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AVERTING CATASTROPHE:

ENSURING THE SECURITY AND AFFORDABILITY OF BRITAIN'S ENERGY SUPPLIES 2011-2050

by

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[1] Held at Cromwell Barn, St Ives, Cambridgeshire, PE27 3LY, organised by Rev. Philip Foster of St Matthew Publishing Ltd and Strategic Conferences Ltd, Grantham, Lincolnshire, NG31 6LU. Paper is updated to May 31 2011.

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EXECUTIVE SUMMARY

Emissions and Renewables Targets

In its 2009 paper "Renewable Energy Strategy" (RES), which is still the Government's Green Energy Strategy, the Department of Energy and Climate Change (DECC) sets out its twin objectives for 2020:

- a further 15% reduction from UK 2008 emissions of CO_2 and other "greenhouse" gases (i.e. 34% from 1990 levels)

- that the proportion of electricity derived from "low carbon" sources should be raised from about 20% in 2009 (essentially nuclear and hydro) to 40% by 2020.

Additionally the Climate Change Act (CCA) of 2008 lays down a legally binding target of an 80% reduction in emissions from 1990 levels from *all* energy related processes by 2050, not just from electricity production.

- A further target[4] or "ambition" by the Climate Change Committee set up under the CCA has been accepted by the government, namely a 50% reduction of emissions from 1990 by 2027[5]. (The EU target is 50% reduction by 2050.)

- The objective of having 40% of electricity generated by "renewables" by 2020 in the RES is actually higher than the EU set target of 30%. It now seems that, at French insistence where nuclear is already responsible for 75% of electricity output, the EU will allow this phrase to mean "low carbon" sources – which would include electricity generated by nuclear powered processes as well as the usual "renewables", wind, hydro, wave and tidal, biomass, and solar. If this group alone were allowed to count, the UK government now appears to recognise that the targets would be physically impossible for the UK to achieve.

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[4] Report May 9 2011; 4th Carbon Budget 7 December 2010

[5] This decision will be reviewed in 3 years' time should the other European countries not have followed suit.

MAIN CONCLUSIONS

- It is absolutely clear from the analyses in this paper taken as a whole that no renewable process, including wind, biofuels and solar, can make any but a marginal or very costly contribution to Britain's energy supplies. Persistence in the government's present policy of putting its emissions and renewable energy targets ahead of a secure and affordable energy supply system is taking the country to industrial catastrophe and widespread energy poverty.

- Not only will the resultant costs place British industry at a huge and unnecessary disadvantage in the cut-throat world of international competition, but the supply interruptions arising from the policy's projected reliance on wind energy for between a quarter and one third of our electricity supply will cause havoc to the country's IT systems and the several million businesses which depend on them.

- Besides excessive domestic costs, there will be a huge additional burden on the balance of payments, already massively in deficit, due to the gas imports needed to provide supply when wind-turbines are not generating (for about 73% of the time [Table 11, Figures 2, 3]).

- An alternative Secure Energy Strategy (SES) – a *predominantly* nuclear-based electricity supply system as proposed in this paper – would give not only security of supply, but would actually lead to lower emissions from 2030 on, and substantially lower costs over the whole period from 2010 to 2050 than those predicted in the government's "Green Energy Strategy" (GES) as being interpreted by the Climate Change Committee[4]. In fact the SES would be around 23% lower in cost than the GES from 2021/22 onwards, mainly due to not having to pay for gas plants backing up wind turbines.

- These conclusions arise from immovable realities (Tables 6-9, 14)**:** of physics and chemistry; the size and distribution of the UK population; the area of land at our disposal and the latitudes it is situated in.

- The three leading "renewables" systems considered by the Government's RES to have potentially major roles in our energy supply system – wind power, biofuels, carbon capture and storage (CCS), – would, if persisted in, either fly in the face of these realities, or constitute an enormous misallocation of economic resources, or both[6]. These are analysed in the body of the paper while a summary of the salient aspects now follows:

Wind Power (Section 2.6)

- The 2020 target for installed wind turbines in the RES (originally 32 GW) is now specified by the Climate Change Committee[4] (CCC) as 28 GW nominal capacity (15 GW on-shore and 13 GW off-shore). This broadly is intended to replace 20 GW of capacity being closed between now and 2018, of which 6 GW is nuclear, closed on account of age (Appendix 3), and 14 GW coal, closed by 2015 under the European Large Combustion Plant Directive (LCPD)[7].

- Given that Britain presently has around 5 GW nominal of wind (much of it quite old) and the nominal capacities of the newer wind-turbines are 2.5 to 3.0 MW[8], this means the number to be built over the next 9 years is required to be in the range 16-20 *every week*, an unrealistically high number given the actual rates of installation over the last 2-3 years.

- The measured output from the wind-turbines we have is around 25%, which means actual supply is about 1,200 MW on average, or 2.4% of the total UK winter supply of 50-55,000 MW. In the last two winters, supply from wind hovered around 0.7% of nominal capacity, or about 8 MW for several of the coldest days in both winters, before jumping up temporarily to 40% (Figure 2). This scale of jump would be impossible for any national grid to handle without blackouts if it were reliant on 30 GW rather than 5 GW, no matter what control systems were installed, unless back-up gas stations were running most of the time, in which case what is the point of the investment in wind on this scale?

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[6] Solar is not a serious contender for industrial-scale energy supplies (see Table 8).

[7] However, since 20 GW nominal of coal and nuclear yield about 16 GW actually delivered, while 28 GW of wind delivers only 7 GW, the gap will have to be filled by new gas plants (Figures 4 and 5).

[8] There are design proposals for 6 MW turbines about 500 feet high, but none installed so far.

Biofuels (Appendix 1)

- Five per cent of petrol and diesel fuels are now bio-ethanol and bio-diesel (mainly derived respectively from sugar and waste fats) under the EU Renewable Transport Fuel Obligation (RTFO)[39]. This obligation costs the Treasury around £500 million per annum by reason of the 20 pence per litre remission of fuel duty to the oil companies to cover the costs they have in retuning their refineries and mixing bio-fuels into their standard fuels for the public. British Sugar has one factory producing 60 million litres per annum (50,000 tonnes) of fuel-grade bio-ethanol.

- One acre of annual sugar-beet production supports just over one medium-sized car for a year. If the whole UK 380,000 acreage of sugar-beet were used to make ethanol, it would yield "octane equivalent" fuel per annum for around 450,000 vehicles, or 1.3% of the 2011 vehicle population. If, as has been suggested[9], the whole of the one million acres of set-aside land were cultivated for sugar-beet, it would still only supply about 60% of the UK's RTFO. It would also mean importing all 1.3 million tonnes of refined sugar used in the UK's food production; constructing another 20 sugar to ethanol factories; constructing new road and rail links needed to bring around 35 million tonnes of sugar-beet annually from scattered areas of set-aside land.

- It is not clear why biofuels are regarded as renewable. The weeds on the set-aside land absorb CO_2 anyway. Moreover simply burning the complex molecules which nature has slowly and laboriously constructed (Table 14) seems the negation of sustainability. The whole biofuels policy is at best pointless, and at worst hugely damaging to food production, the balance of payments, and the transport system.

Carbon Capture and Storage (Appendix 4)

- The Climate Change Committee Reports[4] refer to CCS as a means of continuing to use fossil fuels for electricity generation, while contributing to "decarbonisation" of the economy. Appendix 4 (page 46) and Table 16 set out the objective realities of this proposal for 4 GW of capacity (about the size of the Drax coal plant in Yorkshire).

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[9] by the British Association for Biofuels and Oil (BABFO).

- Table 16 shows that approximately 21,000 tonnes of CO_2, 57,000 tonnes of nitrogen and 3,500 tonnes of steam would have to be separated *each day* by a gigantic chemical plant, bigger than the coal station itself[10].

- The huge volume of CO_2 liquified at 50 atmospheres pressure could conceivably be stored in 9,000 km of a one metre diameter pipe on the sea-bed, a distance equivalent to twice round the British Isles *each year*.

- An even more fantastical idea has been mooted – namely to insert liquid CO_2 (at around 50 atmospheres pressure) into the supposedly "empty" complex limestone and sandstone structures from which the oil and gas mixture pushed itself out when being extracted. This is akin to trying to push the entire UK annual consumption of milk back into five and a half billion 1 litre cartons at a depth of least 1,800 feet in the North Sea (to keep CO_2 liquid at 15 °C it has to be kept at this pressure). And this is for just one sixth of the UK's coal-based electricity production. The energy cost of CO_2 separation, compression to the liquid state and pumping would reduce very significantly net output of the power station itself. CCS on a scale to make any noticeable impact on UK emissions is total fantasy.

STRUCTURE OF THE PAPER

There are seven Sections and four Appendices as described immediately below. Recommendations arising from the analyses are listed in Section 7.

The Index at pages (vii)-(x) lists all the 16 Figures and 16 Tables.

- **Section 1** sets out the UK's situation with respect to Emissions, Energy and the Trade Balance.

- **Section 2** sets out the fundamental factors governing electricity generation, including the reality of wind variability and its effect on supply.

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[10] For comparison the largest ammonia plants handle about 8,500 tonnes of nitrogen per day.

- **Section 3** gives the cost and emissions comparisons for electricity generation by 10 different types of system considered by various pressure groups.

- **Section 4** sets out in graphical form in one year intervals to 2025, and five year intervals thereafter to 2050, the implications for electricity supply and for the national economy of the Government's 2009 Green Energy Strategy (GES) as interpreted by the National Grid in their 2009 consultation exercise "Gone Green". An alternative Secure Energy Strategy (SES) proposed by the authors is mapped in the same way for direct comparison (Figures 4-13, pages 22-26).

  The implications are displayed for both strategies in terms of the capital cost of plant, land usage, the overall costs per unit of electricity supplied to the Grid, CO_2 emissions, and the Grid's ability to meet the nation's future electricity demand, making realistic assumptions about the mix of 10 electricity generation processes (biomass, sea [wave and tidal], offshore wind, onshore wind, gas, oil, combined cycle gas turbines [CCGT], hydro-electricity, coal, nuclear power, plus net imports from France via the interconnector) in terms of what presently exists and what can be physically constructed over the period.

- **Section 5** discusses the key aspects of nuclear safety, technology and financing its future investment programme. Also included is a comparison of safety in different power generation processes and the implications for the United Kingdom of a resurrected nuclear Fast Breeder programme.

- **Section 6** sets out the risks and opportunities in the two strategies.

- **Section 7** lists recommendations for UK government energy policy changes which emerge from the six sections above.

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1 BASIC UK POSITION FOR EMISSIONS, ENERGY, AND THE ECONOMY

This paper is written from the perspective of the United Kingdom's interest and in particular its survival as a first world industrial country, able to supports its 60-70 million people in the 40 years from 2010 to 2050. An essential part of the means to secure this future is the provision of secure and cost-effective electricity supplies, both to its industries facing cut-throat competition at home and abroad, and to meet the general needs of its people.

The current UK position is factually summarised under three headings: Climate Change, Energy Supply and Demand, and the Balance of Payments on our exports and imports.

1.1 Climate Change: Emissions

- Britain contributes less than 2% to the world's annual carbon dioxide emissions.
- This is less than China is *adding* to its annual emissions every three years.
- Nothing that Britain does or does not do in the United Kingdom will have any perceptible effect on climate change.
- Hydrocarbon (fossil) fuels when burnt completely to CO_2 and steam
    - emit around 3.1 tonnes of CO_2 per tonne of fuel burnt;
    - release around 14 Giga-joules (GJ) or 4,000 KWh units of heat per tonne of CO_2 emitted.

These chemical realities give rise to the emissions data in Tables 1 and 2.

Table 1: UK Climate Change: Emissions (Targets) and Actual[11]

	1990	2008	2020	2050
Total Greenhouse emissions in millions of tonnes of CO_2 equivalents[12]	775[13]	633	(540)	(155)
CO_2 actual (in millions of tonnes net)	592	484	(461)	(118)
% of CO_2 reductions on 1990 figure	-	18%	(30%)	(80%)
% of electricity from renewables (including hydro)	1.8%	3%	(40%)	?
% of renewables electricity planned in "Going Green"	-	-	(15%)	(20%)

Table 2: Emissions per UK person per annum (2005)

Activity	**CO_2 Emissions per person in tonnes per annum**	**UK Emissions in millions of tonnes per annum**
Breathing (normal activities)	0.25	15
Travel by road[14]	2.1	127
Travel by air[14]	0.6	37
Home heating and power	2.4	146
Industry, commerce and public sector	6.2	385
	Total UK	710

1.2 Energy Demand and Supply 2005-2010

- The UK is dependent on fossil fuels for about 92% of its total energy demand.

- Electricity accounts for about one third of total energy demand and about one sixth of energy delivered to the final customer.

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[11] According to the UK Government's Climate Change Act 2008 and the Strategy paper of the Department of Energy and Climate Change, July 2009

[12] National Statistical Office Blue Book 2008

[13] Kyoto protocol 1990 Baseline: includes CO_2, CH_4, NO_x, HFCs, PFCs and SF_6.

[14] Comparing (say) a flight from London to Geneva (800 km) with a car journey (1,000 km), the medium car with 2 people would emit 121 kg per person. A Boeing 757 would emit 110 kg per person if 70% full.

- For a long time the Government seems to have confused *total energy demand* with the energy required to generate electricity.

- In the years 2000-2006 the UK produced an amount about equal to its total energy demand.

- By about 2025-2030 UK fossil fuel production (at its peak in the years 2000-2006, about equal to total energy demand) will be virtually zero.

- This fact has been available to both to the previous Conservative and Labour Governments from 1990 onwards.

