a result of higher levels of flexibility

Discussion – a fast expansion of critical supply chains is required to meet the modelled trajectories

- All scenarios require an aggressive increase in the deployment rate of heat pumps, particularly from 2030 onward.
  - A nearly ten-fold increase is required by 2025, with 1.4 million heat pumps deployed in 2035 in the Balanced Pathway scenario. [1]
- Rapid ramp up of deployment is also required for energy efficiency measures, with sustained growth in the 2020s.

Yearly deployment of heat pumps and selected energy efficiency measures in Balanced Pathway

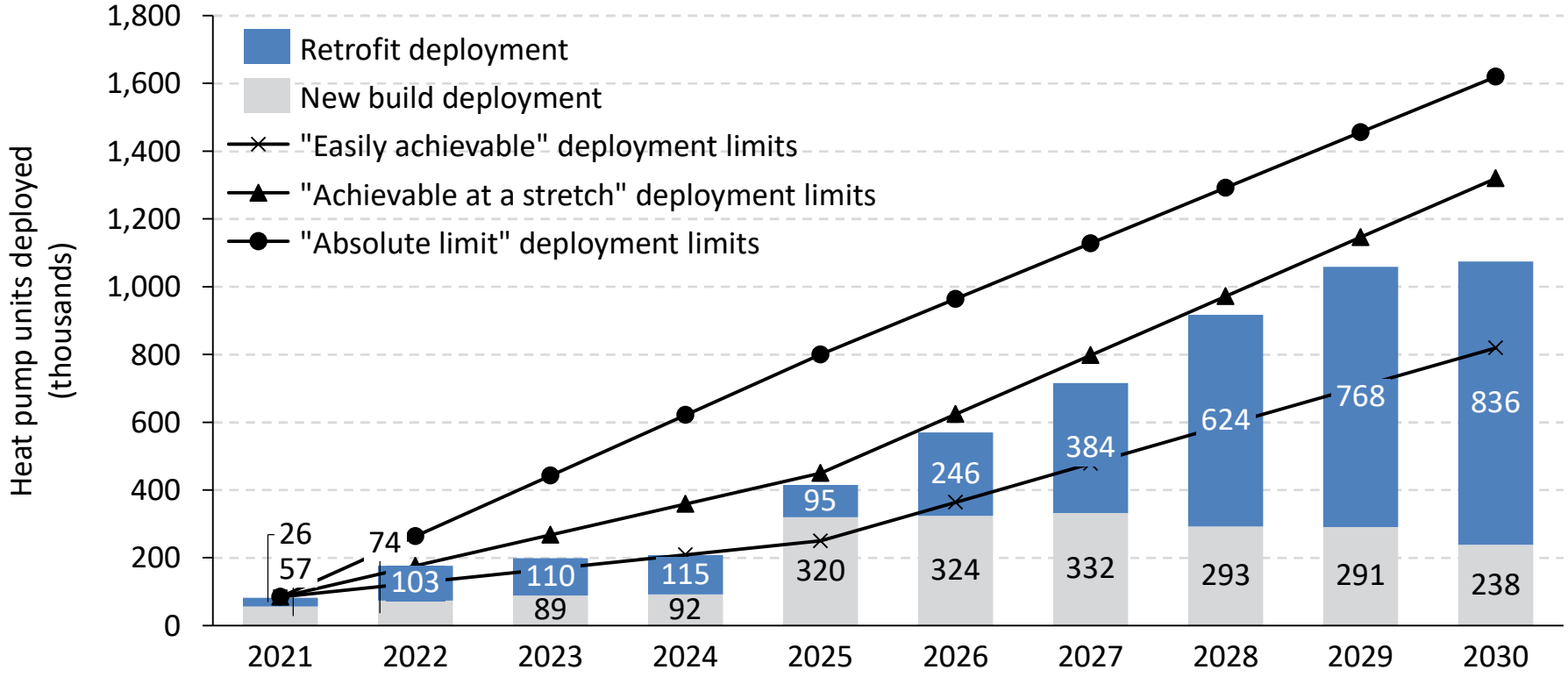


[1] Including new build deployment, which was not directly modelled in this work
[2] Heat pumps, 2018 figures; EE, 2019 figures

Discussion – heat pump deployment ramps-up rapidly in the early years but remains within "achievable at a stretch" deployment constraints

- To meet a net zero target in 2050, a major acceleration in heat pump deployment is required.
  - The envisaged deployment levels up to 2030 – particularly for heat pumps – are ambitious but achievable, being almost at the limit of constraints considered "achievable at a stretch" based on external expert stakeholder feedback in the industry.

Comparison of Balanced Pathway scenario heat pump deployment[1] against technology deployment limits

