ONE MILLION HOMES CONSTRUCTED AS “BUILDINGS AS POWER STATIONS”

- Report of Indicative Benefits

Prepared for SPECIFIC Innovation and Knowledge Centre
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About the Author

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INTRODUCTION

THE CONCEPT OF "BUILDINGS AS POWER STATIONS"

1) The concept of "Buildings as Power Stations" is a term of art originally fashioned by the Innovation and Knowledge Centre, SPECIFIC, and which refers to any building, such as factories, offices, homes and other structures in the built environment, which are equipped to conserve, generate, store and release energy. The purpose of this report is to make an initial estimate of the gross value of Buildings as Power Stations only in the context of domestic dwellings in Great Britain. The report does not address the costs of Buildings as Power Stations, which are being developed separately.
2) Buildings as Power Stations were conceived and designed by the Innovation and Knowledge Centre, "SPECIFIC", one of only six such centres in the UK and which is owned and governed Swansea University. The concepts and designs have been developed and demonstrated in conjunction with SPECIFIC's partners primarily in Swansea University, Cardiff University and Imperial College as well as industry sponsors Tata Steel, BASF and NSG Pilkington.
3) Buildings as Power Stations are characterised by the conjunction of a number of key features as described briefly below for the particular case of domestic dwellings:
   a) Buildings as Power Stations are designed to very high energy efficiency standards that far surpass current housing stock;
   b) It is intended that all Buildings as Power Stations will incorporate:
      i) Electricity generation from roof integrated Solar PV, which also serve as a robust, roof structure to ensure building integrity and to minimise cost of materials, fitting and maintenance;
      ii) An electricity storage system (initially batteries), which may be individual to each dwelling, or shared amongst a small number of dwellings depending on practicality considerations;
      iii) A voltage control system within each dwelling or a collective of dwellings;
      iv) Fiscal sub-meters and electricity meters registrable to or otherwise recognised by the Elexon central systems and which are capable of measuring electricity flows between each dwelling, a local meshed electricity network and the public network;
      v) A heat pump to augment space and water heating.
   c) Where appropriate and economically viable, Buildings as Power Stations may also include:
      i) A Transpired Solar Collector ("TSC"), being a wrap around the body of the dwelling (see the wrap around the upper part of the houses in Figure 1 below) with high solar radiation absorption properties that enable significant volumes of air admitted via perforations to be further heated for space and water heating;
      ii) A heat storage system has been developed and a full-scale demonstrator built which is capable of capturing heat and storing on inter-seasonal timescales. Following additional development to refine system integration and reduce costs, this technology could potentially be used in a number of modes, such as capturing heat in summer and holding it for winter to reduce electricity load, or

to capture and transfer waste heat from industrial process, such as the waste heat from thermal power stations.

FIGURE 1 – ARTIST'S IMPRESSION OF THE "ACTIVE HOMES NEATH" DEVELOPMENT

ESTIMATED INDICATIVE ENERGY COST SAVINGS OF BUILDINGS AS POWER STATIONS HOMES FOR OCCUPANTS

1) This section examines the difference between the energy consumption and carbon dioxide emissions during the occupancy of typical homes in Great Britain today and compares these in homes built as Buildings as Power Stations.

METHODOLOGY

2) These estimates are intended to compare energy use and carbon emissions arising from the substitution of existing dwellings by Buildings as Power Stations. They do not consider further the savings that might arise from changes to construction and supply chain methods that would be revealed by a full life cycle analysis.

FACTUAL AND COUNTERFACTUAL

3) An essential element of the analysis in this report is to assess certain potential benefits of Buildings as Power Stations consumers and society. This requires consideration of counterfactuals. Counterfactuals are not a comparison between 'before and after', but rather the counterfactual should enable an analysis of the incremental difference between having Buildings as Power Stations and not having them at corresponding points in time.

4) The 'factual' in this case is taken to be a continuation of typical current housing. The counterfactual is therefore the existence of Buildings as Power Stations in the future energy system and the factual is the status quo. The following paragraphs explain the reasons for this.

5) Existing typical current housing is a relatively well understood segment for which there is good, publicly available and comprehensive aggregate data for gas and electricity consumption. These data represent the world we actually live in rather than possible worlds that may never materialise and which would represent alternative counterfactuals which are speculative for comparison purposes. Moreover, whilst there are existing programmes to construct energy efficient homes, these programmes are not at a scale comparable to the rate at which house building is required not least due to supply chain limitations, leaving open a large element to accommodate the Buildings as Power Stations designs as well as many other additional programmes for house building.

6) Comparisons between competing energy efficient designs are useful for marketing purposes but Buildings as Power Stations represent a class of building and not a particular brand. For this analysis, comparing within this class would result in an arbitrary and meaningless comparison between Buildings as Power Stations and in essence, themselves, because the best alternative designs could have similar characteristics to the Buildings as Power Stations as a generic class of housing.

7) If sufficient housing is to be built and replaced, and if energy savings and carbon mitigation are priorities, the priority should not be to develop a small, over-contested and limited programme of Buildings as Power stations and energy efficient homes, but rather to prioritise the replacement of old, inefficient stock as well as new build.

8) From the perspective of a segment of residents, a choice in practice would be to live in a home built (or converted) according to a Buildings as Power Stations design, or to live in a traditional, existing home. The suggested ‘factual’ and ‘counterfactual’ for this analysis represents this choice.
9) The incremental benefits of Buildings as Power Stations in this report are therefore estimated by comparison between typical existing housing as the ‘factual’ and Buildings as Power Stations as the ‘counterfactual’.

EXPANSION RATES ASSUMED FOR BUILDINGS AS POWER STATIONS

10) The expansion rates assumed for Buildings as Power Stations are not forecasts, which would assume business as usual and be entirely dependent on the reaction of markets to assumptions regarding the existing regulatory regime, government policies and behaviours in markets. This analysis disregards these constraints as it is intended to help answer questions regarding benefits that might arise if a large number of Buildings as Power Stations were delivered and from that, the design of policies, regulations and markets to deliver these benefits can be considered.
11) Moreover, expansion rates might be expected to have other consequences. First, the economic impact of discounting over long periods of time, such as the lead time and life of a large number of future buildings, means that estimating the energy component of value arising from Buildings as Power Stations requires a view on the rate at which they can be developed at scale. Second, the faster the expansion rate, the greater will be the absolute financial, mitigated CO_2 and energy resource savings would be accumulated. Put another way, slower development could be expected to lead to a lost opportunity to mitigate savings, CO_2 mitigation and energy resource savings that can never be recovered.
12) Three scenarios for the expansion rates of Buildings as Power Stations are considered for the purpose of this analysis and given the following names and descriptions:
    - ***Evolution***: Assumes an unaided evolution whereby one million homes are completed in 20 years’ time, by 2037. This is the most gradual of the three scenarios but is still ambitious. If it is considered too ambitious, it should be borne in mind that compared to the rate at which new housing is required in the UK, then 50 thousand per annum and around a 20% share of what the market should be might be considered reasonable.
    - ***Accelerated***: This is the most ambitious expansion rate but still fits easily within the informal goal of the housing minister to build 1 million new homes by 2020[1]. If the supply chain could be adjusted to replace new build with Buildings as Power Stations, either the target of one million would be achievable within in this timescale, or the target itself is unrealistic. In order to allow for supply chain development and adjustment, this scenario targets 2027 for the achievement of one million households as Buildings as Power Stations, which coincidentally is

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[1] “By the end of this Parliament [2020], success I think would mean that we have seen a build in total of something like a million homes.” Brandon Lewis, Housing Minister, BBC Inside Out 19:30 21st September 2015.

the latest reported revised start-up date for the delayed 3.2GW Hinkley Point C nuclear reactor[2].

- ***Already Completed***: The third scenario is not realistic, but supposes that one million households have already been completed. This indicates the economic ‘regret’ that should be accounted for given that such a programme was not commenced as soon as it became technically possible. Considering what such buildings might already be achieving could help to understand the economic, CO_2 mitigation and energy resource regret arising from poor performance and leadership in developing the most vital of the nation’s infrastructure.

13) These three scenarios are shown in Figure 2 below. The two growth scenarios exhibit a slow start to allow for the establishment of manufacturing facilities, supply chain development and adoption by mortgage companies, insurers, planners, house buyers and others. This is followed by a more rapid development until the 1 million Buildings as Power Stations are completed.

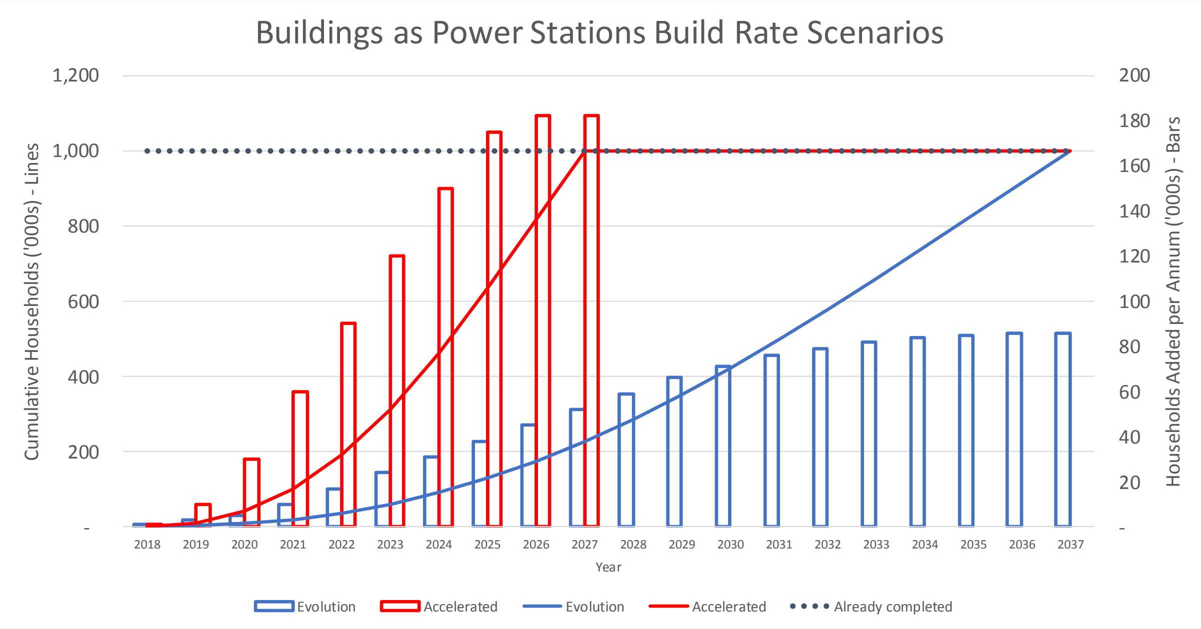

FIGURE 2 - BUILDINGS AS POWER STATIONS: BUILD RATE SCENARIOS

14) The energy performance of future buildings may improve compared with current Typical Domestic Consumption Values (TDCVs) as technologies exist to achieve this. As described in the Section “Factual and Counterfactual” above, since there is no similar plan to implement such developments on a scale large enough to meet one million homes short of all future demand, however, hypothetical counterfactuals reflecting such conceptual improvements would, in effect, be comparing the “Buildings as Power Stations” concept with an alternative version of itself thereby giving a misleading view suggesting that better standards would have smaller benefits than is actually the case.

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[2] http://www.telegraph.co.uk/business/2017/07/03/hinkley-nuclear-costs-climb-almost-20bn-start-delayed/

KEY ASSUMPTIONS

15) Current performance of domestic dwellings was taken from Ofgem's reported "Typical Domestic Consumption Values" (or "TDCVs")[3] published in 2017. TDCVs are calculated based on data from the two most recent years available, separate out gas and electricity consumption and also separate electricity profile classes 1 (for Domestic Unrestricted Customers) and 2 (Domestic Economy 7 Customers). These are reproduced in Table 1 below. For the purposes of this analysis, the three gas consumption values and the three Profile Class 1 electricity values are assumed as the basis for comparison.