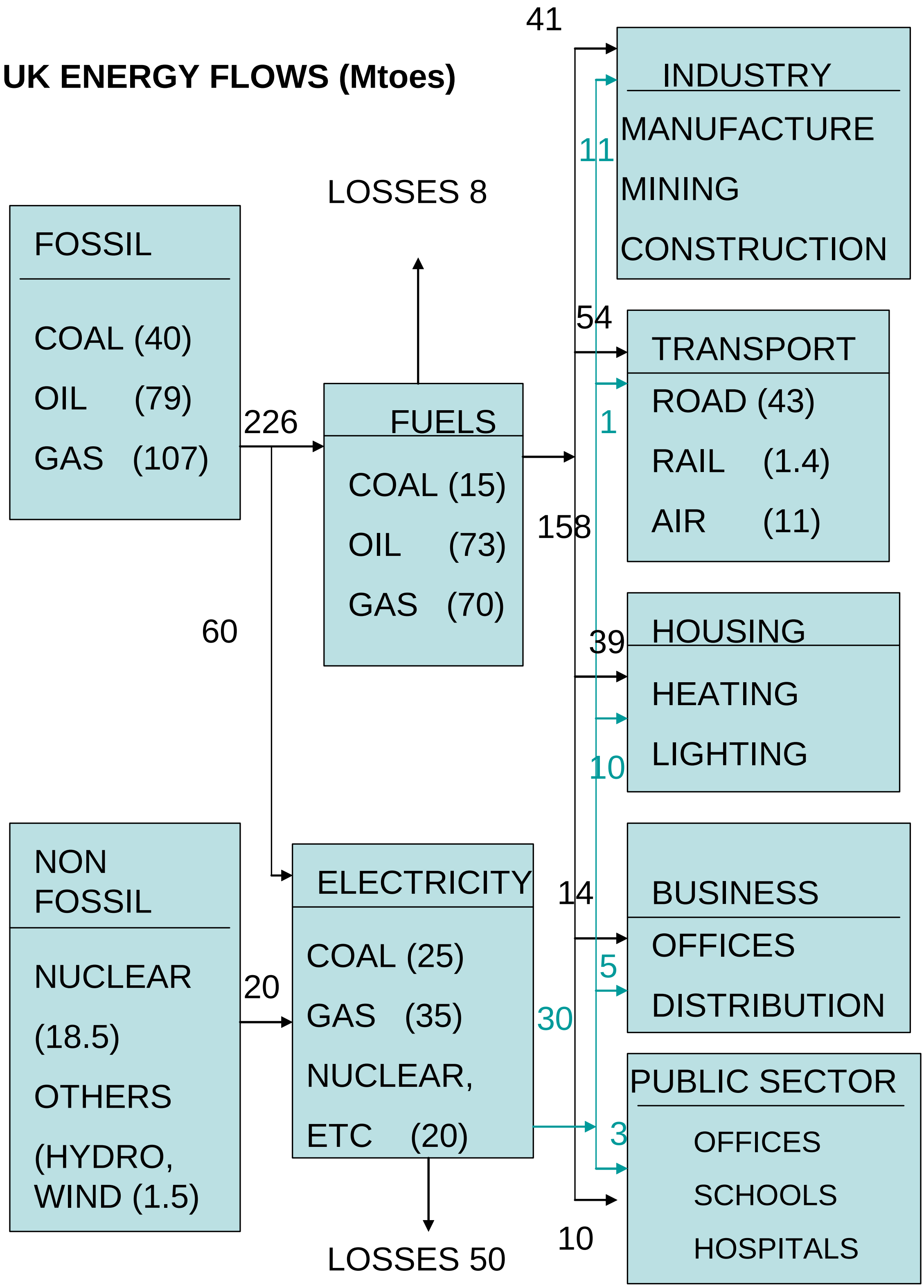
1.3 Energy Sources in Millions of Tonnes of Oil Equivalent (Mtoes)

Generally *Mtoes* is used for energy *sources*, while its electrical equivalent, the kilowatt-hour (kWh) as on electricity bills, is now generally used for energy *consumption,* but they are completely interchangeable:

1 tonne of oil	is thermally equivalent to	approximately 11,800 kWh
1 Mtoe	is thermally equivalent to	approximately 11,800 GWh

In Britain, the average of 26 million households consumes about 2 tonnes of oil equivalent, producing about 6 tonnes of CO_2 per year, which as a gas would fill the average house 7 times over. For comparison four average humans on 2500 calories per day emit a CO_2 volume equal to a house.

Figure 1: UK Energy Flows (Mtoes[15]) in 2005



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[15] Blue figures are electricity flows; black are thermal energy flows. Mtoes means millions of tonnes of oil, or its thermal equivalents for gas, coal, nuclear, hydro, wind, wave & tides, and solar.

1.4 UK Economic Position

There seems to be an almost insouciant attitude around that we can afford to import any amount of gas and electricity (from France, or even North Africa) which we choose. Many energy supply analysts, politicians and other commentators ignore completely the impact of any future energy policy on the country's external economic position.

In fact while presently attention is focussed on the country's huge government deficit and consequent government borrowing (currently £150 billion per annum, but set to fall to around £140 billion over the next 4 years), the trading deficit of around £45 billion (in which the goods deficit is £90 billion) is just as serious, because it too has to be borrowed, but by the private sector and the interest paid in foreign currency. In summary:

- Britain has a massive balance of goods trade deficit of around £90 billion, or about 5.5% of our current income.

- Only a small fraction of this can now be paid for by income from net investment income.

- This is because income from our past investments abroad is now not much greater than the payments we have to make to present investors in this country.

- In fact our net asset position is almost certainly negative, having declined steadily from a net positive position of £285 billion in 1985, despite the huge foreign exchange bonus of North Sea oil.

- The loss over the next 20 years of virtually all our North Sea oil and gas production amounts to a huge loss of national income.

- At today's prices for the pound sterling and a barrel of oil, it amounts to around £55 billion subtracted from our national income and added to our national import bill.

- An average oil price rise of just 3.5% per annum over the next 20 years would double these enormous burdens, even if the pound sterling were able to maintain its present level with the US dollar.

The loss of virtually all major North Sea oil and gas production over the next 15-20 years should focus everyone’s mind on replacing this enormous national asset. Britain, with 92% of its energy needs derived from oil, gas and coal, is the worst placed of *all* the major industrial powers.

If the oil dollar price rise were higher than the 3.5% per annum used in the last bullet point above and the pound were to fall significantly below the dollar (1.5 → 1.6 range), then at anywhere near current fossil fuel usage, we would be looking at catastrophe with a £:$ rate spiralling down.

Table 3 spells out the basic economic facts for 2017 and 2027, as seen in 2007. It will be noted that in 2011, we are already at the $120 a barrel level assumed for 2017.

Table 3: Production and Export/Import of Fossil Fuels

PRODUCTION AND EXPORT/IMPORT OF FOSSIL FUELS

2004-2027

FUEL	PRODUCTION Mtoes	EXPORTS* (IMPORTS) Mtoes	NET* IMPORT COST $ bn
2004			
OIL & GAS	207	21	($70/bbl)
COAL	16	(24)	$1.5 bn
	223	(3)	
2017			
OIL & GAS	83	(103)	($120/bbl)
COAL	16	(24)	$152 bn
	99	(127)	
2027			
OIL & GAS	21	(165)	($150/bbl)
COAL	16	(24)	$250 bn
	37	(189)	

*Assumes Constant Consumption (~ 246) and Nuclear/Others Production (20)

Table 4 gives the recent history of the Trade Balance.

Table 4: UK Trade Balances 1995-2010[16]

	1995 £bn	2005 £bn	2010 £bn ($bn)
GOODS	-11	-67	-80 (-130)
(of which:			
Oil & gas	+5	+10	+8
Pharmaceuticals)	+2	+8	+10
SERVICES	+7	+23	+40 (+64)
(of which:			
Financial	+5	+18	+20
Technical)	+2	+6	+10
NET EARNINGS	-4	-44	-50 (-80)

2 ELECTRICITY GENERATION: FUNDAMENTAL FACTORS

Another key factor which has escaped public discussion of the energy problem is that whereas energy can be delivered to the customer as either fuel to be burned or as electricity, so called "renewables" (excluding solar hot water on micro-sites and biofuels)[17] can only be delivered as *electricity.*

Referring to Figure 1, this means that *any serious reduction in the national dependence on fossil fuels – say 50 Mtoes out of the 2005 figure of 226 Mtoes – must be in the form of a massive increase in electricity production.* A displacement of even 50 Mtoes from primary fossil fuel consumption requires an increase of around 50% in electricity generation at constant total energy demand[18] because, currently, electricity production forms a relatively small part of total energy delivered to UK customers.

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[16] National Statistical Office Pink Books 1999, 2007, 2010

[17] The authors find it bizarre that biofuels (wood chips and sugar based alcohols) can be classified as "renewables" on the grounds that they absorb CO_2 while they grow. A patch of weed does this too.

[18] This is the minimalist assumption. With population increase totalling a minimum of 5% over 20 years, production of electricity would have to increase by this amount, if nothing changed.

2.1 International Electricity Production Comparisons

Table 5 sets out some international comparisons. These are important because our ability to compete in the world depends, in large measure, on having labour and energy costs not significantly different from those of our major competitors in the world, three of whom are included in Table 5.

Table 5: International Comparisons of Electricity Generation & CO_2 Emissions 2008[19]

Country	Installed Electricity generation capacity GWatts	Electricity delivered % by fuel source			Electricity delivered per capita kWh p.a.	CO_2 emissions per capita tonnes p.a.
		Nuclear	Fossil	Other (mainly hydro)		
Britain	67	17	80	3	6420	11.1
Germany	115	19	77	4	6850	9.7
France	117	74	11	15	7900	6.1
Switzerland	16	35	4	61	8380	5.7

Notes

It is no accident that European countries with the highest electricity usage per person have:

(a) the least dependence on fossil fuels for electricity generation;

(b) the lowest CO_2 emissions per head of the population.

Britain has approximately the energy use profile of Germany, but without its ability to pay for our use of fossil fuels in the years ahead (see Table 3).

In 2023 Britain will have, on present form, approximately the same level of indigenous energy resources as France has today, but without France's huge nuclear energy-based electricity sector.

Which fossil fuel is used, and whether it is used to generate electricity or as heating, affects CO_2 emissions very considerably as shown in Table 6. If natural gas is used to generate electricity by what is referred to as the combined cycle gas turbine method, then CO_2 emissions are little more than one-third of those for "high hydrogen" coal.

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[19] Data from the Statesman's Year book 2005 extracted from the World Bank Atlas 2003. The figures in 2010 are likely to be smaller.

Table 6: Fossil Fuels and CO_2 Emissions

Fuel	**Tonnes of CO_2 per tonne of fuel burnt**	**Tonnes of CO_2 per MWh[20] (heat)**	**Thermal efficiency to electricity (η)**	**Tonnes of CO_2 per MWh[20] (electricity)**	**Source of data**
Pure Carbon	3.7	.402	0.35 (standard) 0.45 (super critical)	1.143 -	Perry[21] Table 3-207
"High hydrogen" coal	3.43	.336	0.35 (standard) 0.45 (super critical)	.960 .746	SFB from Perry[21] Table 3-149
Octane (liquid)	3.09	.250	NA	NA	Perry[21] & SFB
Methane (gas)	2.75	.198	0.55 (CCGT)[22]	.360	Perry[21] & SFB
Diesel (oil)	3.14	.247	0.35	.705	HMSO Efficient Use of Fuel

2.2 Different Electricity Generating Systems: Power Intensity

In the design of any system there are usually a number of ruling factors which must be heeded if practical choices are to be made. In the case of electricity generation the power intensity (PI) of the energy resource used is one such, because PI determines the physical space (land use) needed for the conversion of the energy source to electrical power.

Power intensity (PI) means the amount of energy for instance in the sun's rays, the tides and waves, and in the winds, which flows across a given area in a given time. The most generally applied

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[20] The average home uses about 6 MWh as electricity per year and 24 MWh for heating by gas, oil and coal.

[21] J Perry Ed. Chemical Engineers Handbook 1992

[22] Combined Cycle Gas Turbine system.

measure is watts per metre square (W/m^2) as used for the sun's rays. Some typical figures for PI are given in Table 7.

Table 7: Typical Power Intensities

	Type of Energy	**W/m^2**
1	Sun's rays at north European surface averaged over the 4 middle hours of the day.	200
2	Wind passing through the blades of a windmill at 10 m per second.	600
3	Tidal water flowing at 5 knots (e.g. Pentland Firth or the Islay-Jura strait)	24,000
4	120 HP engine in a medium-sized saloon car	400,000
5	Steam passing through the blades of a 500 MW steam turbine in an electricity power station	400 million

The gigantic differences between (1) and (2) on the one hand and (5) on the other show why windmills have to be so tall and why wind-farms and solar panels occupy so much land space to generate the output of a conventional power station (1,000 MW).

There is no magic technology waiting to be discovered to overcome the laws of nature and geometry which determine the differences between windmills and steam or gas turbines.

2.3 Land as a Key Resource

It is important also to realise that in countries with high population densities (PD), land as well as fuel is a key resource whose use in electricity generation must be optimised along with fuel usage and emissions. PD is in fact a second ruling factor which will determine where individual sources of electricity should be located optimally.

In England, where nearly 87% of the UK's energy is consumed, each inhabitant has just 0.6 of an acre (about 50 x 50 metres) for everything: housing, roads, railways, reservoirs, schools, hospitals, factories, shops, recreation, farming, sewage, telecoms, and energy conversion. The UK's energy need per inhabitant is 45,000 kWh (units) per year. At current mean solar panel efficiencies (10%), for example, this would require 450 m^2 per person or about 18% of all land in England covered in solar panels to meet this need. Clearly solar panels can only be a minute contributor to national energy supply.

2.4 Land and Fuel Transport Requirements for different Generation Processes

Table 8 sets out approximate land requirements for 3 different zero carbon electricity generation processes currently being operated in the United Kingdom. Suffice to say solar panels are being installed under a huge subsidy amounting to four times the price consumers pay for the rest of their electricity. Installations are mainly in domestic premises where 20-30 m^2 of panels may generate 10-20% of electricity needs only for those installations.

Table 8: Land area or space occupied by (a) Nuclear, (b) on-shore Wind, (c) Solar panels

	Approx Area[23] (in acres)	**Energy[24] needs served (in numbers of people)**
(a) PWR 1100 MW Nuclear Station (Sizewell B type)	40	200,000
(b) 15 2-MW Wind Turbines	40	1,300
(b) 2,250 2-MW Wind Turbines	6,000 (9.6 square miles)	200,000
(c) 70 million 1 m^2 Solar Panels	17,500 (27 square miles)	200,000

Besides the space required for generation, there is also the space required for fuel deliveries, waste product removal, and cables to distribute the electricity generated (see next section 2.5).

