

small or atomic?

comparing the finances of nuclear
and micro-generated energy

a Green Alliance briefing

“green alliance...

small or atomic? comparing the finances of nuclear and micro-generated energy

by Rebecca Willis
strategic overview by Alan Whitehead MP

Published by Green Alliance, June 2005
Designed by Sally Powell

ISBN 0 9549757 3 1

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Green Alliance is a registered charity number 1045395
Company Limited by guarantee, registered number 3037633

This work was funded by Microgen Energy Ltd and supported by the Micropower Council.

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small or atomic? ~

strategic overview

Alan Whitehead MP

As the nuclear debate intensifies, there is a growing 'wisehead' mantra, which goes roughly thus: 'of course renewables are fine in theory, and it would be nice to think that we could power our country this way, but it's not realistic is it? Now, I'm as keen on the low carbon economy as the next person, but if we're going to get anywhere near the targets we have set on CO₂ emissions, we'll just have to bite the bullet and commission new nuclear. I know it's got problems, but if we don't do something in the next two years or so, you know, the lights will start going out'.

This emerging 'commonsense' has benefited greatly from some assiduous and carefully placed public relations by the nuclear industry, and as with many such sayings, it has more than an element of truth in it. It is not true that 'the lights will go out' if we do not adopt nuclear shortly. It is true, however, that the most likely way to stop the lights going out over the next twenty years, in the absence of anything else, would be to continue to expand investment in new gas plant. The private sector has shown great willingness to put money into gas generation and would continue to do so. Unfortunately, placing reliance on new gas plant would put an end to any ambition of radically reducing CO₂ emissions from energy supply, and would increasingly need to be fuelled by imports from potentially problematic parts of the world.

The UK is now beginning to make real progress with large-scale renewables. Offshore wind, in particular, is coming on stream and with larger scale projects such as the London array taking off, will mean that initial targets for renewable electricity supply are within reach of being met. But even so, the argument goes, over the next twenty years, a successful large scale renewable programme would do no more than stand still as far as CO₂ emissions from energy are concerned, because at the same time, older nuclear power plants would be closing down, so that by 2023, if nothing is done, electricity generation from nuclear plants would reduce from the present 20 per cent to the output of one station only - Sizewell B representing about 2 per cent of electricity generation. So efforts to cut CO₂ emissions from generation would simply be running very hard to stay in the same place.

It is the sheer apparent size of the gap that seems to emerge, that prompts the 'bite the bullet' conclusion. Surely we can't make up all that gap with windmills, untested tidal turbines and hay-burning furnaces? Doesn't it make new nuclear power stations inevitable?

Well, let us go along with the scenario for a while: Let us discount the problem that there are, as yet, no reliable means of disposing of nuclear waste, and the concern that a new generation of nuclear power stations in known and almost unprotectable locations would be high security risks in their own right. Finally, let us ignore the fact that nuclear power is not really renewable, that there is more than a cloud on the horizon of the availability of economically mineable uranium in the medium to long term, and that it is, in any event mined from precisely the same band of potentially problematic countries that we might consider obtaining our long term gas supply from.

Let us, instead, concentrate precisely on the scenario envisaged by the ‘wise heads’ and assume that -say- in 2007 we do indeed take the fateful decision that we, as a country will invest in a new generation of nuclear power stations. We would need to do this in something like that timescale because of the very long lead time before a single kilowatt of electricity would emerge from the first of the new generation of power stations. The process of commissioning, financing, obtaining planning and other permissions would probably mean that the first ‘new generation’ nuclear power would emerge in about ten to twelve years time - that is, between 2017 and 2019. With a bit of luck and some stretching of life before decommissioning, we would still have somewhat more than 2 per cent of electricity generated by nuclear - perhaps the Hartlepool and Heysham 1 Reactor would just about still be working, and the Heysham 2 and Torness reactors would certainly be producing. That is, there would be an overlap: at the point new capacity came on stream we might find that 6 per cent of our needs could reliably be met by the fag end of ‘old’ nuclear, and a further 4 per cent possibly.

So if we want to make progress on CO₂ emissions, and large scale renewables do as well as we think they will there would still be a big gap between the decision point and the year in which the new generation came on stream. The gap would be notched - that is, it would widen in steps as large nuclear plant closed down - 4 per cent per year in 2008-9, almost 6 per cent in 2010, and then up to 14 per cent in 2014. We would, in the meantime, still need to make this gap up, and the gas generation route would be the only way to do it, assuming large-scale renewables cannot be ramped up further. We could invest in some medium term gas, and take a hit over the years 2010 -2020 on CO₂ reduction. In order to remain on track for later we would have to compensate with a nuclear programme far larger than simply replacing the present power stations as they go out of commission - we would have to ‘row back’ that 10 per cent and make an accelerated dent in emission figures over the following decade. This brief analysis suggests that, in order to compensate for the long time lag between commissioning and production that would be an inevitable consequence of a new generation of ‘going nuclear’, we would have to commission, over the next few years, far more than a simple replacement programme for existing nuclear generation.

But even if we only commissioned a replacement programme, what would it cost? In taking the decision to commission, we would have to know that the funding was available as it were, ‘on the table’. The financial dimension of the decision would have to be judged in terms of the capital cost of building sufficient reactors, and could not take into account the amortisation of the cost over the subsequent life of the reactor. The nuclear industry, in presenting cost models is coy on this point, referring to costs per kilowatt over the lifetime of reactors, rather than up-front cost. As Rebecca Willis demonstrates in her analysis, it would be likely to cost, before any new power was generated, a minimum of £10 billion, assuming that the whole programme, unlike all previous nuclear commissions, came in on budget.

Furthermore, unless such a programme proved unlike any other major nuclear project past or present, the vast majority of such money would need to be found from Government, either directly or indirectly. There are currently, for example, no private sector takers for new nuclear reactors in the United States, despite the existence of a favourable climate for such investment. Some investment might be engineered in by guarantees of favourable prices subsequently, or by extensive underwriting schemes, but in truth, the Government would have to commit itself to this order of forward

finance either as actual payment or guarantee, over the next four to five years, in order to start and continue an effective programme.

So if, having taken the best possible case for replacement nuclear power and discarded the costs and dangers of its side-effects, we are left with a likely up-front bill of £10 billion or more, a reasonable question to put into the debate is, what CO₂ efficient renewable or near renewable plant could be purchased with such an amount, and would it have a better effect on power supplies than a new nuclear programme?