TABLE 1 - TYPICAL DOMESTIC CONSUMPTION VALUES IN KWH. SOURCE: OFGEM, PUBLISHED 2017

Gas Consumption	Low	8,000
	Medium	12,000
	High	17,000
Electricity Consumption (Profile Class 1)	Low	1,900
	Medium	3,100
	High	4,600

16) The consumption of gas and electricity for Buildings as Power Stations is based on parameters for a set of 16 dwellings which have already been designed to be constructed in Neath, South Wales by the Pobl Group. Buildings as Power Stations reduce overall energy consumption through highly efficient structures that are near to Passivhaus standards. Space and water heating are driven entirely by electricity and provided by a combination of solar heating, solar PV and when necessary, grid electricity. The net effect of this on an annual basis is that if the buildings perform in accordance with the Active Homes Neath energy design, all gas consumption would be displaced completely, electricity consumption would rise to supply heating, but this rise would be more than offset by PV generation.

17) In order to allow for possible systematic variations in performance from forecasted levels, two sensitivities were assumed, one of which would be better performance than Active Homes Neath (allowing for further improvements arising from the learning from a large-scale development programme such as a very modest contribution from heat storage) and the other would be worse than Active Homes Neath, which allows for poorer performance, such as might be the case if occupants waste energy or if significant gas connections were installed to compensate for performance issues or in case of "cold feet". These assumptions are summarised in Table 2 and Figure 3 below.

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[3] https://www.ofgem.gov.uk/gas/retail-market/monitoring-data-and-statistics/typical-domestic-consumption-values

TABLE 2 - ACTIVE HOMES NEATH ENERGY CONSUMPTION FORECAST. SOURCE OF "ACTIVE HOMES NEATH DESIGN PERFORMANCE": AUXILIUM ENGINEERING SERVICES IN BOLD

GAS Consumption	Worse than Active Homes Neath	4,000
	Active Homes Neath Design Performance	**0**
	Better than Active Homes Neath	0
Electricity Consumption (net of PV generation)	Worse than Active Homes Neath	4,000
	Active Homes Neath Design Performance	**2,230**
	Better than Active Homes Neath	1,634

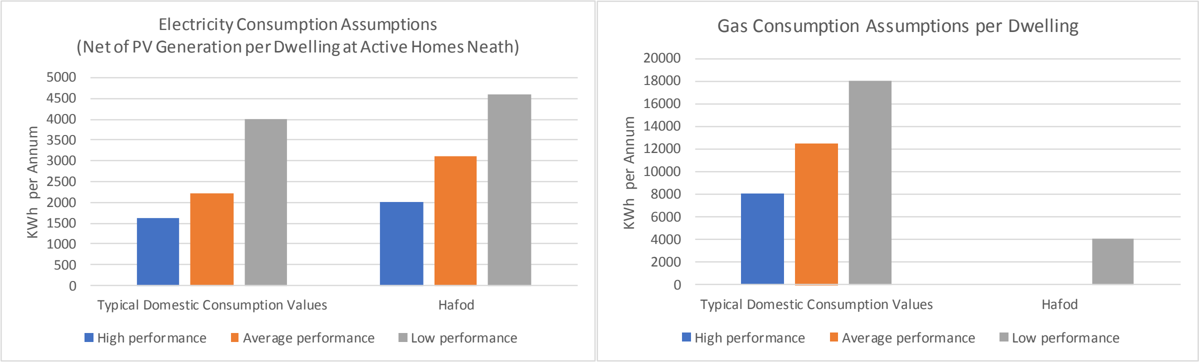

FIGURE 3 - ELECTRICITY AND GAS ANNUAL CONSUMPTION FOR ACTIVE HOMES NEATH AND TYPICAL DOMESTIC CONSUMPTION VALUES

18) Assumed wholesale and retail prices for gas and electricity (illustrated in Figure 4 and Figure 5 below respectively) are based on representative prices recently available in the market and are projected forward by escalating the wholesale price element by wholesale price forecasts used by National Grid in the 2016 Future Energy Scenarios[4]. For this purpose, system and operational costs are assumed to be fixed.

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[4] http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/FES/Documents-archive/

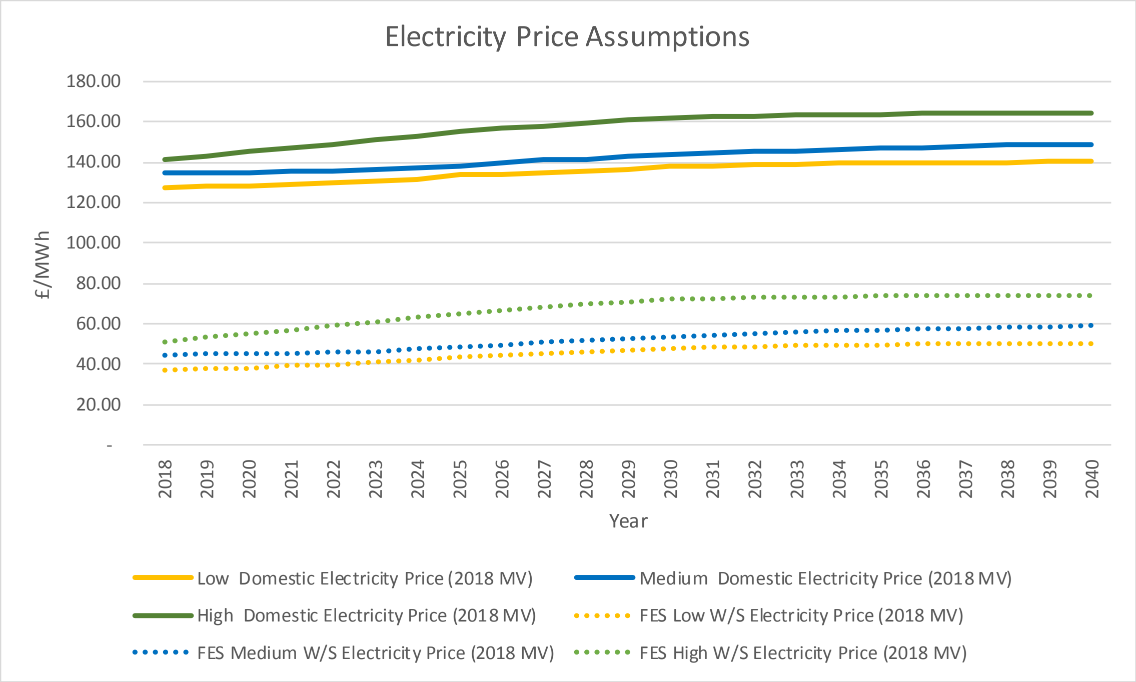

FIGURE 4 - ASSUMED RETAIL AND WHOLESALE ELECTRICITY PRICES. SOURCE: WHOLESALE PRICES, NATIONAL GRID, FUTURE ENERGY SCENARIOS 2016

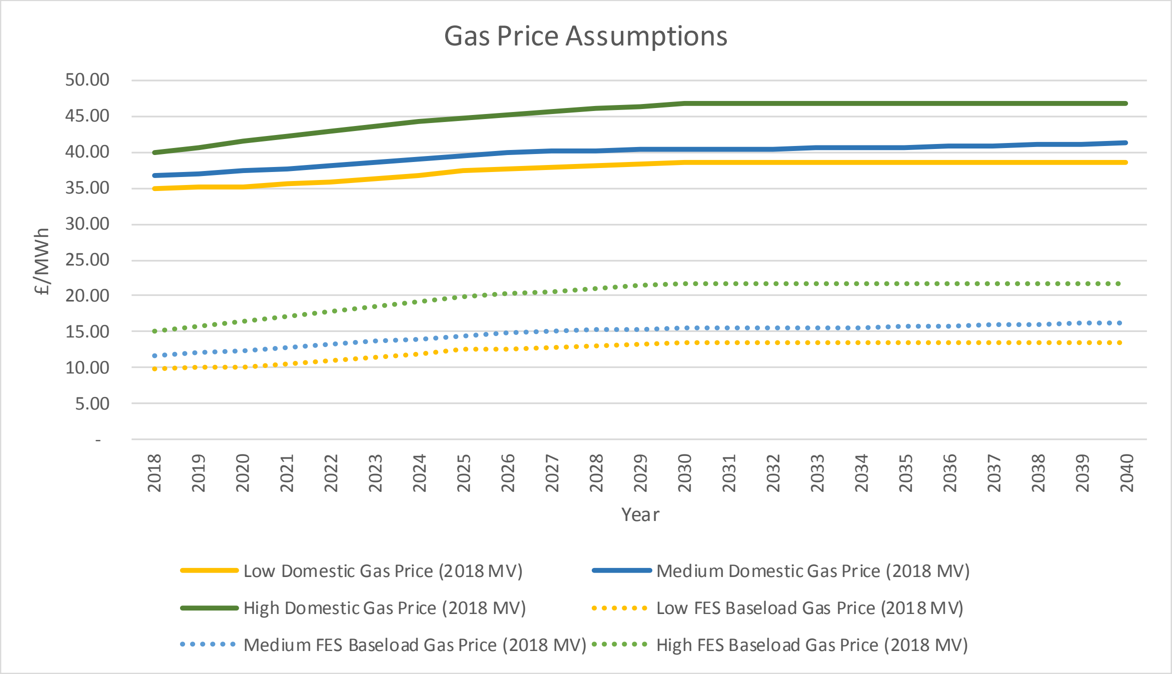

FIGURE 5 - ASSUMED RETAIL AND WHOLESALE GAS PRICES. SOURCE: WHOLESALE PRICES, NATIONAL GRID, FUTURE ENERGY SCENARIOS 2016

ESTIMATED ENERGY COST SAVINGS TO OCCUPANTS OF BUILDINGS AS POWER STATIONS

19) Based on these assumptions, economic savings are estimated over a forward period of 40 years applying a real discount rate of 2%. Savings in energy and CO_2 mitigation are not discounted.
20) The choice of a discount rate is not simple given the timescale of the economic life of houses. Benchmarks for discounting very long term cash flows exist in the nuclear industry, where liabilities that persist for decades and centuries are estimated in present value terms. A real discount rate of 2% is slightly below the discount rate for assessing nuclear liabilities (although recently the implied real discount rate for these was temporarily negative due to the historically low Bank of England interest rates).
21) The savings in this section are divided into two parts. First, the savings that are most likley to accrue to householders who occupy Buildings as Power Stations and secondly, the savings to society as a whole.
22) Annual savings to housholders through bills were calculated for the 27 permutations for each year until 2037 for: high, medium and low fuel prices; high, medium and low TCDV values; and high medium and low Buildings as Power Stations.
23) The bills for gas and electricity were closely calibrated to the "Average annual domestic gas bills by home and non-home supplier" and "Average annual domestic electricity bills by home and non-home supplier" calculated by National Statistics and published by the Department for Business, Energy and Industrial Strategy on 30th March 2017[5]. They were adjusted to take account of the difference in the basis of these statistics and the medium TDCVs published by Ofgem as the former are normalised to a gas consumption of 15,000 kWh per dwelling per annum compared with a medium TDCV of 12,500, and an electricity consumption of 3,800 kWh per dwelling per annum compared with a medium TDCV of 3,100 kWh per dwelling per annum. Also, there was a small normalisation adjustment for 5% VAT charged on domestic energy consumption which is included in the National Statistics figures.
24) Standing charges for gas are avoided completely by Buildings as Power Stations. These charges vary greatly from supplier to supplier (including zero standing charges where suppliers smear these costs into the unit rate) and from offer to offer. Taking account a range of publically available standing charge figures[6], 18p per day was assumed.
25) Savings for the combination of all medium assumptions for the first year per average dwelling are summarised in Table 3 below. (Note that this value will vary from the averages depending on the size and configuration of specific dwellings).

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[5] See Annual domestic energy bills here: https://www.gov.uk/government/statistical-data-sets/annual-domestic-energy-price-statistics and Quarterly energy prices here:
https://www.gov.uk/government/collections/quarterly-energy-prices

[6] To its great credit, npower publishes full details of current open and closed tariffs. See https://www.npower.com/at_home/applications/product_comparison/tariff.aspx/tariffratesandchargeslookup

TABLE 3 – ANNUAL ENERGY AND BILLS SAVINGS OF BUILDINGS AS POWER STATIONS COMPARED WITH MEDIUIM PERFORMANCE TDCV DWELLINGS

	TDCV HOMES (MEDIUM PERFORMANCE)	BUILDINGS AS POWER STATIONS (ACTIVE HOMES NEATH PERFORMANCE)	SAVINGS ARISING FROM BUILDINGS AS POWER STATIONS
ELECTRICITY CONSUMED NET OF SOLAR PV GENERATION (KWH)	3,100	2,230	870
GAS CONSUMED (KWH)	12,500	0	12,500
ELECTRICITY COST (£ PER ANNUM PER HOUSEHOLD)	418	301	117 (28%)
GAS COST (£ PER ANNUM PER HOUSEHOLD)	524	0	524 (100%)
ENERGY COST (£ PER ANNUM PER HOUSEHOLD)	942	301	641 (68%)

26) Rises in gas and electricity prices, substitution for homes less energy efficient than medium TDCV would all cause an increase in savings.

