The cost of a 60% cut in CO2 emissions from homes: what do experience curves tell us?

Mark Hinnells

Abstract
The UK has a target to reduce CO2 emissions by 60% by 2050, and is pressing through the G8 that this target be adopted more widely. Such cuts in CO2 imply significant policy and technical change. The Buildings sector accounts for around 22% of UK Greenhouse gas emissions and is therefore an important sector which would see dramatic change if this target is to be achieved. One vision of how emissions might be reduced to 40% of current levels is described in the 40% House report.

However, the report did not discuss the costs of implementation for a number of reasons, eg because the costs of energy and investments could change radically over such a long period. Whilst many technologies to reduce CO2 emissions from buildings are currently expensive, current cost effectiveness is not a good guide to future cost effectiveness.

The literature on how cost of a technology reduces with time (variously described as technology learning, experience curves, and ‘learning-by-doing’) is reviewed. There is a significant amount of literature in renewables (especially at large scale) but little in building integrated renewables or CHP, or in energy efficiency. There has been little use of experience curves in the UK (though wide use in the US, Europe, Japan and at IEA level). The possible reasons for this are discussed.

The cost of a technical change is strongly dependent on a number of factors, which are explored in the paper. In particular, policy plays an important role in the cost of change, and in allocating the cost between public sector and private investors.

The change in cost effectiveness for a range of building integrated renewables, CHP and energy efficiency technologies is discussed. Under a 40% House scenario, experience curves and energy price scenarios suggest dramatic changes in cost effectiveness, bringing the payback of measures down to very reasonable levels, thus making the scenario plausible.

The paper covers a range of themes of interest to the conference including: moving to a low carbon economy; demand policies; Technology and innovation; and incentives versus regulation.
1 Introduction

The UK has a target to reduce CO2 emissions by 60% by 2050, and is pressing through the G8 that this target be adopted more widely. Such cuts in CO2 imply significant policy and technical change. The Buildings sector accounts for around 22% of UK Greenhouse gas emissions and is therefore an important sector which would see dramatic change if this target is to be achieved. One vision of how emissions might be reduced to 40% of current levels is described in the 40% House report.

However, the report did not discuss the costs of implementation. This paper seeks to explore costs and benefits of 40% House through expected changes in demand for energy in these households, changes in energy price and externalities, and in particular, through experience curves. Whilst many technologies to reduce CO2 emissions from buildings are currently expensive, current cost effectiveness is not a good guide to future cost effectiveness. Experience curves in particular may inform the assessment.

2 A step change: the 40% House

40% House (Boardman et al 2005) postulated an internally consistent scenario whereby emissions from the UK Housing stock could be reduced to 40% of current levels, even with a 33% increase in the number of dwellings by 2050, as well as an expectation of more heat, more hot water per person, and a greater penetration of appliances. To achieve this reduction, under this scenario, requires:

- A fourfold increase in the demolition rate and replacement with new dwellings. The demolition rate is historically very low at present and demolition rates are assumed to return to levels seen in the 1960’s. New build is assumed to achieve close to zero net space heating energy use by 2020 at the latest;

- A step change in efficiency of existing dwellings through refurbishment (See Figure 1. This implies a move from an average SAP rating of 51 currently to around 80, excluding improvements due to the heating system. This implies all buildings have super-insulated windows, all cavities are filled and most solid walled properties remaining have external wall insulation).

- Perhaps the most challenging proposition was that the dominance of the gas central heating boiler is broken, and instead, around 53 million low and zero carbon technologies (LZC) would be installed, equivalent to around 1.7 per dwelling (Figure 2). LZC provide heat and, or, electricity from devices which are integrated into the building or community (such as CHP, PV, solar thermal, building integrated wind, heat pumps etc). The scenario was based on a patchwork of studies of the potential for each technology in particular markets, aiming at the majority of energy being provide from LZC by 2050. In the particular scenario put together, 80% of heat and 110% of electricity was generated in LZC. A growth in uptake of 30% p.a. was assumed– as fast, but no faster, than historical growth rates for new energy technologies such as nuclear and renewables.
In terms of lights and appliances, the two crucial changes are that all lights are light emitting diodes (LED) because of their efficiency as well as lighting quality, and all refrigeration appliances utilise vacuum panel insulation, which reduces heat gain by these appliances to one-fifth of current levels.