Rebecca Willis analyses what it would cost to purchase a portfolio of micro-generation capacity - domestic CHP, Solar PV and home-based wind energy, and the answer in these terms is - quite a lot could be purchased for £10 billion and it would, overall have a comparable effect on power supplies. It is difficult to make exact comparisons because in neither instance does capacity equal output - in the case of renewable and micro generation, because output at any one time would only be a fraction of capacity, and in the case of nuclear power stations, unless a monopoly of power supply were granted to nuclear, output would equate to what was produced from the grid on the basis of a future version of BETTA. Even so, for a cost in the region of £10 billion, more capacity would be brought than if the same £10 billion were invested over the same time scale in new nuclear. Such investment would not do more than make up the gap - renewable and near -renewable electricity sources would thereby account for perhaps double the current projected target by 2023, but the majority of power would still be provided by other means and would sustain an easily adequate base load capacity. In its own right, though, a distributed generation capacity would, through the aggregate decisions of the millions of small power generators it encompassed, provide an additional reliable base load, and at little additional cost in conversion works to the national grid system.

But there would be two additional factors to be taken into account in this counter-scenario. Firstly, the calculation is based on the assumption that the micro generating plant would simply be given away (or in the case of CHP boilers, replaced at the same cost as that of a conventional boiler). It also - conservatively - discounts the economies of scale that would apply to the cost calculations were such a large programme of domestic CHP wind and PV to be introduced. It is likely, however, that a programme would not need to be completely free to succeed. The very modest Clear Skies programme has demonstrated how incentives can drive take up, and it would be likely that some cost element of the installation could be recouped, making the programme, unlike the comparable fixed cost of new nuclear stretch far further for a £10 billion input. Scale cost reductions would further strengthen the efficacy of the investment.

Secondly, and perhaps most importantly, CO₂ reductions would start the day after the investment started being spent. Domestic wind turbines start saving on conventional electrical demand the moment they are plugged into the mains and CHP boilers produce electricity the moment they are fired up. Such boilers, incidentally, use approximately the same gas to function as condensing boilers do currently: the generated electricity would not only be on stream immediately, but would in real terms be a completely carbon free bonus to the grid. There would be no residual 'gap' as we waited for new plant to be commissioned, planned and built.

There are two versions of the 'go nuclear now' argument. One suggests that nuclear power would produce electricity alongside a surge in renewables and near renewables, and would act as a clean partner of those different sources. The other suggests that

renewables will simply fail, and that we should contemplate investing in replacement nuclear capacity only as a first part of a predominantly nuclear future - further tens of billions of pounds invested decade by decade leading up to 2050. On the line of argument presented here, generous as it is to the side arguments about the intrinsic desirability of nuclear power, we would have to commit to the second scenario if we started down the route of replacement nuclear power: government, in order to make up the gap in CO₂ reduction now facing us even if we started almost immediately, would have to commit more and more money to further nuclear capacity between 2020 and 2040. In doing so it would effectively crowd out renewables by placing almost all public underwriting in the nuclear basket, and it would crowd them out completely if, in order to entice industry to come up with even a small part of the investment needed, it artificially fixed the price of nuclear sourced electricity in the years ahead.

In short, the nuclear option is probably the worst one we might consider, even if we analyze it on finance alone. On timescale and capacity it doesn't add up. Even if we really did simply give everyone a free boiler or windsaver it would probably amount to a better long-term choice for future energy. If we want to make early sustained and secure reductions in CO₂ energy emissions, the micro-generation option, in addition to the development of large-scale renewables and greater energy efficiency and conservation makes elementary sense. It's downside is that it doesn't sound half as reassuring as the ability to pull a big lever in a large building somewhere and watch the expensive and eventually highly poisonous electricity flow.

small or atomic? comparing the finances of nuclear and micro-generated energy

Rebecca Willis

summary

Most nuclear power plants in the UK will reach the end of their working life over the next twenty years, removing around a quarter of the UK's electricity generation capacity. Replacing this capacity with new nuclear stations would involve investment of at least £10 billion to construct new stations, and further costs for fuel, maintenance, waste and decommissioning.

£10 billion represents a substantial investment in electricity generation capacity. Before any decision about new nuclear plant is made, the opportunity cost of any investment should be considered. Would the money be better spent elsewhere? The closure of nuclear stations, and the need to invest in electricity generation, could be seen as a window of opportunity for other technologies and approaches to energy generation. It offers the opportunity to move to a more flexible, decentralised model of energy generation, as envisaged in the Energy White Paper.

This paper assesses the cost implications of different approaches. Firstly, it surveys the costs involved in building and running a new fleet of nuclear stations. It then looks at the costs of three forms of 'micro-generation' - micro combined-heat-and-power, small-scale wind power and solar photovoltaics. For all the technologies surveyed, cost estimates are drawn from a range of government, industry and academic sources. Lastly, it compares the costs of nuclear power and micro-generation, and argues for radically increased investment in small-scale solutions.

This analysis does not seek to imply that all nuclear capacity should simply be replaced by micro-generation alone. There is clearly a role for much greater energy efficiency, and other renewable and low-carbon generation, all of which would benefit from greater investment. However, this paper concentrates on the opportunities of micro-generation because these technologies currently attract much less political attention, policy support and funding.

This paper argues that the investment needed for new nuclear stations would be more effectively spent on small-scale energy solutions, combined with greater investment in energy efficiency and renewable technologies.

where are we heading? the energy white paper and beyond

The UK is committed to tackling climate change. The 2003 Energy White Paper set out a clear pledge to reduce carbon dioxide emissions by 60 per cent over the next fifty years, to 2050. This will require a fundamental shift in the way that we use energy. The White Paper offers a vision for the energy system in 2020:

“We envisage the energy system in 2020 being much more diverse than today. At its heart will be a much greater mix of energy, especially electricity sources and technologies, affecting both the means of supply and the control and management of demand... There will be much more micro-generation, for example from CHP plant, fuel cells in buildings, or photovoltaics... New homes will be designed to need very little energy and will perhaps even achieve zero carbon emissions...”¹

(see full text at Annex A)

There is a further energy challenge facing the UK over the next twenty years – the declining contribution from nuclear stations. In 2002, nuclear power provided 9 per cent of the UK’s primary energy demand, or 23 per cent of electricity needs.² However, many nuclear stations are reaching the end of their working life. Between now and 2023, all but one of the UK’s nuclear stations will reach the end of their projected lifespan, with the loss of around 11GW of electricity generating capacity.³ Annex B sets out the UK’s existing nuclear plant, and its projected lifespan. Although some plants may be granted lifespan extensions of a few years, this will do no more than postpone the inevitable.