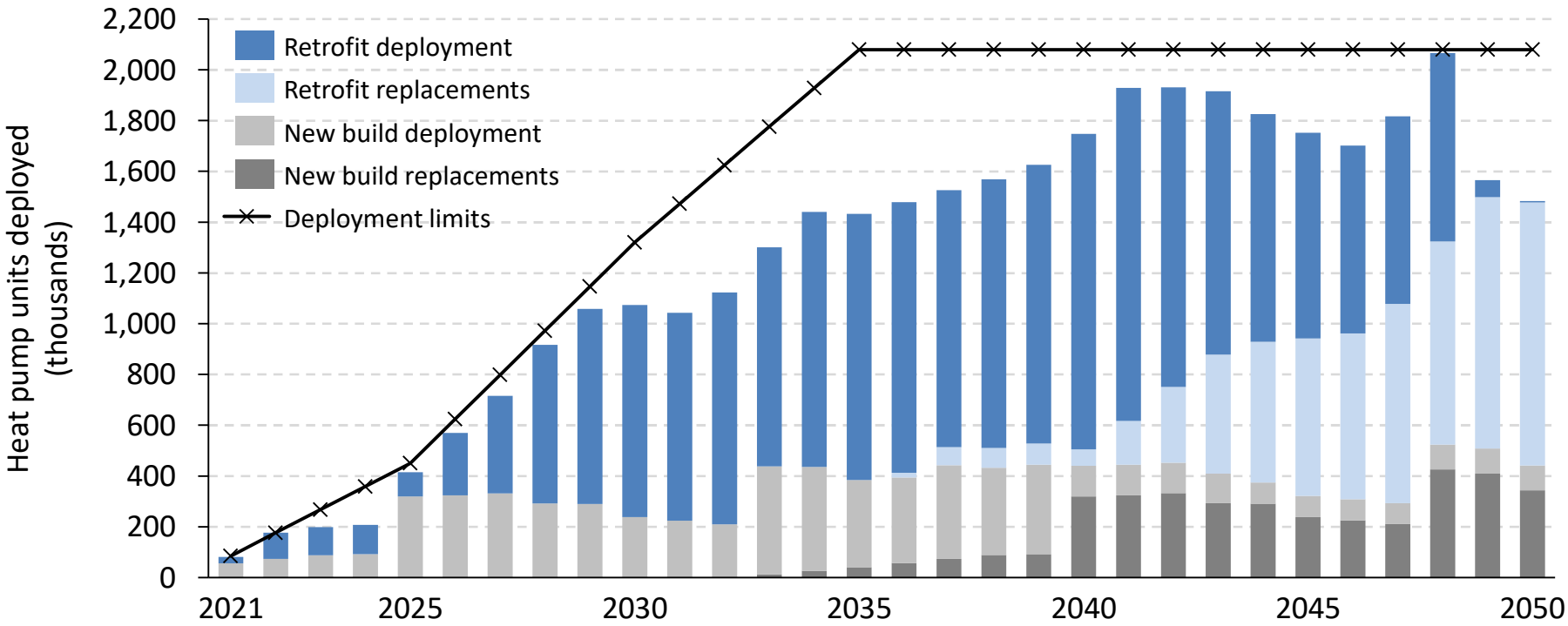


[1] Includes new build heat pumps, which were not directly modelled in this work

Discussion – total heat pump deployment represents a smooth ramp-up

- With new builds and replacements taken into account, the modelled heat pump uptake trajectory delivers a relatively smooth ramp-up of deployment. After 2030, deployment rates keep increasing, but at a slower rate than deployment limits.
- In the 2040s replacements become a significant part of total deployment, with new installations and replacements together approaching the deployment limits.
  - The limits are modelled as constant after 2035 but in reality would be expected to further increase, albeit at a slower rate compared with the period before 2035.

Comparison of Balanced Pathway heat pump deployment[1] against heat pump deployment limits



[1] Includes new build heat pumps and new build replacements, which were not directly modelled in this work. Replacements assume a 15-year heat pump lifetime for ASHPs and 20 years for GSHPs. New build replacements before 2036 are due to new build deployment before 2021, not shown in the graph.

Discussion – technology deployment at key dates

Cumulative deployment for selected technology groups
k: thousands; m: millions

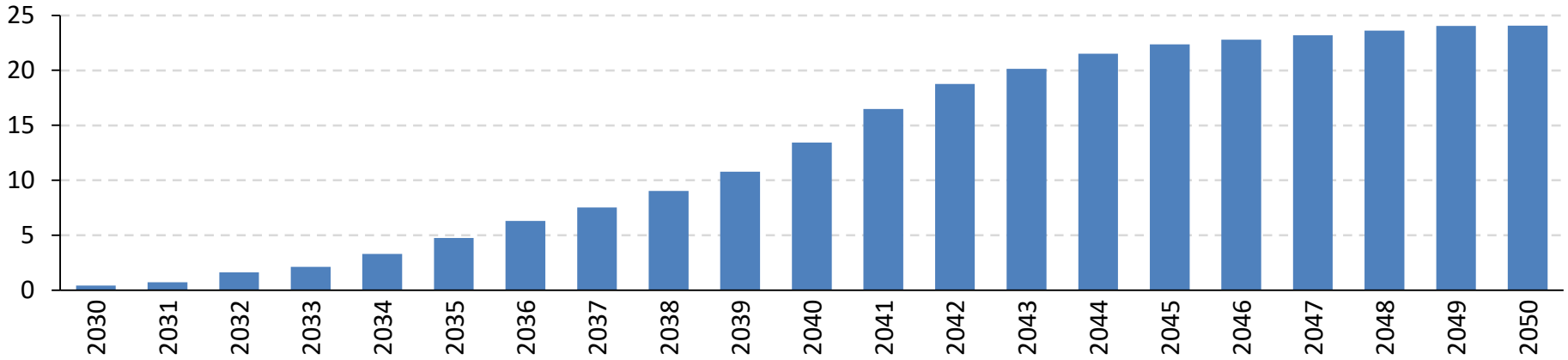
	Balanced Pathway deployment [range across scenarios]					
Low carbon heating technology group	**2022**	**2025**	**2028**	**2030**	**2040**	**2050**
Heat pumps	70k [24k – 70k]	240k [88k – 260k]	1.3m [450k – 1.5m]	2.7m [640k – 3.2m]	10.5m [1.6m – 16.1m]	16.2m [1.9m – 20.2m]
Hybrid heat pumps	59k [0 – 59k]	210k [10k – 240k]	450k [190k – 800k]	570k [250k – 1.4m]	3.0m [270k – 6.2m]	4.8m [280k – 11.0m]
Electric storage	7k [2k – 8k]	23k [8k – 28k]	56k [40k – 150k]	110k [80k – 340k]	390k [280k – 1.9m]	490k [330k – 3.3m]
Electric resistive	8k [2k – 8k]	26k [7k – 26k]	85k [45k – 120k]	180k [89k – 300k]	890k [310k – 2.5m]	1.4m [370k – 3.2m]
Hydrogen heating (boilers only)	0 [0 – 0]	0 [0 – 3k]	0 [0 – 12k]	0 [0 – 330k]	0 [0 – 6.6m]	0 [0 – 9.3m]
Hydrogen heating (boilers + hybrid H_2 heat pumps)	0 [0 – 0]	3k [0 – 75k]	12k [0 – 350k]	80k [0 – 1.1m]	2.2m [0 – 11.5m]	3.9m [0 – 18.8m]

- The table shows cumulative deployment of several low carbon heating technologies in selected years in the Balanced Pathway scenario, with the range across scenarios shown in square brackets.
- It is important to note that hybrid H_2 heat pumps may be deployed before grid conversion, and are assumed to operate on gas, in hybrid mode, until hydrogen becomes available.

Discussion – hydrogen trajectory assumptions and implications

- The trajectory for deployment of heating technologies using hydrogen is based on a set of assumptions describing a small set of illustrative approaches to a phased conversion of the gas distribution grid[1].
- The grid conversion trajectory, which is aligned with the parallel analysis on the industry sector for the 6CB, involves conversion of the gas grid between 2030 and 2050 over an increasing catchment area associated with seven identified industrial clusters.
  - Separate deployment of hydrogen trials – 12,300 units – in the 2020s is also assumed to occur.
  - Once homes fall within the radius of conversion, they are assumed to have potential access to hydrogen. This does not necessarily mean the entire grid within that radius is assumed to convert to hydrogen, as explained further below.
- In scenarios where the grid fully converts i.e. Headwinds, the conversion trajectory results in 4.7 million (20%) of current grid-connected homes having access to hydrogen by 2035, 13.4 million (56%) by 2040 and 24.1 million (100%) by 2050.
- For all other scenarios, the hydrogen conversion trajectory above does not assume that the grid is fully converted but assumes partial conversion of the grid in areas designated for conversion – this analysis does not attempt to specify which areas should be designated for conversion. Partial conversion is represented differently in different scenarios, with some assuming conversion of all homes in radius (with radial expansion limited) and others assuming partial conversion in radius (with radial expansion unlimited).
  - In the Tailwinds scenario, homes receiving hydrogen boilers are assumed to be in areas surrounding the industrial clusters.