Around two-thirds of the carbon saving in this scenario come from energy efficiency measures, and around one-third came from LZC technologies. Of course, this is not the only way of achieving a reduction in emissions to 40%, and it is, in no way a forecast. But it illustrates the level of change needed to achieve this scale of reduction.

A set of policies were proposed that could transform the market and bring this scenario about, based around information, incentives (support for innovation), and regulation (appliances standards and building standards). Cost effectiveness at commercial rates is not necessarily required to deliver it.

However, no attempt was made to cost this scenario, for the following reasons:

The financial costs and benefits of particular technology adoptions in future scenarios are difficult to estimate, both in principle and in practice, for a number of reasons:

- The cost of any given technical improvement is not a given, but strongly dependent on policy (Hinellls and McMahon 1997).
- The cost of any given technical improvement is dependent on the timescales for implementation. If changes can be made to fit with natural product improvement cycles, changes can be met at much lower, zero or even negative costs.
- The cost of future technical options is not fully known and will depend on a wide range of factors which determine economies of scale.
- Cost, both initial and life-cycle cost, is not the only criterion on which consumers base their decisions. A number of other factors, including the level of service, style preferences and availability, all come into play.
- The cost/benefit of external effects is unclear, ie the societal value of a tonne of carbon saved varies with projections of climate change and timescale. The value in 2050 may be very different to current expectations.

Although costs and financial benefits are of importance, particularly on shorter timescales, they were considered to be a second order effect in terms of the modelling, particularly given the inherent uncertainties that exist over a timeframe of 50 years. The main drivers of policy over this time will be factors such as population, household numbers and household size, building and demolition rates.

The aim of this present paper is to begin to explore costs and benefits of the scenario, through expected changes in demand for energy in these households, changes in energy price and externalities, and in particular, through experience curves.

### 3 Changes in energy demand from homes

Reductions in energy demand from homes may affect the cost effectiveness of LZC. Figure 1 shows the change in useful energy demand under the 40% House scenario, to
2050 compared to the 1996 stock average. Whilst there is expected to be a significant reduction of space heating through improved insulation, some of this is taken as an increase in temperature. Hot water demand is not expected to decline. In all, there is a reduction of 35% in 2050 in useful energy demand compared to today. The remaining reductions in emissions are made through more efficient provision of heat and electricity through LZC. The impact on cost effectiveness of LZC may be that gradually over the period:

- the running hours to provide the heat could be reduced, thus reducing the savings from LZC, or
- the size of a given LZC installation could be reduced, thus making some saving in capital cost compared to a device needed for a given installation today.

If it is assumed that over the timeframe and across the portfolio of technologies these two effects might be about equal, then the value of the savings from LZC that supply heat (but not electricity) could deteriorate by around 18% by 2050.

**Figure 1: Useful energy demand from homes 1996-2050**
4 Changes in energy price

Projecting energy prices over a long timescale is clearly contentious. Oil is used as an indicator since there is a good correlation between oil and gas prices and between gas and electricity prices. Figure 3 shows history to be littered with oil price projections that haven’t come true. There is uncertainty over demand (eg rates of growth in demand in China, or growth in demand for aviation); supply, with many energy producing regions unstable; and in conversion (eg new power generation technologies). The graph only goes out to 2020. By 2050, scarcity may have a much bigger effect on price.

Figure 3 Oil prices actual compared to forecast (1970 to 2020)

As well as price, there is the extent to which external costs (eg cost of climate change) might be internalised through for example, emissions trading or carbon taxation.