27) **No Government market support through solar PV feed in tariffs has been assumed in the above.** This is not to suggest, however, that Buildings as Power Stations should not or would not take full advantage of support mechanisms where they are available.

28) The main reason for not including solar PV feed in tariffs as part of the savings is so as not to overstate the long-term expectations for savings on the vast bulk of the one million homes. In general, market support schemes for energy generation technologies is intended only to assist them to achieve sufficient maturity to be competitive in the normal market. As solar PV costs fall and market penetration increases, solar PV feed in tariff decrements are applied and the case for continuing support for domestic solar PV may disappear entirely.

29) Moreover, Feed in Tariffs, Renewable Obligation Certificates, Contracts for Difference and Climate Change Levy exemptions are all counted within the Levy Control Framework. As gas and electricity prices have not risen as much as forecast at the time of the policies, the costs recoverable from consumers to fund these policies has increased to the point where there has been great pressure on Government to rein in spending.

30) Finally, income from subsidies could be regarded as taking from society rather than making a new incremental contribution and sharing the benefits, as can be fairly claimed in relation to the savings shown in Table 3 above.

31) If solar feed-in tariffs are included, however, additional savings that would accrue to the average Active Homes Neath dwelling could be calculated as shown in Table 4 below.

32) This suggests that the total savings to Active Homes Neath occupants (but not all Buildings as Power Stations into the future) could be £823 per annum, with a residual annual energy bill of £119, a total saving of 87% before any income for battery trading is taken into account.

TABLE 4 - POTENTIAL SOLAR PV FEED IN TARIFF ANNUAL INCOME FOR ACTIVE HOMES NEATH FOR 25 YEARS

Total PV generation per dwelling	kWh	4,501
Total PV exports per dwelling	kWh	2,164
Generation Tariff[7]	p/kWh	1.62
Export Tariff	p/kWh	5.03
Generation Income	£ per annum	73
Export Income	£ per annum	109
Total FIT Income	£ per annum	182
Grand total of Savings	£ per annum	823

ESTIMATE OF INDICATIVE BENEFITS OF ECONOMIC, ENERGY, AND CO_2 SAVINGS BUILDINGS AS POWER STATIONS

ADDITIONAL ASSUMPTIONS

33) In the previous sections, energy savings to occupants of the Active Homes Neath Buildings as Power Stations was estimated based on the energy efficiency of the homes, the avoidance of gas for heating and reduced electricity consumption due to the generation of electricity at the homes using Solar PV. The Feed in Tariff income was also identified which could potentially be secured by Buildings as Power Stations in the early stages of development. In this section, certain wider societal benefits are identified, which include resource conservation and CO_2 mitigation as well as the energy cost savings excluding any subsidies such as Solar PV Feed in Tariffs.

34) To assess CO_2 mitigation, account is taken of the greenhouse gas intensity of both avoided gas and net change in use of electricity from the public networks at the relevant carbon intensity as projected into the future. The greenhouse gas intensity of natural gas is unlikely to change throughout the period, unless indirect emissions such as from gas leaks or other process emissions are added to the direct intensity. For the purposes of this analysis, the direct intensity on a net CV basis of 0.204 kg CO_2 per kWh is assumed[8]. For electricity, the carbon intensities specified in the National Grid Future Energy Scenarios 2017 for the most decarbonised future electricity grid are assumed[9], which is also the most conservative baseline. Other scenarios would be expected to show greater carbon savings and this assumption represents the most conservative, but which is also most consistent with the policy goal of decarbonising grid electricity to 50g CO_2 per kWh.

35) Buildings as Power Stations also use surrounding heat and light to displace fossil fuels in the form of gas and fuels to generate electricity. These energy resources are therefore conserved to the benefit of society as a

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[7] For 50 – 250 kW installations for March 2019, the handover date for the project. Capacity band assumes Active Homes Neath PV is considered a single installation. Solar PV Feed in Tariffs can be found on Ofgem's website at https://www.ofgem.gov.uk/environmental-programmes/fit/fit-tariff-rates

[8] Greenhouse gas reporting – conversion factors 2016, Department for Business, Energy and Industrial Strategy. (https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2016)

[9] See the relevant workbooks in Future Energy Scenarios 2017 for the Two Degree Scenario at Figure 4.3 here: http://fes.nationalgrid.com/fes-document/fes-2017/

whole. In order to express this resource conservation from multiple sources in common units, units of energy are used.

ESTIMATED ECONOMIC, ENERGY RESOURCE AND CARBON MITIGATION SAVINGS TO SOCIETY

SUBSTITUTING ONE MILLION HOMES BUILT AS BUILDINGS AS POWER STATIONS

36) Figure 6 below summarises the results of the estimates based on the assumptions for all 27 permutations of three fuel price assumptions, three performance levels for existing domestic dwellings and three counterfactual performance levels for Buildings as Power Stations. In all cases, the “Two Degree” grid carbon intensity is assumed.

37) The far left of Figure 6 shows the three fuel price scenarios (high, medium and low for both electricity and gas) which are further subdivided into different performance levels for the Active Homes Neath design of homes constructed as Buildings as Power Stations. The horizontal axis separates the three expansion rate scenarios.

38) These figures are before the impact of any electricity or heat storage within the Buildings as Power Stations is taken into account, which is considered in the next section of this report. The figures are derived from the summation of 40 years of savings representing the high end of a mortgage term. The economic savings are discounted at a real rate of 2% as previously described.

39) (Although not discussed at any length in this report, there is a strong scientific case for discounting mitigated CO_2 as a function of time because CO_2 avoided in the present has a greater effect on mitigating global temperatures than delayed avoidance. If this principle were applied, the CO_2 mitigation impact could be calculated in present value tonnes of CO_2. This would better reflect embodied CO_2 in manufacture and construction not only in buildings, but also for some power stations that require large amounts of carbon release followed by a long payback period. A suitable method for this calculation has not been widely established and is not considered further here).

40) Within the ranges of the assumptions tested, all return positive savings, suggesting that the deployment of Buildings as Power Stations is likely to be a ‘no regret’ opportunity. This is reinforced by the observation that the more rapid the deployment, the greater the benefit across all three categories of saving.

Fuel Price Scenarios			Evolution	Accelerated	Already completed
	High	Better than Active Homes Neath	£ 6,246 *M* 377 *TWh* 69 *MtCO2*	£ 8,167 *M* 469 *TWh* 87 *MtCO2*	£ 9,967 *M* 559 *TWh* 104 *MtCO2*
		Active Homes Neath Energy	£ 5,523 *M* 361 *TWh* 69 *MtCO2*	£ 7,225 *M* 449 *TWh* 86 *MtCO2*	£ 8,819 *M* 535 *TWh* 103 *MtCO2*
		Worse than Active Homes Neath	£ 1,944 *M* 205 *TWh* 47 *MtCO2*	£ 2,554 *M* 255 *TWh* 58 *MtCO2*	£ 3,122 *M* 304 *TWh* 68 *MtCO2*
	Medium	Better than Active Homes Neath	£ 4,696 *M* 377 *TWh* 69 *MtCO2*	£ 6,102 *M* 469 *TWh* 87 *MtCO2*	£ 7,477 *M* 559 *TWh* 104 *MtCO2*
		Active Homes Neath Energy	£ 4,129 *M* 361 *TWh* 69 *MtCO2*	£ 5,370 *M* 449 *TWh* 86 *MtCO2*	£ 6,580 *M* 535 *TWh* 103 *MtCO2*
		Worse than Active Homes Neath	£ 1,388 *M* 205 *TWh* 47 *MtCO2*	£ 1,821 *M* 255 *TWh* 58 *MtCO2*	£ 2,229 *M* 304 *TWh* 68 *MtCO2*
	Low	Better than Active Homes Neath	£ 3,979 *M* 377 *TWh* 69 *MtCO2*	£ 5,197 *M* 469 *TWh* 87 *MtCO2*	£ 6,355 *M* 559 *TWh* 104 *MtCO2*
		Active Homes Neath Energy	£ 3,491 *M* 361 *TWh* 69 *MtCO2*	£ 4,564 *M* 449 *TWh* 86 *MtCO2*	£ 5,580 *M* 535 *TWh* 103 *MtCO2*
		Worse than Active Homes Neath	£ 1,154 *M* 205 *TWh* 47 *MtCO2*	£ 1,519 *M* 255 *TWh* 58 *MtCO2*	£ 1,855 *M* 304 *TWh* 68 *MtCO2*
			Build Rate Scenarios		

FIGURE 6 - SUMMARY OF DIRECT ECONOMIC, ENERGY RESOURCE AND MTCO₂ SAVINGS TO SOCIETY OF 1 MILLION BUILDINGS AS POWER STATIONS (EXCLUDING VALUE OF CO₂, STORAGE, TRADING AND FEED IN TARIFF BENEFITS)

41) The economic figures only include the direct avoided costs of electricity and gas, but do not include the value of avoided carbon, as the price of carbon into the future is particularly uncertain. Figure 7 below shows the assumptions for CO_2 prices used in the 2017 Future Energy Scenarios by National Grid based on European Emissions Scheme traded prices and the UK Carbon Price Support.

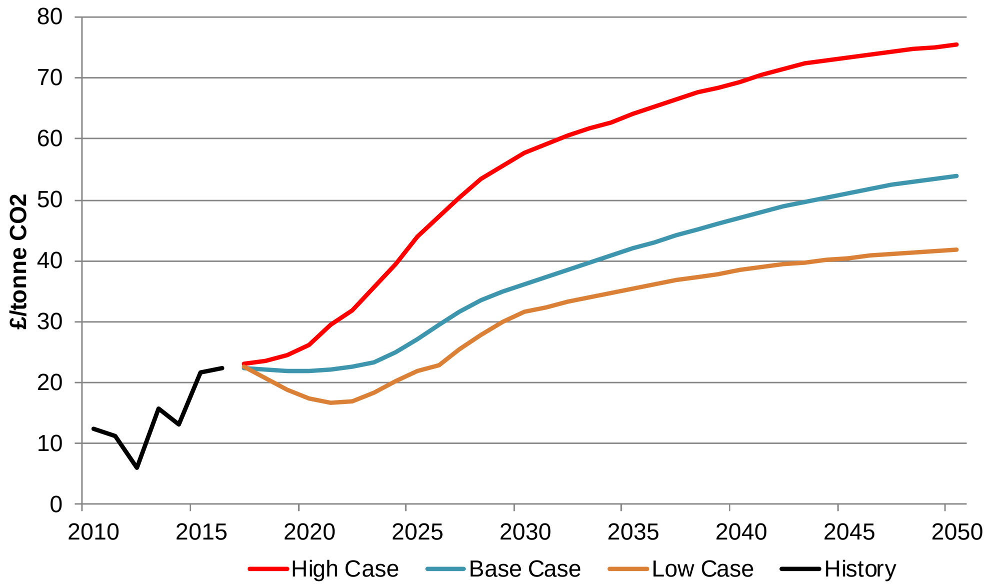

FIGURE 7 - CO₂ PRICE ASSUMPTIONS. SOURCE: FUTURE ENERGY SCENARIOS 2017, NATIONAL GRID

42) The “Base Case” carbon price assumption is applied to the scenarios so far analysed in Figure 6 above, to produce Figure 8 below.