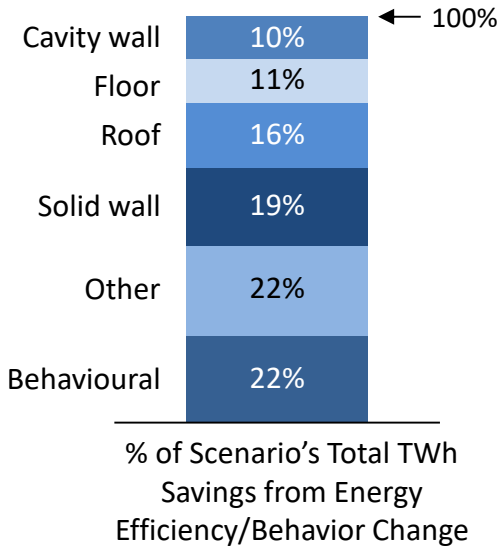
Homes with potential access to hydrogen

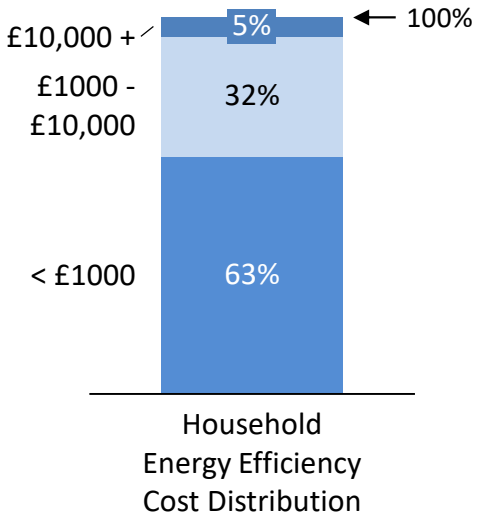


[1] The actual deployment of heating technologies using hydrogen varies between scenarios (see previous slides)

Discussion – substantial behavioural and energy efficiency savings in the scenarios can be delivered at low cost

- 63% of all homes need spend no more than £1000 on retrofitting energy efficiency measures, with these homes delivering 30% of the scenario-wide energy savings in the Balanced Pathway scenario.
  - 30% of all energy savings from energy efficiency in the Balanced Pathway scenario are associated with measure packages costing under £1000.
  - These are expected to typically be homes with behavioural and other measures (draught proofing, hot water tank insulation) only or with loft / cavity insulation alongside.
- The measures generating the highest savings in the Balanced Pathway scenario include behavioural measures, solid wall insulation, and 'other' measures, together making up around 3/5 of savings.
  - 'Other' measures include draught proofing and hot water tank insulation. Most of the savings here are expected to come from draught proofing as it delivers savings of ~3% per home, applied to the majority of the stock.
- 49% of savings in the Balanced Pathway scenario come from homes with retrofit packages costing between £1000 - 10,000.
  - These are largely concentrated in the able-to-pay owner occupied stock.
- The cheapest retrofit packages (under £1000) deliver on average 8.7% savings per home, whilst the mid-range packages (£1000 - £10,000) deliver 21% savings on average. The most expensive retrofits in the Balanced Pathway scenario cut heat demand by approximately a third.[1]





[1] The numbers provided for this point are derived from simple averages, rather than weighted by uptake, which would likely lead to lower values.

Discussion – energy efficiency measures contribute to bill savings, as well as delivering wider benefits

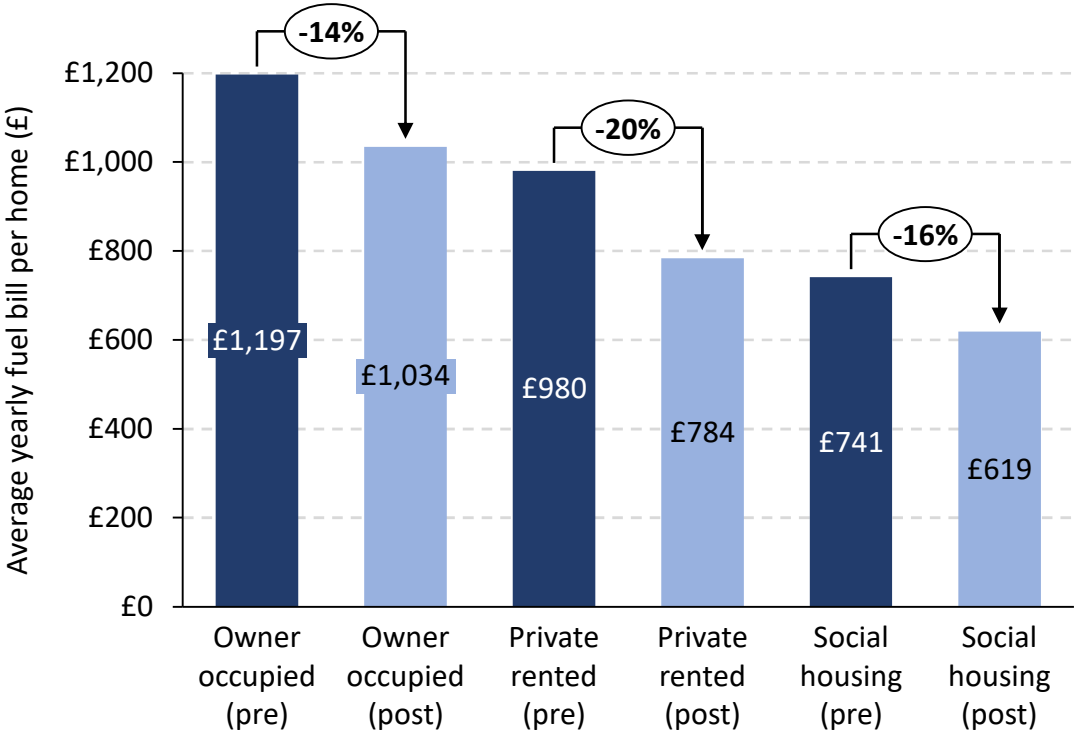
- Energy efficiency measures and behavioural changes should be deployed/implemented early and widely across the stock to drive down fuel bills in homes. This is valuable both to manage heat pump electricity demand and the high opex costs associated with any hydrogen use.
- Energy efficiency deployment in the early years is dominated by the local authority and private rented sectors, in addition to fuel poor homes.
- In terms of cost effectiveness towards abating CO_2 emissions, there is a wide range of benefit from different fabric measures for retrofit. For example, for a medium-sized terraced house:
  - Easy to treat cavity wall insulation is a low cost, high benefit measure, with an average cost effectiveness of -£94/tCO_2.
  - Based on the updated cost and savings assumptions, replacing old (pre-2002) double glazing with new double glazing is a higher cost, lower benefit measure, with £/tCO_2 cost effectiveness in the thousands. The scenarios do not model glazing upgrades (except as part of deep retrofits), but upgrades can still offer improved comfort in homes and current rates of upgrade would be assumed to continue.
- Though the direct heat demand savings are modelled in this work, there are a range of wider benefits[1] that the installation of energy efficiency would render including the following:
  - **Economic**: public and private sector investment and job growth.
  - **Health**: decreasing the number of cold homes and the near-term reduction of carbon-intensive supply.
  - **Flexibility**: (via pre-heating or other demand side response) for the grid.