It is thus possible to envisage a scenario where the real value of the fuel savings doubled in real terms to 2050. This is not a prediction but a scenario, and might be through

- changes in energy prices
- carbon taxation
- cost reflective pricing (eg changes to use of system charges to reflect real use of the network of electricity generated locally)

5 Experience curves

5.1 What are experience curves

Experience curves are also known as technology learning and in some literature as ‘learning by doing’. In the management literature, and in common parlance, the phenomena are also known as learning curves. In essence, the theory goes, for every doubling in global installed capacity or sales, there is a corresponding reduction in costs which is remarkably consistent for a given technology over successive doublings. If plotted over a log/log scale (eg price against volume of sales) the relationship becomes linear (Figure 4). The slope of the line is known as the progress ratio.

The phenomenon has been observed for a wide variety of products, technologies and industries over a period of time. It first made significant appearance in the management literature with Boston Consulting in 1968. Progress ratios average around 82% (i.e. prices decline to 82% of former levels after each doubling), however, progress ratios have been observed between 60% and 95% (Figure 5), with
only one observation of costs increasing with volume (in the airline industry and put down to changes within the company that led to a loss of learning).

**Figure 5 Progress ratios across 108 case studies**
(in IEA 2000, adapted from earlier work)

The literature (especially IEA 2000) describes a number of modifications to this theory including:

- **Learning** may apply at different rates to different elements of a technology. For example, with combined cycle gas turbine technology, there could be a different progress ratio for gas turbines as opposed to steam turbines (because achieving a doubling in capacity of steam turbines is harder than a doubling in gas turbines); or for PV there could be different progress ratios for installation costs, electric interface costs (which may be common to more than one DC generation device) and device costs.

- The main effect is a global one, since learning is global in nature, though there can be a limited national effect where, for example, there is little experience in a country, the country can enjoy a faster progress ratio for a short period, or where learning processes are different (Kamp et al 2004).

- The evidence appears to be that the progress ratio is similar across many doublings, but this may not hold true across whole range.

- There can be discontinuities or changes in progress ratio as a result of a change in technology (eg if PV were to move from silicon cells on glass, to say titanium technology on a polymer substrate). Progress can be held back because of market imperfections – eg one can see that with light pipes, patents preventing new market entrants. Once patents expire, learning should be rapid for a period with new market entrants.

- The theory applies to costs not prices. Whilst costs may fall, prices may not be cost reflective for many reasons (lack of competition, profit-taking, currency fluctuations, cost of borrowing). Often, research which covers a range of products from competing manufacturers has to be based on price not cost. Cost data would simply be unavailable for commercial reasons. This is clearly a drawback in the evidence base.
5.2 Predicting breakeven point

One of the uses of experience curves is to predict the point at which investment could become cost effective compared to an incumbent technology (for example, when might PV be cost competitive with fossil?). Figure 6 (from IEA 2000) shows that taking historical data for PV and projecting forward, and assuming that the alternative is fossil plant at 0.5US$/Watt (peak), the ‘learning investment’ (the additional cost per kW times the number of kW) is the shaded triangle. For PV, the learning investment is estimated at US $60billion. One could also impute that (again based on IEA 2000) with historical annual global growth rates of 15% or thereabouts, break-even could be around the year 2025. However such a projection is fraught with difficulty. Progress ratios may vary for technical or market reasons, and even a small change (given the scale below is a log scale) implies a large change in break-even point. The range in estimated learning investment is from US $40 billion to US $120billion. In addition, the cost of the alternative is changing with time. In particular, capital cost of the alternative might mean very little if fossil fuels change in price through scarcity or through taxation on carbon.

At some point along this learning trajectory, a technology may not be fully commercial, but its prospective costs and performance might be sufficiently attractive prompt market actors to risk their own learning investments. This point is described in the literature as the docking point. Before this point, it is assumed that private investors would be put off by risks, and so public support is needed if a promising technology is to develop. After this point, it is assumed that private investment (perhaps underpinned by public policy such as building standards, no cost to taxpayers, transferring the cost to the investor) is sufficient. Policy thus determines whether public money or private money contributes to the ‘learning investment’.