We therefore face a fundamental energy choice: whether to replace this capacity with new nuclear plant, or whether to invest in other low-carbon options – renewable energy and energy efficiency. The White Paper gave a clear indication of the way ahead, but did not rule out new nuclear build:

“Although nuclear power produces no carbon dioxide, its current economics make new nuclear build an unattractive option and there are important issues of nuclear waste to be resolved. Against this background, we conclude it is right to concentrate our efforts on energy efficiency and renewables. We do not, therefore, propose to support new nuclear build now. But we will keep the option open”.⁴

This paper looks in turn at the investment needed in new nuclear build, and in small-scale energy solutions, or micro-generation. It argues that the investment needed for new nuclear stations would be more effectively spent on small-scale energy solutions, combined with greater investment in energy efficiency and renewable technologies.

how much does nuclear power cost?

It is very difficult to assess accurately how much it would cost to proceed with a new generation of nuclear power stations. Only one new station – Sizewell B – has been built in this country in the last twenty years; in Europe, the first new station for a decade is about to be built in Finland. This makes cost assessments very difficult, as there is little precedent. Any estimate of costs will also depend on a wide range of assumptions or parameters, including: the discount rate used,⁵ the costs of decommissioning plant once it reaches the end of its working life, the costs of dealing with nuclear waste, the costs of environmental damage (eg from nuclear waste) and environmental benefits (low-carbon), costs of the decision-making process including planning, insurance costs and so on. Some of these are discussed in further detail below. However, some estimates have been made – both of likely construction costs, and of likely costs per unit of electricity generated.

construction costs

The International Energy Agency (IEA), in its recent report on electricity costs, surveys the ‘overnight construction costs’ of nuclear plant, “defined as the total of all costs incurred for building the plant accounted for as if they were spent instantaneously”.⁶ These vary from US\$1000 per kW capacity⁷ in the Czech Republic and Korea, to around US\$2000 in the US, Finland and the Netherlands, and US\$2500 in Japan.⁸ However Greenpeace International criticises the IEA study because it underestimates investment costs. As electricity markets are now liberalised, cost estimates must include regulatory, political, technological and fuel cost risks.⁹ A recent study by Massachusetts Institute of Technology in the US¹⁰ estimates US\$2000 per kW capacity. A University of Chicago study notes the wide range of estimates for construction costs in the US – from US\$1,100 to S\$2,300.¹¹

The new station being built in Finland is predicted to cost around £1.7 billion¹² for construction, and will provide 1600 MW¹³ capacity. This is equivalent to £1062 per kW capacity (around US\$2000), similar to the IEA estimates listed above. However, these figures are disputed. Greenpeace International claims that the plant is benefiting from hidden subsidies: “The French company Areva, who will build the plant, obtained a guarantee from the French Export Credit Agency Coface, a bizarre measure in an internal European market. Furthermore, Areva offered the Finnish utility a ‘fixed price’ contract for 3.2 billion Euros, probably far below the real cost. Areva – partly a French state-owned company, will thus pay for the rest”.¹⁴

In the UK, British Energy, in its submission to the Government’s PIU¹⁵ Energy Review (the study conducted as background to the White Paper), proposed the construction of ten new nuclear stations, on the site of existing stations, at a cost of £10 billion, not including maintenance or decommissioning. Each station would provide 1000-1200 MW capacity, totalling up to 12000MW or 12 GW. This would replace the capacity of the old nuclear stations – in the words of British Energy, it would ‘replace nuclear with nuclear’.¹⁶ The cost per kW capacity would be £833 - £1000, similar to the Finnish example and the IEA estimates. These costs are optimistic if compared with the actual cost of Sizewell B, at £3000 per kW capacity – three times this amount.

costs per unit of electricity generated

The investment needed to construct new nuclear power plants is significant, but it is also necessary to consider running costs, maintenance, waste and decommissioning costs. The IEA estimates that investment costs represent about half of total costs for nuclear power, assuming a 5 per cent discount rate: “investment costs represent the largest share of total levelised costs, around 50 per cent in average while operation and maintenance costs represent around 30 per cent and fuel cycle costs around 20 per cent”.¹⁷ This ratio is the same from country to country, although actual costs vary considerably. A report by UBS Investment Research estimated costs of decommissioning (as distinct from running costs and maintenance) at around 500 euro or £344 per kW capacity, though this report also cautions that it is difficult to assess decommissioning costs accurately.¹⁸

Many estimates look at costs per unit of energy. In theory, these figures take all costs into account, though in practice, there are considerable uncertainties surrounding some costs, such as waste and decommissioning, as discussed below. Costs per unit of energy are expressed as pence per kilowatt-hour, or p/kWh. The actual cost of Sizewell

B is around 6p/kWh.¹⁹ Future stations could provide cheaper power. The PIU review stated that “The costs of producing electricity from a new nuclear station are uncertain, probably in the range of 2.5-4.0 p/kWh in 2020, using a mix of PIU and industry analysis. Industry estimates lie at the bottom of this range, and are predicated on assumptions of series build, rapid construction and very good operating performance and relatively low discount rates”.²⁰ The PIU did not expect these costs to decrease significantly over time – in other words, technological or other improvements are not expected to reduce costs. The MIT study suggests similar costs of 6-8 cents/kWh, equivalent to 3-4p/kWh;²¹ and the University of Chicago study quotes a range of cost estimates from US\$39 – US\$83 /MWh, or 2-4p/kWh.²²

In contrast, the IEA data show lower costs: “At 5 per cent discount rate, the levelised costs of nuclear generated electricity range between 21 and 31 USD/MWh except for the two plants in the Netherlands and Japan”.²³ This equates to between 1.1p/kWh and 2p/kWh. The Japanese plant, the most expensive, is 50 USD/MWh, or 3p/kWh. Similar figures are quoted by a Royal Academy of Engineering report – around 2.3p/kWh.²⁴ However, this figure is disputed by many, such as Steve Thomas from the University of Greenwich Business School. He argues that assumptions made about construction costs, capital costs, and operating efficiency are overoptimistic, and that using less optimistic assumptions, costs could be predicted at around 6p/kWh.²⁵

This survey shows that there is little consensus about the costs of new nuclear power, with estimates varying from 1p to 6p/kWh, depending on assumptions used.