[1] Energy Savings Trust: Capturing the "multiple benefits" of energy efficiency in practice: the UK example

Discussion – installing low carbon heating and energy efficiency leads to a 16% average reduction in fuel bills for households

- Installing energy efficiency and low carbon heating leads to a significant reduction in fuel bills for households.
  - The largest saving is seen in the private rented sector, where average yearly fuel bills decrease by 20%, or just over £200.
  - The smallest saving is in the owner occupied sector, where bills decrease by 14%, or about £160.
- This modelling does not include cooking decarbonisation or lighting and appliance efficiency which would be expected to drive additional savings.
  - The CCC's scenarios estimate additional savings in the order of £1.2 billion pounds per year across the existing stock by 2050 associated with lights and appliances.

Average yearly fuel bills[1] for homes before and after energy efficiency + low carbon heating installation, by tenure type



[1] Includes costs not associated with space or water heating, including cooking, lighting and appliances. Non-heating fuel use estimated from ECUK end-use data tables (2018 values)

Discussion – significant investment is required across stock segments both for energy efficiency measures and low carbon heating

Estimated investment costs to 2030 by scenario (billions)

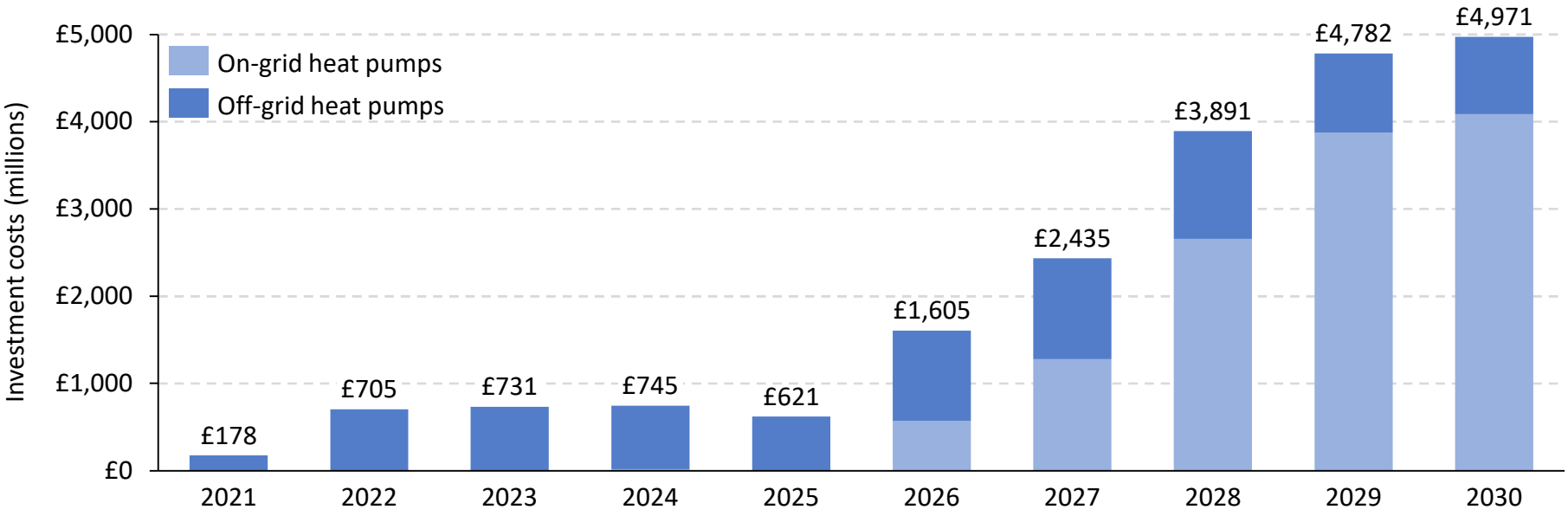
Stock segment	Balanced Pathway	Tailwinds	Headwinds	Widespread Engagement	Widespread Innovation
Fuel poor, owner occupied energy efficiency	£4.5 - £8.9	£3.8 - £6.6	£4.5 - £8.9	£4.5 - £8.9	£52.2 - £46.3
Social housing energy efficiency	£3.1 - £4.0	£8.3 - £8.8	£3.3 - £4.1	£5.0 - £5.9	£13.0 - £14.1
Private rented energy efficiency	£11.1 - £13.5	£19.3 - £20.9	£8.8 - £11.2	£14.0 - £16.4	£31.5 - £34.7
Non-fuel poor, owner occupied energy efficiency	£10.6	£41.4	£14.4	£24.6	£1.1
Heat pump scale-up	£20.6	£14.0	£10.9	£21.9	£13.1
Heat networks	£9.9	£9.9	£9.9	£9.9	£9.9

- The table shows total investments to 2030 for various stock segments, separating energy efficiency investment in various stock segments from investment in heat pumps and heat networks.[1]
  - Where ranges for energy efficiency investment are shown, the lower bound excludes costs associated with installing floor insulation in fuel poor homes, whereas the upper bound includes the costs of all appropriate energy efficiency measures. The floor insulation costs in fuel poor homes are excluded in the lower bound as they were a by-product of installing "High" energy efficiency packages in those homes to achieve the desired uptake – and accompanying wider benefits – of other energy efficiency measures in those homes, in particular wall insulation.
  - The high costs of energy efficiency in the Widespread Innovation scenario are due to the modelling of significantly more expensive deep retrofits (which are rarely taken up in the non-fuel poor owner occupied sector). This remains a first step in modelling deep retrofits in homes, and does not reflect the accompanying benefits that might be associated with retrofit models such as Energiesprong (which incorporate onsite generation and a business model which includes management of maintenance spend against the counterfactual).
- Total estimated investment costs for energy efficiency in the Balanced Pathway scenario amount to **£45** billion by 2035 and **£55** billion by 2050[1].

