1 Micro-CHP

Much has been made recently of Micro-CHP. [Ref. BRE]. These are devices that are fuelled by natural gas, and intended to generate heat and electricity for a single dwelling or building. Prototypes have recently become available from WhisperTech (1 kWe/6 kWth), Advantica (1 kWe/4 kWth), and Sigma (3 kWe/9 kWth). However :

a) They are fuelled by natural gas, which contains carbon, and is not a sustainable solution.
b) They use Stirling engines, which impose great demands on materials and precision manufacture. The lifetimes between major, expensive overhauls may be short – e.g. less than a year.
c) In all power conversion machines there is a scale effect. Clearances and design compromises are relatively large in small units - and losses are proportionately higher.
d) The top temperature is low, so the electricity efficiency is low, perhaps only 10 - 15 %, and the 'thermodynamic' heat 'efficiency' is also low, even though the total energy efficiency may be 80 or 90 %.
e) The electricity efficiency of GTCC for central CHP is over 50 %. Hence the 'thermodynamic' heating efficiency of Micro-CHP is much lower than that of DH-CHP, and the carbon savings only about half.
f) The specific capital cost per kWe varies as about the 2/3rds power of the rated output. Therefore small units (kWe) are much more expensive per kWe than large units (MWe).
g) The devices are very expensive, at about £ 2000, even in high volume. [Ref. 24/10/01 Presentation by EA Technology on Micro-CHP].
h) The WhisperTech and Advantica units have heat outputs which are too low for most existing dwellings in the UK. This means that auxiliary heaters (or burners) - at additional expense - will be needed to meet the full design heat load.
i) The take-up of condensing boilers has been low in the UK, at around 10 %, so the prospects for even more expensive devices seems extremely poor.
j) As individual devices supplying individual homes, Micro CHP units do not benefit from the 'diversity factor' (of perhaps 0.7) of large networks, or from the storage of heat in District Heating pipes. This increases the capital cost from a national perspective.
k) They require connections to both gas and electricity supplies. In particular, the complex electrical connections should allow export as well as import - and possibly 'remote dispatching' - in order to improve the economics. There are already concerns about the shortage of skilled gas fitters. The complex electrical connections and high maintenance requirements of Micro-CHP units would make matters worse. [Ref. H & V News, ?? Nov. 2001, p 1].
l) If they became at all widespread, the electrical tariffs would be low for export at low demand periods and high for import at high demand periods. This would simply reflect the costs that they impose on the external system. This means that exporting any surplus electricity would do little to improve the economics.
m) Fuelling with hydrogen is not credible. At present it is made from natural gas anyhow. Later it might be made by electrolysis, but this is still inefficient. Hence Micro-CHP - as well as being more expensive - would use far more energy than District Heating from central CHP.
n) Micro-CHP or small fuel cells for heating would also have an opportunity cost. They would be a distraction from a better solution, such as District Heating from CHP.
o) Micro-CHP may satisfy the agenda of some energy suppliers, but it does not best meet the national criteria of carbon reduction, energy security and sustainability. Therefore it should be discouraged.

2 Hydrogen Networks for Heating

a) As a combustible gas, hydrogen has too high an energy quality for building heating. Hence it would do nothing to increase the exergy efficiency of the UK, which is currently very low.
b) For the same reason, it is unsuitable for harnessing reject heat from industry, waste incineration, and biomass, and from large-scale solar collectors.
c) The cheapest way of producing hydrogen is from natural gas, but this requires expensive plant, and incurs appreciable losses.
d) The production of hydrogen from biomass requires expensive plant, and incurs greater losses.

e) The production of hydrogen by electrolysis requires expensive plant, and incurs considerable losses.
f) The above result in energy penalties compared with natural gas, and hence increased carbon emissions.
g) Hydrogen has the smallest molecule, and is therefore extremely prone to leakage. Also, being a gas, it is invisible. Indeed, the leakage could easily be so large that the energy loss would be prohibitive.
h) When it leaks, hydrogen is dangerous. It is flammable over a very wide range of concentrations in air. Moreover, (unlike natural gas) it contains no carbon, so it often burns with an invisible flame.
i) Because it is flammable and potentially explosive, hydrogen would attract unwanted attention from terrorists.
j) Hydrogen is associated with the embrittlement of all metals, leading to their failure under stress.
k) Hydrogen networks have no track record, so would be difficult and expensive to finance.