Figure 6 projected breakeven point for PV (source IEA 2000)

5.3 What drives learning?

There is little or no attempt in the literature to explain what constitutes ‘learning’, or to allocate relative importance to different factors. The literature simply maintains that what is observable is more than simply economy of scale. This lack of evidence is not
surprising. To unpack the relative contribution of different elements in a range of competing products over time would need access to commercial data.

In this paper learning is taken to be a complex interaction of

- Development of a mature regulatory framework for installation and use
- The reduction of technical and commercial risk with increased learning
- Reduced risk means reduced cost of finance and insurance
- Amortisation of R&D and tooling
- Economies of scale (ranging from increased buying power for raw materials to establishing volume manufacturing facilities)
- Value engineering (in which there is a whole profession, taking cost out of products and maximising functionality, - see for example, [http://www.value-eng.org/](http://www.value-eng.org/))
- A good understanding of how products fail, and redesign to reduce failure rates in products, together with reduced product returns, litigation, and reduced customer dissatisfaction
- Learning in the supply chain, and increased ability to contract out elements of production and installation
- A reduced need for marketing as customers understand what a new product (like micro CHP) does
- A trained installation and maintenance force
- Competition in supply, leading to continual innovation to differentiate between products, often on the basis of price
- Learning processes in different countries and markets (Kamp et al 2004).

To illustrate the complex interaction of issues, compare a gas boiler (£800-1000 off the shelf) and Stirling engine micro CHP at the present time (£3000 off the shelf).

Boilers are well understood in terms of risks (eg of explosion and carbon monoxide poisoning) and the regulatory framework is stable; they are made in volume; have been through umpteen redesigns and benefited from a huge investment in value engineering; boilers needs no marketing because everyone understands what a boiler does; there is a trained workforce familiar with installation and maintenance requirements. There are innumerable alternative suppliers.

Micro CHP on the other hand, suffers huge regulatory uncertainty about grid connection and electrical protection, and about how much government is prepared to value the savings; is made with money borrowed from venture capitalists; in a workshop in low numbers, with no economies of scale, no value engineering experience; no-one understands it or trusts it so a huge marketing effort is involved to communicate the potential benefits to customers; there is no trained installation and maintenance workforce; and only one manufacturer currently offering a product on a commercial basis.

Saying micro CHP costs £2000 more than a boiler is no more valid than saying that, with learning, micro CHP can be installed at no additional capital cost. One is an engineering cost (or rather a current sales price) based in todays reality, and one is based on future possible costs understanding the possible effects of learning which
may be a future reality. They are different but equally valid. Interestingly, the industry itself, postulating an installed base in the UK of some 12m units, suggests the additional price might be around £400. Experience curves tell us the cost differential may become even narrower.

5.4 Experience curves in the UK

Whilst learning curves are used extensively in energy policy in the US, Japan, and Europe (see IEA 2000, McDonald and Schrattenholzer 2001, IEA 2003, etc), few examples of its use are known in UK energy policy circles (though an internet search will show widespread presence in the management literature). One example of its use in the UK is the Cabinet Office PIU report on Energy. Although background work for this study applied experience curves to large scale renewables over a time frame to 2020 (PIU 2001h), the approach was not applied to energy efficiency, which was looked at over a shorter time to 2010 (PIU 2001c), nor to building integrated renewables or CHP (either micro or community heating scale). This paper does look at these technologies.

Gross (pers comm., and a member of the PIU team) suggests that experience curves have not had great traction in the UK because:

- The size of the learning investment can be large before costs reach break even
- Engineers find it too simplistic
- Deterministic seeming projections of the future are fraught with risk – extrapolation of market growth etc that might not materialise
- It can lead to results that appear optimistic, particularly when a few years on we may appear to be off trajectory

Whilst there is validity in these views, the alternative is to work on current cost estimates, which is to ignore history. An appropriate way forward may be to use the approach, but because the relative importance of the underlying factors will be different for different technologies and arguably at different times, a certain amount of scepticism is needed in utilising them.