[1] Energy efficiency values exclude behavioural measures

Discussion – investment required for heat pumps increases rapidly from current levels with a 25-fold rise between 2021 and 2030

Investment costs for heat pumps in Balanced Pathway in the early years, by grid connection status[1]



- Significant investment is required for heat pumps in the next 10 years, with a total of £20.7 billion to 2030:
  - Investment costs are relatively constant between 2022 and 2025, to accommodate increased deployment of heat pumps in new builds in this period without breaching deployment constraints.
  - Heat pump investment is dominated by off-grid homes to 2025, and by on-grid homes to 2030.
  - Total investment in off-grid heat pumps to 2030 is £8.2 billion, compared to £12.5 billion for on-grid heat pumps.
- Cumulative investment in low carbon heat networks to 2030 is estimated at £9.9 billion to 2030. However this is subject to higher uncertainty given the different approach used for costing these systems.
- Cumulative investment in direct electric heating technologies[2] (electric resistive and electric storage) to 2030 is significantly lower, at £400 million.

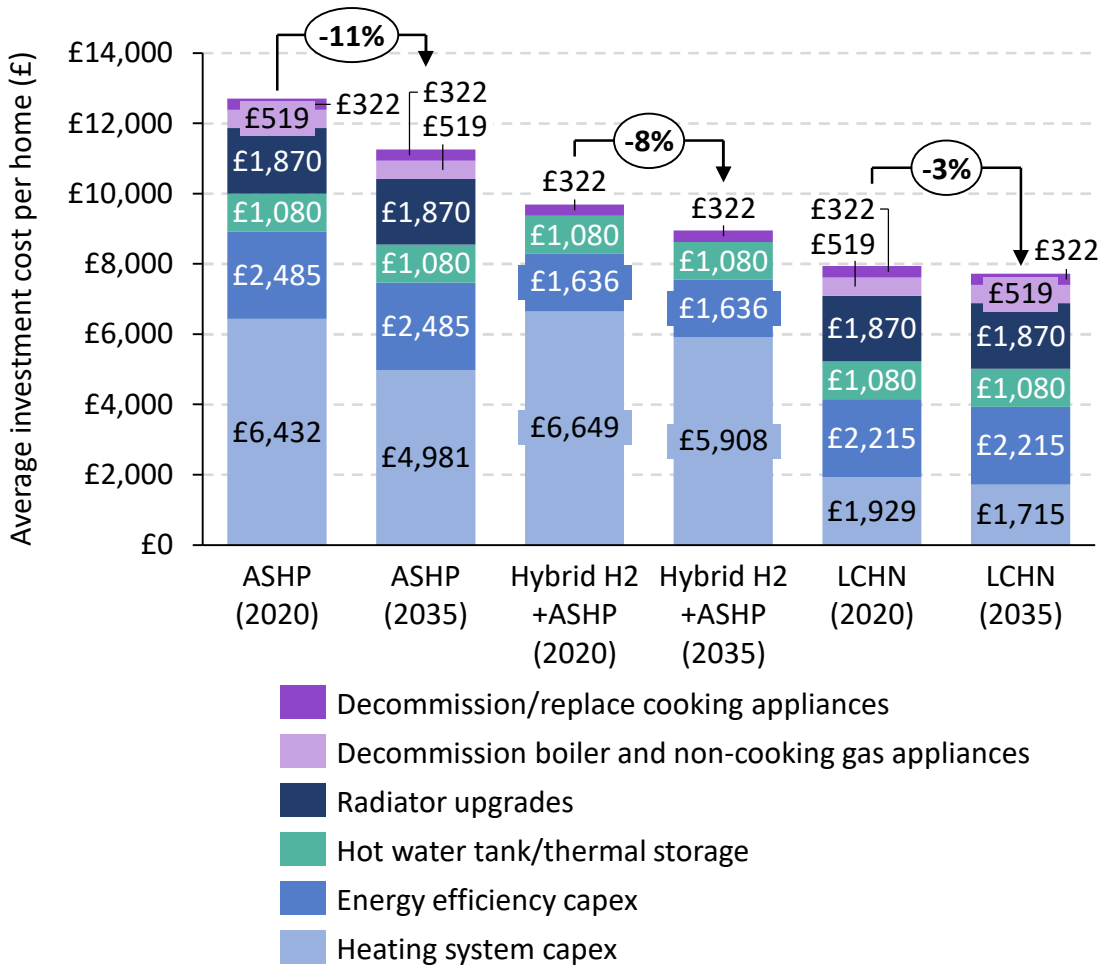
[1] Existing homes only

[2] Includes configurations with solar thermal

Discussion – average investment costs for households can vary substantially depending on the heating technology

- Across the stock, the average net investment per household in the Balanced Pathway scenario is £9,000.
- For an average household getting an air source heat pump and a suitable energy efficiency package, the total investment cost required in 2020 is just over £12,000.
  - This falls by £1,500 for a household upgrading in 2035, due to projected reductions in the capital costs of heat pumps.
  - The average size of an ASHP in the scenario is 5.4 kW.
  - In some instances, a buffer tank is also required when installing a heat pump. This would incur an additional cost of £300 for a medium-sized tank.
- For an average household connecting to a low carbon heat network and getting an energy efficiency package, the investment cost in 2020 is just under £8,000, reducing only marginally in 2035.
- Households may also require an additional investment for ventilation measures or shading:
  - £541 (extract fans, common)
  - £650 (high specification internal blinds, common in flats).