3 Solar Photovoltaic Electricity

The Carbon Trust Draft Strategic Framework report assumes that PV arrays mounted on roofs and walls of buildings and 'may, between 2020 and 2050, supply considerable quantities of electricity (up to 200 TWh)' (meaning per year). [Ref. ICCEPT, 'annexe.pdf'] However:

a) The energy supply options in the Framework are said to be based on the ETSU Study on New and Renewable Energy of March 1999. Yet in this document, Solar PV only just shows as a tiny fraction in 2025, with a discount rate of 8 %.

b) The output of PV arrays is nil at night and least in the winter (whereas that of wind turbines is equal night and day, and more in winter than summer). With such characteristics, PV would reduce the load factor on the mains supply when it was already low, and have an adverse effect on the economics.

c) Moreover, PV suffers from extreme intermittency - as when a cloud passes over the sun. (Conversely wind turbines have at least the 'flywheel' effect of the blades - especially for variable speed machines). This extreme intermittency increases the requirement for storage, or for 'spinning reserve' - both costly.

d) The PV arrays are assumed installed on individual buildings, which implies complicated export and import arrangements to improve the economics for their owners, but there would be no profit in it for the energy service companies.

e) Energy service companies would not want to own and operate plant on individual buildings. This would be complicated by problems of the ownership of buildings, (often other than the occupants, who pay the bills), and of access. Also, the installation and maintenance of many small, complicated systems would require far too much work, when skills are already short.

f) Many roofs and facades would not be suitable, on grounds of appearance, orientation, shading, and being of made up of only small contiguous areas.

g) Some advocates claim that such 'distributed generation' reduces transmission and distribution losses. However, these are only 7.4 % for the UK as a whole, and there would be losses in converting the DC output of the PV arrays to AC for use in most electrical equipment. (see h) below).

h) The energy payback times are often quoted as 3.3 years for PV arrays using crystalline silicon, and 1.8 years for arrays using thin film copper-indium-diselenide. [Ref. K. E. Knapp and T. L. Jester, 'paybackstudy.pdf']. These must be divided by 0.8, to account for system losses due to wires, inverters, cell operating temperatures etc. The energy payback times then become about 4.1 and 2.2 years respectively. However, these are for an insolation of 1700 kWh/m2,y, which is an average figure for the USA. With an insolation of 920 kWh/m2,y for the UK and Northern Europe, the energy payback times are considerably longer, at 7.6 and 4.1 years respectively. It would take even longer to earn a significant 'energy profit', and thus save carbon emissions.

i) Moreover, the life cycle greenhouse gas emissions are 98 to 167 g CO2 equivalent/kWhe output. [Ref. B. Norton, 'Power Engineering Journal', 2/99, pp 6-12]. This is roughly equal to 27 to 46 gC/kWhe.

4 Nuclear Fission Electricity

This has long been advocated as an essential part of the UK energy system. However, privatization of the electricity supply industry revealed that it was an orphan which no-one wanted to adopt. Any discussion of operating and energy costs is meaningless, since nuclear facilities are uninsurable, and only operate under special dispensation from the Government. This amounts to an infinite subsidy. Both Sweden and Germany are phasing out nuclear power, and our European neighbours would not take kindly to being downwind of any nuclear accident.

4.1 Energy Form

Nuclear energy is usually a source of electricity only. The power station reject heat is usually not harnessed for District Heating, because the water could become radioactive, and this would be carried to homes and offices. Yet electricity is (quantitatively) the least important of the forms of delivered energy in the UK, which are approximately: heating fuels 48 %, transport fuels 34 %, and electricity 18 %. [Ref. Department of Trade and Industry, "UK Energy in Brief", July 2001, p 5].

