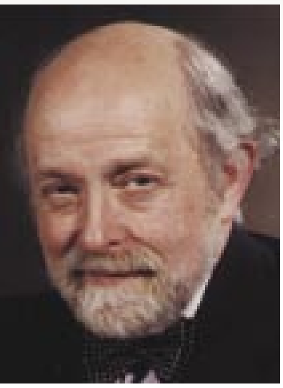
Cutting greenhouse gas emissions – a pragmatic view

Alastair Fells, **Ian Fells** and **John Horlock** cut through the spin and lay bare what cuts are realistically feasible



AS the effects of global warming are becoming felt, the need for industrial nations such as the UK to develop an energy policy designed to reduce carbon dioxide emissions is becoming widely recognised. In the UK, the Royal Commission on Environmental Pollution (RCEP) has suggested that a massive reduction of 60% in CO_2 production is required by 2050, if there is to be any chance of stabilising man-made CO_2 emissions at twice the pre-industrial figure of 270 ppm – and even then there will be profound effects on the weather machine.

But looking at the issue pragmatically, one wonders how much of a reduction can realistically be achieved. We base our analysis on the technology that is immediately available, or will soon become available, and on maintaining a mix of primary energy fuels. On that premise, and assuming considerable government intervention in the energy market, we believe that the best we can hope to do is to reduce CO_2 25% by 2025; after that any further efforts will be governed by the law of diminishing returns. It is likely that similar scenarios will apply to other industrialised countries struggling with the same Herculean mission to reduce man-made greenhouse gas emissions.

an alternative approach

Several earlier reports on cutting greenhouse gas emissions took as their starting point the ambitious goal set by the RCEP figure of 60% CO_2 reduction by 2050 and worked backwards trying to find a way of reaching this goal (see opposite, *Ambitious plans*). It is our view that in order to meet the 60% target, these scenarios had to suggest changes that are so large that the whole scenario tends to lose plausibility (though this may have been a deliberate intention of the RCEP, in order to shake the UK government out of complacency).

Our approach is different and more pragmatic in that we assess what technological developments are available now, assess the feasibility of introducing various technologies and then outline where we consider it is possible for the UK to move over the next 20 years, ie to 2025.

In our pragmatic approach we do not extrapolate so far into the future with as yet undeveloped technology. Instead, we review the current scene in energy production within the UK. We first list the simple technologies that are immediately available and economic to use. We then look at the additional technologies that would become available within the time span of 20 years that we have set ourselves, but only if sufficient capital funding, fully or partly from the state, became available. Finally we list the advanced technologies that could possibly be developed for use in due course, if capital were made available and/or the energy produced were made economically saleable through subsidy from central government sources. We appreciate that the use of technologies in our second and third categories would not be supported by those free marketeers who believe that the market should entirely control such new developments. But as we argued before in 1993, we do not consider that a satisfactory energy policy can be developed under entirely free market rules. As RCEP emphasised, the situation is so serious that the future of the planet cannot be left within a fully free market philosophy.

simple technology

Simple, relatively low-grade technologies which are immediately available and do not have any adverse economic cost, in major capital cost and/or running costs, include the following:

- Building insulation.
- Small-scale solar heating, particularly for domestic hot water.
- Small cars; also widespread use of the hybrid car (such as the Toyota Prius with an optimised petrol or diesel engine which can also charge a battery and deliver electric traction, that can reduce CO_2 pollution by 40%).
- Small- and medium-sized combined heat and power plants (CHP), for industrial use, hospitals, blocks of flats, supermarkets, public buildings.
- Heat pumps, for uses roughly as CHP above.
- Wind farms, primarily on-shore (although there are environmental objections; the capital costs are also high and substantial subsidy is required).
- Bio-mass and waste energy fuels.
- Replacement PWR reactors (but note the remaining problems with waste disposal).

additional technologies

Here we list additional technologies that are already within reach, not demanding significant technological advance but major capital investment:

- Passive safe nuclear reactors, generating only 10% of the radioactive waste of current reactors.
- Integrated gasification combined cycle power plants (IGCCs), coupled with carbon sequestration and storage in appropriate strata, some under the North Sea (C/S plants).
- Major tidal schemes.

All these technologies are available now or very soon. The expenditure required is not therefore for new r and development but primarily for major state capital investment, to subsidise electricity costs, particularly of the early plants. This is particularly true of the obvious tidal scheme, the Severn barrage.