			Build Rate Scenarios		
Fuel Price Scenarios			Evolution	Accelerated	Already completed
	High	Better than Active Homes Neath	£ 8,240 M 377 TWh 69 MtCO2	£ 10,620 M 469 TWh 87 MtCO2	£ 12,800 M 559 TWh 104 MtCO2
		Active Homes Neath Energy	£ 7,511 M 361 TWh 69 MtCO2	£ 9,667 M 449 TWh 86 MtCO2	£ 11,630 M 535 TWh 103 MtCO2
		Worse than Active Homes Neath	£ 3,285 M 205 TWh 47 MtCO2	£ 4,189 M 255 TWh 58 MtCO2	£ 4,982 M 304 TWh 68 MtCO2
	Medium	Better than Active Homes Neath	£ 6,690 M 377 TWh 69 MtCO2	£ 8,555 M 469 TWh 87 MtCO2	£ 10,309 M 559 TWh 104 MtCO2
		Active Homes Neath Energy	£ 6,118 M 361 TWh 69 MtCO2	£ 7,813 M 449 TWh 86 MtCO2	£ 9,391 M 535 TWh 103 MtCO2
		Worse than Active Homes Neath	£ 2,729 M 205 TWh 47 MtCO2	£ 3,455 M 255 TWh 58 MtCO2	£ 4,089 M 304 TWh 68 MtCO2
	Low	Better than Active Homes Neath	£ 5,972 M 377 TWh 69 MtCO2	£ 7,650 M 469 TWh 87 MtCO2	£ 9,188 M 559 TWh 104 MtCO2
		Active Homes Neath Energy	£ 5,480 M 361 TWh 69 MtCO2	£ 7,007 M 449 TWh 86 MtCO2	£ 8,392 M 535 TWh 103 MtCO2
		Worse than Active Homes Neath	£ 2,495 M 205 TWh 47 MtCO2	£ 3,154 M 255 TWh 58 MtCO2	£ 3,715 M 304 TWh 68 MtCO2

FIGURE 8 - SUMMARY OF DIRECT ECONOMIC, ENERGY RESOURCE, MTCO$_2$ SAVINGS AND VALUE OF CO$_2$ SAVINGS TO SOCIETY OF 1 MILLION BUILDINGS AS POWER STATIONS (EXCLUDING STORAGE, TRADING AND FEED IN TARIFF BENEFITS)

43) As with all long-term projections, some caution is necessary regarding the value of CO$_2$. The European Emissions Trading Scheme requires CO$_2$ emitters in covered sectors (such as power generation) to match European Emissions Allowances (known as “EUAs”) to amounts of CO$_2$ emitted. The certificates acquire a traded value provided the cap on total emission in the covered sectors is less than the total emissions would be without the cap. EUAs can be traded by undertakings in covered sectors to the extent that the cost is exceed by the value of being permitted to operate. The cap is set by the European Commission which in effect, defines the price. In the UK, the Carbon Price Support puts a floor on this price. This means that the value of carbon and to whom is entirely in the hands of Governmental bodies.

ESTIMATED BENEFITS STORAGE OF BUILDINGS AS POWER STATIONS

ELECTRICITY STORAGE

44) Buildings as Power Stations are assumed to be equipped either with individual electricity storage or a share of common electricity store serving a small cluster of Buildings as Power Stations (as is most likely in the Active Homes Neath project). It is assumed that the storage can be aggregated and dispatched through the local distribution network so that electricity stored or released can be directly netted from underlying

demand at Grid Supply Points, where the distribution networks exchanges power with the Transmission Network.

45) The storage used is not presumed to be of any particular type, and indeed it seems likely that during the course of the life of Buildings as Power Stations the electricity storage systems could be replaced within the existing infrastructure.

46) The characteristics adopted for this estimation, however, are most typical of the type of battery storage likely to be deployed in the Active Homes Neath project rather than supercapacitors or other technologies. The storage may be used for a number of purposes, such as trading electricity from periods of lower price to periods of higher prices (not considered here). Services can also be provided to the electricity system operator, such as frequency response and demand turn-up or turn-down.

47) For the purposes of this estimate, the storage is assumed to provide capacity services that help to reduce stress on the electricity transmission network during times of peak demand. Currently, this is done primarily via the Capacity Market, which is designed to ensure that capacity is rewarded for being available at times of a potential shortfall of generation to meet peak demand in Great Britain[10].

48) The current Capacity Market rules, however, would not necessarily deliver peak reduction from battery storage. Batteries have secured 15-year contracts in the capacity market to date based on their classification as “storage” along with pumped storage. Based on historical performance, the installed capacity of pumped storage is derated to 96% and as this was the best available benchmark, batteries received the same derating. It has become apparent, however, that some batteries in the Capacity Market can deliver their declared capacity for only half an hour, which is the minimum period of operation that must be demonstrated in qualifying tests. It is beneficial to battery owners operating in the Capacity Market for a battery to be rewarded on its maximum performance for just half an hour because capacity payments are based on a £/kW reward. Given that stress periods could last as long as two hours, (or even over four hours in exceptionally improbable circumstances), the capacity of batteries has been somewhat exaggerated and overrewarded. These same batteries could, however, make a meaningful contribution to security of supply if they were discharged at lower power and over a longer period. (The Department for Business, Energy and Industrial Strategy is currently consulting on proposals to reflect the duration of batteries for their declared capacity[11]).

49) In order to attempt to understand better the true value of storage and correct for the Capacity Market design flaw described in 48) above, for modelling purposes it is assumed that batteries are dispatched according to the following simple rules:

    a) If electricity capacity exceeds demand:

        i) If the state of charge of Buildings as Power Stations storage is less than its user set maximum charge, the storage charges at the lower of its maximum user pre-set rate of charge or the excess

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[10] More detail regarding the Capacity Market can be see here: https://www.gov.uk/government/collections/electricity-market-reform-capacity-market

[11] https://www.gov.uk/government/consultations/capacity-market-consultation-improving-the-framework-detailed-proposals

capacity available until the user pre-set maximum charge is reached, or electricity capacity ceases to exceed demand; OR

    ii) If the state of charge of Buildings as Power Stations storage is equal to its user set maximum charge, the storage neither charges nor discharges.

b) If electricity capacity is less than demand:

    i) If the state of charge of Buildings as Power Stations storage is greater than its user set minimum, the storage discharges at the lower of its maximum user pre-set rate of discharge or the shortfall of capacity available until either the user pre-set minimum charge is reached, or electricity capacity ceases to be less than demand.

50) By this simple response to the state of the system, the storage in Buildings as Power Stations would automatically dispatch capacity when the system is short and otherwise maintain a state of maximum readiness allowed by the storage settings. (In reality, many factors would determine the operation of batteries, including the trading incentives at times when prices may be extremely elevated and volatile. These considerations are ignored here because if the market is well designed, batteries should serve the system optimally and if the above dispatch rules are sub-optimal, they only risk a conservative estimate of their true value).

51) Batteries are also likely to perform a range of value-adding services in addition to serving the Capacity Market as already described. This might mean reserving part of the storage for these functions. The key settings, in summary, are as follows:

a) Maximum allowed charge level and Minimum allowed discharge level (as the Buildings as Power Stations or storage aggregator may want to reserve charge for other purposes, such as frequency response and some types of storage may perform better over the long term if the range of cycling is limited);

b) Maximum and minimum rates of charge and discharge (a design and safety feature of batteries in particular is a parameter enabling the user to decide how charge should be rationed over time to achieve a generating capacity with a given period of endurance and allows for a derating factor);

c) Efficiency of cycling (which is not used as it is assumed to be balanced by offsetting distribution losses);

d) Total capacity of Buildings as Power Stations storage.

52) For the purposes of the estimates here, the battery capacity allocated to each of the Buildings as Power Stations is illustrated in Figure 9 below.

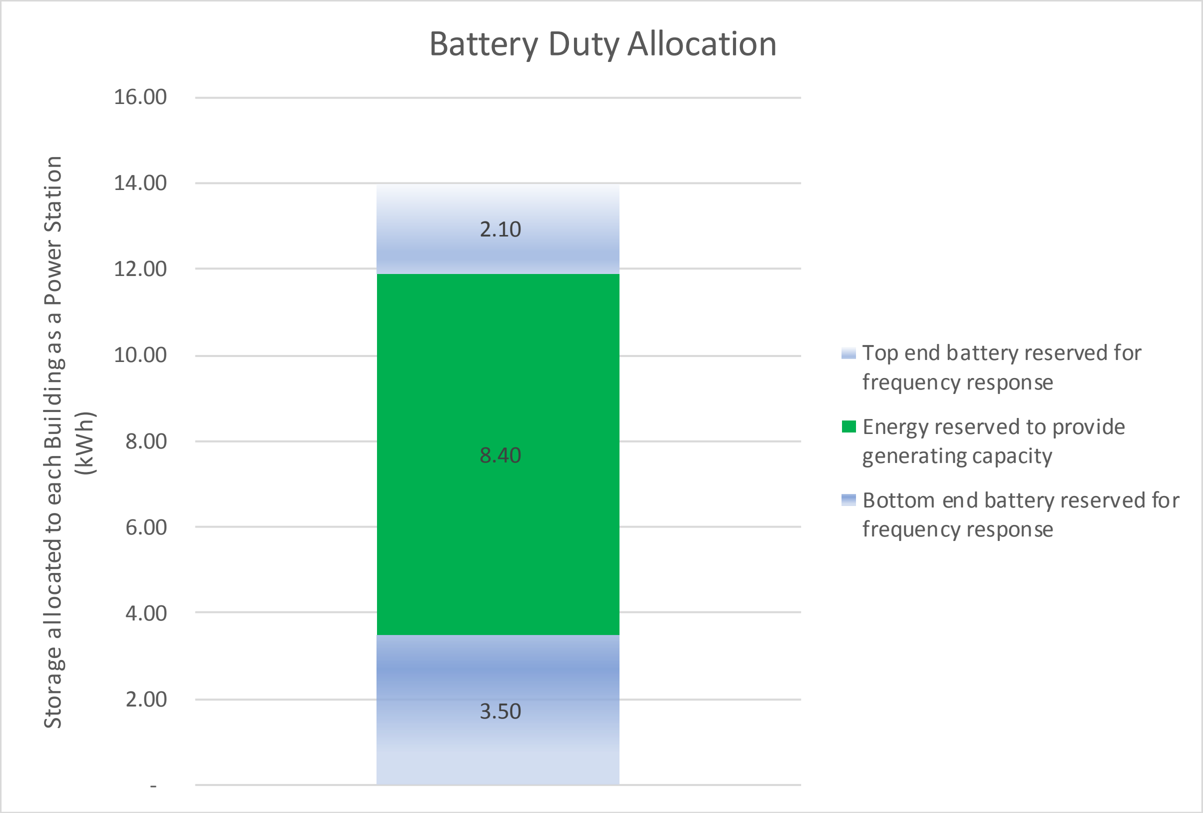

FIGURE 9 - ALLOCATION OF THE ELECTRICITY STORAGE CAPACITY FOR EACH OF THE BUILDINGS AS POWER STATIONS

53) These and other performance specifications for modelling purposes are shown in Table 5 below.

TABLE 5 - PERFORMANCE CHARACTERISTICS OF ELECTRICITY STORAGE FOR BUILDINGS AS POWER STATIONS

Battery Name Plate Capacity allocated to a dwelling	14.00	kWh
Top end battery reserved for frequency response	2.10	kWh
Bottom end battery reserved for frequency response	3.50	kWh
Energy reserved to provide generating capacity	8.40	kWh
Time for complete discharge of nameplate capacity	6.67	hours
Reserved Capacity of each battery	8.40	kWh
Minimum time for complete discharge of reserved capacity	4.00	hours
Time for complete battery charge	2.00	hours

METHODOLOGY

MEASURE THE DIFFERENCE IN GENERATING CAPACITY REQUIRED TO MAINTAIN THE ELECTRICITY RELIABILITY STANDARD WITH AND WITHOUT BUILDINGS AS POWER STATIONS

54) National Grid, in its capacity as the Delivery Body for Electricity Market Reform, has a statutory duty to make an annual recommendation to the Secretary of State for Business, Energy and Industrial Strategy regarding the capacity that needs to be secured in Capacity Market auctions in order to meet a reliability standard also defined in legislation. The Reliability Standard is 3 hours of expected loss of load per capacity year[12].

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[12] http://www.legislation.gov.uk/uksi/2014/2043/regulation/6/made

‘Loss of Load’ does not mean blackouts, but commences at the point when National Grid needs to take emergency actions to avoid disconnections if possible.

