White Paper:
Overcoming challenges for new network connections

20th May 2021

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Date of issue: 20th May 2021

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Introduction

Obtaining electricity network connections for new housing developments is often constrained by the current regulatory investment methodology as well as by technical and other factors.

This is being exacerbated by increasing electrical demands arising from the electrification of heat and mobility to meet decarbonisation targets.

This can result in sub-optimal investment decisions focused primarily on short-term compliance workarounds, rather than lifetime performance on either environmental or economic grounds.

Today, in order to justify any network investment which is to be included within a DNO's regulatory asset base (RAB) there must be a demonstrable immediate need for network capacity. This means that, even if there is a clear future need for, say, an investment in a particular area adjacent to a site already under construction, unless an application is imminent, it is not permissible for the DNO to make anticipatory investments. This often results in sub-optimal network design (which is developed piecemeal rather than strategically) and results in long delays for new or upgraded connections.

Such delays may result in a project representing too high an investment risk for a potential developer and will at least result in increased costs being passed on from the DNO to the developer. It may even result in certain sites which might otherwise represent good investment opportunities becoming unviable to the commercial loss of the developer, but also to the detriment of communities which need additional homes, or to the environment if potential renewable generation cannot be connected economically.

Potential solutions in this area have been discussed over many years. However, the increasing urgency to both stimulate economic growth in the wake of the global pandemic and to develop sufficient numbers of low carbon homes have added a new imperative to the debate.

A number of actions are required including the development of implementable solutions to the specific regulatory, technical, economic and other obstacles. This paper explores these challenges and makes a number of recommendations.

Decarbonisation through electrification

UK decarbonisation targets are heavily dependent on electrification using low carbon energy sources. To some, the assumption of zero carbon electricity and its use in every possible application has become something of a mantra, regardless of the cost, deliverability or acceptability to consumers.

Direct electrification will remain the cornerstone of decarbonisation policy, providing a viable and effective solution to carbon mitigation in many applications. However, to support these applications and direct electrification, whole-system energy thinking is critical.

We need more homes for a growing population and an evolving demographic

One area where electrification is being promoted through policy and legislation is that of new build housing.

In order to meet the societal need for housing we need more homes and to meet the challenges of net zero we need them to be as near zero emissions as possible. As the primary form of low carbon energy today is low carbon electricity, this implies a need for easy electricity network access.

For housing developers, it is relatively straightforward to overcome the practical on-site challenges of heat pumps for example as they can be planned within the housing design. They thus avoid the space, disruption and other practical obstacles faced in retrofit installations.

But the increasing demand for electricity inevitably imposes additional demands on network capacity, which may not be readily available in the right place at the right time.

Even without the electrification of heat and mobility there have been challenges in this area. Often developments are significantly delayed, or additional costs imposed where networks are constrained. Given that new homes might have a peak electrical demand 2-5 times higher than previously, this challenge will become increasingly severe.

Why can we not simply plan the essential infrastructure investment in a timely manner?

The current regulatory regime does not effectively incentivise the DNO to meet these high peak demands, nor to invest in anticipation of this demand.

On the first point, although it is the transport of energy (kWh) which provides the income to DNO from residential consumers, their costs are determined by peak network capacity. Historically it has been assumed that there is a direct correlation between power and energy. This is no longer the case, and the cost of making new connections may increase significantly.

Already we have seen connection costs rising to well in excess of £10,000 per home in some cases. In one instance, a new housing development faced costs of around £6.8 million for the connection of 500 homes, representing a cost per home of £14,000, based on the specification of electric heat pumps to provide space and water heating. Taken together with the cost of the heating system itself, this clearly represents a significant additional cost which must be passed on to the house purchaser.

Interestingly this total cost per home is close to the estimated cost of building an entire microgrid including renewable generation, energy storage, controls and network infrastructure. This concept is described in more detail later in this paper.