Gas and oil can be piped into generating stations and refineries via already existing installations. A 4-GW nominal coal station (e.g. Drax) generates around 29 TWh or 7% of total UK output. It requires around 3 million tonnes of coal per year, 8,200 tonnes per day, 400 20-tonne railway trucks

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[23] In the UK each person has only 1 acre; in England only 0.6 of an acre for everything: home, industry, transport and all services including recreation.

[24] In 2010 these amounted to about 45,000 kWh (electricity units) for the home, industry, transport and all services per person.

or lorry loads per day from the East Coast terminals – a massive burden on the landscape. The other 20-GW of coal-based generating capacity needs about the same pro rata supply.

Nuclear stations like the 1.1 GW PWR type at Sizewell B by contrast need around 20 tonnes each of fresh fuel rods and spent fuel rods per month, say 5 tonnes per week, which is well within the capacity of a single rail spur from a main line or class C road.

There is in addition some hundreds of acres of space required to store spent rods at the reprocessing sites at Sellafield in Cumbria and Capenhurst in Cheshire, plus room for underground long-term storage of by-products. However, such has been the advance in fuel technology over 40 years, it is estimated that the required storage space from a new fleet of 16 GW stations will take up less than 20% of the total already accumulated waste burden. Were fast-breeder technology to be adopted (see Appendix 1) the required long-term storage would be much smaller again.

2.5 Electricity Distribution: Geographical and Population Density Factors

In Ref 1 (Table 3) the authors set out estimates region by region of the cost (totalling £4 billion) of joining the planned expansion of wind generated supply to the National Grid. These investments will have to be made early on in the expansion programme (i.e. very soon) in order to make use of the additional wind turbines as they are commissioned.

The National Grid will expect to be paid up front to make these investments, which will mostly earn nothing until they are complete and passing electricity. Most expenditure will need, on present plans for wind-farm siting, to be in Scotland. These sites are typically 400 miles from the main electricity-using centres in England. The inability to absorb even the existing wind-farm output on a good day in Scotland itself, was graphically demonstrated in the week beginning 1 May 2011. The Grid paid wind-farm operators to switch off their windmills as there was found to be insufficient cable capacity to absorb the output locally or transport it into the rest of the national network.

This was the reverse of the experience in February 2010 (Figs 12 and 13) when in the coldest days of the winter, virtually all the wind turbines were becalmed under the influence of the normal high pressure zone of the British Isles at that time of year.

2.5.1 Realities of Population Distribution

These cases are graphic illustrations, if any were needed, of the dangers of establishing energy supplies a long way from centres of population. Two-thirds of Britain's population live south of the line Manchester to Hull, mostly in a rectangle of 100 x 160 miles. To the wind turbine capital cost of around £3 billion per GWd[25] needs to be added about £0.8 billion (or 35%) for 400 miles of cable costs at the 2 GW capacity level (2 GW would provide the peak supplies to about 200,000 homes).

2.6 Realities of Wind Supply Variability

Any electricity supply system must cope with variations in both supply and demand. In Britain, the National Grid has developed probably the most sophisticated system in the world for managing predictable winter-summer and hour to hour variations in *demand*. Unpredictable variations in *demand* at the .5-1% level can also be handled to keep its alternating current frequency within the narrow band of 50 ∓ 1 Hz (cycles per second) on which all electrical power equipment depends.

Where a generating station representing upwards of 1.5% of total capacity has to be shut down, there will generally be enough spare *supply* capacity to replace it at short notice. However, the proposal in the Government's Green Energy Strategy (GES) will, if implemented, involve variations in *supply* of up to 20 times these percentages.

This comes about because, as described in section 4, the GES envisages 32 GW maximum wind turbine capacity by 2020. While on *average* wind output will be only 27% of 32 GW (Table 10 and footnote 16 below), over a 10 day period in February 2010 supply from all the wind turbines connected to the Grid and monitored by the authors fluctuated by nearly 50% of maximum installed wind capacity (Figure 2). Translated to the planned 2020 position, this would be an unprecedented, enormous reduction of 15 GW in supply, which could only be managed by switching in around 15 gas-fired stations built for this very purpose – but for the rest of the year mostly standing idle.

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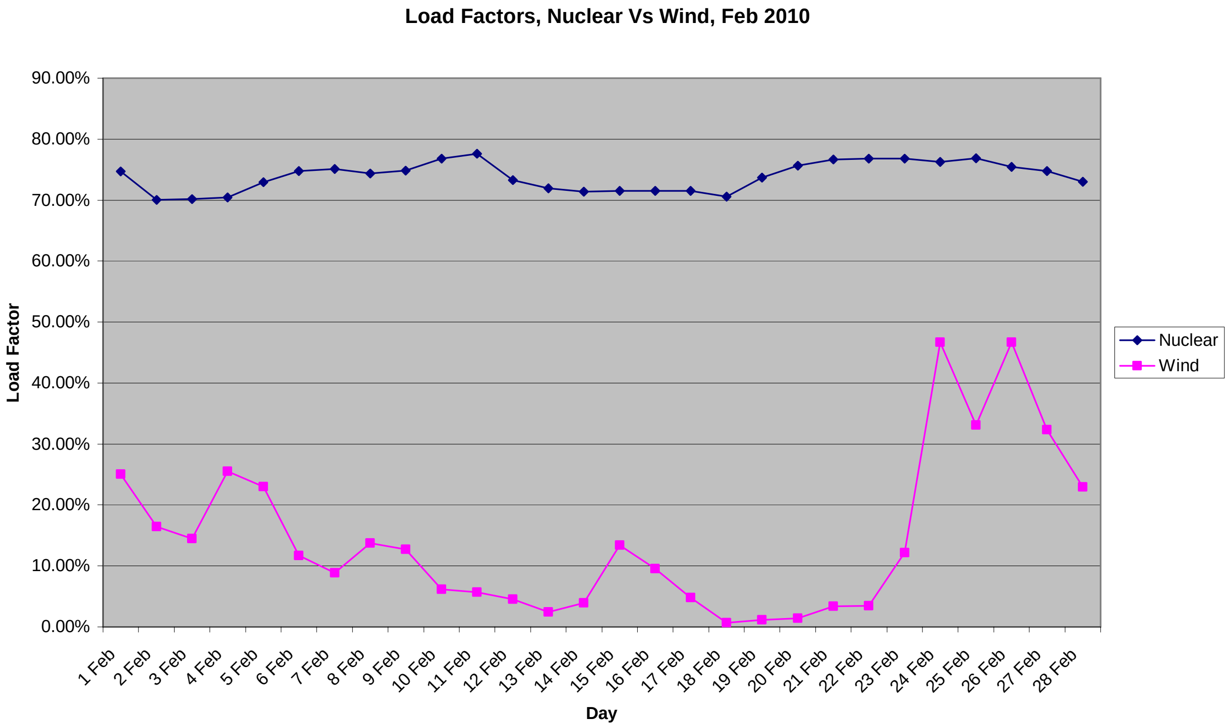
[25] d stands for average delivered per year.

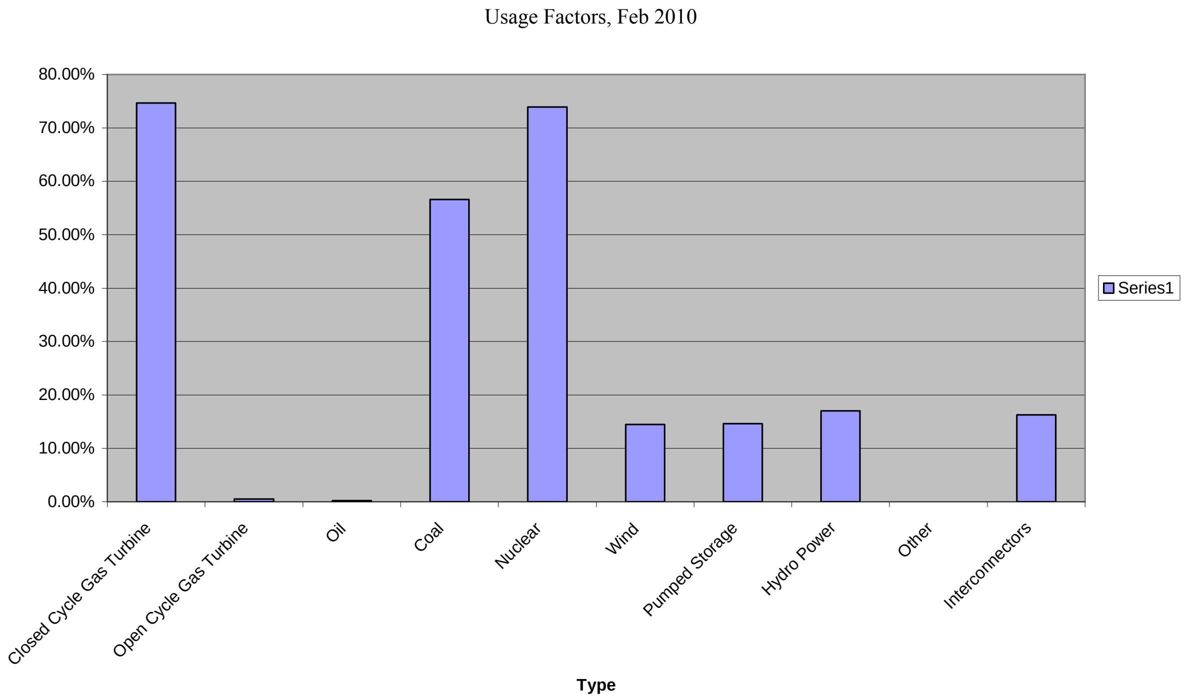
Figure 2: Load Factors, Nuclear and Wind, Feb 2010



Lest the volatility shown in February 2010 (Figure 2) be thought to be unusual, the monitoring exercise has recently been repeated by Stuart Young in March 2011. Mr Young recorded (Ref 3) on 28 March that the entire 3226 MW wind capacity connected to the National Grid and spread over 30,000 square miles was reduced to 9 MW at one point (i.e. to 0.27%). Three days later output was 2618 MW (i.e. 81%), a switch in 2020 terms of 25 GW – even greater than in February 2010.

Taken over a whole month, February 2010, one of the coldest on record, the recorded usage factors for each of the 10 systems connected to the Grid are shown in Figure 3. Closed cycle gas and nuclear chugged away steadily at 74% of total capacity, coal at 56%, while the "renewables", wind, hydro and pumped storage (though given priority over gas as suppliers) managed only about 15%. The sudden removal or arrival (see Figures 2 and 3) of even one third of the 32 GW wind capacity predicted in the Government's 2009 White Paper, would therefore result in widespread blackouts ("load shedding") as remarked by the National Grid Chief Executive on the BBC (Ref 2).

Figure 3



The reality is that wind power can efficiently only supply relatively scattered populations where there is back-up from local diesel generation, which can dependably supply electricity when the wind is either too strong or not blowing, the two types of generation linked into a local network detached from the National Grid.

2.7 Different Electricity Storage Systems: Energy Density (ED)

Such systems depend practically on their energy densities (ED).

There has been much vague talk as to how energy storage can be used to offset power variations including the effects of wind variability. There is in fact no way of directly storing quantities of electrical energy for several weeks, or even days, which would be essential if wind turbines were to be used to anything like their rated capacity.

Some proxy storage systems are possible involving mechanical or chemical systems. Electrically pumped water storage is an example of the former; hydrogen by electrolysis an example of the latter.

Energy density is a concept which determines the volume occupied by fuel for power stations and transport vehicles. More than anything it determines the feasibility of energy storage systems. For power stations and land vehicles the appropriate unit is Energy per unit volume (MJoules/m^3) (as volumetric space is usually limiting), and for aircraft the unit is Energy per unit weight (KJ/kg) as weight is usually limiting. Comparative figures germane to the current debates are given in Table 9.

Table 9: Energy Storage Capabilities of Different Energy Sources

Fuel	**MJ/m^3**	**KJ/kg**
Coal (anthracite)	36,000	26,000
Natural gas at 10 bar pressure	372	52,300
Gasoline/kerosene/diesel	31,000	44,200
Hydrogen at 10 bar pressure	107	118,700
Uranium fuel (enriched to 2% U^{235})	26,300 million	1,650 million
Lead-acid battery	400	150
Water stored at 1,000 m	10	10

The numbers here indicate the enormous starting advantage that Uranium has over any fossil fuel in terms of its compactness by volume and even by weight. It is this property which enables nuclear submarines to stay submerged for a year or more without refuelling. We note also from Table 9, the relatively modest energy density obtained with hydrogen at 10 atmospheres pressure, or even at 1,000 atmospheres, which would pose extremely demanding storage problems, thus limiting its use to smooth out variations in wind energy, as has been proposed on occasion. Its low energy per unit volume compared with gasoline or diesel, makes it an unlikely candidate for transport, even supposing its production and emissions costs could be made competitive, which is also very unlikely.

3 COST & EMISSIONS COMPARISONS FOR 10 DIFFERENT TYPES OF ELECTRICITY GENERATION

Ten different systems are compared by cost and emissions in Table 10. Technology and costs are at constant 2010 prices. Hence no attempt has been made to allow for cost increases in the future above the RPI, nor for the costs of any enhanced construction and operational security systems which may be demanded in the future[26]. The generating cost charged to the electricity distribution companies is based on a return on investment of 6% and depreciation over 40 years, i.e. 2.5% per

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[26] E.g. in the light of the report from the Nuclear Safety Inspectorate on lessons from the Fukushima disaster.

annum, except wind where the depreciation period is 20 years on-shore and 12 years off-shore. Fuel costs are those for 2010. No carbon taxes are included.