Assuming that a substantial new nuclear programme was eventually able to supply three-quarters of the electricity, and that the power station reject heat is not harnessed, this would require about 20 to 30 GWe of nuclear capacity, but supply only 13.5 % of delivered energy. To meet 100 % of delivered energy, including heat and transport fuels, would require 100/13.5 = 7.4 times as much. Although electricity could be used for all heating, massive upgrading of the transmission and distribution system would be needed. Similarly, electricity could be used to make portable fuels for transport, such as hydrogen. However, this would require massive new plant, an all-new distribution infrastructure, and major changes to all vehicles.

4.2 Global Warming

It is often claimed that nuclear power plants can reduce Carbon Dioxide emissions, and thus global warming. However, this overlooks the energy involved in the manufacture of the components and embodied in the plant. This can take a decade or more to pay back before any net reduction occurs. Indeed, during manufacture and construction, Carbon Dioxide emissions would be increased.

Nuclear power plants have low thermal efficiencies - around 32 % - partly to reduce the risk of failure (which may result in a radioactive release). Moreover, since they are fuelled by a non-solar source, their total heat release contributes to global warming. Compared with a substantial nuclear programme supplying three quarters of the electricity delivered in the UK, the total heat release associated with meeting 100 % of delivered energy would be about 7.4 x 100/32 = 23 times as much. This would greatly increase the global warming contribution of the UK, and thus be quite unsustainable.

In order to have a sufficient impact on global Carbon Dioxide emissions, any energy technology must be capable of being adopted on a vast scale world-wide – especially in developing countries. However, nuclear power plants produce only electricity, are usually large in unit size, and are very expensive, and so are wholly unsuited to developing countries. Moreover, exporting nuclear technology leads to nuclear proliferation. Several developing countries to which nuclear plant was exported (e.g. under the Eisenhower 'Atoms for Peace' programme) have used it to develop nuclear weapons. These include India and Pakistan. Since it is also unsustainable, exporting nuclear technology would be against the self-interest of the UK. Any nuclear plant built in developing countries would have to be heavily subsidised. Yet they may be less safe in construction and operation. Even if the physical fallout from an accident was limited, the economic consequence may be a demand for all nuclear plant world-wide to be shut down.

4.3 Safety

A nuclear programme that met the needs for heating and transport fuels, as well as three-quarters of the electricity, as noted above, would require immense amounts of nuclear fuel. Not only would this greatly reduce fuel diversity but – being imported – it would constitute a massive strategic risk and attract terrorists.

Nuclear plants are dangerous – witness the accidents at Windscale, UK, Three Mile Island, USA, and Chernobyl, Ukraine, among others. Formal reactor safety studies, such as the first, attempt to quantify Risk in terms of Probability x Consequences. [Ref. US Nuclear Regulatory Commission, WASH-1400, 1975]. The Probability of a radioactive release of a given magnitude is estimated by fault-tree analysis. However, it is usually not acknowledged that the Probability of each release is intrinsically an under-estimate, since - through ignorance or a lack of imagination - some possible chains of events are invariably omitted. Hence the total Probability of all releases is under-estimated to an extent that is not merely unknown, but unknowable, and a given release may therefore occur sooner rather than later. Moreover, many of the operating and fault modes of nuclear reactors are inherently unstable, which can lead to runaway (the China Syndrome). The Consequences are due to each of the radioactive releases from accidents. They are measured in deaths and injuries – both prompt and long-term - and by property damage, which may be expressed in billions of dollars or in land area contaminated. The actual Consequences have increased progressively for Windscale, Three Mile Island, and Chernobyl – to the point where they are unbearable. Amazing self-sacrifice was shown at Chernobyl, but the Consequences were still horrendous. Moreover the radioactive fallout is no respecter of frontiers, and can travel immense distances. Hence no nuclear power plants have been built since the Chernobyl accident.

A Swedish Reactor Safety Study noted 'In contrast to the WASH-1400 method, policy makers in evaluating risks where the potential consequences of a major accident are very large, which true for a nuclear disaster, may make their decision based primarily on the potential disaster size (consequences) alone'. [Ref. Industridepartmentet, Energikommissionen, Ds I 1978:1] This amounts to acknowledging that the Probability of such an accident is intrinsically an under-estimate. The same study estimated the total Consequences as prompt fatalities of 100,000 and the land area contaminated as 10,000 to 100,000 km2, (where that of the UK is 244,000 km2). This prompts the question as to where any survivors would go.