The complexities of offshore wind generation and transmission mean that very large subsidy will be required for many years, and this feature could mean that offshore wind farms move into this second "additional technology" group from the first "simple technology" category.

advanced technologies

The advanced technologies we list below are within sight but not yet within easy reach. They will require substantial research and development within our time-frame of 20 years if they are to become widely applicable in the subsequent 25 years:

- Hydrogen-fuelled transport. Here the hydrogen fuel cell itself could perhaps be placed within our second category above, but for widespread application a comprehensive hydrogen gas network must be developed and the source of the hydrogen also presents a problem. Reforming natural gas is clearly out of the question because of the extra demand on a fossil fuel with the associated CO_2 production. But electrolysis using CO_2-free energy means that renewable or nuclear power is required. Thus a major switch to hydrogen would mean approximately doubling the size of the electricity supply. The safety implications of a hydrogen economy have also yet to be fully considered and costed.
- Fast reactors or breeder reactors using uranium, which are 60 times more efficient than today's thermal reactors. A 600 MW fast reactor has been operating successfully in Russia for 20 years.
- Photo-voltaic cells on a large scale, particularly for building cladding.
- Fusion reactors; a prototype power reactor is now forecast for 2035.

We do not include use of any of these advanced technologies within our proposals below, for the next 20 years.

an energy policy for 2025

To formulate our proposals for 2025 we first analysed the position for 2000 using published information, mainly from the DTI digest of energy statistics, including data on carbon calculated on the UNECE basis. Briefly, the UK overall primary energy demand in that year was some 220m t of oil equivalent (mtoe) from which about 149m t of carbon emissions (MtC) was produced, including 43.1 MtC from electric power generation, 71.5 MtC from the heat load in the domestic, services and industry sectors, and 34.5 MtC from transport.

transport

Our first hypothesis is based on our reluctant acceptance of the rigid inelasticity of the transport energy sector; so we conclude that the best that can be done over the next 20 years is to hold the carbon production at the 2000 figure of 34.5 MtC. This will be difficult

Ambitious plans: How to curb emissions by 60% – or not?

Since the Kyoto agreement came into force, several studies have tried to suggest how the UK might achieve its targets. Notable among those studies is that by the RCEP in 2000, and a report by PIU in 2002, leading to the Government White Paper in 2003. We would describe these reports as primarily "scenario-led", in that they start from the heroic target set by the RCEP of a 60% reduction in CO_2 production by 2050. The basic assumptions made in these scenarios – primarily the initial choice of the balance between demand-led and supply-led actions – are then crucial in the development of the recommendations for energy policy.

The main virtue of the RCEP report was perhaps its illustration of the enormous societal problems associated with any one of its four scenarios, indeed so enormous that one is tempted to say they are virtually impossible to achieve. There is an element of our approach within the 2003 White Paper, in that one of its goals was "to put ourselves on a path to cut the UK's CO_2 emissions by some 60% by about 2050, with real progress by 2020." But our philosophy is more pragmatic in that we place an emphasis on extrapolating from our present technological base, rather than aiming for the long-term 2050 target.

the RCEP report

RCEP introduced four basic scenarios aimed at achieving their 60% target, one dominantly supply-led and three demand-led.

The first assumed that 1998 demand would be held to 2050 (a major challenge in itself when viewed against the anticipated growth in GDP) and that massive changes would be made in energy supply. In particular, new and renewable energy supplies would increase 20-fold. The nuclear supply would increase fourfold, to 46 times the Sizewell B power output of 1.2 GW; or equivalent generation would come from fossil fuel plants with carbon sequestration and storage, so-called C/S plants. A Severn barrage would be built and thousands of combined heat and power (CHP) plants would be introduced to provide low-grade heat as well as electricity. Electrically-driven heat pumps would be widely used. Transport energy demand would increase but the fuel use and CO_2 production would be held back by the use of increasingly-efficient vehicles and hydrogen fuel cells, as is also assumed in the later scenarios.

The second and third scenarios were primarily demand-led, both requiring a 36% reduction in primary energy, through low-grade heat reduction and through the use of CHP systems. But the assumptions on the supply side were different between these two scenarios. In the second, no nuclear contribution was assumed, but a major expansion of renewable generation (to 45 GW – well over half the current total UK installed generation capacity) was advocated. The third scenario postulated a mix of renewable (wind, wave and tidal stream), nuclear and C/S generation. In total this change in supply was equally dramatic, the nuclear component alone corresponding to 19 Sizewell B plants. This emphasis on new electricity generation would enable electricity-driven heat pumps to supply large quantities of low-grade heat.