Table 10: Cost Assumptions for the different strategies (Ref 1)

System	**£M Capital Cost**		**(3) Generation cost in pence per kWh (Units)**	**(4) CO_2 emissions in '000s tonnes per GWh delivered**
	(1) per rated maximum output in GW	**(2) per average[27] output in GWd**		
Biomass	1,000	1,250	4.0	.15
Wave & Tidal	2,500	11,400	9.0	.01
Off-shore Wind	2,700	10,500	8.0	.01
On-shore Wind	800	2,960	4.7	.01
Open Cycle Gas[28]	500	550	3.5	.70
Oil[28]	1,000	1,250	4.0	.70
Closed Cycle Gas	650	810	3.0	.37
Coal[28,29]	1,000	1,320	3.4	.96
Imports[30]	500	2,500	3.4	.045
Nuclear	1,600	2,100	3.2	.037
Hydro	2,000	3,500	2.8	-

Of the low carbon systems in Table 10 which can be built in the period 2010-2050 on a significant scale (see Appendix 1 for a note on Biomass), on-shore wind and nuclear are the two cheapest. Table 11 compares what each technology can do at a nominal output capacity of 1,500 MW with respect to the economy (import savings in £M) and emissions (millions of tonnes of CO_2):

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[27] The average outputs in column 2 allow for one month in 12 outage for maintenance, except for wind, where the average output has been taken as 27% of the rated output based on measured performance over 2 years of the 3226 MW wind turbines connected to the Grid (Ref 3). (Early ones are more like 20%). Measured wind outputs are very variable, falling to around 1% of rated output in February 2010 (see Fig 2).

[28] These relate to existing installations. Oil and some coal plants are assumed to be closed down after 2015 under the European Large Combustion Plant Directive.

[29] CO_2 emissions from coal are assumed to be .961 million tonnes per TWh in 2010, falling to .854 in 2020 and .747 in 2025 as less efficient plant is closed down or modified.

[30] These are assumed to be via the interconnector cable between Britain and France.

Table 11: What can Nuclear and Wind Do?

One 1,500 MW Nuclear Reactor saves per year				
Fossil Fuel Imports	Import Costs[31] (averaged throughout the year)			**CO_2 Emissions in millions of tonnes per year**
	2010	**2017**	**2027**	
	£ Million			
2.2 Mtoes	900	1,100	1,500	**6.6**
750 2-MW Wind Turbines @ 29% on-line save per year				
Fossil Fuel Imports	Import Costs[31] (averaged throughout the year)			**CO_2 Emissions in millions of tonnes per year**
	2010	**2017**	**2027**	
	£ Million			
0.75 Mtoes	290	350	460	**2.2**

4 GREEN ENERGY (GES) AND SECURE ENERGY (SES) COMPARED

The results of applying the cost and emissions parameters in Table 10 are shown graphically in Figures 4-13 for each of the two strategies whose basic assumptions are as follows. (The Green Energy Strategy is referred to in the figures as "Extended Gone Green" because it represents an extension of the National Grid's interpretation of the Government's 2009 Green Energy White Paper from 2020 to 2035.)

For both the Extended "Gone Green" (GES) and SES scenarios, the requirement for electrical power is assumed to rise (as predicted by National Grid) from the current 357 TWh to 448 TWh by 2025 and thereafter by 2% per year to 535 TWh by 2035, thus facilitating additional electric power for transport and space heating. The winter peak load requirement is assumed to rise (as predicted by National Grid) more slowly from the current 60 GW to 65 GW in 2035 with an additional 7% "spinning reserve". In the worst case the wind turbines are assumed to be contributing only 5% of their rated capacity (in February 2010 there were times when they fell below this).

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[31] Fossil Fuel cost at mean equivalent oil prices of 90, 110 and 150 US Dollars per barrel and $:£ exchange rate of 1.55. This assumes that the thermal equivalent of all fossil fuels will cost much the same.

4.1 Green Energy Strategy

This scenario is based on the National Grid "Gone Green" assumptions, but modified at the front end with the on-shore and off-shore wind turbine programmes already built, under construction, or approved, and also assuming a nuclear programme for six 1.5 GW generators, which come on line at the rate of one per year between 2020 and 2025, so we end up with 10.5 GW in 2025. It is also assumed that coal plant, which does not meet the large combustion plant directive, is phased out around 2015, but this is partly replaced by gas fired plant sufficient to meet the total generation requirements. There is also a 10 GW gas plant programme between 2025 and 2035 to replace the remaining coal fired plant and compensate for the poor availability factor of "renewables" and increases to 44 GW in 2035. This new gas fired plant compensates for the total generation requirements, but not for the peak load where the wind is low, so there will have to be some controlled power. The cost of servicing the grid is added to the generation costs and is assumed to be 5% of power generated, plus 10% per annum of the cost of the additional £15 billion which will be spent on extending the grid for renewables, which is added as the money is spent.

4.2 Secure Energy Strategy

For the SES scenario, the first new 1.5 MW PWR is assumed to come on line in 2019, the second in 2020 and thereafter there are 2 per year until 2028 when the rate increases to 2.5 per year, until we end up with 50 GW of nuclear power capacity by 2035. It is assumed that we keep all our current coal fired plant until 2025 and then gradually phase it out from 2025, ending up with only 6 GW of new build in 2035. Gas plant increases from 30 GW now to 32 GW in 2013 and starts to decline from 2030 (as the new nuclear kicks in) to only 25 GW in 2035. The wind turbines and biofuel plant currently in operation or under construction are retained. The cost of servicing the grid, added to the generation costs, is assumed to be 5% of power generated.

The merit order for both scenarios is assumed to be as follows:

Hydro, Renewables, French interconnector and Nuclear
Gas fired plant
Coal fired plant
Open circuit gas turbines and Oil fired plant

Existing planned renewables capacity is maintained in both scenarios.
Figures 4 and 5 show the different installed capacity (GW) and production for the government's present Green Strategy (GES) under these assumptions in yearly intervals to 2035. Figures 6 and 7 provide the same data for the Secure Energy Strategy being proposed here. Figures 8, 9 and 10 show the capital expenditure on new construction over the same period, year by year and cumulatively.

Figure 11 shows demand versus availability from 2009 to 2035 under the two strategies. As may be seen, GES involves a persistent shortfall from the years 2016/17 onwards, owing to the Green Strategy's insistence on shutting down coal stations before adequate replacement capacity can be ready.

Figure 12 compares the generation costs of each strategy with the data taken from Table 10 year by year. From 2011/12 the Green Strategy is increasingly more expensive than the Secure Energy Strategy, reaching a differential of 22% in 2020/21 and 27% in 2031/32.

CO_2 emissions are compared for the two strategies in Figure13. While SES has higher emissions in the early years – owing to the retention of the coal plants until new nuclears can be built – from 2030, when most of the coal has to be phased out, SES gives less emissions than GES. In fact by 2035 SES emissions represent a reduction of 62% on 2010 figures, the biggest possible reduction from a single source (i.e. electricity production).