On the second point, as noted above, for a DNO to include an investment within its regulatory asset base (RAB) there must be a demonstrable immediate need for network capacity. This often results in sub-optimal network design (which is developed piecemeal rather than strategically) and results in long delays for new or upgraded connections.

So how do we facilitate affordable new connections to meet the need for new low carbon housing?

The solutions will need to be pragmatic, and should include innovations in regulatory frameworks, creative approaches to the design and operation of networks and, most importantly should reflect whole energy system impacts, not just specific components of the system.

Technology solutions

Energy system impacts can often be minimised by considering the synergies between different components. For example, the high peak demand from heat pumps in mid-winter might be efficiently met by hydrogen fuel cells. The generation profile of the fuel cell aligns well with the electrical demand from the heat pump; both are aligned with the production of heat.

At the same time, generation from solar PV which might otherwise be a burden rather than an asset in summer (when electricity demand is low and generation is high), might be mitigated by EV charging scheduled to absorb excess solar generation.

Both of these examples and many more require system thinking, not a dogmatic, prescriptive approach to technology selection. Numerous studies have shown how a systems approach can not only be cheaper in terms of investment cost, but can also avoid many of the operational and implementation challenges of a single energy vector scenario such as 100% direct electrification.

TOTAL SYSTEM INVESTMENT	
Imperial College analysis for Committee on Climate Change	
Electric pathway	£92 bn/year
Hybrid pathway	£88 bn/year

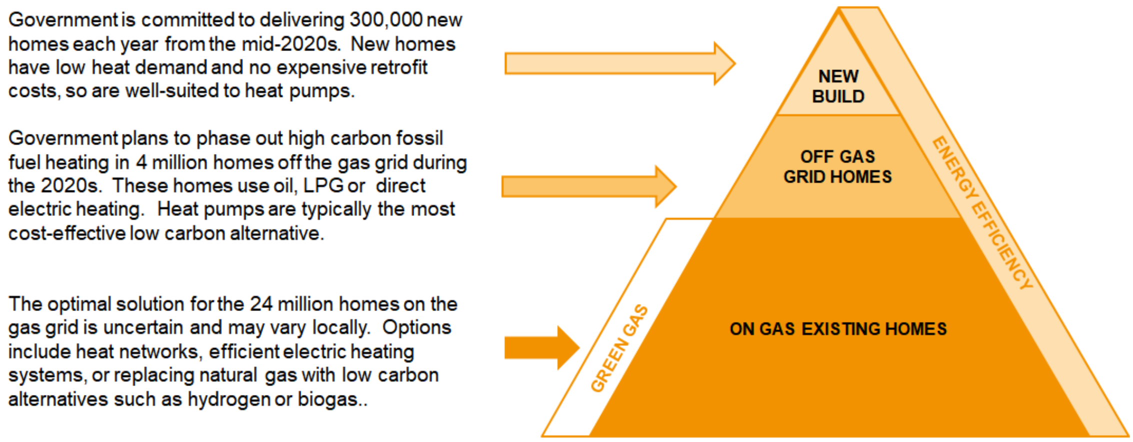
Figure 1 Total UK infrastructure costs for decarbonisation scenarios

Today this seems obvious. However, we should bear in mind that only a decade ago, the decarbonisation of heat through electrification alone was being pursued in UK policy as the default solution. It has taken some time for the potential of heat networks and low carbon gases to be recognised.

It is for this reason even if for no other that an approach which simply bans one solution on the basis that it faces difficulties today may not result in an optimised energy system. While it is dangerous to rely too heavily on unknown or unclear future developments to hit our net-zero targets, we need to properly consider probable and likely future developments. This paper explores these how future developments may help to overcome the challenge to network connections.

But haven't we already decided on technology solutions for new build?