55) In this analysis, it is assumed that National Grid has secured the system by analysing and correctly recommending the amount of generating capacity that must be secured to meet the reliability standard. The impact of the battery storage provided by 1 million Buildings as Power Stations is then estimated by testing how much other generating capacity in the system can be relinquished in order to meet the same reliability standard. The quantity of relinquished generating capacity can be notionally assessed using values of capacity in the Capacity Market.

56) This methodology is summarised as follows:

- The Factual
    - Historical half hourly system state over a five-year period
    - Assume that generation is set exactly equal to demand
        - “Equal to demand” can be judged in three different ways:
            - Capacity exactly equals peak demand at its highest point in the year
            - Capacity results in three hours’ lost load in the year (as per the Reliability Standard)
            - Energy Unserved / Power Unserved is measured for three hours’ lost load and used as the equaliser for the counterfactual
- The Counterfactual
    - Include Buildings as Power Stations and storage as described
        - i.e. storage capacity, whatever PV might be generated and the shifted load shape for Buildings as Power Stations by substituting 1 million regular TDCV dwellings for Buildings as Power Stations
    - Reduce the amount of generation assumed in the factual until demand remains only just met
- Incremental difference between factual and counterfactual
    - Measure the change in capacity required to meet demand by the same three metrics

57) The most appropriate way to do this would be to run fully stochastic simulation of the entire system to take account of all system state scenarios into the far future. As a first approximation for an indicative initial answer, however, this analysis uses actual half-hourly demand data over a five-year period from 2009/10 to 2013/4 and applies perturbations that adjust the data according to changes that might occur on the system in the future.

58) In summary, the level of electricity capacity available is set by the user in the model in order to make it possible to calculate the difference in capacity required to achieve exactly the same level of supply security with Buildings as Power Stations as would have been achieved without them by adjusting the capacity. This indifference test can be carried out using reliability standards that are qualitatively different.

59) The measures of security of supply used by the model include: exactly matching demand with generating capacity; achieving a specified number of hours of lost load (as currently used for the Reliability Standard); and achieving equivalent levels of energy unserved, meaning the shortfall in energy during the whole of a

stress event as well as the peak power unserved which indicates the depth of the stress event. Each of these can lead to a different level of required generating capacity and each is described in more detail below.

EXACT MATCHING OF GENERATING CAPACITY TO DEMAND

60) Since we are only interested in the difference in generating capacity required to meet a defined security standard, the model can set generation, one approach to finding this is to set generating capacity equal to demand first without Buildings as Power Stations and then with Buildings as Power Stations with storage. For example, if peak demand is 50GW on a particular day, system capacity could be set also to 50GW to achieve an exact balance. If a given number of existing homes are replaced in the model with an equivalent number of Buildings as Power Stations, the model will recognise that Buildings as Power Stations storage can discharge at the peak and reduce net demand. The model can then reduce the system generating capacity until the net demand is met at a lower level of generation. The difference between these two values is a measure of the reduction in capacity that can be achieved using Buildings as Power Stations. (Additionally, the Buildings as Power Stations' own generation capabilities and load curve are also taken into account in the substitution).

61) To clarify this concept further, this approach is illustrated for a single day in Figure 10 below. (A single day is illustrated but over a five-year period is tested in the modelling at half-hour granularity). The dotted red line shows total electricity demand (lines on left axis) in Great Britain on 20th December 2010 during the coldest December since temperature records began in 1910[13]. To meet peak demand at 5.30 pm, around 60 gigawatts of generating capacity was required. If one million "Buildings as Power Stations" had been in existence at the time, each with its own networked battery, it would have been possible to meet the same peak demand with the reduction or deferment of 3.5 gigawatts of generating capacity as indicated by the solid black line, equivalent to over half the 2010 coal-fired generating capacity of Drax. When generating capacity falls short, the batteries could discharge (as shown by the green shaded portion plotted against the right axis) and supply would have met demand. In this case, the batteries were assumed to discharge 'smartly' as a 'generator of last resort' resulting in discharge over three hours, whereas if they had discharged at full rate, at the onset of the stress event the energy reserve of the batteries might have been dissipated in less than an hour the full generating capacity would still have been required. This illustrates the potential benefits of smart energy networks that optimise the use of assets.

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[13] http://www.bbc.com/news/science-environment-12119329

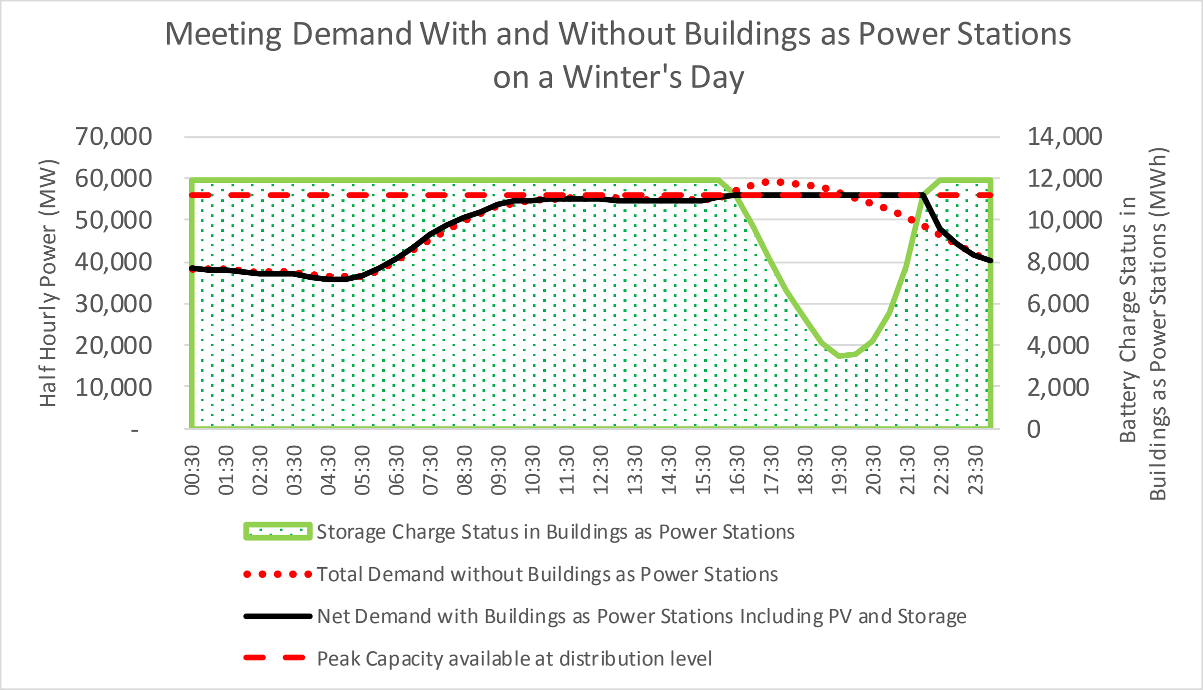

FIGURE 10 - MEETING DEMAND ON A SINGLE DAY WITH AND WITHOUT BATTERY STORAGE IN 1 MILLION HOMES

SETTING HOURS OF LOST LOAD

62) The Reliability Standard currently mandated by UK legislation of “3 hours of expected loss of load per capacity year” means that if the electricity system were to be operated over multiple iterations in a Monte Carlo fashion such that all the probabilistic functions (e.g. weather conditions, renewable output, forced outages of generating plant, interconnector availability and so on together fully interlinked by correlations), then the generating capacity would be expected to be less than demand for three hours. Note that the reliability standard is neither a maximum nor a minimum, but a target. Figure 11 below illustrates a difference between hours of lost load both with and without the storage system of one million Buildings as Power Stations for a particular sample day.

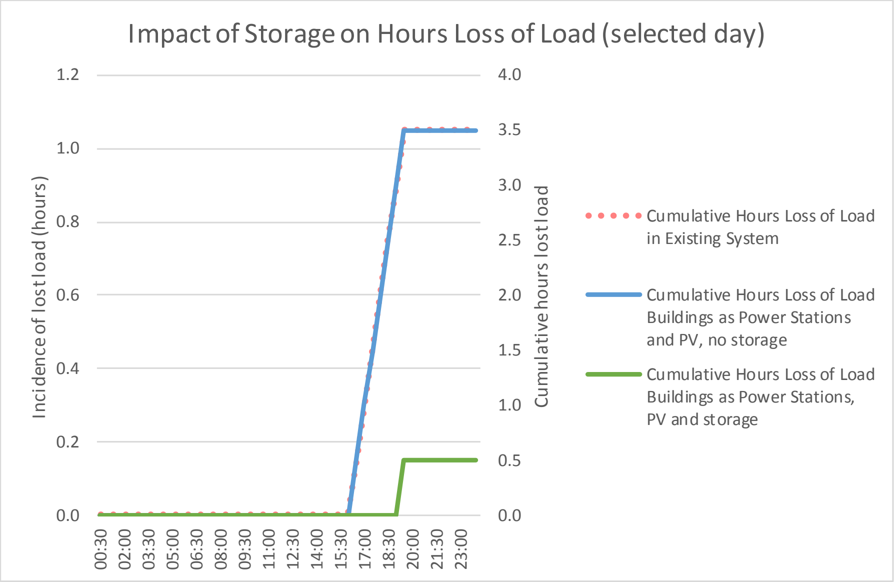

FIGURE 11 - ILLUSTRATION OF MEASUREMENT OF HOURS LOST LOAD

63) This ‘indifference’ test may also be viewed over a full year as shown in Figure 12 below. The difference between the intersection of a vertical line at 3 hours lost load and the relevant curves locate the generating capacity required to maintain the reliability standard. In this case, the difference is approximately 3,000 MW.

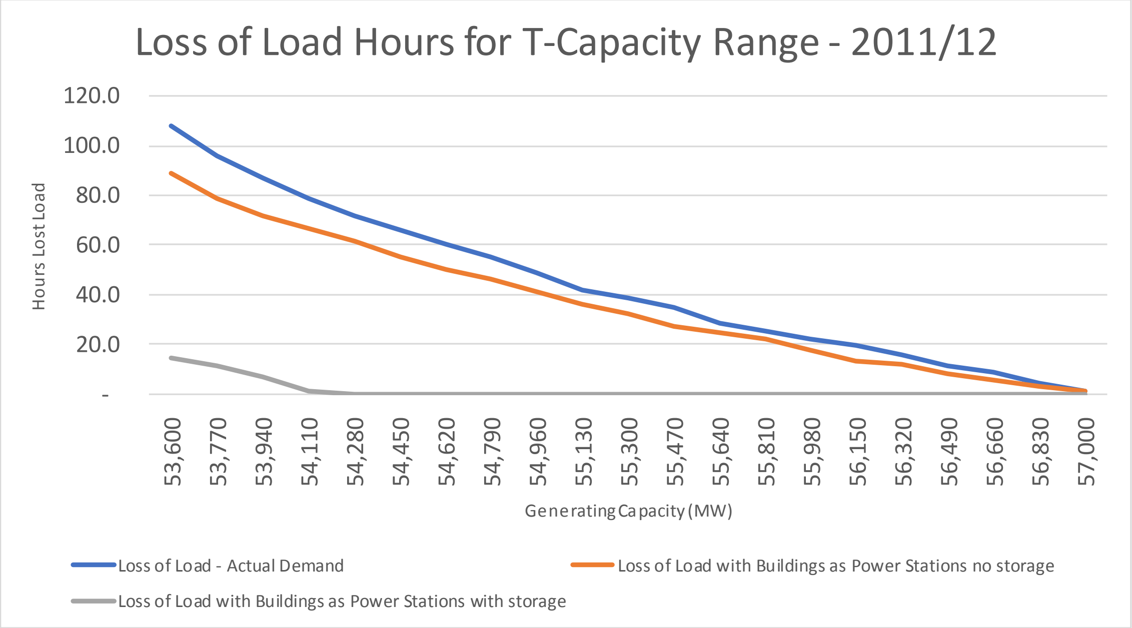

FIGURE 12 - LOSS OF LOAD COMPARISON MEASURED OVER A FULL YEAR

ENERGY UNSERVED

64) The Reliability Standard measured in expected hours of lost load has significant weaknesses which may be addressed by alternative or complementary standards at some point in the future. One is that it takes no account of differing manifestations of loss of load. An hour’s lost load that only requires a very small reduction in voltage may be entirely unnoticed by any consumers. In another situation, an hour’s lost load

may require disconnections and leave consumers without power. Thus the ‘depth’ of a loss of load can have consequences that are not measured by hours of lost load. For this reason, the model also allows the user to measure ‘energy unserved’ meaning the megawatt hours of shortfall between generation supplied and demand, as illustrated in Figure 13 below.