Figure 4

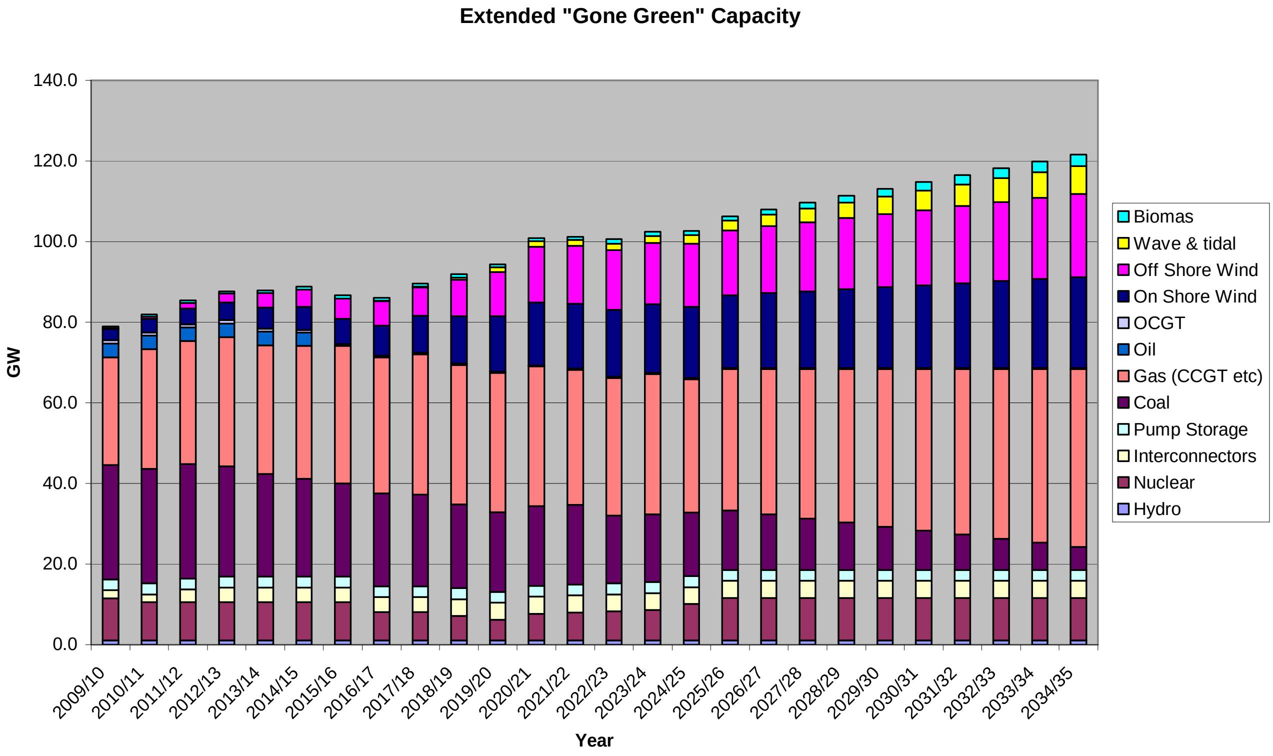


Figure 5

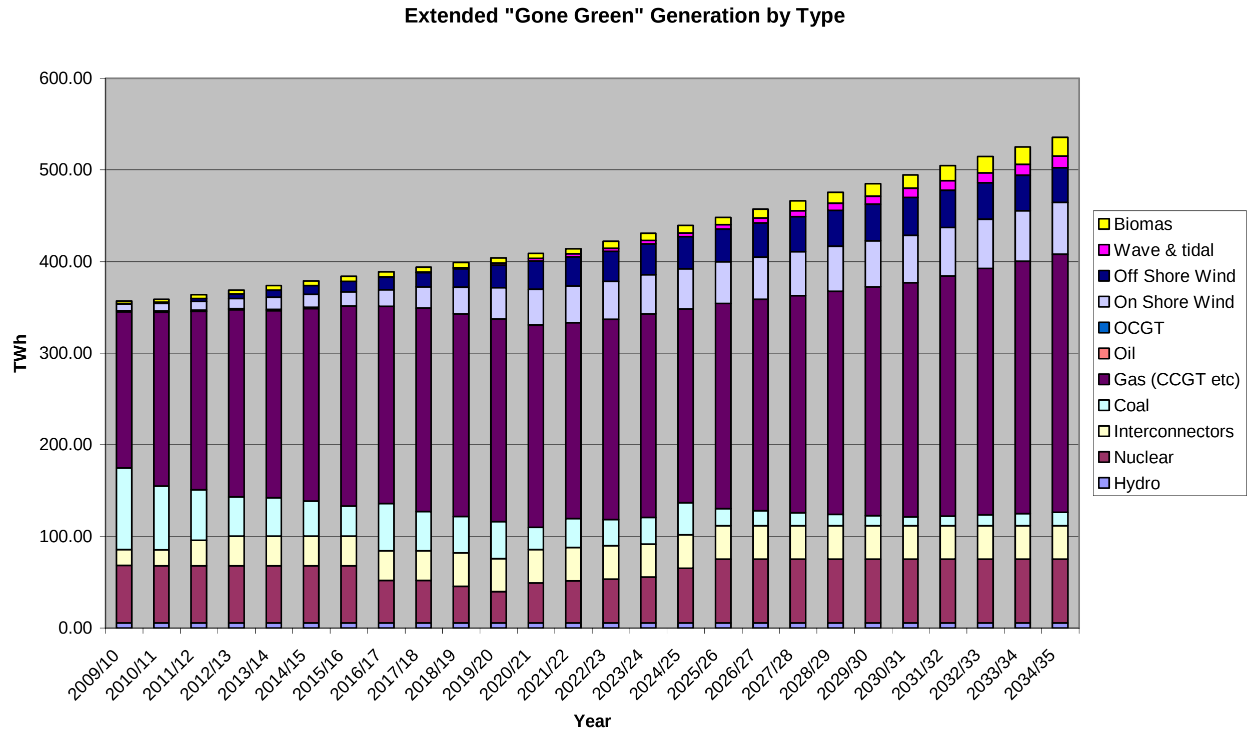


Figure 6

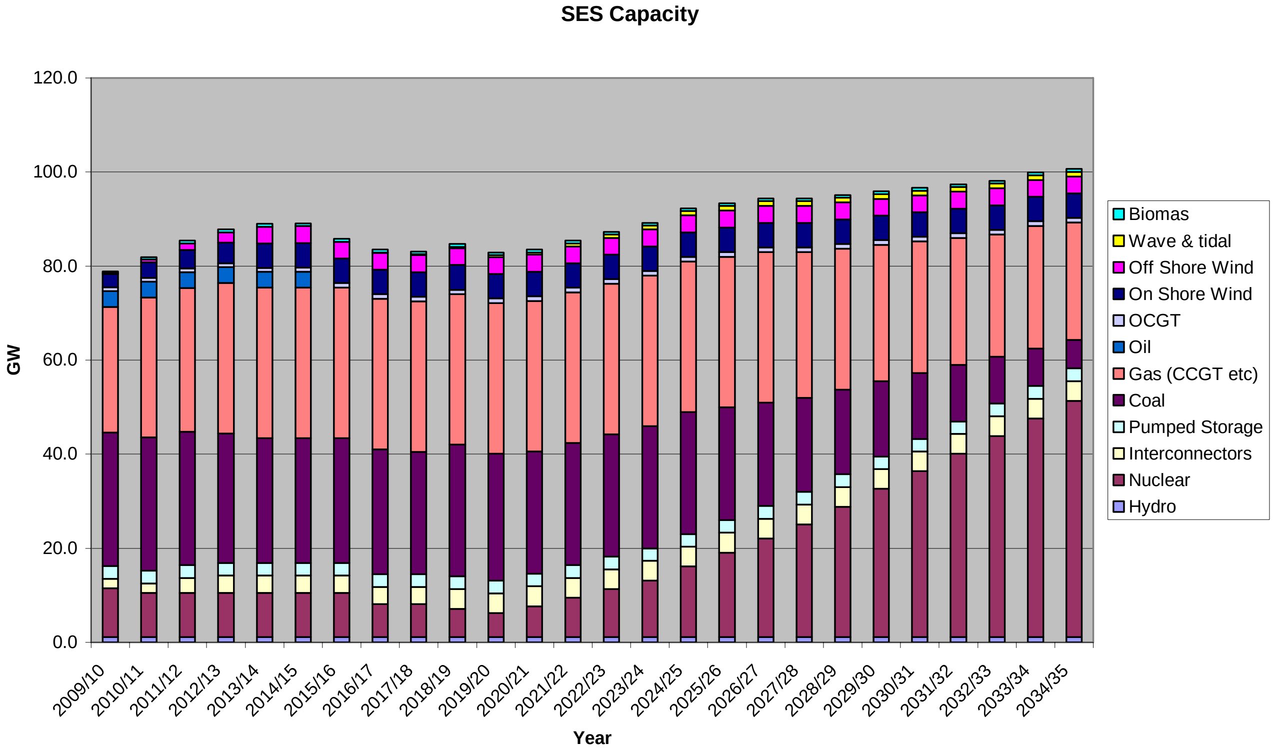


Figure 7

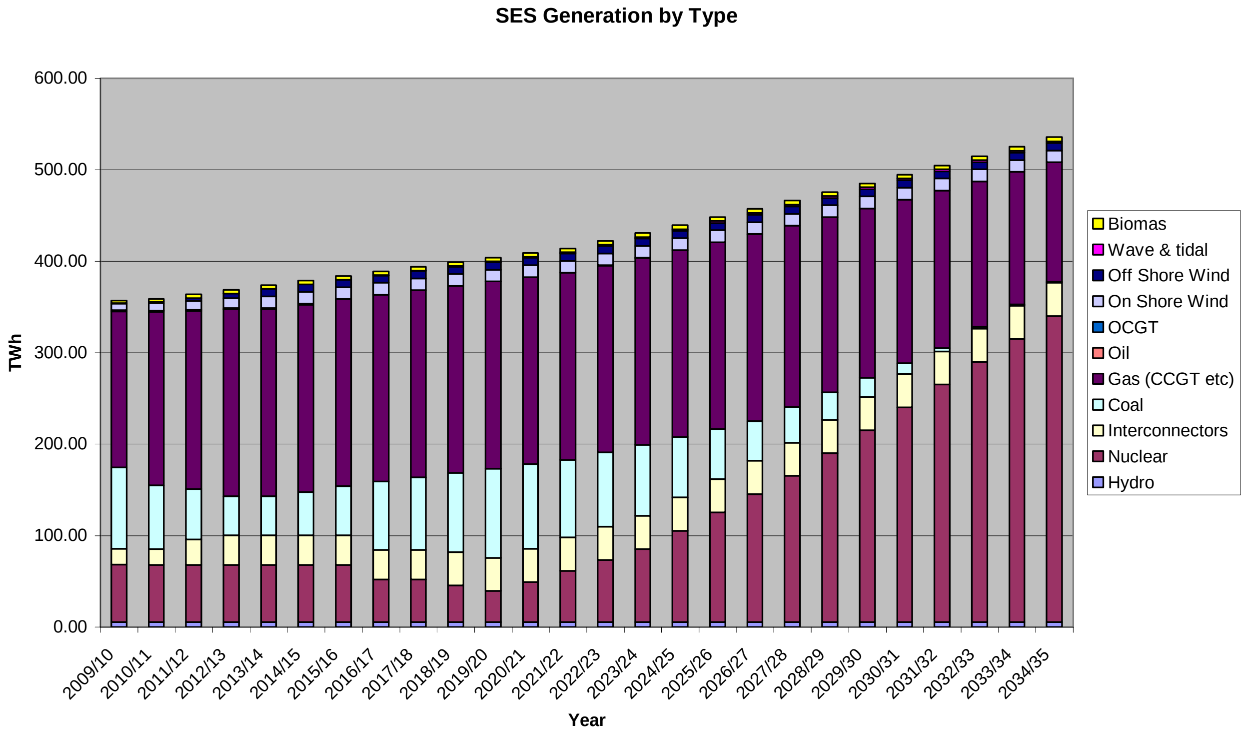


Figure 8

Capital Expenditure for Extended “Gone Green”