The future homes standard does implicitly propose a ban on fossil gas in new build. But, considering the outcomes we are trying to reach, perhaps we should take a more nuanced whole energy system approach in cases where networks connections are a challenge. The UK government (BEIS) have developed a strategy for decarbonisation of heat visualised as a pyramid structure which considers three principal sectors to be addressed with low carbon fuels.



Source: BEIS

Figure 2 UK Government (BEIS) heat decarbonisation strategy

At the top are the new build homes which are currently open to whatever is deemed the "best" solution.

Next comes the off-gas grid homes which tend to be dependent on high carbon and expensive fuels such as oil and LPG.

At the bottom, the vast majority of homes, around 85% which are currently heated using natural gas central heating. Clearly this latter sector represents by far the biggest opportunity for carbon savings using lower carbon options including electrification or low carbon gas.

For off-gas homes electrification is somewhat easier to rationalise in that they already face higher than average fuel bills; for them the baseline represents less of a challenge. From a deliverability perspective, it is also more likely that these homes, often in rural locations, will have more space available to implement solutions which are virtually impossible in many urban homes.

Which leaves us with the new-build sector. It is easy to see how tempting it is to focus on this sector as one where gas should be avoided. Indeed, electrification is an obvious route in situations where electricity network capacity is readily available, but as we have already pointed out, this is not always the case.

We will consider now alternative approaches which might be more appropriate where electricity networks are constrained.

Is there a role for gas in mitigating electricity network constraints?

Some assume that the gas network will continue to supply natural gas at a carbon level inconsistent with our emissions goals – and therefore should not be used at all in buildings. This may be unduly pessimistic.

Against the expectations of many, the UK electricity system has demonstrated remarkable rates of decarbonisation. It continues to do so.

Might we not expect a similar decarbonisation of our gas supply? This depends on four factors which must all be met.

- The availability of low carbon gases in sufficient quantities so that it can be used to decarbonise sectors where other solutions are not available.
- The affordability of low carbon gases.
- A suitable gas distribution infrastructure.
- Appliances which can run on low carbon gases, specifically hydrogen.

The gas infrastructure decarbonisation roadmap?

The recently published UK Energy Networks Association (ENA) hydrogen roadmap sees that over the period of 2025 – 2030, hydrogen-ready boilers start rolling out at ~1.5m / year. At the same time, we expect increasing blending up to 20% hydrogen within the gas mix, as well as large pilots of 100% hydrogen in homes.

By 2035-2040, wide domestic conversion begins – shifting from low carbon blending to 100% hydrogen.

This is one of a number of hydrogen deployment scenarios (others include those from the CCC, National Grid) that see rapid deployment of hydrogen in residential buildings.

Gas infrastructure is already being upgraded through the IMRRP, and by 2032 will have invested £28bn in creating a hydrogen-ready gas grid across the country.

The ENA has published a credible roadmap which sees the full decarbonisation of the gas network by 2050. Indeed, we are already seeing rapid progress in the development of hydrogen and other low carbon gases, although we are still at the early stages of this journey and many uncertainties remain.

Taking a hybrid system approach

Although proscribing gas in new housing might eliminate one source of emissions at the point of use, the exponentially higher demand for electricity to power heat pumps during extreme cold weather will result in relatively high peak demands. This is a challenge both for the network and for peak generation which tends to be higher than average carbon.

Even as space heating demand falls and this issue becomes less of a challenge, the lower performance of heat pumps in providing high temperature domestic hot water (DHW), an increasing demand, presents similar challenges. However, although the COP in producing high temperature DHW is low, at least it is possible to shift its production to mitigate peak demand and as an added benefit, to lower carbon periods, provided that the home is equipped with a suitably large hot water cylinder.

This problem can also be alleviated by using hybrid technology. Trials of hybrid heat pumps which provide the majority of their heat using an electric heat pump, but which use gas boilers to avoid electricity demand during peak demand periods are proving rather successful at an individual house level.