Another reason for their absence from UK policy making may be to suggest that, (with the arguable exception of wind turbines in the UK) UK policy has not run programmes for long enough, nor has a sufficiently open attitude to data, for the information to be available to test the theory, and if the UK doesn’t look for experience curves, then (surprise, surprise) they won’t be found.

A third explanation for scepticism in the UK, is that the UK is a relatively small market compared to the US, or Europe and so the UK can’t have an impact at global level. We are in effect a recipient, not an influencer of learning. This is true for many technologies (nuclear, gas turbines, steam turbines). But may not be true for many new and cutting edge technologies (micro CHP using Stirling engines, or fuel cells in CHP applications) where our (in-) temperate climate, poor housing stock, liberalised but regulated energy market, and good access to gas make the UK a prime market for micro CHP (Faber Maunsell et al 2002), and where the UK could influence global learning.
5.5 Experience curves and energy efficiency

Energy efficiency measures are critical to achieving the 40% House, particularly insulation, lighting and cold appliances. However, as has been noted, there is little in the literature about experience curves and energy efficiency. This issue therefore needs exploring in more depth.

One of the difficulties is that often, energy efficiency means making the same products (houses, cars and fridges) in a different way. Thus, there is an underlying experience curve from making an appliance, and then a different curve for making a more efficient appliance. The cost of energy saved can be plotted against number of efficient appliances or number of efficient windows sold or (arguably more usefully, since U values can change) against cumulative useful energy conserved.

5.5.1 Insulation

In the UK, Shorrock (1999) described reductions in cost in insulation under the influence of Government programmes, and from this and other data, PIU (2001h) estimated a progress ratio of around 88% for insulation. Jakob and Madlener (2003) found a progress ratio for wall insulation of between 82% and 85% based on Swiss data (Figure 7). However, experience curves may be very different for new technologies, for example for external wall insulation based perhaps around vacuum insulated panel, than for well known rockwool or foam products. 40% House postulated some 7million homes with external wall insulation.

Figure 7 Progress ratio for insulated facades (cost of energy conserved against energy conserved, from Jakob and Madlener 2003)

![Graph showing progress ratio for insulated facades](attachment:image)

5.5.2 Lighting

Iwafune (2000) suggests a progress ratio for compact fluorescent lamps of 84%. However, a change in technical trajectory to Light Emitting Diodes (LED’s) is possible. These devices are in common use in power electronics and computing and
may not experience the same learning. However, their application in room lighting would see larger brighter devices, and a learning rate of 84% cannot be assumed.

5.5.3 Appliances
The major issue for appliances in 40% House were cold appliances. Much energy policy analysis assumes that improved efficiency costs money and calculates a payback for the additional investment. Analysis which supports efficiency standards for appliances works on this basis (for example, GEA 1993 and 1995).

However, Hinnells and McMahon (1997) challenge this notion that an engineering analysis can easily identify the additional costs associated with future efficiency improvements and the resulting consumer price. They show that for refrigeration appliances, actual prices for energy efficient products appear lower than engineering estimates used as the basis for efficiency standards.

Greening et al (1996) analysed two rounds of refrigerator standards in the US using a dataset from retailers representing 2-3% of refrigerator sales, and actual prices paid before and after standards. The 1989 standards required a 10% improvement, and 1993 required a 30% improvement. As a result of the standards, average annual energy consumption in new refrigerators dropped from 974 kWh/year in 1987, to 653 kWh/year in 1994. Prices increased by between 1.4 and 1.5 percent per year from 1987/88 through 1993, and when increases in size are accounted for, the average annual increase was 1.25%. In general, the units meeting the 1990 standard levels had either similar level of features or an improved level of features, as manufacturers took the opportunity of redesign to update their product range. These results are consistent with a previously observed annual increase in current refrigerator prices of 1.1% between 1948 and 1983. This is an important conclusion, since analysis prior to standards (DoE 1989) had predicted that there was likely to be a cost penalty for improved efficiency. However, Greening also found a doubling of capital investment over the period since 1989 and a decrease of 1/3 in labour costs over that time. In other words, manufacturers may have found efficiency improvements in production (less labour, different materials) while improving energy efficiency improvements in products. Dale et al (2002), and Nadel (2002) has updated this work and concurs with the broad conclusions.