Average required capital expenditure[1] in Balanced Pathway for a home getting an air source heat pump (ASHP)[2], Hybrid ASHP and H_2 boiler, and a home connecting to a low carbon heat network (LCHN)[3], in 2020 and 2035

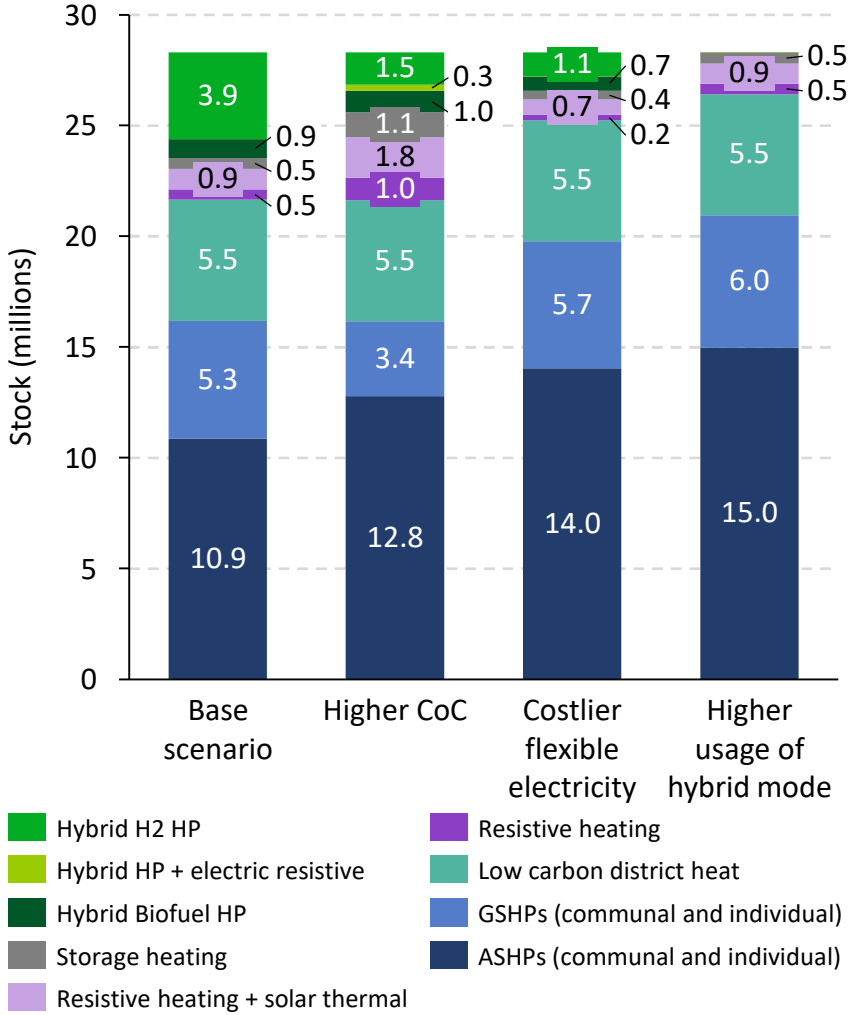


[1] Costs are absolute costs, not net costs i.e. the cost of a counterfactual system has not been subtracted. [2] HP costs correspond to the most common technology configuration rather than an average of all modelled configurations, which is only slightly different. [3] For low carbon heat networks, the heating system capex is the cost of a heat interface unit (HIU) and a heat meter

Discussion – slight changes to some of the assumptions can lead to significant differences in the technology mix, as a result precise technology mixes in the scenarios should be interpreted as illustrative

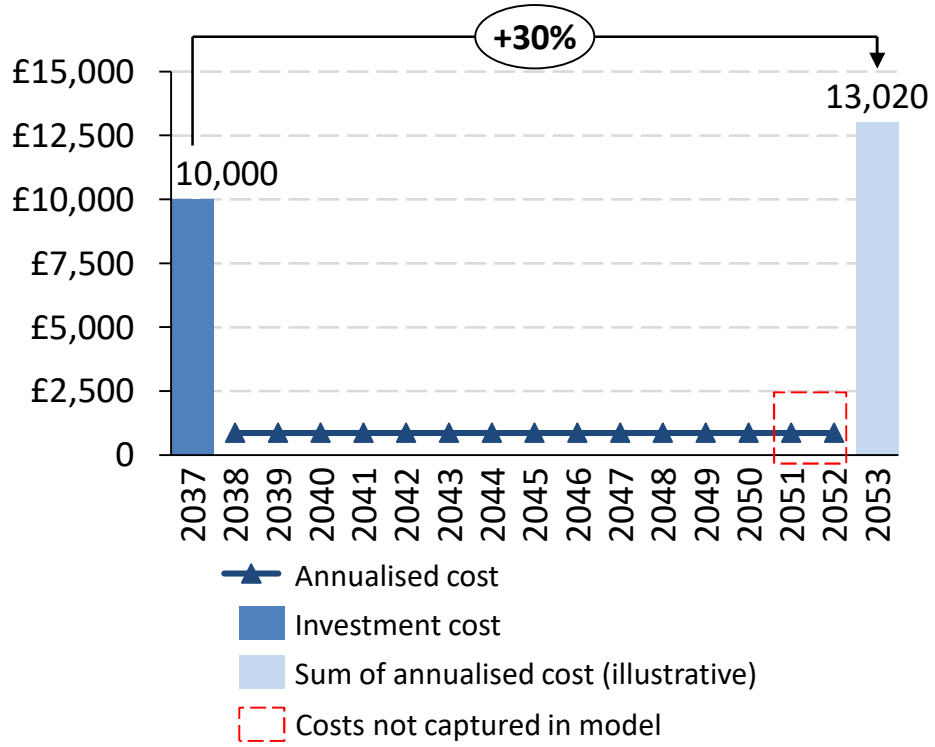
- To address some of the largest uncertainties in the analysis, several sensitivities were run to investigate the effect of different assumptions in areas where there is high uncertainty:
  - **Cost of capital (CoC):** A higher cost of capital increases annualised capex. With the discount rate fixed, the share of capex as a percentage of total costs increases. A higher cost of capital therefore favours lower capex technologies, leading to reduced deployment of hybrid H_2 heat pumps and increased deployment of electric resistive heating. ASHPs also become more favourable than GSHPs.
  - **Gains from flexible operation:** There is high uncertainty over the savings which could be gained from flexible operation of low carbon heating technologies. With lower savings (modelled as higher costs for flexible electricity), deployment of hybrid heat pumps – both biofuel and H_2 – reduces significantly in favour of higher deployment of pure ASHPs.
  - **Hybrid heat pump operation:** The operation of hybrid heat pumps – the percentage of time during which they will operate in heat pump mode versus hybrid mode – is also subject to high uncertainty. Modelling operation in hybrid mode 50% of the time (compared to 20% in the baseline case) leads to the cost-effective uptake of hybrid heat pumps falling from nearly 5 million in the baseline case to zero. The hybrids are replaced by conventional heat pumps, both air-source and ground-source. Accompanying measures such as smart controls are expected to be necessary to support effective use. Hybrid heat pumps are also identified by the CCC as offering a wider range of other benefits for the low-carbon transition.