This hybrid approach might also be considered at a system level, as mentioned earlier. We might see some homes with electric heat pumps and others with (low carbon) gas fuel cells or even packaged together as "super-hybrids", providing valuable flexibility to the wider electricity system.

Today this might seem an exotic and expensive solution, but we have seen significant developments in fuel cell technology recently. These are likely to be further encouraged to meet the development of green (electrolysed) hydrogen production which uses broadly the same technology. In this context it therefore seems premature to proscribe new gas connections which might supply these technologies either now or in the future.

Will new homes need that much energy for heating?

We have seen significant reductions in the demand for heat in homes over the past decades as insulation standards have continued to deliver better performance. Whilst there is still room for improvement, many homes being built today will have negligible demand for space heat.

Indeed, DHW will represent a larger proportion of the total heat demand than space heating. Although it might seem like a minor technicality, the performance of heat pumps in delivering the high temperatures required for DHW is not as good as for low temperature space heating. Again, it is for this reason that hybrid heat pumps are able to deliver significant savings by meeting this high temperature demand.

As insulation standards improve and demand for DHW continues to rise, the proportion of heat for space heating continues to fall. Accordingly, the need for the low-grade heat which the heat pump provides so well falls with it. Already some developers building to passive house standards which require virtually no space heating, are meeting that residual demand using direct acting electric heaters and providing DHW with instantaneous gas boilers.

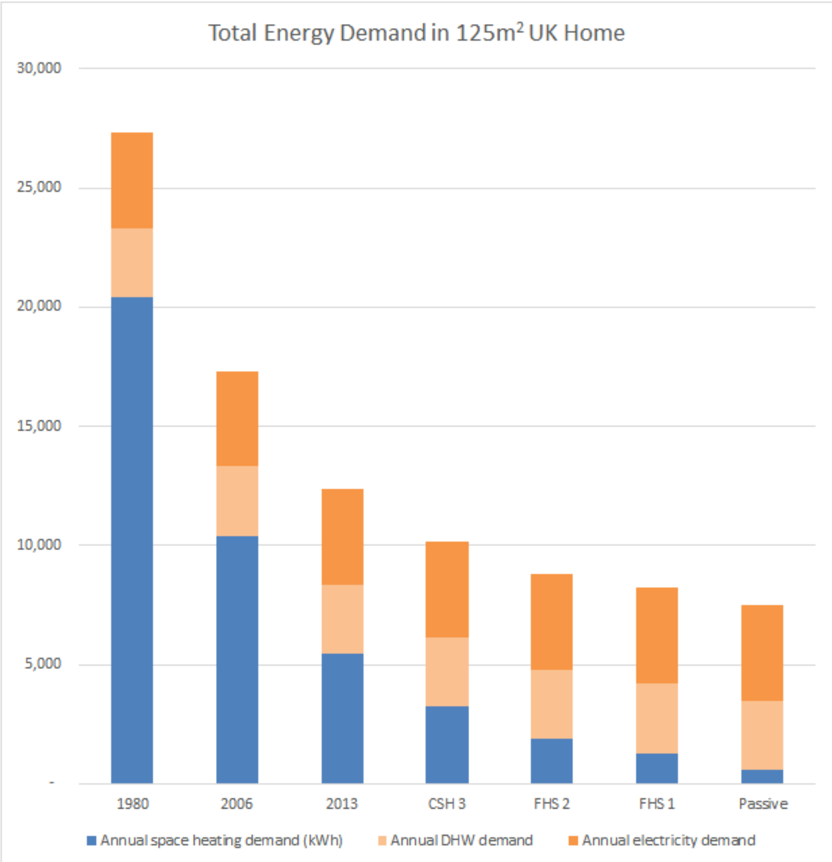


Figure 3 Space heating demand has fallen dramatically over the past few decades. Today DHW dominates thermal demand.

Is it worth providing a gas connection to supply such a small demand?