costs to the domestic consumer

Costs to consumers will, however, be higher, because of all the other costs associated with supplying electricity. The cost to the consumer of electricity supplied through the grid is around 6-8p/kWh.²⁶ Only around 37 per cent of the cost of domestic electricity is the wholesale price of electricity, according to an Oxera report for the DTI.²⁷ Distribution and metering costs make up a further 25 per cent; supply costs and margin 26 per cent (this includes marketing and invoicing/billing). Similarly, the IEA writes that their cost data “do not include transmission and distribution costs which may, in some cases, represent a significant part of the costs”.²⁸

other factors to consider

In assessing the costs of nuclear power compared to other options, there are a number of other factors that should also be considered, including:

timescales

As Annex B shows, nuclear stations will come offstream one at a time between now and 2023. We will lose an average of 550MW a year up to 2023. However, new nuclear stations take a long time to build. The International Energy Agency estimates that construction of new plant will take 5-10 years.²⁹ This does not take into account government decision-making and the planning decisions, which can be very time-consuming. In the White Paper, the government set out the procedure for authorising new nuclear capacity: “Before any decision to proceed with the building of new nuclear power stations, there will need to be the fullest public consultation and the publication of a further white paper setting out our proposals.”³⁰ Sizewell B took 15 years from its proposal to electricity generation, including a two-year public inquiry. It is clear, therefore, that if the government follows the process outlined in the Energy

White Paper, new nuclear stations would take at least 15 years, and probably longer, from the start of the decision-making process to the point at which electricity was produced. Given that nuclear stations will be closing steadily between now and then – six will close over the next four years, for example – old stations cannot simply be replaced by new. Any new nuclear stations will have a negligible impact before 2020, the focus of many existing government policy initiatives stemming from the UK Climate Change Programme.

flexibility

British Energy's costs for new nuclear stations are premised on series build, in other words, building all ten stations in order to benefit from economies of scale. This is necessary in order to keep costs down, but it is an inflexible approach – it is a case of all-or-nothing. As the PIU states, “the desire for flexibility points to a preference for supporting a range of possibilities, rather than a large and relatively inflexible programme of investment such as is being proposed by the nuclear industry”.³¹

actual costs

Because no new stations have been built for some time in the EU or UK – with the exception of the Finnish station which is just about to be built – it is not clear how much the final costs will actually be. Sizewell B cost more than twice the original budget. Neither is it currently clear how much it will cost to decommission nuclear stations, or deal with nuclear waste. The PIU paper states that “nuclear waste policy remains an unresolved issue and this may, or may not, constitute a large obstacle to new nuclear investment”³². The World Bank will not provide investment support for nuclear stations because of the costs and uncertainties. A World Bank paper notes that “the cost figures usually cited by suppliers are substantially underestimated... nuclear plants also involve substantial financial and technical risks”.³³

waste

There is little consensus on how to deal with nuclear waste, and by extension no consensus on the costs of waste storage or treatment, as a PIU Working Paper shows: “Currently waste policy is possibly even more uncertain than it was in 1995 (given the abandonment of the NIREX Rock Characterisation Facility in 1997). It is therefore impossible to estimate waste management costs in any useful way at present”.³⁴ The Royal Commission on Environmental Pollution stated in its 2000 report that “New nuclear power stations should not be built until the problem of managing nuclear waste has been solved to the satisfaction both of the scientific community and the general public”.³⁵ The Committee on Radioactive Waste Management, established in 2004, is currently undertaking a consultation process on options for nuclear waste, to report next summer.³⁶

financial uncertainties

The financial uncertainties surrounding nuclear power, and particularly the unknown costs of decommissioning and dealing with nuclear waste, mean that the liabilities of the nuclear industry are uncertain. The Government's provision of a £650 million loan for British Energy in 2002, to prevent the company going into administration, added greatly to this uncertainty. The company's difficulties were caused by their spent fuel liabilities and an oversupply of electricity generating capacity, which depressed wholesale prices. In providing the loan, to help the company to restructure, the Government also acknowledged that it would need, in the words of the Secretary of State for Trade and Industry, to “contribute significantly to the company's £2.1 billion of historic nuclear fuel liabilities that are managed by BNFL and

extend to 2086. The cost to the Government will average £150 million to £200 million a year for the next 10 years and will fall thereafter”.³⁷

The Government made clear that it was willing to help British Energy in order to maintain nuclear safety, rather than to help the industry. It is, therefore, unclear how the liabilities of new nuclear plant would be handled. It seems unlikely that private sector investors would be willing to commit to new nuclear build without financial support, and underwriting, from Government. A report by investment analysts UBS states that “the risk inherent in new nuclear may not necessarily be suited to traditional equity investors”, and that “the next generation of power plants is likely, once again, to be built with some form of state guarantee”.³⁸ The new Finnish station is being built by a non-profit organisation, with government backing, and support from French export credit guarantees. A report by Standard & Poor’s also expresses caution about the potential for private investment in nuclear plant, without significant support from government.³⁹

public acceptability

Polling data and public opinion surveys consistently show generally negative views on nuclear power, with small amounts of support.⁴⁰ This would make the planning and construction of new stations difficult and potentially more expensive.

the micro-generation alternative

If the UK did not invest in new nuclear power, what alternatives would there be? Much work has been done to assess the costs of energy efficiency measures, and large-scale renewable energy solutions such as onshore and offshore wind.⁴¹ The consensus is that energy efficiency is by far the cheapest solution, with options like cavity wall insulation having an extremely low, or even negative, net cost. Large-scale wind energy is comparable in cost to nuclear power, and, depending on assumptions used, can be cheaper. This is why the 2001 Energy Review and the 2003 Energy White Paper decided in favour of a strategy based on greater energy efficiency and renewables.

There are other, small-scale technologies which could also make a contribution - micro-generation technologies such as micro-CHP, small-scale wind power and solar photovoltaics.⁴² Micro-generation, or micropower, is the generation of low-carbon heat and power by individuals, small businesses and communities to meet their own needs. Power generated in this way can be linked to the national grid – micro-generators can, in theory, sell excess power back to the grid; they can also use grid electricity when they are not generating enough power for their needs.

Micro-generation is a very different approach to energy use. We are accustomed to an energy system based on big, centralised generators. The transmission systems, energy supply and distribution companies, and government policy frameworks all support this centralised system. This makes it difficult to change. Investment – of time, attention, policy and money – will be needed to create a system that encourages small-scale as well as large-scale generation. To date, there has been limited policy support or encouragement for micro-generation, though capital grants are provided for some projects.⁴³ Recently, the government has taken an increasing interest in the potential of micro-generation, and the DTI is currently drawing up a micro-generation strategy, as required under Section 82 of the Energy Act, to be published in 2006.

The closure of nuclear stations over the next twenty years provides a real opportunity for change. Considerable new investment will have to be made in energy capacity, to replace the output from the old nuclear plant. Money for this investment will come from both private and public sources. The new investment provides an opportunity to do things differently – to move from a centralised, grid-based system to a more flexible, two-way model of energy generation, as envisaged in the White Paper. The remainder of this paper sets out what could be achieved from considerable investment in micro-generation.