End-state low carbon heating uptake in the Balanced Pathway scenario for selected sensitivities



Discussion – cost of capital and discount rate have a major effect on abatement costs but not on investment costs

- **Cost of capital:** a higher cost of capital (used in the Widespread Innovation and Tailwinds scenarios) leads to an increase in the annualised capex, disadvantaging technologies with high capital costs such as H_2 hybrid heat pumps.
- **Discount rate:** the discount rate is fixed across scenarios, at 3.5%, and is equal to the cost of capital except in the two above scenarios where it is lower. When the discount rate is lower than the cost of capital technologies with lower capital cost are favoured.
- Both the above factors influence the abatement costs, as those are calculated using the net present value of annual costs.
  - For technologies deployed after 2035, the annualised cost does not capture full lifetime costs but only costs up to 2050.
- Investment costs are unaffected by the cost of capital and discount rate since they are calculated in-year rather than annualised.
- The graph shows an illustrative comparison between investment cost and annualised cost:
  - For an illustrative £10,000 investment in a low carbon heating system assuming a cost of capital of 3.5% and a lifetime of 15 years, the annualised cost over the 15-year lifetime is £868. This rises to £1,133 with a cost of capital of 7.5%.
  - Summing the annualised cost over the lifetime gives a value of £13,020; this is higher than the investment cost by a factor of 30%, which is equivalent to the average discounting factor over the 15-year lifetime[1].
  - For a technology deployed after 2035, the portion of the annualised cost which occurs after 2050 is not captured in the model, as shown in the graph.
  - Total annualised costs also include fuel costs and opex (which are discounted using the discount rate), whereas investment costs only include undiscounted in-year capex.



[1] Discounting factor = $1 / (1 + r)^t$ where t is the year and r the cost of capital

Discussion – numerous factors drive investment and operational costs

Investment Cost

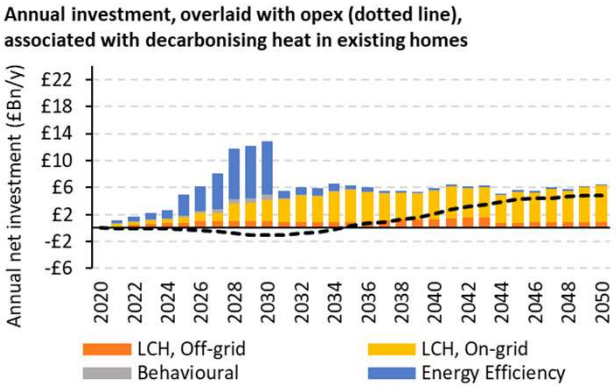
Investment costs are in-year values based on uptake of energy efficiency or low carbon heating measures/systems, affected by:

- choice of low carbon heating system and required system size (based on heating demand requirements),
- choice of energy efficiency package and applicable measures (based on existing insulation levels),
- year of uptake, particularly for low carbon heating systems which have cost reduction projections, and
- scenario, as this will affect the prices for measures and heating systems.

Operational Cost

Operational costs are in-year values required to maintain/achieve the heating requirements of the dwelling, affected by:

- heating system operational / maintenance costs (based on heating system choice),
- decrease in heating demand (based on level of fabric / behavioural measure uptake and climate warming),
- fuel type and level of use (based on the choice of carbon heating system and heating demand requirements),
- scenario, as this will affect fuel costs, and
- year in scenario, as this affects the fuel costs and level of climate warming.



Headwinds presents a unique case where there is a lower level of initial investment in energy efficiency and low carbon heating; however, this scenario is contrasted with higher energy demand and higher-cost fuel (H_2).

- With the lower level of energy efficiency, this scenario has minimal reduction in heating demand (i.e. that could offset high fuel prices).
- With similar heating demand and resulting required H_2 fuel use, this scenario sees a net increase in operational costs, with household fuel bills increasing (e.g. proportion of households paying <£1000/yr decreases from 52% to 41%).

Measures to address poor thermal efficiency, overheating, indoor air quality and moisture must be considered together when retrofitting homes [1/2]

- Whilst it has not been possible to undertake a detailed assessment of the overheating and ventilation measures which would need to accompany the scenarios, some indicative ranges of potential costs have been developed based on the housing stock.
- The below table sets out some of the shading measures which could help mitigate overheating risk. All costs are rounded to the nearest 10.
- These costs would be additional to the energy efficiency and low carbon heat costs discussed elsewhere in this slide pack.

Measures		Cost ranges for a large flat		Cost ranges for a typical semi-detached home		Total cost ranges where measures applied across stock to 2050	
		Min (£)	Max (£)	Min (£)	Max (£)	Min (£m)	Max (£m)
Low-regret (zero cost)	Existing curtain closure during the day to limit solar gains.	0	0	0	0	0	0
Medium intervention	Existing curtain closure during the day for all properties. In addition high specification internal blinds for all flats. Lower cost bound represents blinds with reflective backing, whilst higher bound represents blinds fitted to window which allow opening during use.	650	810	0	0	3,920	4,880
High intervention	Existing curtain closure during the day for all properties. High spec internal blinds fitted to all properties. In addition either external shading (external venetian blinds, roller screens or markisolettes) or external awnings fitted to all flats. Lower cost bound reflects the cheaper measures.	2,680	4,310	950	1,230	42,280	58,480

Source: CCC analysis based on evidence provided by the British Blind and Shutter Association

Measures to address poor thermal efficiency, overheating, indoor air quality and moisture must be considered together when retrofitting homes [2/2]

- It is critical to ensure that ventilation is considered as part of holistic home retrofits, to ensure that both indoor air quality and overheating risk can be addressed alongside carbon emissions reduction.
- The below table sets out a non-exhaustive list of ventilation measures which could help address indoor air quality and overheating risk. Other measures not costed (such as trickle vents) remain important components of in-home ventilation strategies.
- These costs are additional to the energy efficiency and low carbon heat costs discussed elsewhere in this report. All costs are rounded to the nearest 10.

Measures		Cost ranges for a large flat		Cost ranges for a typical semi-detached home		Total cost ranges where measures applied to relevant stock to 2050	
		Min (£)	Max (£)	Min (£)	Max (£)	Average (£m)	
Zero cost measures	Informed window opening including: - Opening of windows when room temperatures reach 22 degrees and fully open when indoor temperature reaches 28 degrees. - Windows remain closed if outdoor temperature is higher than indoor. - Night time ventilation through opening windows above ground floor during the night to purge heat. Ground floor windows shut for noise, security and air quality.	0		0		0	
Medium cost measures	Extract fans in kitchens and bathrooms installed where not already present.	540 [1]		540 [1]		~8,500[2]	
High cost measures	Lower bound reflects all homes which receive deep retrofits in the Widespread Innovation scenario having mechanical extract ventilation installed. Higher bound reflects these same homes having mechanical ventilation and heat recovery installed instead.*	1,670 [3]	3,340 [3]	2,060 [3]	4,120 [3]	14,030	20,620**

* This costing also accounts for non-deep retrofits (i.e. low and medium package uptake households) installing extract fans in kitchens / bathrooms where not already present

** A similar cost is realised in the Balanced Pathway scenario in the case where all homes which receive standard high packages install mechanical extract ventilation.