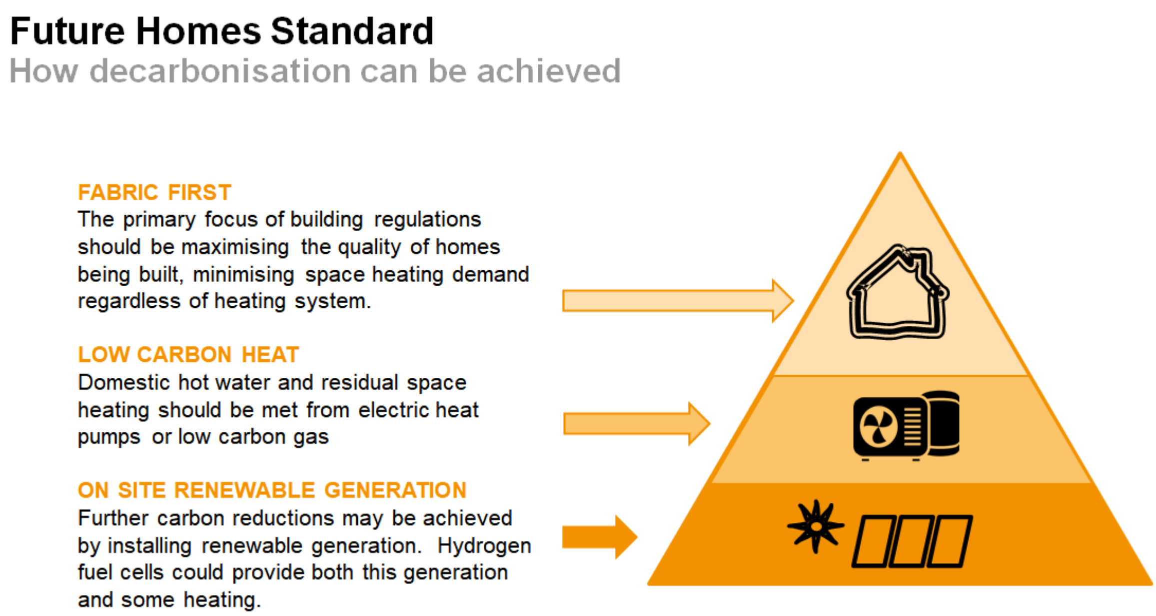
All this does rather beg the question as to whether a gas supply, supplying low carbon gas to meet our decarbonisation goals, will be economically viable for well-insulated new homes. On this point it seems logical to let the market decide. Housebuilders are sensitive to the demands of prospective purchasers and will respond accordingly. If it is deemed to be commercially desirable then it will happen, if not then not. There seems little reason to impose a statutory ban to enforce such a market decision.

It also raises questions regarding the appropriateness of hydronic (radiator based) heating systems at all in new build housing. Should we not be focussing on fabric to minimise heating requirements as described in the next section. And whatever fuel or heating appliance is specified, it will perform better if it feeds into a low temperature heat distribution system. This applies to heat pumps, (low carbon) gas boilers, fuel cells, and heat networks, the contenders for mass new-build housing.

What other technology solutions are there?

Although (low carbon) gas offers one potential solution to reducing the necessary capacity of network connections where electricity networks are constrained, others are also available.

We noted earlier the trend towards ever lower space heating demands, resulting from building better insulated homes including efficient ventilation systems.



The Future Homes Standard proposals for further improvements are a step in the right direction. However, new homes built today will all still be around in 2050 by which time we are expecting to achieve net zero carbon.

At least the focus on “fabric first” approach remains, addressing concerns that some developers might depend on low carbon heat technologies to achieve compliance whilst providing lower insulation. However, there is still some way to go in achieving passive house standards which not only virtually eliminate space heating, but also provide much enhanced thermal comfort and healthier homes with very low running costs.

But it is not just heat which poses the challenge for electricity network connections

Leaving aside the challenge of mitigating peak electrical demand for heating, we are still left with the electrical demand for other uses.