The fourth scenario was based on a gigantic reduction in primary energy demand, of 47% from that of 1997. This was to be achieved by a 70% reduction in low-grade heat and a 30% reduction in the other components of primary energy supply. The shift to renewable generation was not as dramatic as in the other scenarios, but still involved some 20 GW compared with the baseline figure of 3 GW. Unlike the other three scenarios, no Severn barrage was assumed in this fourth scenario.

These scenarios don't only suggest immense changes, they are also dependent upon some technological developments which are a long way down the line for the UK. For example, the widespread use of hydrogen for transport is likely to depend on major research and development in the US and Japan, as the world's main automobile manufacturers, rather than in the UK. A parallel large development of the UK hydrogen supply network would also be required.

These changes should be contrasted with the conclusions of the 1999 Royal Society report *Nuclear energy – the future climate,* which suggests a doubling of primary energy demand by 2050, with the comment that "it would be unwise to anticipate a growth factor of less than 1.25 by 2020".

the PIU Report and the white paper

The PIU report (2002) similarly uses a number of scenarios. The two that led to the RCEP target of 60% CO_2 reduction were labelled GS and LS – "globally sustainable" and "local stewardship" respectively.

The GS scenario is again essentially demand-led, with primary energy for transport held constant, but that for industry reduced by about 50% (surely implying the end of UK manufacturing industry), and that for domestic and services reduced by about 20%. These reductions lead to an overall reduction in primary energy of 20%. The associated and required reduction in CO_2 of 60% from the 2000 figure of approximately 149 MtC is then achieved by changing the supply fuel mix – zero coal, the phasing out of nuclear power and an expansion of renewables generation to twice the 2000 (renewables plus nuclear) figure.

The LS scenario is even more demand-led, and assumes a 40% reduction in primary energy. The key feature is now the reduction of energy for transport by about 40%, which assumes a dominant role for hydrogen-powered vehicles. The fuel mix is thus changed substantially, with oil more than 50% down, gas some 25% down, and renewable generation alone equal to rather more than the sum of renewables and nuclear for 2000.

The White Paper does not recommend any one of these long-term scenarios for 2050, but wisely discusses an 'on-the-way' position, to which the country might move by 2020. The proposals are not entirely specific but involve an emphasis on energy efficiency (demand modification) and an 8% contribution to primary energy from remaining nuclear plus renewables (supply modification). The latter involves a massive move to renewable electricity generation – to some 20% of total generation.

IGCC plants – like this in Puertollano, Spain – provide relatively clean coal power

(top) Wood chip will fuel the 24.5 MW biomass power plant in Vienna
(below) New turbine designs will continue to improve efficiency (photo courtesy of Siemens)

enough in view of the continuing expansion in road and air transport (we note that some international agreement will be required on accounting for CO_2 production from aircraft flying across national boundaries). But the use of heavy taxation on large vehicles and aircraft fuels, coupled with lighter taxation on small cars and the introduction of hybrid vehicles like the new Toyota Prius may stop the position from worsening.

It would be unrealistic to expect the overall UK transport demand for primary energy to be reduced. But of course a fiscal instrument such as a large carbon tax or a road mileage charge could have a profound effect.

heat load

Our first category of "simple" technology can be used to make reductions in the carbon production from the national heat load. The PIU made an excellent assessment of the potential energy savings (mainly heat) in the domestic services and industrial sectors and we broadly accept their proposals.

In the domestic sector, required comfort standards will not change significantly so the internal heat demand will essentially be unchanged. But reduction in external heat losses and improved efficiency of heating devices should provide the necessary reduction in primary energy supply here. The reduction in primary energy should be achieved mainly by use of improved building insulation, more efficient domestic boilers, subsidised solar heating of domestic hot water and heat recovery from air-conditioning systems. Micro CHP systems are also poised to enter the market place.

Similarly, low-level technologies can be used in the services sector.