In the UK, Boardman (2004) analysed data over the period in which mandatory efficiency standard were introduced and showed a 10% price fall alongside a 25% improvement in efficiency and 15% increase in volume (Figure 8). However, this was not set against the long run change in the cost of appliances.
Why does it appear that efficiency can be achieved through standards at low cost or even free? There are several factors identified by Hinnells and McMahon (1997):

- There is strong evidence for a range of appliances that price is determined by many features other than efficiency. For example with cold appliances, size brand, and features such as frost-free explain most price variation. For washing machines, brand and spin speed which are important additional factors (GEA 1995).

- The introduction of efficiency through mandatory standards with sufficient lead time may imply no increase in fixed costs if normal tooling or design changes are not accelerated. Analysis of data from market research firm GfK shows that half the models on the market survive only 2 years, but these modifications may only be slight. Every few years, the whole range is likely to undergo substantial redesign to optimise manufacturing processes. If efficiency is an element in an existing process - rather than the exclusive trigger for a new cycle of redesign - then there is no reason why redesign and retooling should be a significant additional cost.

- Improving energy efficiency, may, in production terms, simply mean not making certain variants, rather than adding new and innovative products. This may actually cut production costs by reducing tooling changes during production.

Although the appliance literature has not, to date, used experience curve methods of analysis, the evidence is in tune with the literature: that is, when efficient appliances are made in volume, eg through efficiency standards, the cost of doing so is cheaper than engineering analysis suggests, and may even not affect underlying price trends in the market in question. They may be considered free. This holds for quite large changes in efficiency (up to 40% in the US). However further improvement may involve a change in insulation technology to Vacuum Insulated Panel. Whilst this may not be free, it is likely to be much lower cost than engineering estimate have implied to date.
5.6 Experience curves and 40% House

Experience curves have been demonstrated with progress ratios of 80-85% for a range of technologies including PV, insulation and CFLs. This evidence on experience curves is now applied to the uptake described in the 40% House scenario.

The technologies in Table 1 are ranked in terms of the number of doublings to be expected in the 40% House scenario compared to current world market. To the left, are well known technologies like heat pumps and community heating where a low progress ratio and the limited effect the UK alone would in world markets would have only a minor effect on costs. On the right are technologies where, even if the UK were to ‘go it alone’ with a 40% House scenario, the effect on costs in 2050 compared to today would be dramatic. If other countries were to follow the same development path the benefits from learning would be greater.

### Table 1 changes in capital cost by 2050 through learning based on uptake in 40% House

<table>
<thead>
<tr>
<th>Heat Pump</th>
<th>Community Heating</th>
<th>solar HW</th>
<th>Energy efficient fridge</th>
<th>LED lighting</th>
<th>New insulation material for housing</th>
<th>biomass</th>
<th>Bi Wind</th>
<th>stirling dCHP</th>
<th>PV</th>
<th>fuel cell dCHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Number of doublings UK</td>
<td>1.0</td>
<td>1.0</td>
<td>4</td>
<td>12</td>
<td>7</td>
<td>16</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>2 Number of doublings EU</td>
<td>4</td>
<td>4</td>
<td>7</td>
<td>15</td>
<td>10</td>
<td>19</td>
<td>11</td>
<td>13</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>3 Assume progress ratio</td>
<td>92%</td>
<td>92%</td>
<td>92%</td>
<td>92%</td>
<td>82%</td>
<td>92%</td>
<td>82%</td>
<td>82%</td>
<td>82%</td>
<td>82%</td>
</tr>
<tr>
<td>4 Estimated cost change UK</td>
<td>0.92</td>
<td>0.92</td>
<td>0.72</td>
<td>0.37</td>
<td>0.25</td>
<td>0.26</td>
<td>0.20</td>
<td>0.14</td>
<td>0.09</td>
<td>0.05</td>
</tr>
<tr>
<td>5 Estimated cost change EU</td>
<td>0.72</td>
<td>0.72</td>
<td>0.56</td>
<td>0.29</td>
<td>0.14</td>
<td>0.21</td>
<td>0.11</td>
<td>0.08</td>
<td>0.05</td>
<td>0.03</td>
</tr>
</tbody>
</table>