When considering electricity demand on the network we need to consider two factors. The total annual energy consumption which provides the basis for DNO revenue, and the peak demand which drives the DNO investment cost.

The annual energy demand from appliances within the home can be minimised by installing more efficient appliances, but this has already become common practice; there is little room for significant further improvements.

The opportunity for solar PV

A 3.5kW system in the south of England will produce ~3,700 kWh per year. Although solar PV generation aligns poorly with typical UK demand profiles, it is the simplest technology to install in most homes and importantly provides generation capacity within the low voltage network.

Solar Energy UK estimate the potential for ~300MWp annually as the solar PV potential on new build homes in England by 2024.

This new build capacity forms the majority of annual installed capacity needed to meet an estimated required UK rooftop capacity of 12GW for net zero by 2030 (from 3.2GW installed in 2019).

Home generation, such as solar PV, can play a role in further reducing electrical **energy** demand from the grid over the course of the year. Unfortunately, its contribution in winter to meet space heating is relatively trivial and it is unlikely to play a significant role in reducing electrical **power** demand.

Indeed, it is believed that in many cases the DNO makes no allowance for this potential contribution. Anecdotal evidence suggests that in some cases, where the DNO imposes limits on the installed solar PV capacity or requires that any PV generation is consumed within the home or otherwise curtailed from export, devices are installed which simply dump this electricity.

If we are to benefit from this potential source of renewable generation, we will need to provide adequate network capacity to accommodate its transfer between prosumers and consumers. It must not simply be wasted.

The importance of demand response

From the power capacity perspective, although having little impact on the annual energy consumption of the home, there are measures which can reduce the peak demand and hence the cost of the connection.

It is quite possible to manage the timing of loads using demand response approaches which shift loads from peak demand periods to times when the network is less constrained. As noted above, this can be further enhanced if additional energy vectors are included, particularly when those fuels are used to generate additional electricity within the home. These solutions provide the highest levels of flexibility.

By optimising on-site generation, demand response and efficiency measures together, it should be possible to significantly reduce the nominal connection capacity of a new home. If this can be achieved, the solar powered home may come closer to balancing on site generation and consumption over the course of the year.

The application of electricity storage in the form of batteries, whilst currently expensive, does hold considerable promise, increasing value to both the consumer and the system, reducing network impacts:

- It reduces import of electricity from the grid by increasing self-consumption of solar generation
- It can reduce export at peak times and reduce peak demands if properly managed. Already today, some housing schemes are using demand response co-ordinating BESS and electricity demands to minimise impacts on the network. However, this has yet to be recognised in network design nor reflected in regulatory rewards
- It can provide a new source of system flexibility and a potential income source for households
- It can increase autonomy even to the extent of providing a back-up power supply in the event of grid failure

But we will still face increased connection ratings as electrification accelerates

Regardless of the technology solutions outlined above, there is likely to be an increasing demand for electricity as we see heat, mobility and working from home all impose additional demands on the network. Indeed, our increasing dependence on electricity exacerbates the huge technological challenges on the other side of the supply/demand equation from the increasing levels of intermittent renewable generation embedded within the distribution network.

Even in the unlikely event that there was no additional demand, we would still be faced with the existing challenges of recovering the cost of asset investment by the DNO.

As noted earlier, under current conditions, any network investment which is to be included within a DNO's RAB must demonstrate an immediate need for network capacity.

It is encouraging to see that OFGEM has already initiated change in this area, including proposals for shallow network charges which only require developer contributions for the immediate upgrade rather than indirect upgrades higher up the system.