This analysis does not seek to imply that all nuclear capacity should simply be replaced by micro-generation. There is clearly a role for large-scale renewables, increased energy efficiency, and more efficient fossil-fuel generation such as gas-fired CCGT plant. Policies to support these options – such as the Energy Efficiency Commitment and the Renewables Obligation – exist, but will need to be strengthened if we are to meet carbon targets, as the Government admits in its current Climate Change Programme Review. However, this paper concentrates on the opportunities of micro-generation because there is currently much less funding and policy support for these technologies.

how much does micro-generation cost?

It is difficult to estimate how much micro-generation will cost. The reasons for this are discussed later, but include: the newness of the technologies; the lack of economies of scale; problems of comparing heat-generating technologies with electricity-generating technologies; transmission and distribution costs; costs to the network of incorporating micro-generation; the variability of output depending on wind speeds or sun; and so on. However, some attempts have been made to cost these technologies. Here, three examples are used: micro-wind turbines, solar PV and micro-CHP. There are a range of other technologies which are not considered in this analysis but which could also make a contribution.⁴⁴

The company Encraft have developed a model, using data from existing micro-generation projects, to predict costs of projects in different situations – taking into account climatic factors and so on. This is used primarily as a tool for customers considering micro-generation investments, but also provides useful information for policy assessments. Annex C sets out some findings for the model, based on a typical house in the Midlands. The Encraft model does, however, demonstrate the difficulties of trying to establish ‘typical’ or average costs of micro-generation.⁴⁵

micro-wind turbines

There are two near-commercial roof-mounted wind turbines: the Swift Turbine produced by Renewable Devices, and the Windsave model. According to the manufacturer of the Windsave turbine, “the current cost would be in the region of £1250, plus approximately £250 for installation. Future costs, given the economies of scale, are likely to decrease by approximately 25 per cent”.⁴⁶ One turbine has a 1kW capacity. Similar numbers are used by Merton Borough Council, who use the planning system to ensure that developers install micro-generation technologies in new developments of a certain size. They estimate £1500 per 1kW turbine. Swift Turbines are currently considerably more expensive, at around £8000. This is because they are not yet manufactured in volume. Costs are likely to be reduced to £1,500 once manufacturing is under way.⁴⁷

Costs for micro-wind are largely incurred through the initial investment. Although there will be maintenance costs, there are obviously no fuel costs. However, costs per kWh of micro-wind vary hugely depending on siting, and average wind speeds. According to the DTI's Distributed Generation Working Group, micro-wind costs around 4.63p/kWh to deliver to a low voltage network customer⁴⁸, but this is only an estimated average. Encraft's model (see Annex C) shows that annual energy output of the same turbine can vary by a factor of three or more across the country, depending on average annual wind speed where it is sited. Encraft's cost estimates of micro-wind, based on existing turbines accredited by the DTI's Clear Skies programme, are around 7p/kWh.

Because micro-wind turbines are still at an early stage of development, data for this technology was not included in assessments made as part of the PIU or Energy White Paper process.

solar PV

The capital costs of solar photovoltaics are considerably higher than other forms of micro-generation. Government estimates, based on costs of projects under the Clear Skies grant programme, are around £6,296 per kWp⁴⁹ for small-scale and individual installations.⁵⁰ Merton Borough Council assumes similar costs of around £7,000. Case studies from Solar Century include £3922 / kWp for a 102 kW solar roof on an indoor athletics training centre⁵¹, £7333 per kWp for solar-powered homes in Edmonton.⁵² Although capital costs are high, PV arrays can replace roofing materials, saving other building costs, especially on new developments. In addition, capital costs of PV are reducing all the time, due to innovation and economies of scale. The DTI estimates reductions of around 7 per cent per year.⁵³ Finally, there are no fuel costs involved, and little maintenance is required.

In terms of costs per unit of electricity, the PIU estimated 70p/kWh.⁵⁴ They stated that we are "likely to see sustained and substantial cost reductions over the next 20 years, but PV will inevitably do best in countries with the most sun: the cost in the UK could still be as high as 10-16 p/kWh".⁵⁵ The DTI's Distributed Generation Working Group estimated that PV costs around 33.75p/kWh to deliver to a low voltage network customer⁵⁶; the Encraft model suggests 17.7p, though this includes government grants – unsubsidised, this rises to 32.9p (see Annex C).

micro-CHP

Micro Combined-Heat-and-Power (mCHP) boilers can be installed in houses instead of conventional boilers. As well as heating, they provide electricity that can be used in the property or exported to the grid. As mCHP uses gas, it is not renewable electricity, but is low-carbon due to its efficiency. In other words, if a mCHP boiler operates at the same heat efficiency as a condensing boiler, the additional electricity generated will be 'free' in carbon terms.

Currently, mCHP boilers are around £500 more expensive than conventional condensing boilers, and have a generating capacity of around 1-1.5kWe.⁵⁷ Costs per unit of electricity generated are hard to assess, as the benefit of mCHP lies in the efficiency of generating heat and electricity at the same time. However the PIU estimated that "the effective generating cost is around 3.5 p/kWh, perhaps falling to 2.5 p/kWh as the market grows."⁵⁸ The DTI's Distributed Generation Working Group estimates are similar, at around 4p/kWh to deliver to a low voltage network

customer.⁵⁹ As the PIU state, “The economics of micro-CHP appear to be very favourable at the costs and efficiencies assumed by the manufacturers, but this has yet to be tested in the market.”⁶⁰

Every year 1.3 million boilers are replaced.⁶¹ If a percentage of these replacement boilers are mCHP, this will result in a steady increase in generating capacity and carbon saving over the next twenty years.