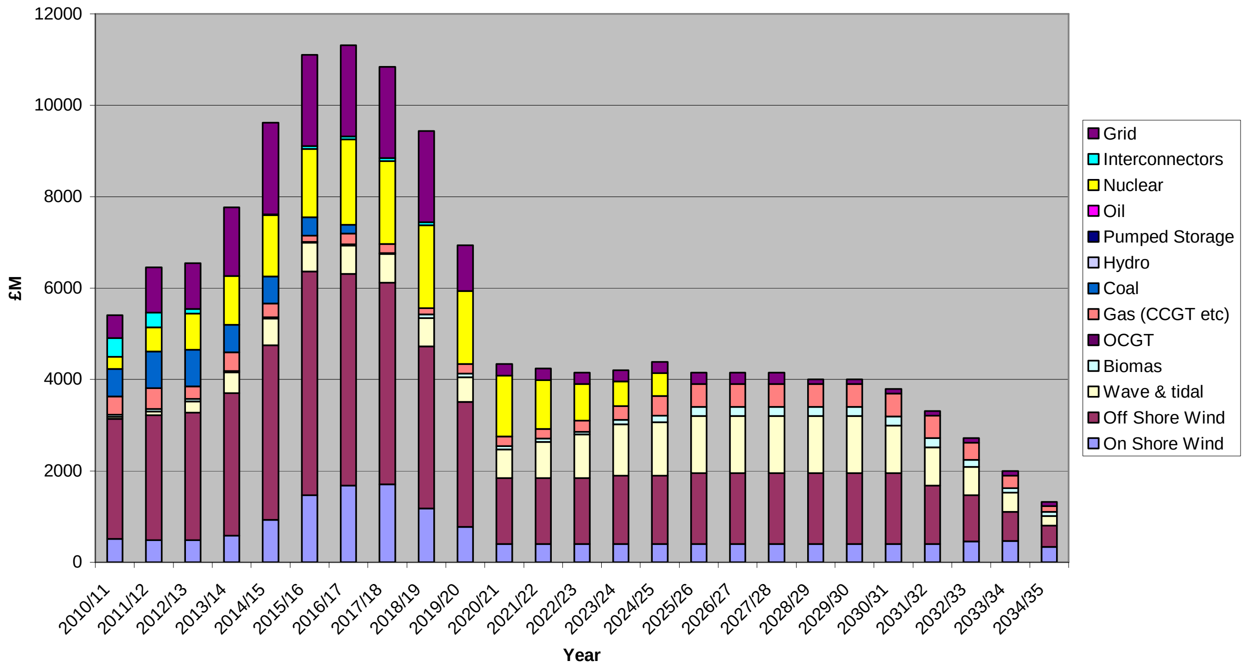


Figure 9

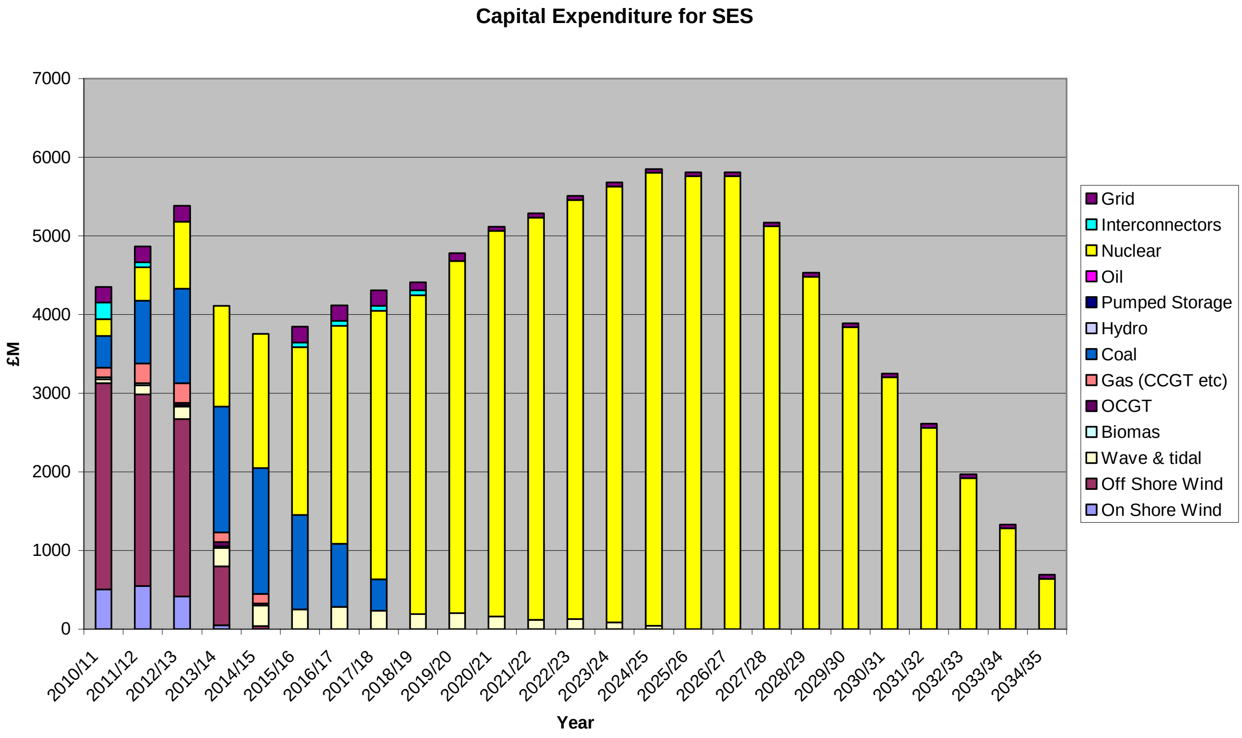


Figure 10: Cumulative Capital Costs for the two strategies

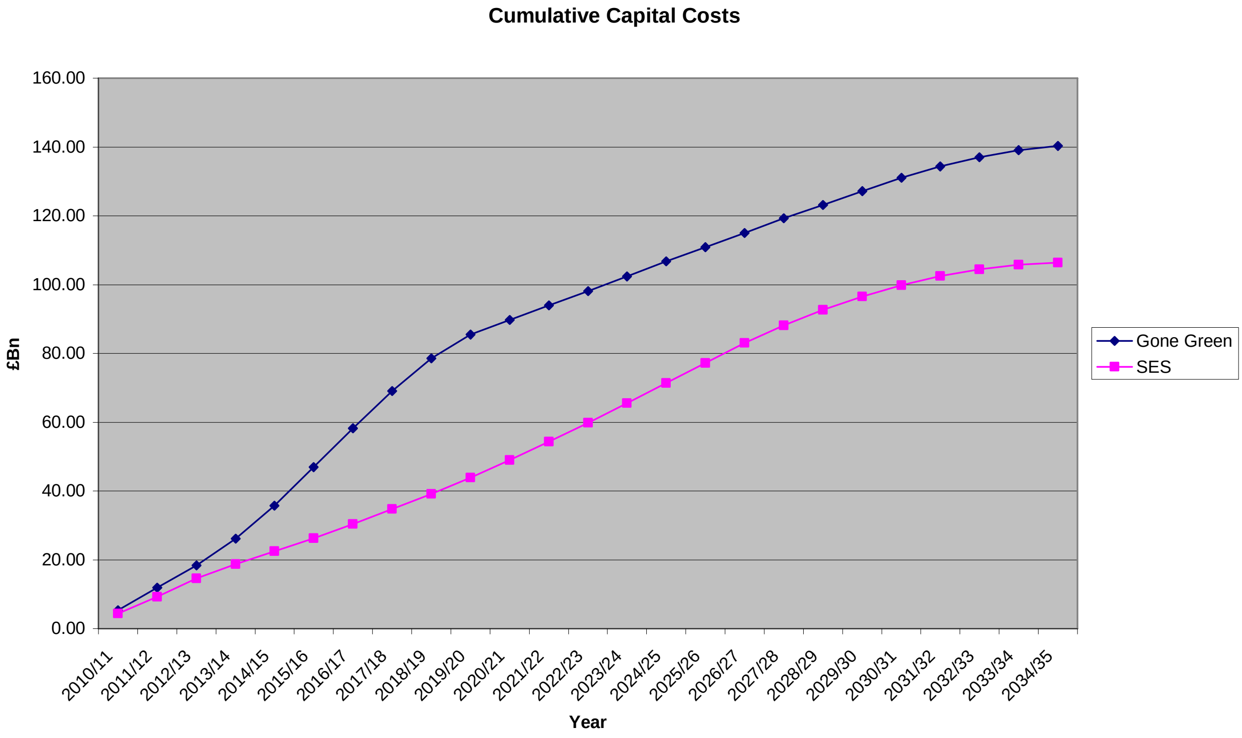


Figure 11: Demand versus Availability for the two strategies

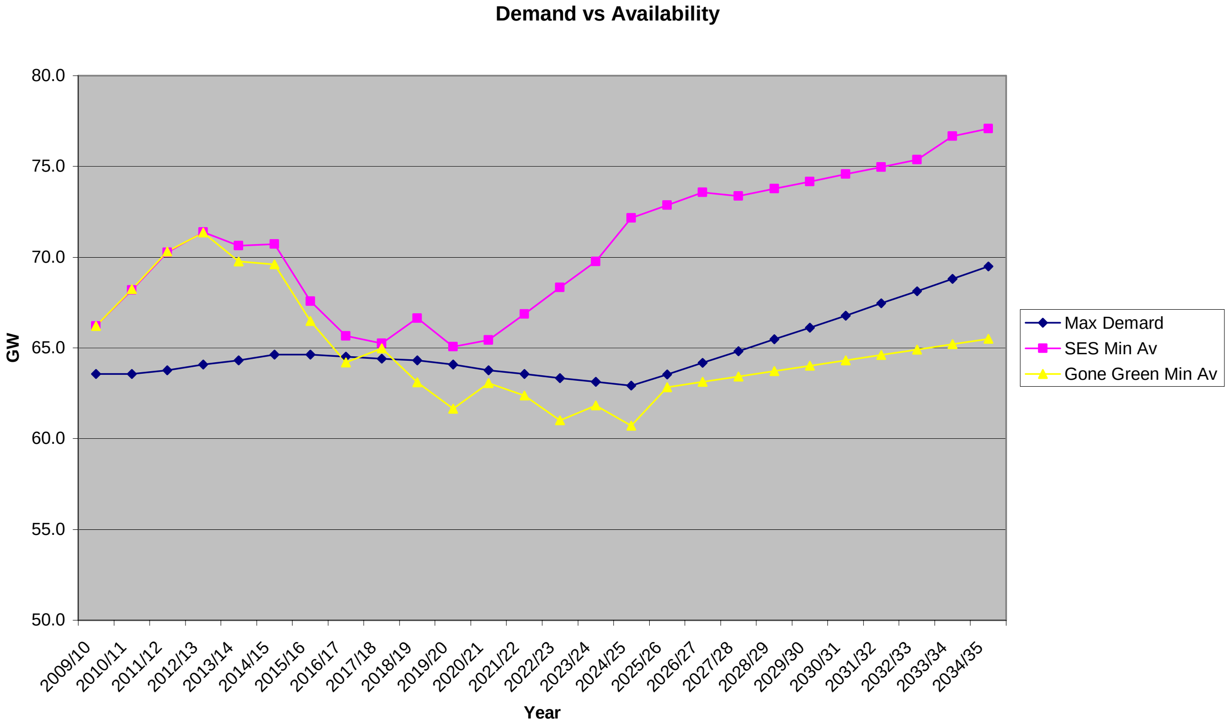


Figure 12: Generation Costs for the two strategies

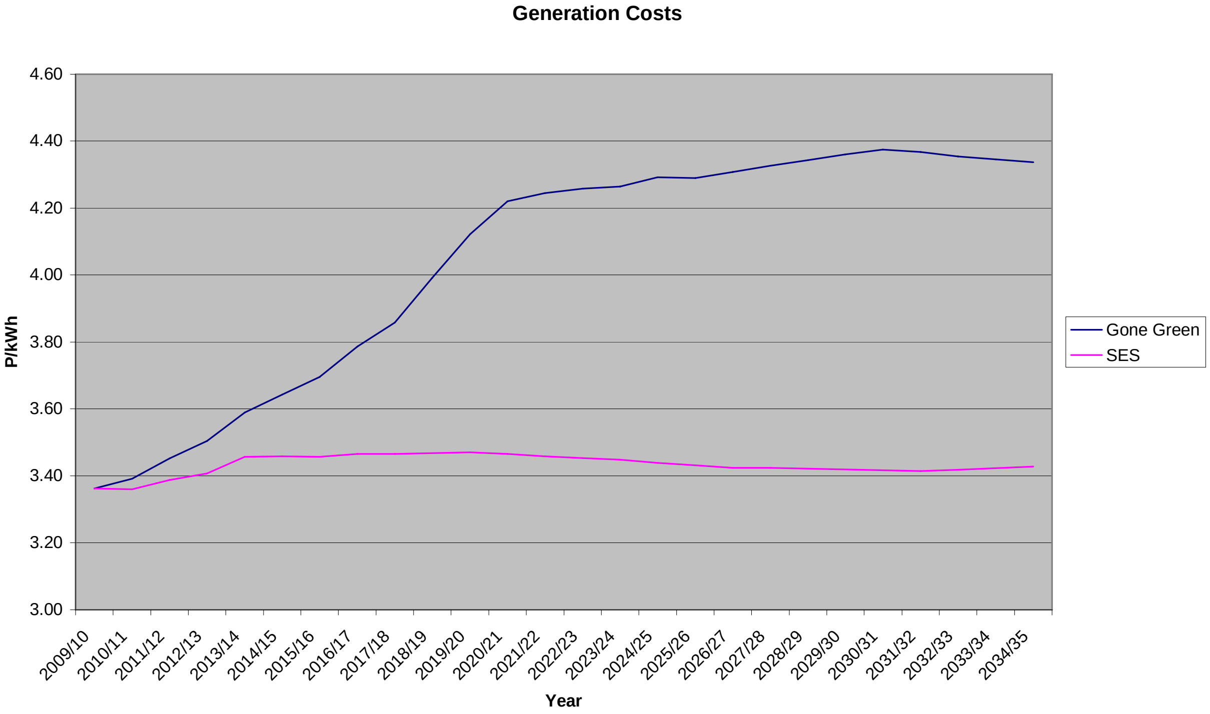


Figure 13: CO_2 Emissions for the two strategies

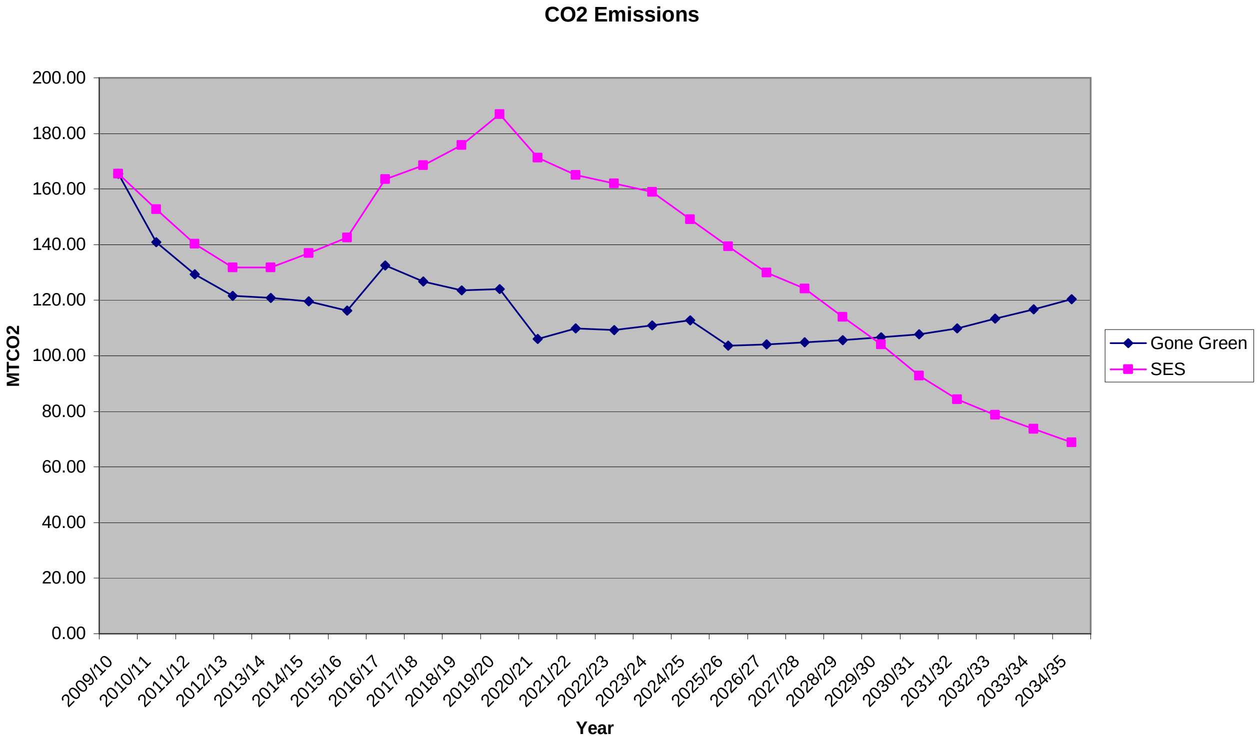
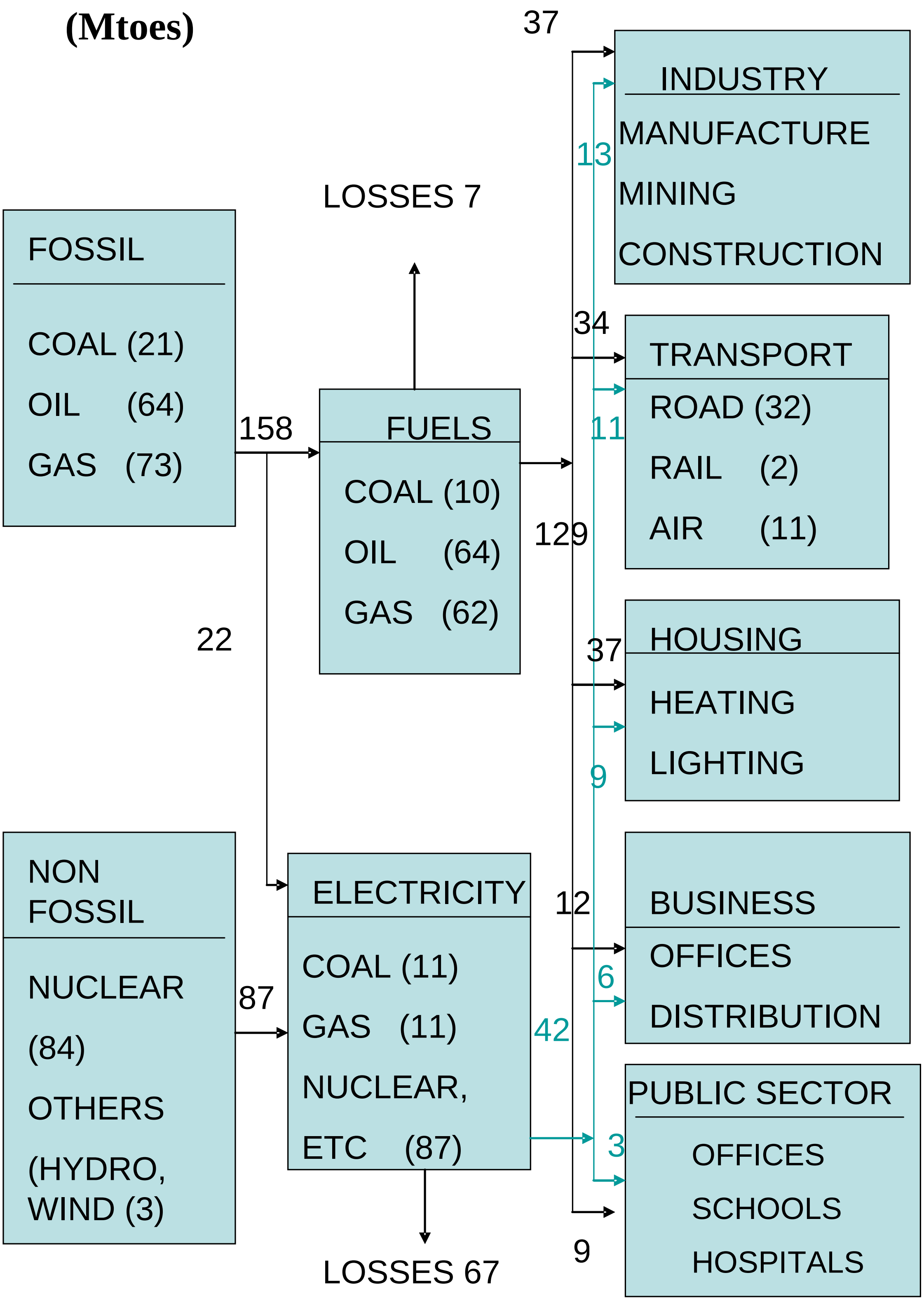


Figure 14: Possible UK Energy scenario in 2033 with around 50 GW of "new" nuclear capacity operating (One million tonnes of oil equivalent [Mtoes] ~ 11.8 Tera Watt hours [TWh])



5 FUTURE NUCLEAR INVESTMENT: SAFETY, TECHNOLOGY, FINANCE

The critical importance of nuclear power to Britain’s future electricity and energy supplies is seen in sections 3 and 4 comparing the government's Green Energy Strategy (GES) with the alternative Secure Energy Strategy (SES) proposed in this paper. This naturally focuses attention on the safety and development issues, particularly in the light of the Fukushima disaster in Japan in March this year and the Chernobyl disaster in 1988 in the Ukraine when it was part of the USSR.

5.1 Fukushima and Chernobyl

Fukushima and Chernobyl are entirely different. Following a 9 Richter scale earthquake 50 km offshore, the six reactors' coastal site at Fukushima was overwhelmed by a succession of tsunami waves which came over the 10 metre walls surrounding the reactors, but did not actually breach the containment vessels, still less the reactors themselves. Buildings in Fukushima itself were largely destroyed, while the nuclear plants' control systems worked perfectly to close the reactors down.

The principal difficulties encountered have centred on the failure of the cooling systems in three of the reactors as a result of the tsunami cutting off the outside electricity generator supplies to them and there being no independent emergency electricity supply from local diesel generators to replace them.

Both this lack and the antiquated cooling system dating from the 1960's Boiling Water Reactor (BWR) system were not approved by Britain's nuclear safety inspectorate at the time. Present designs incorporate so called "passive" natural convection cooling, which does not need pumps, and therefore the reactors do not need electricity for this crucial purpose (Figure 15). By contrast the BWR design at Fukushima features many pumps which rely on an uninterrupted electricity supply (Figure 16).

The disaster at Chernobyl in 1988 happened because the control systems in place allowed the operators to carry out an experiment with the reactor apparently operating at full power. No British commercial reactor design has ever been licensed to do such an experiment or, indeed, would be physically capable of so doing.