However, there remains scope for additional more innovative measures such as:

- Forward planning. Encouraging the DNO to reflect housing developer plans more fully into their forward planning.
- Incentivise system optimisation (e.g. locational pricing)
- Cost reflective system charges. For example, basing incentives around capacity, rather than volume of electricity supply.
- Consider innovative regulatory approaches to communally owned assets
- Encourage commercial enterprises such as microgrid as a service
- Allow Energy Communities to work collaboratively. For example, incentivising the co-ordination of new DER (generation) aligned with new housing (load) developments.
- Facilitate private wire networks and new approaches to competitive supply for co-operatives, including a review of the current de minimis limits for supplier exemption.

Can we avoid network connections altogether?

So far we have discussed fairly well established technology solutions to minimising the rated capacity of and thus facilitating new network connections. However, there are other, more innovative technology solutions such as microgrids which may overcome the connection issue altogether.

A microgrid is a small energy system of interconnected loads and distributed energy resources (DER) within a clearly defined boundary, and with a single point of coupling to the wider electricity distribution grid. Such a system is designed to make optimum use of locally available resources to match the demands from within its boundaries. They are capable of operating either in parallel with the wider grid or in so-called island mode, so provide a significant additional level of resilience to their consumers. For this reason, they are widely used globally and are of increasing interest in areas, such as California, where the grid is unreliable and fails to provide the desired level of resilience.

However, whilst they are capable of operating completely disconnected from the grid at all times, there are significant benefits in retaining some degree of connectivity. There are economic benefits arising from an additional source of revenue for services provided to the grid, and from reducing the energy storage requirements within the microgrid.

The ability to disconnect at times of stress, however, does mean that microgrids need never impose a capacity burden on the distribution network. That is, their connection will always be beneficial, never a burden. In the extreme case of 100% island operation, it would in principle be possible to develop a new housing site regardless of the availability of the distribution network. However, it must be emphasised that the optimal economic model will almost invariably involve connection with the wider energy system.

Interestingly, the potential of such systems which may operate as private wire networks owned by the community also opens up some highly innovative business models where residents might enjoy capped energy prices for their lifetime based on their ownership of their local energy system.

It also means that the developer will have complete transparency of the infrastructure costs involved. It is for this reason that we are already seeing the emergence of pilot schemes here in the UK where generation from locally available DER is available to match community demand.

What other costs are involved?

So far we have focused mainly on infrastructure costs, for it is these which are directly relevant to the question of achieving new connections; they will of course be passed on by the builder to the homeowner.

However, we also need to be mindful of the cost of the heating or other energy technology within the home, which also affects the overall cost of the home.

The following table shows typical costs for the installed appliance and its associated infrastructure costs, although it should be noted, as mentioned earlier, that these can vary enormously depending on available network capacity.

Appliance	Installed cost of appliance	Infrastructure cost	Total cost per home
Natural gas boiler	£2,500	£300-1000	£2,500
H2 boiler	£3,000	£500-1200	£3,000
Hybrid heat pump	£6,500	£600-2000	£7,800
Electric heat pump	£7,500	£1200-2400	£9,300
Gas heat pump	£10,000	£300--1000	£10,000
PEMFC m-CHP	£12,000	£300-1000	£12,000
Heat network	£2,000	£8,000+	£10,000

Figure 4 Typical current heating appliance and infrastructure costs (Source: Delta-EE research)

Of equal importance, we need to consider the running costs of any system proposed. This will comprise the costs for space heating, DHW and general electricity use within the home.

To make the comparison simpler and fairer, we consider a whole of system and whole of life approach. We addressed the total energy system impact earlier in this paper and showed clear benefits from balanced or hybrid scenarios.

Here we will consider the Levelised Cost of Energy (LCOE) from space and water heating from the householder perspective. The following graph illustrates the LCOE for a selection of technology solutions and for a range of house demands. Note that there are many assumptions and uncertainties involved and this graph shows just one scenario.

While the findings should not be used as a forecast, they do illustrate an interesting point: no one solution is consistently cheaper. The optimum solution depends on the thermal demand of the property.

In this scenario, even excluding infrastructure costs, hydrogen boilers appear to offer the cheapest form of heating for homes with an annual thermal demand of less than around 11,000kWh. This represents the vast majority of new build homes.