In the industry sector there should be opportunity for the use of more capital-intensive and sophisticated technologies, eg CHP and heat pumps, particularly for reasonably large units. For example, if 3–5 GW of existing large-scale electricity generation were replaced by locally-distributed generation CHP the carbon reduction comes almost 'for free'. The replacement of central high-efficiency power station generation by local, less thermodynamically-efficient distributed CHP stations would require a higher fuel input overall. But this should be greatly outweighed by the fact that heat formerly rejected by the big stations is lost whereas the 'rejected' heat from the small CHP stations (somewhat greater than the assumed 3–5 GW of electrical output) would be utilised. This saves the equivalent 'boiler' fuel in the heating devices now discarded. However we note that at the present time, CHP is disadvantaged by government rules for electricity trading.

The PIU made detailed analyses of the economically-possible savings in the heat load area, and argued that about half of these should be possible by 2010. We follow this line, but assume that all their economically-possible savings should come through by 2025. The PIU estimates were that these would be about 17 mtoe in the domestic sector, 4 mtoe in the services sector and 9 mtoe in the industrial sector, a total of some 30 mtoe.

The corresponding carbon savings depend on the mix of fuels used in the heating area, and the nature of the various technologies used for savings. Ratios of carbon savings to energy savings (MtC/mtoe) corresponding to those given by the PIU for different fuels are about 0.63 for gas, 0.85 for oil, and 1.08 for coal, all for assumed complete combustion to CO_2. Since most of the savings will be of gas and oil we take a mean ratio of 0.8 MtC/mtoe, so the economically-possible carbon savings by 2025 should be of the order of 24 MtC.

generation

The modest but realistic proposals we have made above for transport and heat load mean that we must expect the electricity generation sector to continue to make a major contribution to carbon reduction.

The Kyoto-type reductions in UK CO_2 production between 1990 and 2000, which were of the order of 13%, were achieved mainly by converting coal-fired stations to gas-fired, but this introduced a strong gas dependency into the country's primary fuel demands. Gas currently supplies some 46% of the primary fuel used in electricity generation but the White Paper suggests that this figure will reach 80% by 2020, with most of the gas being imported. We argued against going too far in this direction in our 1993 paper and we repeat our point here; indeed we shall assume no additional gas-fired generation. (Incidentally, it is disappointing to record that CO_2 emissions have been rising for the past three years and that they are back to the 1997 figure).

However this abstinence means

A feasibility study in Scotland will test the viability of the Pelamis generator (photo courtesy of Amec)

that much must come from other areas. We accept the PIU and White Paper proposal for some 80 TWh of renewable generation in 2025, giving it an 18% share of total generation, and this should meet most of the anticipated growth in demand for electricity, which is estimated at 90 TWh over the period of 25 years at 1% pa.

But in addition we suggest that three major engineering projects need to be considered. These do not require new technology but fall into our second "additional technology" category; they require major capital funding and in our view this will have to come mainly from the state.

The projects are as follows.

Figure 1: A pragmatic proposal for carbon savings in 2025

Transport (34.5 MtC in 2000)

Hold energy demand to about 40 mtoe by use of smaller cars and hybrids. Carbon unchanged.

Heat load (71.5 MtC in 2000)

- Demand roughly held constant but reductions in primary energy obtained by improved energy efficiency.
- Energy saving of 30 mtoe as PIU proposal leading to *carbon saving of 24 MtC.*

Generation (43.1 MtC in 2000, of which coal was about 27 MtC)

- Coal: one third of 2000 plant (9 GW) to C/S to give *carbon saving of 8 MtC*; one third of 2000 plant (9 GW) replaced by tidal to give *carbon saving of 5 MtC*
- Gas and oil held at 2000 figures, carbon unchanged.
- Nuclear held at 2000 by new build of Westinghouse AP1000s or EPWRs.
- Renewable (mainly wind, hydro) as PIU proposal, 15–20% of total generation. This is assumed to meet the increase in overall demand for electricity.
- Miscellaneous, such as imports, as 2000.