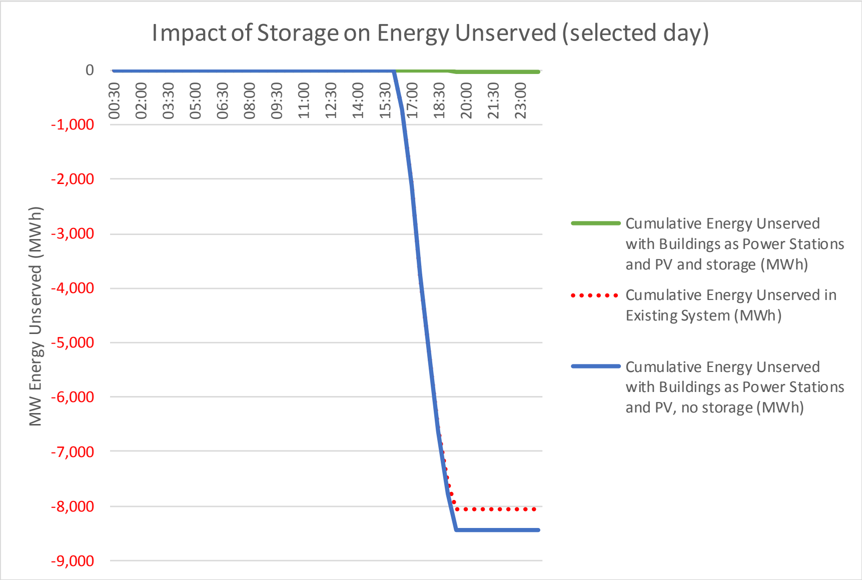

FIGURE 13 - ENERGY UNSERVED WITH AND WITHOUT STORAGE OF BUILDINGS AS POWER STATIONS

65) Figure 14 below shows the result of comparing energy unserved equivalence for storage in Buildings as Power Stations with the existing system over a whole year. Again, the displaced generating capacity requirement is approximately 3,000 MW.

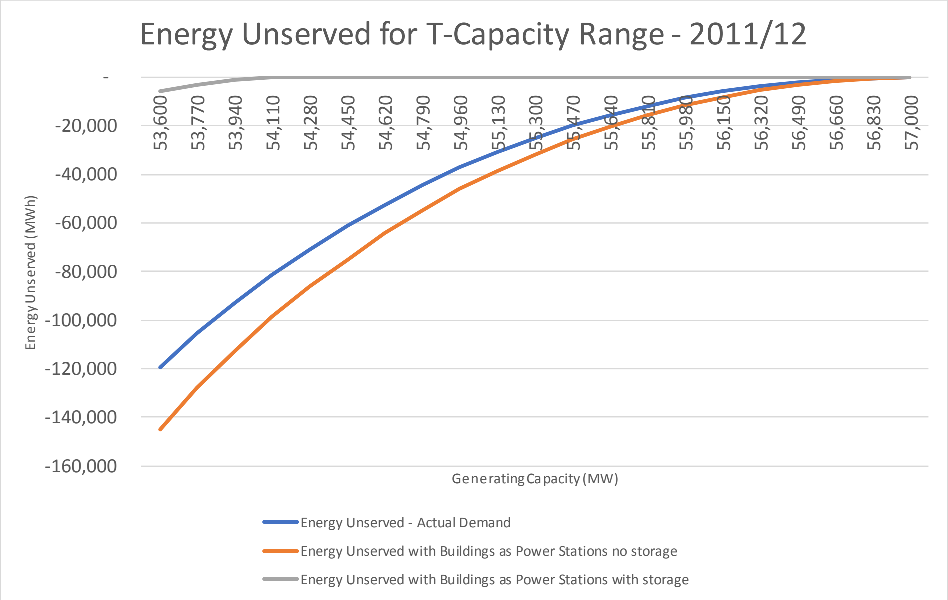

FIGURE 14 -ENERGY UNSERVED COMPARISON MEASURED OVER A FULL YEAR

66) Also, the modelling carried out for this report measures peak power unserved which gives information about the depth of the loss of load and therefore an indication of the risk of disconnections. Figure 15 below illustrates how the depth of loss of load in each half hour is measured in the modelling, indicating the true

severity of the impact a loss of load that cannot be easily detected either by hours of lost load or energy unserved.

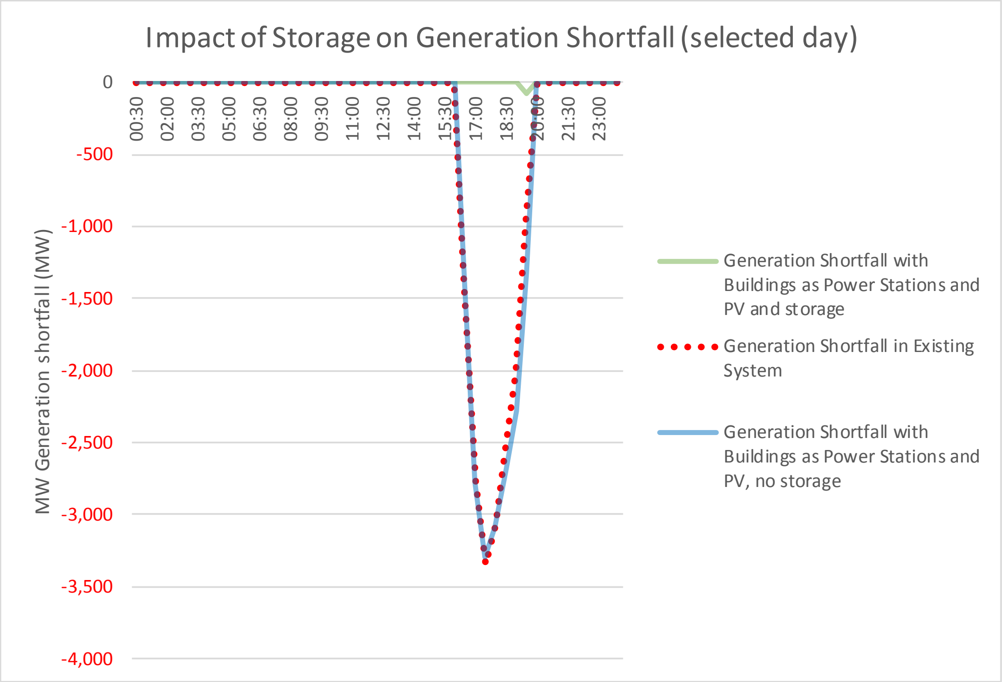

FIGURE 15 - POWER UNSERVED WITH AND WITHOUT STORAGE OF BUILDINGS AS POWER STATIONS

Taking Account of Different and Future Electricity System States

67) The displacement of generating capacity under recent historical system conditions is explored using historical demand data together with forecast loads of Buildings as Power Stations as described above, but it is also helpful to test what capacity could be displaced under a variety of alternative scenarios that might, for example, be more representative of future system states. This is enabled in the modelling by superimposing a variety of 'perturbations'. For example, the arrival of electric vehicles might change the underlying demand in a number of ways. The model therefore allows the superimposition of perturbations to the historical data and to repeat the capacity indifference tests to determine what generating capacity differences achieve the above reliability tests both with and without Buildings as Power Stations.

Estimates of the Contribution of Storage in Buildings as Power Stations

Peaking Capacity Avoidable by Storage for Historical Demand Shape

68) Modelling historical load shapes and targeting 3 hours lost load as the indifference measure gives the results shown in Table 6 below.

TABLE 6 - CAPACITY REDUCTION ACHIEVABLE WITH ELECTRICITY STORAGE WHILE TARGETING 3 HOURS LOSS OF LOAD BASED ON HISTORICAL HALF-HOURLY DEMAND WITH NO PERTURBATIONS

Substitute One Million Homes for Buildings as Power Stations with Electricity Storage and PV	2009/10	2010/11	2011/12	2012/13	2013/14
Capacity required for 3 hours loss of load without 1 million Buildings as Power Stations (MW)	59,503	60,175	56,150	56,927	53,490
Capacity required for 3 hours loss of load with 1 million Buildings as Power Stations having PV but no storage (MW)	59,466	60,100	55,971	56,811	53,278
Capacity required for 3 hours loss of load with 1 million Buildings as Power Stations having PV but with storage	55,628	56,757	52,900	53,883	49,799
Peaking capacity avoided by Buildings as Power Stations (MW)	**3,875**	**3,418**	**3,250**	**3,044**	**3,691**
Energy Unserved for 3 hours loss of load without 1 million Buildings as Power Stations (MWh)	-758	-493	-1,225	-237	-191
Energy Unserved for 3 hours loss of load with 1 million Buildings as Power Stations having PV but no storage (MWh)	-577	-1,616	-3,257	-863	-1,135
Energy Unserved for 3 hours loss of load with 1 million Buildings as Power Stations having PV but with storage (MWh)	-4,185	-2,745	-7,103	-1,447	-4,731

69) In each case, the peaking capacity that could be avoided exceeds 3,000MW.

Peaking Capacity Avoidable by Storage for Historical Demand Shape with Electric Vehicle Demand

70) If electric vehicles are charged on the system in a smart fashion, they will absorb energy away from peaks and peak prices. More useful for this analysis is to test the impact of charging that is less smart and which encroaches on periods of time when the electricity system is under higher load. Figure 16 below shows a hypothetical future electric vehicle charging shape where avoidance of peaks is poorly controlled. 10 million vehicles with an average daily charging requirement of 4kWh was assumed. The resulting electric vehicle load was added to national demand and the amount of peaking capacity that could be removed when one million Buildings as Power Stations were substituted while maintaining the Reliability Standard of 3 hours of lost load was calculated. (For comparison, National Grid FES 2017 puts high EV case in 2032 at 12,759,222 and forecasts an increase in peak demand of about 10 GW).

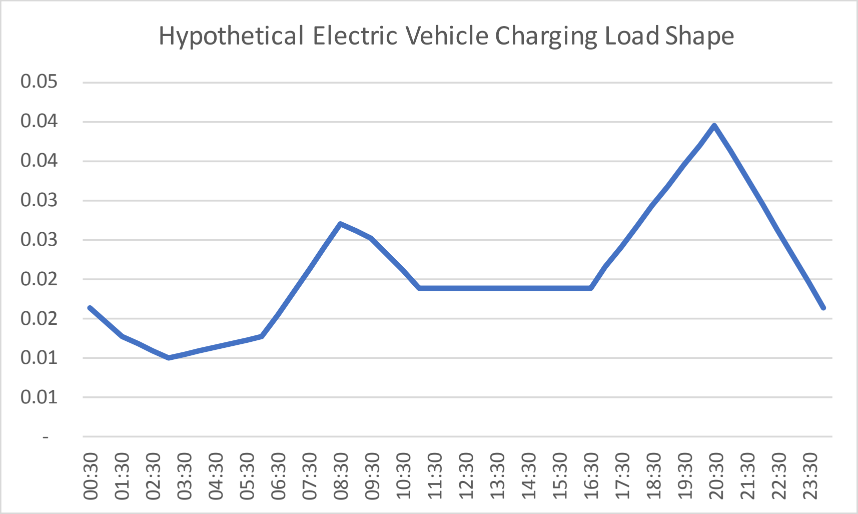

FIGURE 16 - POORLY CONTROLLED ELECTRIC VEHICLE CHARGING LOAD SHAPE

71) The absolute number of electric vehicles is not as important a measure as the amount of charge required and 10 million electric vehicles consuming a daily average of 4kWh could represent either more vehicles consuming less on average or vice versa, as illustrated in Figure 17 below.