6 Costing the 40% House

The paper has drawn together evidence on three key issues to costing new technologies in 40% House:

- For LZC in particular, improved insulation may reduce demand, and thus cost effectiveness of those technologies that supply heat by an average of around 18% by 2050
- The value of energy savings, through increased energy prices, and internalisation of costs may have increased by a factor of 2 by 2050
- Experience curves applied to the 40% House scenarios show many new technologies falling to a fraction of their current price.

From this, the change in costs, and benefits and therefore cost-effectiveness compared to today, can be estimated. Given the huge range of uncertainties over the period, the aim can only be a broad one, of identifying the relative importance of the different influences on cost effectiveness in the future compared to today.
The consequent change in capital costs of learning is shown in Table 2. Information on current costs and benefits of technologies is contained in DTI (2005) and in the 40% House report. Costs are stated on the basis of the additional cost over the alternative (eg in relation to a gas boiler). The additional cost for example for a fuel cell over a gas boiler could become negligible.

**Table 2 Capital costs**

<table>
<thead>
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<th>Heat Pump</th>
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<th>Stirring dCHP</th>
<th>PV</th>
<th>fuel cell dCHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Current cost</td>
<td>8000</td>
<td>4000</td>
<td>3250</td>
<td>50</td>
<td>20</td>
<td>10000</td>
<td>3000</td>
<td>20000</td>
<td>2000</td>
<td></td>
<td>12600</td>
</tr>
<tr>
<td>2 2050 capital cost UK 40% House</td>
<td>7,360</td>
<td>3,680</td>
<td>2,328</td>
<td>18</td>
<td>5</td>
<td>2,634</td>
<td>613</td>
<td>2,749</td>
<td>185</td>
<td>642</td>
<td>255</td>
</tr>
<tr>
<td>3 2050 capital cost EU 40% House</td>
<td>5,731</td>
<td>2,866</td>
<td>1,813</td>
<td>14</td>
<td>3</td>
<td>2,051</td>
<td>338</td>
<td>1,516</td>
<td>102</td>
<td>354</td>
<td>140</td>
</tr>
</tbody>
</table>

Currently, simple paybacks for many LZC technologies are poor (line 1 Table 3), often beyond than the life of the asset. The impact of learning (even with the reduced heat loads expected in 2050) is sufficient to bring payback periods well within the lifetime of equipment (line 2). The impact of a possible doubling of energy prices, or the EU following the 40% House path, would further bring down payback times (lines 3 and 4).

**Table 3 Simple payback (years)**

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<th>PV</th>
<th>fuel cell dCHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Current cost effectiveness (years)</td>
<td>13</td>
<td>15</td>
<td>37</td>
<td>2</td>
<td>6</td>
<td>53</td>
<td>15</td>
<td>29</td>
<td>21</td>
<td>126</td>
<td>30</td>
</tr>
<tr>
<td>2 Cost effectiveness in 2050 (UK 40% House todays energy prices)</td>
<td>12</td>
<td>14</td>
<td>26</td>
<td>1</td>
<td>2</td>
<td>14</td>
<td>3</td>
<td>4</td>
<td>2</td>
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<td>2</td>
</tr>
<tr>
<td>3 Cost effectiveness in 2050 (UK 40% House double energy prices)</td>
<td>7</td>
<td>8</td>
<td>16</td>
<td>0.4</td>
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<tr>
<td>4 Cost effectiveness in 2050 (EU 40% House double energy prices)</td>
<td>5</td>
<td>6</td>
<td>13</td>
<td>0.3</td>
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Of course, learning is not confined to energy beneficial technologies: new uses of energy (like home entertainment electronics, which accounted for a large increase in
electricity demand in 40% House, as well as patio heaters, and small taxi aircraft that used to cost £30 million and now only cost £1m) also benefit from learning. The implication is that by 2050 we should expect to be using energy in ways we can’t at present anticipate. The key though, is that learning investment by Government can be focused on ways of reducing the impact of energy use.