Micro-CHP boilers obviously only produce electricity when they are producing heat – in other words, when central heating systems are on. This is, however, likely to coincide with peak electricity demand, in the evening and in winter, for example. So the electricity generated is more valuable because of these time-of-day benefits.

other factors to consider

intermittency

Most micro-generation technologies do not produce energy at a constant rate. Their output depends on climatic conditions, or patterns of use for mCHP. This intermittency means that they contribute differently to power needs. One kW capacity for solar PV or micro-wind will in practice operate at a fraction of this capacity, on average. It is not, therefore, possible to make a straightforward comparison between a kW capacity of micro-generation and a kW capacity from a centralised source like gas-fired power stations or nuclear power. Intermittency can, however, be dealt with. It is not necessarily a disadvantage – particularly if, as in the case of mCHP, there is more power provided at times of peak demand. The University of Oxford Environmental Change Institute has carried out modelling to assess this effect. Its main conclusion was that optimising the distribution of renewables reduced impacts of intermittency significantly. They also found that aggregating the output from complimentary technologies, in this case wind, domestic combined heat and power (CHP) and photovoltaics, massively reduced the need for additional balancing services.⁶² The IEA makes a similar point, saying that micro-generation “...adds flexibility to the overall generation system. Conventional cost assessments of generating options tend to understate the value of flexibility... Many distributed generation technologies are flexible in operation, size, and expandability” and thereby provide a hedge for use in peak periods.⁶³

distribution and connection costs

Much has been written about the issue of connecting micro-generators to the national grid. A recent study by Mott McDonald for the DTI showed that although changes need to be made, they are cost-effective: “...the network costs of integrating micro-generation into the GB networks are comparatively small and that they would be outweighed by the benefits. Benefits in terms of network deferral and reduced network and system operation costs are difficult to quantify precisely; however after allowance for the estimated operational and reinforcement costs, the net benefit is likely to be of the order of £35 million per annum for a high micro-generation scenario in 2020. These net benefits are estimates and further work is required to define more precisely the extent of deferral savings and capex reinforcement costs due to unusual networks. Benefits directly related to the network however are small in comparison to the broader system benefits that arise from the reduced need for centrally connected generation, which arise from avoided capacity, energy and emissions costs. In the high micro-generation scenario these benefits would be around £1.2 billion. Of course, these

broader benefits must be weighed against the capital and operating costs of micro-generation installations.”⁶⁴

links to energy efficiency

Because micro-generation technologies are embedded in buildings, they tend to link more directly with energy efficiency savings. It becomes very clear to building owners or managers that there is little point in installing micro-generation if the equivalent amount of power is being lost through inefficiency. Part of any micro-generation project is, therefore, likely to be a thorough energy efficiency audit, to reduce the amount of power needed. This added incentivisation helps meet goals for energy efficiency, and reduces the total amount of energy needed.

costs of generation or costs to the consumer?

Costs per kWh for centralised generation do not take into account the other costs of getting that power to the final consumer. As the PIU review says, remote sources need to compete against wholesale electricity prices (currently around 2p/kWh) and need to be transported at a cost to consumers, while deeply embedded sources, like building integrated PV, have the less stringent target of retail prices in commercial and domestic sector (around 5-7 p/kWh).⁶⁵

investment choices: nuclear power or micro-generation?

As this paper makes clear, it is very difficult to compare nuclear generation with micro-generation, as the two sets of technologies operate in very different ways. However, it is clear that the huge amount of investment needed for new nuclear build could be used in other ways, to provide equivalent amounts of low-carbon energy. Although cost comparisons should be approached with caution, the following estimates are illustrative.

how much will we need to spend on nuclear power?

As explained above, the most optimistic cost estimates suggest that replacing the decommissioned nuclear stations with a series of new stations will cost:

- £10 billion in construction costs, according to British Energy
- £10 billion in running costs, decommissioning and waste, using the IEA's assumption, quoted above, that running costs equal construction costs
- Potential further costs for decommissioning and nuclear waste, given the uncertainties that surround the waste issue
- Costs of delivering centralised generation to the consumer, which, according to the Oxera report outlined above, represents over half the total cost of retail electricity.

This investment will result in a generating capacity of 11GW, running at around 70-90 per cent of full capacity.

what could this buy instead?

The above analysis shows that at least £20 billion, and probably considerably more, will need to be spent on nuclear power over the next twenty years, if a decision is taken to build new stations. This is a huge investment in energy generation, and should

not be undertaken without a thorough investigation of alternative uses for the investment.

What, for example, could be achieved by considerable investment in micro-generation?

micro-CHP

As shown above, the current price differential between a conventional boiler and a mCHP boiler is £500. If half of the 1.3 million boilers replaced every year were mCHP, 650,000 units could be installed per year at an additional cost of £325 million a year, or £6.5 billion for 13 million units over 20 years. Assuming a capacity of 1kW per unit, this would result in 13GW of capacity.

This is not equivalent to 13GW of capacity from a centralised power source, such as a nuclear or gas-fired station, because mCHP only generates electricity when used for space or water heating. But it will provide most power during the winter peak, when demand for electricity is at its highest.

solar PV

A £3 billion investment in solar PV, at £6000 per kW capacity, would add a further 0.5GW capacity. In practice solar PV operates at a fraction of this capacity. However some costs could be offset through using solar PV tiles as replacements for conventional roof tiles.

micro-wind

A £3.25 billion investment in 2.17 million micro-wind turbines would provide over 2GW capacity, though like solar PV, micro-wind operates at a fraction of this capacity.

other technologies

Other micro-generation solutions include ground-source heat pumps, air-source heat pumps, solar thermal, micro-hydropower, woodfuel boilers and stationary fuel cells. These are likely to result in further significant carbon savings. The cheapest solutions of all are, of course, energy efficiency investments, and, as the Energy White Paper showed, greatly increasing investment in energy efficiency would make both financial and environmental sense. More work needs to be done to quantify the possible gains in these areas.

conclusion

The above analysis shows that an investment of around £13 billion in three micro-generation technologies – considerably less than that needed for new nuclear plant – would provide around 15 GW additional capacity. Because of the different load factors and the way in which micro-generation is used by consumers, this cannot be directly compared to the output from nuclear plant. However, it does show that micro-generation technologies provide a cost-effective, low-carbon alternative to nuclear power, when combined with investment in energy efficiency, and other large-scale generating technologies such as wind power and efficient gas-fired plant. Likely innovation and economies of scale in micro-generation technologies will reduce costs further.

A recent report by Oxford University's Environmental Change Institute confirms this analysis, demonstrating how significant micro-generation could be, if the right investments are made. Under the report's low-carbon house scenario, by 2050, houses could be self-sufficient in energy, and exporting power back to the grid. They write that "new capacity will certainly be required – the question is, what form should this take? The 40 per cent house scenario envisages a capacity of 55.6GW in residential LZC [low and zero carbon technologies] by 2050, sufficient to meet the majority of heating and electricity demands in households... major changes in policy and investment patterns will be required".⁶⁶ Whilst this task may seem daunting, the report points out that central heating was virtually unknown in 1950, and is now in 90 per cent of houses. Over time, as investments are made in housing infrastructure, heating and electricity, a shift to micro-generation is possible.

This paper aims to compare, as far as possible, the costs of nuclear power with the costs of small-scale energy generation. It does not seek to imply that all nuclear capacity should simply be replaced by micro-generation. There is clearly a role for much greater energy efficiency, and other renewable and low-carbon generation, all of which would benefit from greater investment. However, it does present a case for much greater investment in small-scale technologies, and a strong policy framework to support them.