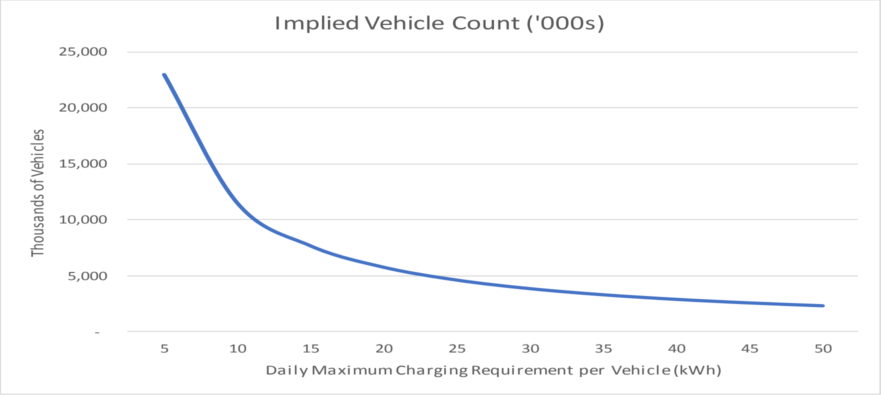

FIGURE 17 - RELATIONSHIP BETWEEN NUMBER OF VEHICLES AND AVERAGE DAILY CHARGING REQUIREMENT

72) Figure 18 below shows the results of adding substantial and poorly coordinated charging of electric vehicles.

Substitute One Million Homes for Buildings as Power Stations with Electricity Storage and PV	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**
Capacity required for 3 hours loss of load without 1 million Buildings as Power Stations (MW)	61,345	62,275	58,560	58,968	55,423
Capacity required for 3 hours loss of load with 1 million Buildings as Power Stations having PV but no storage (MW)	61,506	62,200	58,260	58,996	55,231
Capacity required for 3 hours loss of load with 1 million Buildings as Power Stations having PV but with storage	58,092	59,013	55,350	56,043	52,244
Peaking capacity avoided by Buildings as Power Stations (MW)	**3,254**	**3,263**	**3,210**	**2,926**	**3,178**
Energy Unserved for 3 hours loss of load without 1 million Buildings as Power Stations (MWh)	-1,496	-	-1,051	-331	-307
Energy Unserved for 3 hours loss of load with 1 million Buildings as Power Stations having PV but no storage (MWh)	-741	-759	-3,372	-860	-1,900
Energy Unserved for 3 hours loss of load with 1 million Buildings as Power Stations having PV but with storage (MWh)	-1,559	-784	-4,390	-3,103	-1,858

FIGURE 18 - CAPACITY REDUCTION ACHIEVABLE WITH ELECTRICITY STORAGE WHILE TARGETING 3 HOURS LOSS OF LOAD BASED ON HISTORICAL HALF-HOURLY DEMAND AND 10 MILLION EV (POOR CHARGING CONTROL)

73) Even though the peak has been extended, the storage in Buildings as Power Stations would have led to around 3,000MW being avoided.

PEAKING CAPACITY AVOIDABLE BY STORAGE FOR HISTORICAL DEMAND SHAPE WITH HEAT PUMP DEMAND

74) It is possible that large numbers of heat pumps could be deployed in the future. Figure 19 below shows the load shape assumed for heat pumps over a winter period. 10 million heat pumps are assumed to consume 23kWh per day each.

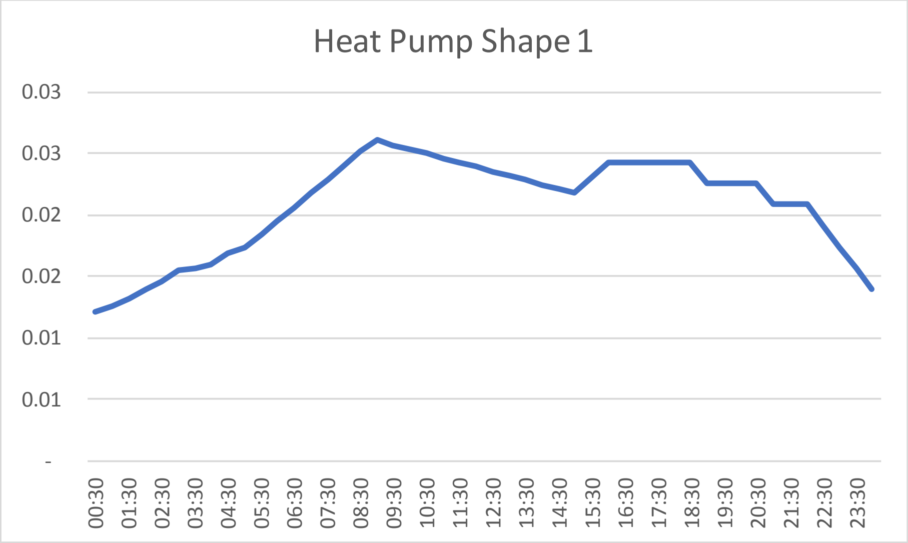

FIGURE 19 - ASSUMED WINTER LOAD SHAPE FOR HEAT PUMPS

75) Figure 20 below shows the results when heat pumps are included, this time without electric vehicles.

76) **Substitute One Million Homes for Buildings as Power Stations with Electricity Storage and PV**	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**
Capacity required for 3 hours loss of load without 1 million Buildings as Power Stations (MW)	70,771	71,725	67,633	68,118	64,967
Capacity required for 3 hours loss of load with 1 million Buildings as Power Stations having PV but no storage (MW)	70,976	71,440	67,379	68,157	64,754
Capacity required for 3 hours loss of load with 1 million Buildings as Power Stations having PV but with storage	66,842	67,840	64,094	64,833	61,094
Peaking capacity avoided by Buildings as Power Stations (MW)	**3,929**	**3,885**	**3,539**	**3,285**	**3,872**
Energy Unserved for 3 hours loss of load without 1 million Buildings as Power Stations (MWh)	-1,451	-287	-866	-997	-163
Energy Unserved for 3 hours loss of load with 1 million Buildings as Power Stations having PV but no storage (MWh)	-1,319	-1,317	-2,426	-1,062	-958
Energy Unserved for 3 hours loss of load with 1 million Buildings as Power Stations having PV but with storage (MWh)	-3,924	-2,398	-5,771	-4,230	-2,474

FIGURE 20 - CAPACITY REDUCTION ACHIEVABLE WITH ELECTRICITY STORAGE WHILE TARGETING 3 HOURS LOSS OF LOAD BASED ON HISTORICAL HALF-HOURLY DEMAND AND 10 MILLION HEAT PUMPS

77) Once again, the capacity that could have been avoided through the use of the storage in Buildings as Power Stations, exceeds 3,000 MW.

Peaking Capacity Avoidable by Storage for Historical Demand Shape with both Electric Vehicle and Heat Pump Demand

78) Figure 21 below shows the load shape that arises from the combined presence of electric vehicles and heat pumps using the same assumptions as in the previous paragraphs.

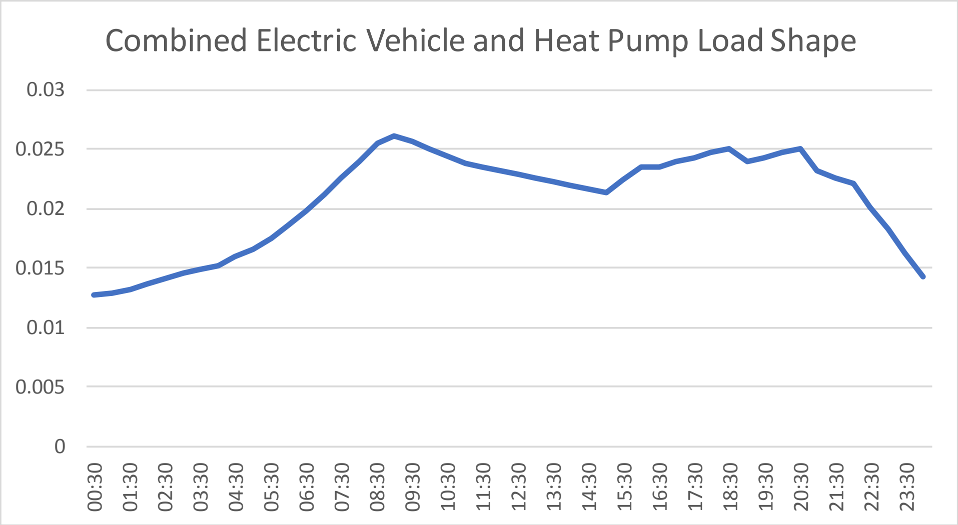

FIGURE 21 - VOLUME WEIGHTED LOAD SHAPE FOR ELECTRIC VEHICLES AND HEAT PUMPS COMBINED

79) Figure 22 below shows the result of combining both electric vehicles and heat pumps. Note that although the total capacity required rises each time a new set of electricity consuming technology is added, storage in Buildings as Power Stations can reduce what would otherwise have been required by some 3,000MW.

Substitute One Million Homes for Buildings as Power Stations with Electricity Storage and PV	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**
Capacity required for 3 hours loss of load without 1 million Buildings as Power Stations (MW)	72,923	73,725	69,954	70,425	66,984
Capacity required for 3 hours loss of load with 1 million Buildings as Power Stations having PV but no storage (MW)	72,864	73,620	69,806	70,193	66,754
Capacity required for 3 hours loss of load with 1 million Buildings as Power Stations having PV but with storage	69,121	70,050	66,646	67,084	63,270
Peaking capacity avoided by Buildings as Power Stations (MW)	3,802	3,675	3,308	3,341	3,714
Energy Unserved for 3 hours loss of load without 1 million Buildings as Power Stations (MWh)	-877	-270	-670	-178	-151
Energy Unserved for 3 hours loss of load with 1 million Buildings as Power Stations having PV but no storage (MWh)	-758	-958	-1,654	-1,807	-1,301
Energy Unserved for 3 hours loss of load with 1 million Buildings as Power Stations having PV but with storage (MWh)	-2,779	-3,587	-2,456	-4,011	-3,334

FIGURE 22 - CAPACITY REDUCTION ACHIEVABLE WITH ELECTRICITY STORAGE WHILE TARGETING 3 HOURS LOSS OF LOAD BASED ON HISTORICAL HALF-HOURLY DEMAND AND 10 MILLION HEAT PUMPS AND 10 MILLION ELECTRIC VEHICLES

80) Note that although the total capacity required rises each time a new set of electricity consuming technology is added, storage in Buildings as Power Stations can reduce what would otherwise have been required by some 3,000MW.

81) In summary, around 3,000MW of peak capacity can be deferred or displaced by the 8.4MWh of battery storage in 1 million homes, giving a displacement rate for modelling purposes of 0.357kW per kWh of installed operating electricity storage capacity in each Building as a Power Station. If the Government's own estimates of the Net Cost of New Entrants ("net CONE") as used in the Capacity Market[14] is assumed as a long-term representative value of avoided capacity at £49 per kW, then using the same scenarios as previously, the combined benefits are as summarised in Figure 23 below.

Fuel Price Scenarios			Build Rate Scenarios		
			Evolution	Accelerated	Already completed
	High	Better than Active Homes Neath	£ 10,664 M 377 TWh 69 MtCO2	£ 13,831 M 469 TWh 87 MtCO2	£ 16,611 M 559 TWh 104 MtCO2
		Active Homes Neath Energy	£ 9,936 M 361 TWh 69 MtCO2	£ 12,878 M 449 TWh 86 MtCO2	£ 15,442 M 535 TWh 103 MtCO2
		Worse than Active Homes Neath	£ 5,709 M 205 TWh 47 MtCO2	£ 7,399 M 255 TWh 58 MtCO2	£ 8,793 M 304 TWh 68 MtCO2
	Medium	Better than Active Homes Neath	£ 9,114 M 377 TWh 69 MtCO2	£ 11,766 M 469 TWh 87 MtCO2	£ 14,121 M 559 TWh 104 MtCO2
		Active Homes Neath Energy	£ 8,542 M 361 TWh 69 MtCO2	£ 11,024 M 449 TWh 86 MtCO2	£ 13,203 M 535 TWh 103 MtCO2
		Worse than Active Homes Neath	£ 5,154 M 205 TWh 47 MtCO2	£ 6,666 M 255 TWh 58 MtCO2	£ 7,901 M 304 TWh 68 MtCO2
	Low	Better than Active Homes Neath	£ 8,397 M 377 TWh 69 MtCO2	£ 10,861 M 469 TWh 87 MtCO2	£ 12,999 M 559 TWh 104 MtCO2
		Active Homes Neath Energy	£ 7,905 M 361 TWh 69 MtCO2	£ 10,217 M 449 TWh 86 MtCO2	£ 12,203 M 535 TWh 103 MtCO2
		Worse than Active Homes Neath	£ 4,920 M 205 TWh 47 MtCO2	£ 6,365 M 255 TWh 58 MtCO2	£ 7,527 M 304 TWh 68 MtCO2

FIGURE 23 - SUMMARY OF DIRECT ECONOMIC, ENERGY RESOURCE, MTCO2 SAVINGS AND VALUE OF CO_2 SAVINGS TO SOCIETY OF 1 MILLION BUILDINGS AS POWER STATIONS INCLUDING STORAGE (EXCLUDING TRADING AND FEED IN TARIFF BENEFITS)

82) The substantial aggregate of all the enduring benefits analysed in this report and shown in Figure 23 above is robust under all scenarios considered.