It has been suggested that the 40% House model be re-run, with different technologies competing on an economic basis, taking into account learning. It is expected that this would not significantly disrupt the scenario. In early years, community heating, solar thermal and heat pumps dominated LZC. Most of the new technologies -PV and fuel cells- installed under the scenario came late in the scenario, with learning.

None of the above is a prediction. Even if changes become much more cost effective, it doesn’t mean they will happen. It just means that it would then be economically rational for it to happen, and thus more plausible that changes on this scale could happen.

### 7 Conclusions

Whereas experience curves have seen most application in new and often large-scale supply technologies, this paper has shown they have application in building integrated generation and energy efficiency measures. Whilst the relative contribution of different learning issues in manufacturing are not well understood, they nevertheless remain real. And whereas there is little UK literature, the theory does have important policy implications for the UK. However, it is important not to over-interpret particular learning rates or implied learning investments, because circumstances, technologies and markets can change.

Under a 40% House scenario, energy demand changes, experience curves and energy price scenarios suggest dramatic changes in cost effectiveness, bringing the payback of measures down to reasonable levels, thus making the scenario plausible. The scenario in the 40% House report could be delivered by a combination of information, incentives and regulation known as market transformation.

### 8 Implications for policy

**Cost effectiveness**

This work has shown that Current cost effectiveness is no guide to future cost effectiveness, and that Government would not get best value for money by focusing on current cost-effectiveness alone.

**Implications for Government investment programmes**

A key conclusion of this work is that the UK is not a mere recipient of technology learning that goes on ‘somewhere else’. The UK can have significant impact on learning rates without the rest of world, but most especially in new technologies (biomass, building integrated wind, PV, and micro CHP technologies). The rest of the world has much more effect on the cost of established technologies (CH) where it is
hard for the UK to achieve doublings in global market share (heat pumps and community heating).

**Energy Services Companies**
One of the key learning issues might not be technical but organisational: a move towards energy services companies. If customers had more than one LZC in a dwelling, the design, installation, commissioning, finance, operation and maintenance becomes a whole lot harder. Higher levels of installation of LZC would therefore seem synonymous with the development of ESCos. This kind of arrangement might foster a whole-life cost attitude to investment (where payback within the life of a technology at low discount rates makes it attractive) and a portfolio attitude to investment (eg developing a set of investments that together give a load curve that matches demand, rather than assessing investments on an individual basis).

**Micro CHP**
At the more extreme levels of learning, micro CHP could in the long term be implemented with little or no cost implication over and above a gas central heating boiler.

**EU level appliance standards**
It is worth noting that the payback period of the lighting and refrigeration energy efficiency measures is very low, even with UK-only learning and no changes in the value of energy. However, product regulation takes place at the level of the single European market to avoid barriers to trade. Indeed, EU level regulation affects many bordering countries that trade into Europe (like Iran, Syria, Russia etc). The learning effect of EU standards is such that efficiency standards can be had virtually for free, though perversely, efficient refrigeration appliances without the volume effects created by standards are likely to remain expensive.

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About the Author
Dr Mark Hinnells manages the Building Market Transformation programme. BMT is funded by Carbon Trust and the EPSRC. It seeks to identify what policy actions are needed to reduce carbon emissions from the entire UK Building stock by 50% by 2030, given what we know of the technical options, energy markets, social trends, and impacts of climate change on energy use in buildings. Mark is also part of the Demand Management theme of the UK Energy Research Centre (www.ukerc.ac.uk). Prior to this Mark was a programme manager at the Energy Saving Trust managing the Community Energy Programme and was a consultant at Future Energy Solutions (part of AEA Technology). At his previous spell at ECI (1994-1998), Mark was involved in policy advice to the UK and EU Governments on policy to reduce energy use in lights and appliances, as part of the GEA (Group for Efficient Appliances).