Figure 15: Pressurised (light) Water Reactor (PWR)

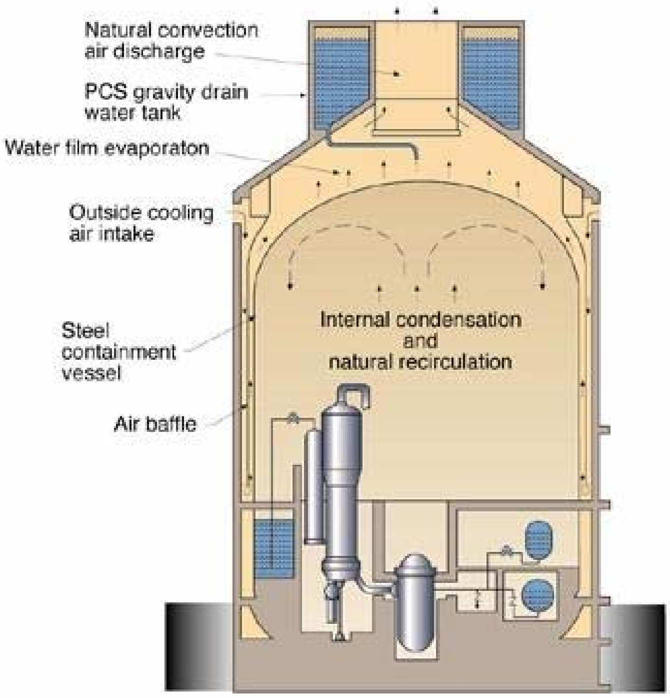
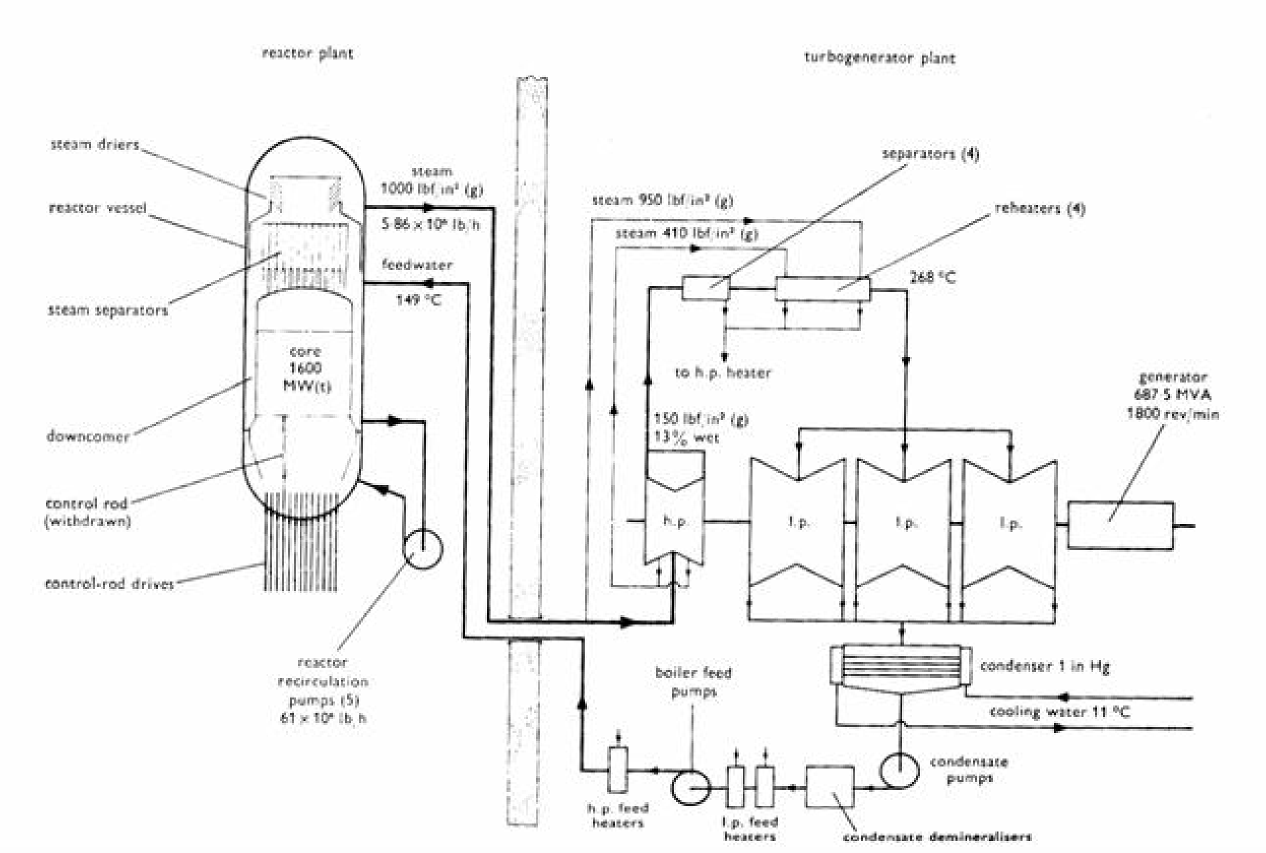


Figure 3. AP600 Passive Containment Cooling System

Source: http://www.westinghousenuclear.com

Passive systems on the AP1000 use gravity, natural circulation and compressed gas - there are no pumps, fans, diesels, chillers, or other rotating machines in the safety sub-systems.

Figure 16: Boiling Water Reactor



5.2 Comparisons of Risks and Fatalities in different industries and occupations

Table 12 gives the reduced life spans of those affected *outside* the Chernobyl nuclear plant and those affected by a life-long tobacco smoking habit.

Table 12: Reduced life-spans for those exposed to:
(a) Chernobyl radiation; (b) Life-long smoking

Source	**People Affected outside the plant**	**Average Reduction in Life-span**[32]
Chernobyl accident	75 in plume downwind of reactor	6 years
Chernobyl accident	Some 11,000s exposed to measurable radiation in Eastern Europe	2-3 hours
Life-long Smoking	50 million in Northern Europe	7 years

Table 13 sets out the fatalities in 4 alternative electricity generating systems as assembled by the Paul Scherrer Institute in Switzerland, which has experience of all four.

Table 13: Deaths in Electricity Producing Industries[33]

Fuel	**Fatalities per 100 TWh**[34]	**To whom**
Coal	3.9	Workers
Natural Gas	.97	Workers and Public
Hydro	10.0	Public
Nuclear	.09	Workers[35]

These figures relate to accidents in mining and transporting fuels, constructing plant, including storages as in hydroelectric power, and operations all for the same amount of electricity generated (100 TWh).

The nuclear industry is evidently by far the safest electricity generator. In fact the nuclear industry is arguably the safest of any process industry, including its nearest analogue the oil and chemical industries. Here we may recall that while there are no actual deaths from the British civil nuclear industry in all 55 years of its existence, we have within the same period witnessed the 1974 explosion in the Nylon plant at Flixborough (28 killed, 89 seriously injured), the Buncefield oil storage depot fire in 2010 (2 dead), the Macondo well explosion (11 dead, vast environmental

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[32] Premature deaths compared with those of similar ages unexposed to Chernobyl radiation. Source: Paul Scherrer Institute, ETH Switzerland (2001).

[33] Paul Scherrer Institute, ETH Switzerland (2001).

[34] To translate figures to current (2009) production: multiply by 3.6 for the UK production of 360 TWh, multiply by 5.0 for France, multiply by 5.6 for Germany, multiply by .63 for Switzerland.

[35] Includes fuel processing.

damage) and also in 2010 the continuing Thalidomide tragedies (thousands affected), and the Dioxin plant explosion at Seveso in Italy in 1982. These are all balanced in the public mind against the huge benefits which the processing of thousands of chemicals, even very toxic ones, bring to society. A single example is chlorine – a very dangerous gas – of which 4,400 tonnes are produced *daily* at Runcorn in Cheshire and shipped or piped safely to its customers.

5.3 UK Nuclear Development

There are two groups of developments which deserve our attention in the context of the 40 year programme envisaged by the SES and displayed in Figures 6 and 7.

- Reactors
- Fuels

5.3.1 Pressurised Water Reactor (PWR)

The pressurised water reactor (PWR) is, for good technical reasons, the design of choice, not least for its "passive cooling" system as referred to above (Figure 15). Britain has one such reactor – Sizewell B – built to the design of the Westinghouse Company which the previous government so improvidently sold to Toshiba of Japan in 2007. We will now in all probability have to buy updated designs from Toshiba (e.g. AP 1000) for any new programme of nuclear investment.

5.3.2 Fast Breeder Reactors (FBR)

The first Fast Breeder Reactors were designed in the 1960's and in Britain commissioned in the 1970's at Dounreay. Having successfully operated at considerable scale (250 MW), the British government first shrivelled the Dounreay plant's development budget down to £10 million in 1986 and then closed it down altogether in 1994 on the grounds that Uranium ore was very cheap (because no-one was then building new nuclear power stations). It is currently being decommissioned while the Uranium ore price has gone up ten times. The FBR is a reactor system which generates more fuel than it consumes. This is because the Uranium^{238} in the fuel rods of a PWR does not contribute to the fission process, but is converted into plutonium^{239} which does. This vastly increases the energy obtainable from natural uranium by a factor of 50 or more and reduces the amount of high active waste by the same factor. Appendix 3 gives an outline of the process in a little more detail.

The successful operation of FBRs in the latter part of the SES programme would mean that the United Kingdom would be self-sufficient in nuclear fuel for the foreseeable future.

5.3.3 Uranium^{235} Fuel Manufacture: URENCO

A key part of making Uranium^{235} fuel rods is the so-called enrichment process, whereby the 0.7% naturally occurring levels of Uranium^{235} are enhanced to 3% or more by a complex process dependent on gas centrifugation, the process of choice for any new entrants to the field (as in Pakistan, India and Iran for instance). This process is carried out by the British-Dutch-German company URENCO, whose British factory is at Capenhurst in Cheshire. Capenhurst accounts for about 50% of URENCO's production, which is about 25% of the world's enriched fuels production and is a major export earner. With an order book of over £10 billion, and with the world-wide energy market set to expand massively, it is a vital national interest to expand our own presence in it. It would be a particular folly to sell Britain's stake, as has been proposed by the Treasury, given the country's need of exports (Table 4) and our own nuclear fuel needs in the next 40 years. Our stake in URENCO would be snapped up by the French (whose enrichment technology is based on the obsolete gas-diffusion process, or by the Japanese who would see it as a good fit with Westinghouse, which was bought from us by Toshiba for £2.9 billion in 2007.

5.4 Nuclear Finance

Having foreign companies being exclusively responsible for the nuclear build programme – as seems to be the intention at the moment – is absolutely undesirable, as all the technical lessons will stay with them and be unavailable to the myriad of British companies supplying the programme, but also wishing to incorporate such lessons into their own products for sale abroad.

In any case it seems very unlikely that the two foreign companies presently in the lead position – Electricité de France (EdF) and the German company E.ON – will commit anything like the £100 plus billion of their own capital needed by the British programme (Figures 9-11). EdF is already under criticism from its major shareholder, the French State, for the £9 billion it paid for a 75% stake in British Energy, owner of the 8 remaining nuclear stations and their sites in Britain (see Appendix 3).

It is clear from continual hints from the government, that EdF and E-ON have been led to believe that they will be able to finance their shares of the nuclear programme by spreading the capital investment cost onto the British consumers through their electricity bills, i.e. the British consumer will pay for the new plant, but end up owning nothing (just like in the Private Finance Initiative).

To reach the 300 TWh of nuclear electricity output envisaged by the SES in 2035 (Figure 7) – or indeed anything greater than the 80-90 TWh envisaged by the government's green strategy (Figure 5), the nuclear sites *not* in the hands of British Energy (Appendix 3) and probably others in England and Wales besides, will be needed.

This is a tremendous opportunity to reconstitute a British-owned nuclear construction and operating company – BNCO plc, say – a mix of state and privately raised capital, with the public at large taking a substantial share as in the gas privatisation in the 1980s.

6 RISKS AND OPPORTUNITIES OF THE TWO STRATEGIES

6.1 The Number One Risk

The number one risk, by far, is that the Government's Green Energy Strategy will lead to electricity blackouts on a significant scale from 2016 onwards (Figure 11).

The number two risk is that when persistence in this strategy finally collapses under the weight of the facts of industrial life, it will also bring about the collapse and dereliction of the "green" industries which have been established to service it.

6.2 Consequences of Electricity Blackouts

It is worthwhile exploring what would be the consequences of electricity cuts if they were imposed region by region by the National Grid ("load shedding").

It would not be like the 3 day week of 1973 where there are vivid memories and pictures of eating and washing by candlelight. People tolerated those primitive conditions for a short period of a few weeks while labour disputes were resolved by the government's capitulating to trades union pressure.

As Figure 11 shows, the 2016 blackouts will not be short-term like in 1973. They will be repeated for years in wintertime until a crash programme of building gas-fired stations is instituted and completed.

The major impact of electricity cuts if they were to occur, would not be limited to lighting and heating failures, they will cause shut-downs of computing equipment across the land, crippling industry – all businesses without generator backup – that is virtually all small and medium-sized enterprises, mail-order firms, which include now virtually all retail stores, accountancy and legal firms, sole traders working from home, as well as homes themselves.

Who can say what civil disorder would result from such a catastrophe. People will remember the absurdly insouciant remarks of the chief executive officer of the National Grid no less, who seemed on Radio4's Today programme of 8th March 2011 accepting of the catastrophe the government's Green Energy Strategy was taking us towards with remarks such as: "We keep thinking that we want it *(the Grid)* to be there and provide power when we need it. We are going to be smarter (sic) than that. We are going to have to change our behaviour and consume it *(i.e. electricity)* when it is available and available cheaply" (Ref 2).

While some of the sub-ampere 240 v supply interrupts can be mitigated by batteries (as with laptops), one wonders what degree of "smartness" could possibly be deployed to overcome the competitive handicap that British business would suffer by its IT communications being continually interrupted by the failure of the electricity supply at random intervals in different parts of the country. No country, least of all our own, should be subject to such a catastrophe.

6.3 Political Roots of the Impending Catastrophe

If this catastrophe were to occur, it would be for entirely political reasons – namely the Climate Change Act of 2008 with its impossible-to-meet[36] emissions reduction targets and the government's following the EU Large Combustion Plant Directive (LCPD) under which around 40% of perfectly serviceable coal-based electricity generating stations (about 16% of total UK capacity) are due to be shut down by 2015 (see Appendix 4 for a note on Carbon Capture and Storage [CCS]). In addition,

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[36] When the Labour Prime Minister, Tony Blair, and his Energy Minister signed up to the EU targets embodied in the Act, it seems from their comments at the time (2003) that they thought they were signing up to reductions in fossil fuel generated electricity emissions only, not total fossil fuel energy emissions, which are three times as large (see Figure 1). Such is the careless approach adopted by the British government to this most vital of matters.

61% of our remaining nuclear capacity will close on grounds of age (Appendix 3) by 2018 before any new nuclear capacity can come on stream.

This is the principal reason why, if the UK government does not obtain a derogation from the LCPD, there will be electricity shortages in the period 2016-2020 onwards (see Figures 2, 3, 11).