The still growing world population means that the next nuclear accident will probably cost even more human lives and suffering than Chernobyl, both directly, and - through the loss of land for houses and growing food - indirectly.

Moreover, nuclear plant incurs severely increased risks in the event of natural disasters such as earthquakes and floods, and of war, terrorism, and civil commotion. This is acknowledged, with the nuclear industry having the only full time armed police force in the UK. Furthermore, no nuclear plant has ever been fully insured, but governments have held them almost completely exempt (i.e. save for a derisory maximum liability). This amounts to an infinite subsidy, but even so, it is a complete sham, since no reparation is possible. The three nuclear accidents mentioned above all occurred in developed countries. One can speculate that – due to construction or operation deficiencies or to natural disasters – the risks would be even higher in developing countries.

4.4 Cost

Nuclear power stations are intrinsically expensive in capital cost, due to their large unit size (usually 1 GWe), which also means a large loss of capacity in the event of a single failure. So far in the UK, each station has been almost unique, and enjoyed no economies of scale through series production. Moreover, due to the very high quality needed to reduce the risks, nuclear plant requires largely specialised labour, rather than local labour. Furthermore, being large scale and potentially dangerous, nuclear power stations are usually sited remote from the loads (towns and cities) - so increasing transmission costs and losses.

From PIU nuclear note, the capital cost of nuclear in 1995 was about £ 1500/kWe.

For nuclear power plant and fuel, there is now only one UK supplier - BNFL.

Also nuclear plants have very long construction times – from 6 to 18 years. This makes them quite unsuited as a 'quick fix', and very hard to finance. Firstly, there is usually some 'legislative creep', requiring additional safety systems to be added during construction. Secondly, there is the risk of a further severe nuclear accident from the ageing pool of existing nuclear plants. There are about 400 nuclear power plants in the world, as well as several major sites for waste reprocessing and short-term storage. This would cause immense public pressure for the immediate shutdown of all nuclear plants world-wide, and the halting of all nuclear construction. Nuclear plants are massive, notably in respect of the pressure vessels and other radioactive containment. All the materials embody a vast amount of energy in manufacture, construction, and the final fabric. This is also true of the initial charge of nuclear fuel. Hence the energy payback time is even longer than the construction time – by perhaps two years.

If an accident forced shutdown before the energy payback time, the whole energy investment would be wasted (since the scope for re-cycling the materials is minimal). If this occurred before the notional economic payback time of any new nuclear plant, all the expenditure would be wasted. If the initial fuel charge had been loaded, it would have to be removed, and further costs incurred. If nuclear criticality had been achieved for even a short period, the costs of removal and cleanup would be even greater. Moreover, we would then have to find and implement another solution - but in less time and at additional expense.

Given that the prevailing winds are from the West, our European neighbours would be very unhappy at the prospect of any new nuclear plant being built in the UK, and would almost certainly demand conditions that could only further increase costs.

Also, continued use of nuclear power would only adding to the world's stock of nuclear waste, when we still do not know how to store it forever. This would increase the costs imposed on future generations, and the present value of an infinite series is infinite – whatever the discount rate ! Any lesser provision amounts to a second infinite subsidy. Imposing such a burden on all future generations is morally indefensible. Since the costs of full insurance and future liabilities are unknown – indeed unknowable – any costs attributed to nuclear energy are under-estimates – again to an unknowable extent. Hence the existing UK nuclear power plants proved unsaleable (through privatisation), and they remain in public ownership. They only continue to operate thanks to the two infinite implicit subsidies above and the explicit subsidy of the Non-Fossil Fuel Obligation. This was £ 1.2 billion in 1998, but this has since ceased. BNFL - the nominal owner (through British Energy) of most of the remaining nuclear power stations - has since made large losses. This is despite the Government paying some £ 250 million a year to address the 'nuclear legacy'.