[1] Analysis Work to Refine Fabric Energy Efficiency Assumptions for use in Developing the Sixth Carbon Budget (2020). [2] Health effects of home energy efficiency interventions in England: a modelling study (Hamilton et al., 2017). [3] The costs and benefits of tighter standards for new buildings (Currie & Brown and AECOM) (2019). N.B. discussions with some technical experts suggest that these costings could be optimistic.

Policy recommendations [1/4]

The 'critical path' and a timeline for policy decisions

Low carbon heating

- The natural replacement cycle of heating systems is of the order 15-20 years. If scrappage is to be minimised, this implies the need for all new heating systems to be low carbon from the mid-2030s in order to achieve net zero by 2050.
- The scenarios have been developed to work within this natural replacement cycle as far as possible. The Balanced Pathway scenario is therefore based on a fossil fuel phase out date of 2033 for on-gas homes (with a range 2030 – 2035 across scenarios) and 2028 for off gas homes (with a range of 2026 – 2028 across scenarios). Whilst alternative regulatory approaches could be possible, they would need to deliver similar levels of ambition.
- The date chosen for on-gas homes in the Balanced Pathway scenario reflects a balance between minimising scrappage risks, remaining within supply chain constraints, and leaving time for energy efficiency deployment to be maximised in advance of fossil phase out. The earlier date for off-gas homes recognises Government ambition, and the fact that low carbon heating is more cost-effective and delivers higher carbon savings in these properties. The smaller number of such homes means the supply chain should also be able to deliver this at an earlier date.
- Whilst these phase out dates are assumed to apply to much of the stock in the Balanced Pathway scenario, there are some technologies (notably hydrogen and district heat) where uptake must necessarily be driven by geographically targeted switchovers rather than phase out dates. These technologies therefore follow geographically-led switchovers in the scenarios. On this basis, the scenarios imply that any homes in areas designated for hydrogen or district heat would need to be exempt from any regulated fossil fuel phase out before the switchover to hydrogen or district heat occurs. This in turn implies a need for areas to be designated as suitable for those solutions ahead of the fossil fuel phase out dates.

Policy recommendations [2/4]

The 'critical path' and a timeline for policy decisions (continued)

Energy efficiency

- An approach which works with replacement cycles for low carbon heating necessarily requires that homes have a sufficient and appropriate level of energy efficiency to ensure that low carbon heating is viable at reasonable cost by the time new fossil fuel systems are phased out.
- This defines the timeline for regulatory drivers relating to minimum standards of energy efficiency in the scenarios, as described on the next slide.
- The proposed fossil fuel phase out and regulations on minimum standards for energy efficiency would need to be set well in advance of the dates they will come into force, to provide a clear signal to the market and sufficient time to plan ahead.
- It will also be crucial for a comprehensive suite of support to be in place ahead of those dates to ensure affordability for every household.

Hydrogen and the gas grid

- Decisions on the future of gas grid across regions are expected to be required from the mid 2020s. Trialling, evidence gathering and analysis must progress in advance of this to facilitate these decisions.
- Fossil fuel phase out dates in the early 2030s mean that any areas to be converted to hydrogen (with conversion taking place from the 2030s) would need to be designated for hydrogen conversion well ahead of time. This is necessary for infrastructure planning and delivery. It also provides clarity over where any exemptions would be in place for fossil fuel phase out, in turn enabling effective planning for both energy efficiency and low carbon heat at a household level.
- Optionality exists over the role that Hyready boiler mandation could play in the transition. The scenarios assume mandation in the mid-2020s on a UK-wide basis, to minimise the potential cost of scrappage of gas boilers in areas of hydrogen conversion, but also in recognition of the economies of scale and cost reduction that would accompany widespread uptake.

Policy recommendations [3/4]

Regional and local approaches to decision-making

- Several components of the Balanced Pathway scenario will rely on a coordinated approach to decision making on the future of low carbon heat.
- Identification of areas suitable for deployment of heat network infrastructure, and the implementation of heat networks, will rely on coordination and decision-making at a local level.
- The decision on the future of the gas grid will likely need to be taken at a regional level. As described on the previous slide, the Balanced Pathway scenario assumes that some areas are designated for conversion to hydrogen before 2033, such that homes in those areas can be exempted from the mandation for low carbon heating systems from that date.
- It is also evident that the rollout of heat pumps would benefit from a detailed, coordinated plan for rollout at a highly local level, in order to plan and deliver required network upgrades without this becoming a constraint on deployment.

Policy recommendations [4/4]

Key regulatory levers and supporting policy measures

- Private and social rented homes are well suited to regulatory levers in the form of minimum standards for energy efficiency and/or carbon emissions, as is recognised by Government policy ambition – the Balanced Pathway scenario is based on a 'backstop' date of 2028 for all such homes to have a sufficient and appropriate level of energy efficiency to ensure that low carbon heating is viable and cost-effective.
- Owner occupiers are more challenging to reach using such levers.
- For owner occupied homes with mortgages, the Balanced Pathway scenario envisages strong incentives for lenders to drive a similar minimum level of energy efficiency by 2033.
- For outright owners of homes, the Balanced Pathway scenario is based on a regulation around minimum energy efficiency at the point of sale from 2028. This approach is already being considered in Scotland[1]
- As described on the previous slide, the scenario proposes a fossil fuel phase out date for all tenures, from which time all new heating systems must be low carbon – this is 2028 for off-gas homes and 2033 for on-gas homes.
- The intention of the scenarios is not to be prescriptive about how the regulations would look in practice (for example, whether minimum standards would be based on EPC rating, energy intensity per square metre, or the equivalent carbon based metrics) but rather to frame the level of ambition that is needed to meet legally binding targets.
- It should also be noted that, while not modelled explicitly, it is expected that a suite of policy measures to accompany these regulatory levers would be introduced. This includes financial incentives, price signals such as levies on fossil fuels and carbon pricing and a comprehensive package of support for supply chain and investment in skills and training.

[1] Energy Efficient Scotland: Improving energy efficiency in owner occupied homes