Total carbon savings 24 MtC (heat load) plus 13 MtC (generation, coal) = 37MtC

2025 carbon =
2000 carbon (149 MtC) – 37 MtC = 112 MtC (25% saving)

a replacement nuclear programme

The objective should be to at least to replace the nuclear power plants falling out of generation over the next 20 years by new "passively safe" pressurised water reactors, such as the Westinghouse AP1000 or the European Pressurised Water Reactor (EPWR), the first of which is being built in Finland. If a start were made on this programme immediately it should be possible for the 2000 nuclear percentage of electricity generation (some 22% – 78 TWh generated from 12 GW installed) to be maintained in 2025, although there may be an interim drop in this percentage. Assuming that Sizewell B continues to operate in 2025, 11 GW of replacement nuclear plant will be required. The new nuclear stations, of modified design, would generate only one tenth of the nuclear waste produced by current PWR stations, which should ease the waste storage problem. However, see the further discussion of the required nuclear build below.

carbon sequestration and storage

Carbon sequestration is now possible by adaptation of the large IGCC (integrated coal gasification combined cycle) plants, eg by modification of the existing large GE IGCC plants. If these were placed on the north-east coast, storage should be possible in the North Sea strata emptied of oil and gas over the past 30–40 years. This practice is already being adopted by the Norwegians in the North Sea and by the Americans in Texas, where the CO_2 provides tertiary oil recovery.

Progressive Energy already has plans for an 800 MW IGCC/CS plant on Teesside. If ten such C/S plants were to replace about a third of the present 27 GW of coal plants, then the 2000 production of some 27 MtC from coal should be reduced, substantially, say by 8MtC – the C/S plants are not entirely carbon free.

a major tidal barrage programme

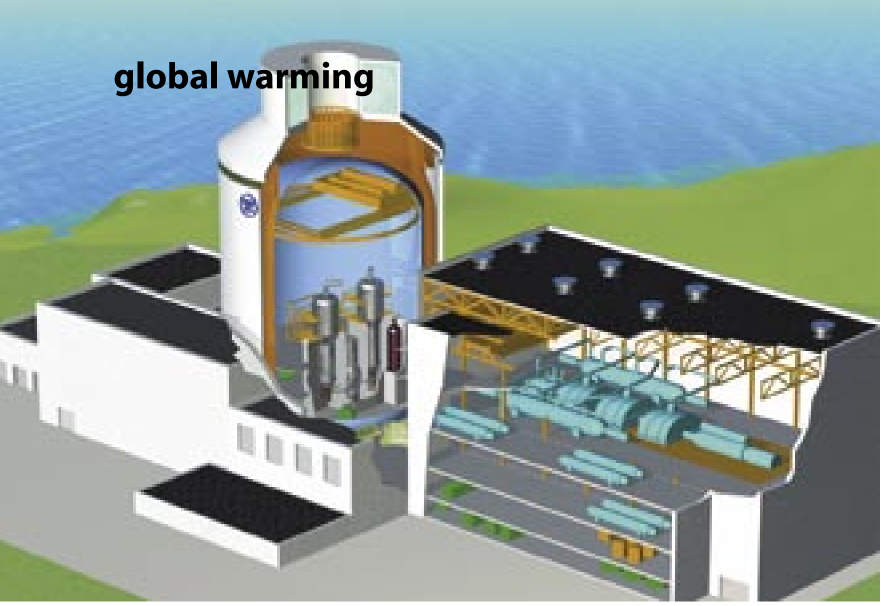
The construction of a Severn barrage of 9 GW would enable a substantial amount of ageing coal plant to be replaced, leading to a further carbon saving of about 5 MtC, and this option has always appealed to the authors. The technology here is straightforward and already known (for example, a tidal barrage at La Rance in France has provided 240 MW for 40 years),

The share of renewable power should rise to 18% by 2025 (photo courtesy of Siemens)

although it has not been implemented on the proposed Severn estuary scale. Environmental objections would undoubtedly be made and a major adaptation of the National Grid will be required. But it should be possible to overcome these problems and for the scheme to be operational in 20 years. Problems of intermittency should be minimised by provision of pumped storage within the scheme. The National Grid has considerable experience with the Dinorwig and Ffestiniog pumped storage plants.

comment

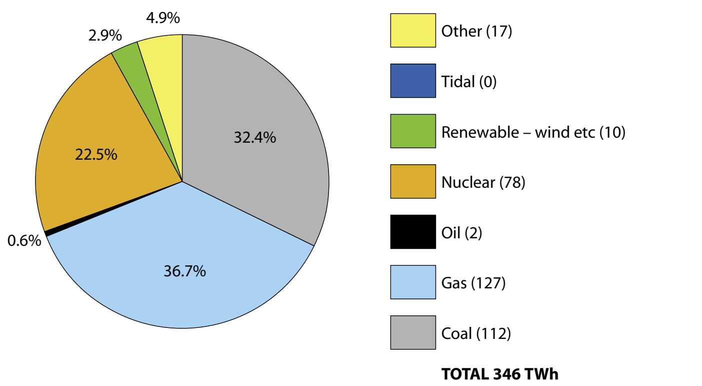
We have not made arguments for the economic cost of the electricity produced by the three "additional technology" plants proposed above, because we consider that the situation is sufficiently serious for these actions to be implemented independent of market considerations of electricity price – it should be a state responsibility. All three projects are capital intensive, so that if state funds were used for part of the capital required then in each case the final costs of the electricity become more acceptably economic. A system of government bonds in a public/private scheme would give confidence to investors and reduce punitive discount