However, this option will only be relevant in those cases where hydrogen is available at the anticipated cost and with sufficient abundance that it can be used in buildings as well as other sectors which are even harder to decarbonise.

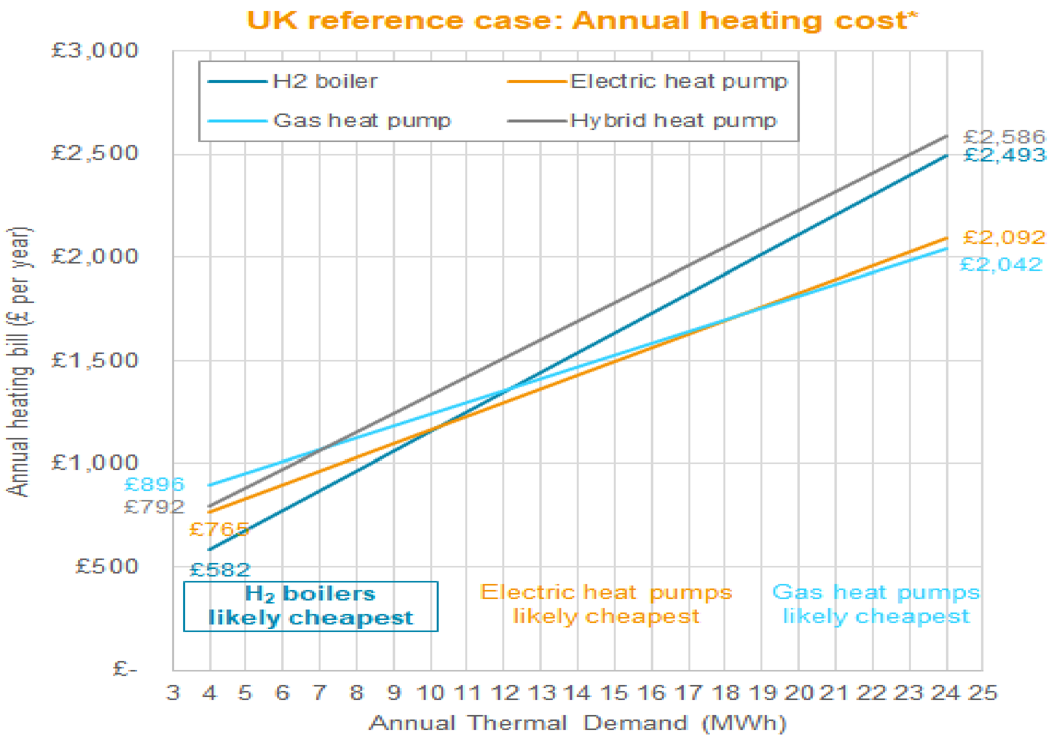


Figure 5 One scenario for LCOE of alternative heating systems for UK homes; assumptions include basing hydrogen prices on anticipated 2030 costs, before which time hydrogen will have very limited availability.

In the short to medium term, as discussed earlier, it would be wise to take a balanced approach that considers the range of solutions to network connection challenges, the wider energy system impacts and the potential synergies between technologies.

Conclusions and recommendations

Housing developers are increasingly facing situations where new electricity connections are either not immediately available or not affordable. This situation is being exacerbated by increasing capacity demands from the electrification of heat and mobility.

The recommendations below are intended to address this one specific area of challenge:

- Regulatory reform for network investment permitting forward investment
- Building regulations for new housing which focus on fabric first, but which also consider an evolving role for low carbon gas as an energy vector to optimise the whole energy system
- Technology innovations including microgrids, demand response and energy storage

Throughout this paper, we have been discussing solutions consistent with the UK government's stated 2050 targets and policy recommendations.

The recommendations in this paper should, if implemented, help to deliver on those targets at the lowest economic cost.