POSSIBLE FUNCTIONS OF PROPOSED HEAT STORAGE FOR BUILDINGS AS POWER STATIONS

83) Figure 24 below shows a typical December day for a Building as a Power Station based on the Active Homes Neath design.

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[14] See the Electricity Capacity Report, Section 1.1 here: https://www.emrdeliverybody.com/Lists/Latest%20News/Attachments/118/Electricity%20Capacity%20Report%202017.pdf

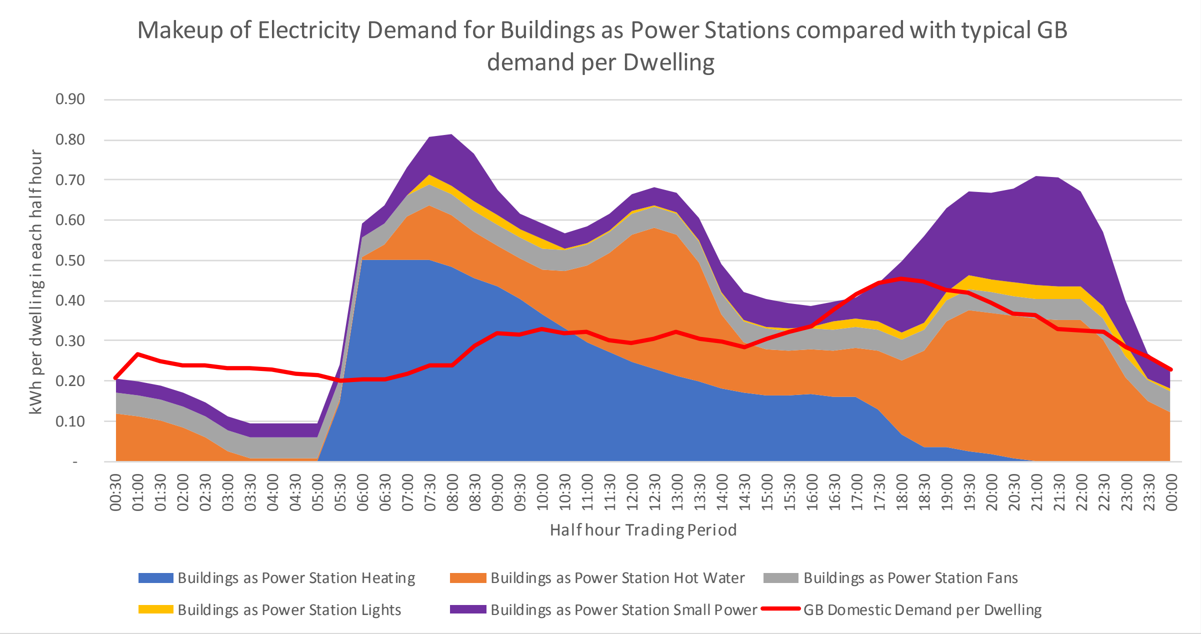

FIGURE 24 - GB DEMAND COMPARED WITH ACTIVE HOMES NEATH BUILDINGS AS POWER STATIONS

84) Buildings as Power Stations do not rely on gas for winter heating. In the Active Homes Neath design, electricity is the sole source of heat. This increases electricity consumption and extends the winter peak. Given the high-energy efficiency of the building, there are opportunities to manage and optimise this. In addition, an interseasonal heat storage system could provide a substitute for electricity and change the electricity load shape and scale.

85) Figure 25 below shows an example of the stored heat contribution that would enable the load shape of a dwelling designed as a Building as a Power Station to maintain the same load shape and scale as domestic dwellings today.

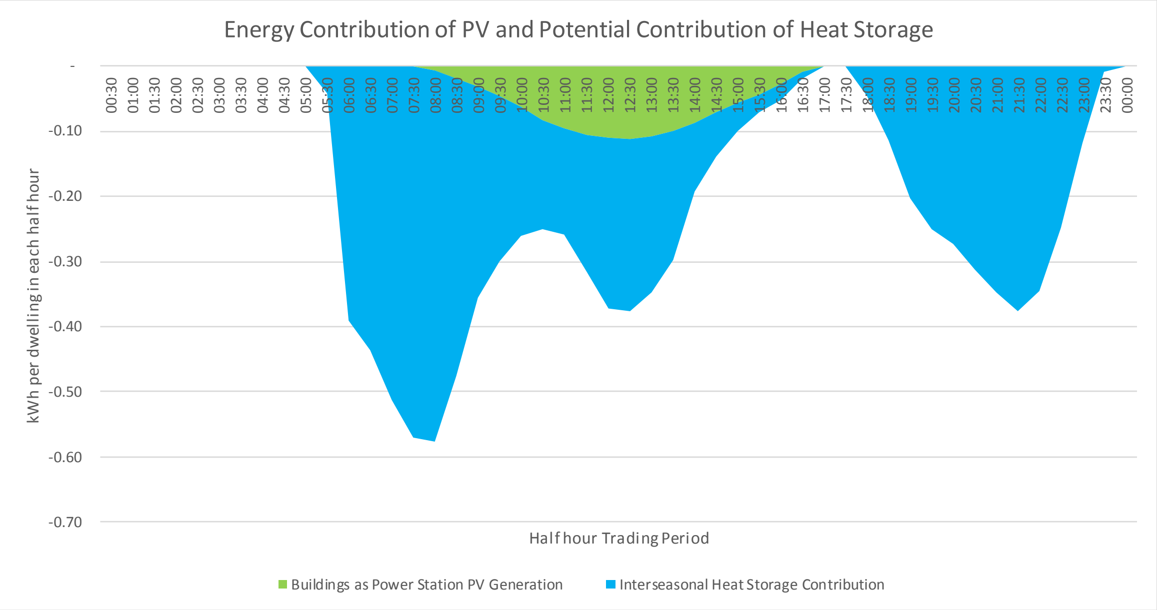

FIGURE 25 - CONTRIBUTION OF PV AVAILABLE AND ADDITIONAL STORED HEAT REQUIRED TO RETURN ELECTRICITY TO GENERAL DEMAND LOAD SHAPE

86) Figure 26 below shows the result on the electricity load shape of a Building as a Power Station using heat storage.

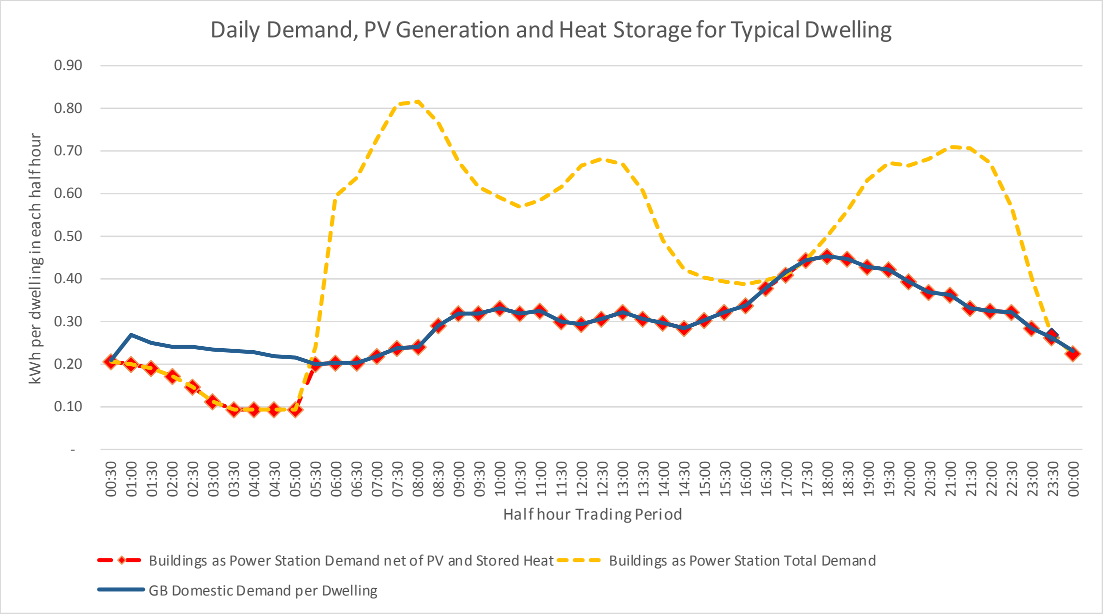

FIGURE 26 - IMPACT OF USE OF STORED HEAT ON ELECTRICITY LOAD SHAPE OF BUILDINGS AS POWER STATIONS

87) If Buildings as Power Stations utilise their heat storage, there would be a choice of storage capacities to target. As described above, the heat could be used to offset electricity requirements to ensure that the Buildings as Power Stations can match the general load shape of domestic demand in winter. This can be calculated as the sum of all the positive differences between the load of Buildings as Power Stations during winter, normalised for an average dwelling. Another alternative would be to generate or recover more energy than is used in the dwelling calculated to offset the entire electricity consumption net of solar PV generation. The heat storage capacities required to achieve each of this is shown in Table 7 below together with estimated heat storage volume required based on a density of 0.3 MWh per m^3.

TABLE 7 - HEAT STORAGE CAPACITIES TO MEET ENERGY OBJECTIVE

Energy Objective	Heat Storage Capacity (kWh per Dwelling)	Approximate Volume (m^3 per Dwelling)
Maintain parity with GB Domestic Electricity Demand on a half hourly basis so that Buildings as Power Stations	600	2
Buildings as Power Stations to generate more energy than they consume over an annual cycle.	2,232	7.5

CONCLUSIONS

88) Until recently, the electricity system could be described at high level in terms of physical generation, transmission and distribution and transactionally in terms of trading and supply. As a result of recent Ofgem consultations, storage is being added to these. Buildings as Power Stations also could be regarded as a distinct asset class within the energy system, along with generation, transmission, distribution and storage for the following reasons:
    a) Although they fall within the domestic sector, they would be interacting with the electricity system in new ways.
    b) Every aspect of the electricity market is created by the hand of Government intervention either directly via legislation or executive authority, or indirectly, via regulatory bodies which either following their statutory duties or by taking direction from Government or powerful energy industry lobbyists. Almost every class of technology participating in today's electricity markets is explicitly named and governed in regulations and policies for support schemes. At present, the concept of Buildings as Power Stations does not fall into any such class, either within energy regulations or building regulations. This means we do not have the language necessary to drive forward the concept efficiently except through piecemeal and faltering adjustments in the regulations of both sectors.
    c) The domestic dwelling would link the development of a number of technologies in tandem.
    d) The set of technologies would be smartly controlled in similar ways across the sector.
    e) Scale: about a third of all electricity is currently consumed within the domestic sector. If and when domestic consumers take full control of their energy management, then treating them as a recognised asset class would allow focus on the specific analytical, technical and regulatory needs of Buildings as Power Stations.

89) The first conclusion, therefore is that Buildings as Power Stations should be considered as a separate energy asset class.

90) The second conclusion is that to realise the benefits of electricity storage, it is essential to incorporate 'smartness' in order to optimise dispatch. There may be more economic ways to utilise batteries, but this report suggests one application. Smart dispatch of batteries, and essential vs non-essential loads, however, could enable further benefits.

91) The third conclusion is the importance of either carbon prices or high emissions standards, without which there may be less incentive to build Buildings as Power Stations.

92) Finally, interseasonal heat storage (and using similar technology, industrial waste heat capture, storage and transportation) could enable very significant efficiencies both in energy use and valuation as it would be a substitute for electricity, particularly during winter.