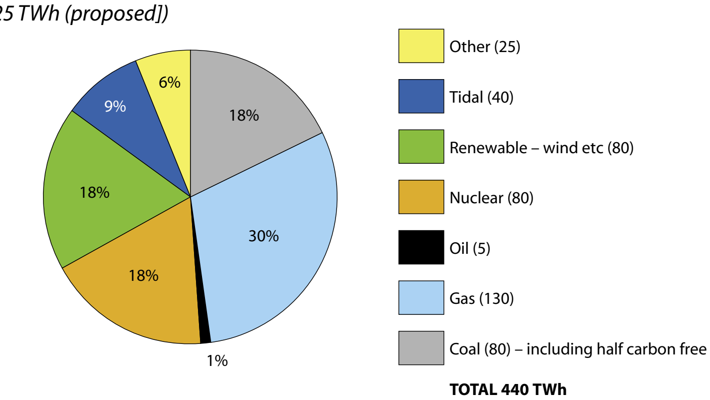
rates that the risk-averse city investors would otherwise apply. For the Severn barrage with a capital cost of £13b, the electricity generation costs would be about 6 p/kWh at a discount rate of 10%. The generation costs would fall with a lower discount rate, but with a lifetime of 130 years and amortisation over 25 years the costs become more acceptable. It may well be argued that it would not be possible for the UK to mount three such major engineering developments at the same time. If that argument were adjudged to carry weight, and environmental objections to the Severn scheme could not be overcome, then the 9 GW of tidal power of 4.3 c would have to be replaced by a matching additional nuclear build (ie a total new build of 21 GW) unless more wind power and bio-mass could be added.

Approximate 2025 total generation is 440 TWh compared with 350 TWh (in 2000), assuming 1% growth pa

2000 TWh (DTI figures)



2025 TWh (proposed])



The mix of fuels proposed for electricity generation in 2025 compares with the authors' 1993 proposal which was: (coal plus gas) = 50% (48% above), (nuclear plus renewable) 33% (36% above), swing 17% (tidal plus oil plus other - 16% above).

summary of the 2025 proposal

A summary of our proposal for 2025 is given in Figures 1 and 2. It leads to a carbon reduction of some 37 MtC in 2025 from about 149 MtC emissions in 2000 – a reduction of 25% over the 20-year period. Carbon trading has not been included in this analysis as it is as yet immature and the current low price of carbon puts future prospects of massive savings in doubt. Hopefully, however, it should make some additional contribution to the proposed carbon reduction in due course.

To achieve this reduction, a huge government-backed initiative is required. It will not be achieved by the current policy of merely subsidising renewables at a rate of about £1b ($1.8b) per year by 2010 and/or leaving the rest to the market. Long-term stability in electricity trading arrangements must be guaranteed and government commitment to nuclear power will have to be made if new build nuclear stations are to be financed and built.

Even if our proposed 25% reduction in carbon dioxide were achieved by 2025, a further move to 60% reduction by 2050 would mean that all future electricity generation would have to be carbon free; this implies huge future investment in renewables and nuclear. The balance of electricity costs between renewables and nuclear will be more clearly seen by 2025 and will affect the choice of new generation in the period 2025–2050.

Our analysis for 2025 is objective, and as practical as we can make it; but it is also optimistic. It would emphasise strengthening of UK technology and engineering, and this should prove of national benefit in itself. But a move to 60% reduction in CO_2 emissions by 2050 will require huge additional investment and, taken with the inexorable rise in transport emissions – particularly air transport – the long-term future looks less optimistic. The chances of achieving the 60% figure must be very slender indeed. **tce**

(Left) The Westinghouse AP1000 is a hot contender if there is a new build of nuclear power plants

(Below left) Figure 2: Proposed generation profile in 2025

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