Investing in new nuclear power stations would have a huge opportunity cost – the opportunity to kick-start a new approach to energy, in which every building and community contributes to generating the power they need. The closure of nuclear plant over the next twenty years should provide an opening into the energy technologies of the future.

acknowledgements

Many thanks to all who helped me with information and advice, particularly: Ron Bailey, Alan Whitehead, Tracy Carty, Russell Marsh, Joanna Collins, Aidan Morris, Oliver Knight, Sara Eppel, Matthew Rhodes, Dave Sowden, David Gordon, John Thorp, Adrian Hewitt, Neil Hollow, John Chesshire, Brenda Boardman, Catherine Mitchell, Jeremy Harrison, Antony Froggatt, Brian Agnew and Bryony Worthington.

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² Figures from The Energy White Paper, *Our Energy Future: Creating a low carbon economy*, DTI / Defra 2003. p9-10 (pdf text version)

³ GW (gigawatt) = 1 000 MW (megawatts) or 1 000 000 kW (kilowatts)

⁴ The Energy White Paper, *Our Energy Future: Creating a low carbon economy*, DTI / Defra 2003. p44 (pdf text version)

⁵ The discount rate is a way of converting future costs or benefits to their present value, expressed as a percentage.

⁶ International Energy Agency, *Projected Costs of Generating Electricity*, 2005 Update, IEA 2005, p35

⁷ kW capacity expresses the amount of electricity that can be produced. 1kW capacity means that 1kW can be generated in an hour, at maximum capacity. However, no technologies operate at full capacity all the time. Different generation technologies have different 'load factors'. Nuclear stations operate at around 70-85 per cent load factor, or percentage of full capacity; wind energy at average of around 20-40 per cent depending on siting. When costs are expressed per kWh (kilowatt-hour), this takes the load factor into account.

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⁹ Greenpeace International, *The real cost of nuclear electricity production*, March 2005 p3

¹⁰ Massachusetts Institute of Technology, *The Future of Nuclear Power: An Interdisciplinary Study*, MIT 2003 p43

¹¹ University of Chicago, *The Economic Future of Nuclear Power: A Study Conducted at the University of Chicago*, August 2004, p3-5

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¹³ MW (megawatt) = 1000 kW (kilowatts)

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¹⁵ Performance and Innovation Unit, now renamed the Strategy Unit

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¹⁷ International Energy Agency, *Projected Costs of Generating Electricity*, 2005 Update, IEA 2005, p45. Note that the IEA also uses a 10 per cent discount rate, at which initial investment accounts for around 70 per cent of costs. However HM Treasury suggests using a discount rate of 3.5 per cent (see greenbook.treasury.gov.uk)

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²¹ Massachusetts Institute of Technology, *The Future of Nuclear Power: An Interdisciplinary Study*, MIT 2003 p42

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- ³⁵ Royal Commission on Environmental Pollution (2000) *Energy - The Changing Climate*.
- ³⁶ See www.corwm.org.uk
- ³⁷ Statement to the House of Commons by Patricia Hewitt, Secretary of State for Trade and Industry, Hansard 28 November 2002 column 489
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- ⁴⁰ See Green Alliance, *Is Nuclear Energy Needed?* 2002, www.green-alliance.org.uk for a summary of polling data and opinion surveys.
- ⁴¹ Both the PIU study and the Energy White Paper study calculate costs of these options.
- ⁴² For a detailed discussion of these technologies and the policies needed to promote them, see Green Alliance's report, *A Micro-Generation Manifesto*, Green Alliance, September 2004
- ⁴³ Some financial incentives exist through the tax system and through the Energy Efficiency Commitment for some forms of micro-generation. There have also been some changes to network connection rules but, according to organisations such as Green Alliance and the Micropower Council, further serious regulatory barriers remain. Examples of grant programmes include the DTI's ClearSkies grants, and the proposed Low Carbon Buildings Programme, to be introduced in 2006 following consultation..
- ⁴⁴ These include: ground-source heat pumps, air-source heat pumps, solar thermal, micro-hydropower, woodfuel boilers and stationary fuel cells. For a discussion of these technologies, see *A Micro-generation Manifesto*, Green Alliance, 2004
- ⁴⁵ Matthew Rhodes, Encraft – personal communication, 13 April 2005
- ⁴⁶ David Gordon, personal communication, 12 April 2005
- ⁴⁷ Estimates from the manufacturer.
- ⁴⁸ Distributed Generation Coordinating Group, Technical Steering Group P02a Work Stream 4,1 *P02a Working Paper 3: The Economic Value of Micro-Generation* November 2004, p4
- ⁴⁹ kWp = kilowatt-potential. A measure of the capacity (see note 7) of solar.
- ⁵⁰ Answer to Parliamentary Question by energy minister Mike O'Brien. 8 March 2005
- ⁵¹ Solar Century, *Case Study 76 – National Indoor Athletics Training Centre*, www.solarcentury.co.uk
- ⁵² Solar Century, *Case Study 26 – Edmonton*, www.solarcentury.co.uk
- ⁵³ Answer to Parliamentary Question by energy minister Mike O'Brien. 8 March 2005
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- ⁵⁷ kWe = kilowatt equivalent. The PIU analysis suggests a premium of £400-£600 compared to a conventional condensing boiler; industry assessments suggest similar figures. All agree that costs will reduce over time.
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Annex A: The energy system in 2020

Extract from the Energy White Paper, DTI / Defra 2003

The energy system in 2020

We envisage the energy system in 2020 being much more diverse than today. At its heart will be a much greater mix of energy, especially electricity sources and technologies, affecting both the means of supply and the control and management of demand. For example:

- Much of our energy will be imported, either from or through a single European market embracing more than 25 countries.
- The backbone of the electricity system will still be a market-based grid, balancing the supply of large power stations. But some of those large power stations will be offshore marine plants, including wave, tidal and windfarms. Generally smaller onshore windfarms will also be generating. The market will need to be able to handle intermittent generation by using backup capacity when weather conditions reduce or cut off these sources.
- There will be much more local generation, in part from medium to small local/community power plant, fuelled by locally grown biomass, from locally generated waste, from local wind sources, or possibly from local wave and tidal generators. These will feed local distributed networks, which can sell excess capacity into the grid. Plant will also increasingly generate heat for local use.
- There will be much more micro-generation, for example from CHP plant, fuel cells in buildings, or photovoltaics. This will also generate excess capacity from time to time, which will be sold back into the local distributed network.
- Energy efficiency improvements will reduce demand overall, despite new demand for electricity for example as homes move to digital television and as computers further penetrate the domestic market. Air conditioning may become more widespread.
- New homes will be designed to need very little energy and will perhaps even achieve zero carbon emissions. The existing building stock will increasingly adopt energy efficiency measures. Many buildings will have the capacity at least to reduce their demand on the grid, for example by using solar heating systems to provide some of their water heating needs, if not to generate electricity to sell back into the local network.
- Gas will form a large part of the energy mix as the savings from more efficient boiler technologies are offset by demand for gas for CHP (which in turn displaces electricity demand).
- Coal fired generation will either play a smaller part than today in the energy mix or be linked to CO₂ capture and storage (if that proves technically, environmentally and economically feasible).
- The existing fleet of nuclear power stations will almost all have reached the end of their working lives. If new nuclear power plant is needed to help meet the UK's carbon aims, this will be subject to later decision.
- Fuel cells will be playing a greater part in the economy, initially in static form in industry or as a means of storing energy, for example to back up intermittent renewables, but increasingly in transport. The hydrogen will be generated primarily by non-carbon electricity.
- In transport, hybrid (internal combustion) vehicles will be commonplace in the car and light goods sectors, delivering significant efficiency savings. There will be substantial and increasing use of low carbon biofuels. Hydrogen will be increasingly fuelling the public service vehicle fleet (for example buses) and utility vehicles. It could also be breaking into the car market.
- Nuclear fusion will be at an advanced stage of research and development.
- People generally will be much more aware of the challenge of climate change and of the part they can play in reducing carbon emissions. Carbon content will increasingly become a commercial differentiator as the cost of carbon is reflected in prices and people choose lower carbon options.

Annex B: The UK's civil nuclear power stations

Information from the DTI showing the nuclear stations operating in the UK, and their published lifetimes.

BNFL Magnox	Capacity MW	Published Lifetime
Calder Hall	194	2003
Chapelcross	196	2005
Sizewell A	420	2006
Dungeness A	450	2006
Oldbury	434	2008
Wylfa	980	2010

British Energy	Capacity MW	Published lifetime
Dungeness B	1110	2008
Hartlepool	1210	2014
Heysham 1	1150	2014
Heysham 2	1250	2023
Hinkley Point B	1220	2011
Hunterston B	1190	2011
Sizewell B	1188	2035
Torness	1250	2023

In addition three of the older Magnox stations (Berkeley, Hunterston A and Trawsfynydd) have been closed and are undergoing decommissioning. A further two Magnox stations (Bradwell and Hinkley Point A) are being de-fuelled. The Prototype Fast Reactor at Dounreay is also being decommissioned.

Information from <http://www.dti.gov.uk/energy/nuclear/technology/history.shtml>

Annex C: Encraft calculations of energy costs to the consumer

Encraft is a company providing independent professional support to quality home energy projects. Their model of energy prices is based only on independent, market-average information from government-accredited technologies installed on actual domestic projects today. It can be used to calculate likely costs depending on geographical and other variables. The table below shows a price comparison for one household in the Midlands. Further information: www.encraft.co.uk.

All the data used in this table is drawn from real or typical projects. Unit costs are calculated with no discount rates by adding initial capital cost to annual running costs summed over the lifetime of the equipment (including any fuel at 2004 prices, plus typical annual maintenance costs) and dividing by total kWh delivered (or demand avoided in the case of energy efficiency).

For large generating plant total kWh delivered are estimated using historical utilization data for this type of plant in the UK.

For small generating plant average annual insolation and windspeeds were for a typical household in the UK Midlands. Midlands data for annual degree days against standard heating regimes were also used to estimate typical utilization of heating and micro-chp equipment in space heating. Typical UK domestic hot water demands of 2000kWh per person per year for a 4 person household were used.

Prices for micro-generation and heating equipment are based on comprehensive UK surveys carried out during 2004 by Encraft 2003 Ltd. All include installation and VAT. Fuel prices come from the DTI database for September 2004 and include VAT. The price of green electricity varies between the same as standard electricity and up to 1p per unit more. There is insufficient statistical data to provide an accurate average.

Source data and lifetime assumptions made are shown in the table below. Micro-generation capital costs include grants.

No allowance is made for income from sale of micro-generated electricity in these figures, except for solar PV where some electricity supply companies pay a fixed amount of 5p per unit generated, without measuring output. This is effectively a fixed ROC allocation, and is deducted from the unit cost of solar PV. Unsubsidised Solar PV costs are 32.9p per unit before grants or ROCs.

Note	Technology used to deliver energy to customer	Effective capacity	Annual output MWh	Capital costs	Annual running costs	Life (yrs)	Cost per kWh (pence)	Price to consumer p per kWh
1	Cavity wall insulation	0.6kW	4	£250	0	50	0.1	0.1
2	Biomass	11kW	8.75	£2.8k	£200	15	4.4	4.4
3	Gas heating	11kW	8.87	£1.7k	£300	15	4.7	4.7
4	Micro-CHP	8kW/1kW	9.1	£3k	£300	15	5.5	5.5
5	Energy efficiency	250kW	1600	£4.8M	0	50	6.0	6.0
6	Nuclear	1600MW	11165000	£2Bn	£66M	40	1.0	7.0
7	Clean coal IGCC	480MW	2988480	£480M	£23M	40	1.2	7.0
8	Small wind	2kW	4	£4.5k	£100	25	7.0	7.0
9	Wind onshore	1.8MW	3000	£1.8M	£30k	25	3.4	7.0-8.0p
10	Solar water	1kW	1	£1.6k	£20	25	8.4	8.4
11	Solar PV	2kW	1.55	£6.6k	£10	25	17.7	12.7

Notes

- 1 Based on insulating 125 sqm of wall in pre-1975 family home. Capacity is displaced coal-fired plant at typical utilization.
- 2 Pellet-fired boiler using 2.1 tonnes of fuel a year. Grant £1500 (Clear Skies 2004)
- 3 Condensing boiler
- 4 Whispergen specification and pricing. No grants or payment for excess electricity.
- 5 Bedzed 82 unit development – total additional costs of measures for 82 newbuild units from “Toolkit for Carbon Neutral Developments – Part II” [Lazarus, N., 2003. Beddington Zero (Fossil) Energy Development. Toolkit for Carbon Neutral Developments – Part II. DTI/Bioregional, 2003. Available from <http://www.bioregional.com/>] Measures include enhanced fabric, glazing specifications and airtightness. Delivered energy savings are based on monitoring results.
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