The LCPD gave coal station operators 20,000 hours of running from 1 January 2009, if they did not install more scrubbing equipment to reach what many regard as unreasonably demanding emissions targets. There is still time (just) for the government to obtain such a derogation from the LCPD and allow all the existing stations to continue to meet a clear national need until they can be replaced by new capacity – as in the Secure Energy Strategy (Figures 6 and 7).

6.4 Opportunities presented by the Secure Energy Strategy (SES)

Besides doing what it says, securing our long-term electricity supplies (see Figure 7 for the SES Energy Flows for 2033), the 40 year nuclear investment programme postulated by the SES (Figure 9) would provide a unique opportunity for the British manufacturing and engineering industries to embark on a 40 year programme to replace the £150 billion per annum of output lost over the last 25 years and the £10 billion of output about to be lost from North Sea oil with all that implies for the economic security of the country and the jobs we can offer our people (Tables 3 and 4).

7 RECOMMENDATIONS

7.1 Official policy should abandon its formal emission targets and the Green Energy Strategy derived from them.

7.2 The Government should obtain an immediate derogation from the EU’s Large Combustion Plant Directive so that coal plants can be kept running until new nuclear electricity plants and industrial gas-fired boilers can be built to replace them over the next 15 years.

7.3 Official policy should put security and cost minimisation at the forefront of its energy policy, meeting our long-term energy needs from sources as far as possible under our own national control. With this objective, engineering and economic reality points inexorably at a nuclear-based Secure Energy Strategy as set out for instance in Figures 6, 7 and 9. The proportion of our electricity which would be nuclear generated would rise from today's 20% (Appendix 3) to about the same as France's today (80%) by 2050.

7.4 Nothing less will meet the economic and security requirement to shift off fossil fuels in a big way, a natural consequence of which will actually be a much bigger reduction in CO_2 emissions from 2030 than will be possible under the government's Green Energy Strategy (Figure 13). This is because natural gas burning stations will not be needed as backup for the huge investment in wind implied by the GES (Figures, 4, 5, 8).

7.5 A corollary of abandoning the GES is to set government subsidies per kWh of electricity generated at the same level for all non-fossil fuel generation. Support for research and development into what are really low-tech wind and solar technologies should be replaced by research and design support for (a) the hi-tech component manufactures needed for the nuclear programme, with all that that will mean for our exports, and (b) a new fast breeder programme with all that that will mean for long-term security of supply of our nuclear fuels[37] (Appendix 2).

7.6 For reasons given in Appendix 1, the Treasury tax discount given for Biofuels should be terminated, along with the requirement that 5% of all fuel sold should be biofuels (ethanol in petrol and biodiesel).

7.7 The entirely fanciful carbon capture and storage (CCS) projects should also be terminated forthwith (Appendix 4).

7.8 There is some case for continuing support of the tide and wave power programme, so long as it is redirected primarily at protecting our vulnerable coastlines from erosion (a truly worthwhile environmental objective).

7.9 At around £120 billion for the SES (£160 billion for the Government's GES), the scale of the investment is so large and so crucial to Britain's very survival as a first world industrial country, that it cannot be left to the vagaries of the capital raising abilities of foreign

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[37] The UK's original Fast Breeder project at Dounreay was actually successful in demonstrating its ability to breed new fuel from the spent uranium fuel rods. Because the newly privatised electricity companies were given carte blanche to build cheap gas-fired power stations in the 1990's (the" Dash for [*British*] Gas") without any provision for when British gas ran out (as it nearly has) in 1994 the government ordered Dounreay to shut down. Decommissioning is nearly complete.

companies. Nor can it be left to a policy of raising the money through the bills charged to the customer. This would mean that at the completion of the investment programme, the British consumer would be financing indefinitely dividends on an enormous accumulation of capital which he has provided the cash for.

7.10 What is proposed here is that a portion of the consumer's bill is identified as investment capital, for which equity on interest bearing bonds is issued, but not encashable or tradable until the end of the programme (say 2035 onwards). The model for this is the World War II system in which a portion of personal taxes were declared a "post war credit" encashable after the war only when the government could afford to repay them (in practice in the 1950's). This way the British consumer would have "ownership" of the investment programme and end up owning a large part of the electricity supply network.

7.11 The two consortia (both foreign-led) who are currently involved in bids to build around 10 GW of nuclear capacity would not be sufficient to finance and construct the 40 GW nuclear capacity envisaged for 2035 under the SES. We therefore propose (5.4) that an entirely British-owned nuclear construction and operating company, BNCO plc say, be set up with a mix of state and privately raised loan capital, with the public taking a substantial share through their electricity bills.

7.12 The government should abandon any idea of selling its stake in the nuclear fuels enrichment company URENCO, which is a major strategic and export asset.

Appendix 1: Biofuels

There are three main biofuel sources which the Government is actively promoting:

(1) Wood chips for power stations
(2) Biofuels for transport
(3) Electricity from waste

Leaving aside (3) which is in essence an alternative to landfill rather than a major source of electric power, (1) and (2) both depend on the low rate of power intensity (PI) due to the sun (Table 7), which in our latitudes provides about 1 GWh per year per acre.

How much of this energy turns up in (1) wood chips, (2) bio-ethanol?

1 Wood chips

The average sustainable yield across UK forests is about 1 tonne per acre after drying down to 35% moisture (Ref 4) (which has to be evaporated off in a burner at a thermal cost of 0.25 MWh per tonne).

One acre or tonne of wood per year yields 2.9 MWh a year as heat (Ref 4) and around 1 MWh as electricity, a conversion rate of 0.3 and 0.1% from the sun's incident energy. This is much less than solar panels, and is therefore an extremely inefficient way of harvesting energy[38]. As stored energy it amounts to about 40% of coal's by weight, 20% by volume. This means five times as many truck journeys are needed for wood as for coal to bring the same amount of energy feedstock to the power station.

From a global energy sustainability point of view, Hillard (Ref 4) estimates that drying and transporting the wood from the sources capable of providing the UK with even 1% of its energy needs (South Africa and the Americas) uses up between 35 and 45% of the wood's energy content, to which must be added felling, chipping, replanting, handling at ports and railheads. It is doubtful if more than one-third of the pitifully low energy yields will survive to make electricity, and all these energy losses create CO_2 emissions which are greater than the reductions claimed for the combined growing-burning process on its own.

Burning wood from trees is an even greater disaster for the UK because it has less tree acreage than any of its competitors, providing less than a fifth of its current needs for construction and furniture. The advent of a subsidised wood-burning industry is yet another burden on British industry and the balance of payments.

2 Biofuels for Transport

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[38] The fundamental reason for this is that the sun's energy is directed by nature at slowly building up complex cellulose molecules in the trees, not in creating stores of energy.

2.1 Present Position

As part of its EU "renewable Transport Fuel Obligation (RTFO)[39], the UK government with no serious opposition in Parliament, has agreed that biofuels are added to standard petrol (octane) and diesel fuels at the following levels:

2.5%	from April 15 2008
3.75%	from April 15 2009
5%	from April 15 2010

Though supporting this scheme originally, the Green lobby has recently put pressure on the government to reduce or abandon its commitments on biofuels on the grounds of their adverse effect on world food production. Accordingly, Ruth Kelly in 2008, Transport Secretary at the time, announced that the Department of Transport would not support the EU proposals to increase the level of biofuel addition from 5% to 10% by 2020 without further study. This is the present position (March 2011).

2.2 Current biofuels for transport

These are:

(a) "bio-ethanol" - (chemically the same as ethyl alcohol as found in spirits, wines and beers) designed to be added to or replace petrol (basically octane).

(b) "bio-diesel" – a mixture of compounds, like diesel fuel itself, which meets a specific combustion standard (BSEN14214) as shown on the forecourt pump.

Bio-ethanol is much the greater in volume sold, engaging a whole British Sugar factory in its production from sugar-beet.

As with wood chips, sugar yields and therefore biofuel yields are limited by the sun's PI at the UK land surface (Table 7) and the conversion efficiency of sun energy into sugar as set out in Table 14.

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[39] EU directive 2003/30/EC.

Table 14: Biofuels – Estimated Energy Yields from Crops

UK yield of cereals or sugars per acre	4 tonnes (106 GJ)
Gross crop energy per acre	29 MWh
After processing to ethanol fuel quality	53 GJ (1,700 litres of octane equivalent)

One thousand seven hundred litres of bioethanol would allow a medium car to travel about 26,000 km, i.e. one acre would be needed to support just over one medium car, even supposing net fuel yield was as high as gross sugar crop energy and allowing for processing energy costs.

2.3 Results to be expected from Biofuels policy

1 The 20 pence fuel duty rebate on 5% biofuels added to petrol and diesel costs the exchequer since 2010 and each year onwards around 50 billion litres delivered to British vehicles x £0.20 x 0.05 = £500 million.

2 If the whole UK 380,000 acreage of sugar beet were used to make ethanol, it would yield "octane equivalent" fuel per annum for around 450,000 vehicles or 1.3% of the 2011 vehicle population.

3 If *all* 1,020,000 acres of UK "set aside" land) were used, as proposed by the British Association for biofuels and oils (BABFO) at the sugar beet yields assumed by BABFO for this land, namely 1,000 litres per acre, this would give octane equivalent fuel per annum for a further 600,000 vehicles or 1.7% of the 2011 vehicle population, making 1,050,000 vehicles or 3% in all.

4 If the whole of the UK sugar beet acreage at present day yields (as in 2) *and* the whole of set-aside at the yields in 3 were employed, this still only provides around 60% of the 2010 5% Renewables Transport Fuel Obligation.

5 It would also mean:

(1) importing all the 1.3 million tonnes of refined sugar presently used in the UK's food production;

(2) converting all four of British Sugar's factories to exclusively ethanol production and constructing another 15-20 similarly sized factories besides;

(3) constructing the road and rail links needed to bring sugar beet to the new factories from scattered areas of set-aside land.

6 If, as has actually been suggested by BABFO, 3 million tonnes of the UK's present wheat exports were converted to biofuels, this would yield *at most* octane or diesel equivalent biofuel of 1 billion litres or enough for a further 600,000 vehicles, bringing the total number of vehicles fuelled by the UK's sugar production, the UK's wheat exports and the UK's set aside used for fuel to around 1.6 million vehicles, or 4% of the estimated 2013 vehicle population. It would also cost the balance of trade £500 million in lost exports in addition to the cost of importing all our sugar (£300 million) (see import/export figures in Table 4).

7 If all current UK wheat production for our home market, 4.6 million tonnes per annum, were diverted to biofuels, this would provide fuel for a further 920,000 vehicles approximately. This would add a further £800 million to our import bill at current world grain prices, that is additional to the £800 million given in point 6.

8 Viewed simply as alternative fuels, for every gigajoule (GJ) of energy released on combustion, octane (petrol) emits 70 kg of CO_2 while bioethanol emits 71.4 kg.

9 The claim that biofuels are "carbon neutral" rests on the assumption that the process of growing their feedstocks on the land absorbs as much CO_2 as is emitted on combustion and in the manufacturing process. This claim ignores the fact that even land used as set-aside absorbs CO_2 growing weeds at rates which may be comparable with those growing sugar-beet – or trees for that matter.

10 In the short term from 2010 our signing up to the Renewable Transport Fuel Obligation will cost the UK well over £1 billion per annum in imported biofuels.

11 As with wood, sugar beet is produced slowly by nature as a complex molecular structure, not as a source of rapidly-used thermal energy. This why the overall conversion of solar energy to ethanol fuel is so low (about 3%).

Appendix 2: The possible role of fast breed reactors

1 In a conventional thermal nuclear reactor, such as a Sizewell B type pressurised water reactor, only U^{235} (which comprises 0.7% of natural uranium) can be used in the fission process, whereas in a fast breeder reactor, most of the remaining 99.3% of predominantly U^{238} can be "bred" to become $Plutonium^{239}$ (Pu^{239}) which is fissionable after reprocessing.

Thus, in a fast breeder reactor, the energy available from natural uranium can be increased, in theory, by more than a factor of 100 (in practice by a factor of at least 50). A further advantage is that, since there is less input of uranium fuel, there is also a very much reduced output of high active waste. With regard to the management of nuclear waste, new techniques such as deep burial underground offer the prospect of safe long-term storage in the UK[40].

2 Some Pu^{239} is "bred" in a conventional nuclear reactor – not enough for a self-sustaining programme, but sufficient to store for the subsequent launch of a fast breeder programme. This would be self-sustaining because in the fast breeder more Pu^{239} is "bred" from U^{238} than is consumed.

3 Experimental fast breeder reactors, using liquid sodium as the coolant, were built and operated in the USA, the UK, France and Japan, but all suffered from minute leaks in the sodium to water boilers, which slowed their development. Since breeder reactors are inherently more expensive to build than conventional thermal nuclear reactors, they become economically viable only when the cost of reprocessed fuel is substantially cheaper than that of natural uranium.

The price of uranium fell dramatically following the Three Mile Island incident (which while deeply regrettable, did not have fatal results, unlike the everyday events in coal mines, oil rigs and gas fields) and the consequent slow down of the worldwide nuclear power programme. As a result the worldwide enthusiasm for the breeder reactor waned. Recently nuclear programmes have expanded throughout the world, forcing up the price of uranium ore and thus enhancing the economic viability of breeder reactors.

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[40] Royal Society of Chemistry: Managing our nuclear waste, Royal Society of Chemistry Policy Bulletin, June 2007.

4 Research and development is now confined to France, Japan and India; the most ambitious and promising programme is being pursued by Japan, a country that has little in the way of indigenous energy resources. A possible way forward could be to seek collaboration with the Japanese to develop a commercially viable fast breeder reactor[41].

Appendix 3

Table 15:

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[41] Mitsubishi to develop Japan's next fast breeder reactor, World Nuclear News, 18 April 2007. Retrieved from : http://www.world-nuclear-news.org/newNuclear/180407-Mitsubishi_to_develop_Japan_s_next_fast_breeder_reactor.shtml

Closure dates of existing nuclear power stations (including extensions of life made in 2008), and closed stations subject to decommissioning[42].

Operator: BNFL Magnox	**Capacity in MW**	**Published Lifetime**
Oldbury	434	1967-2008
Wylfa	980	1971-2010
Operator: British Energy	**Capacity in MW**	**Published Lifetime**
Hinkley Point B	1220	1976-2011 - 2016
Hunterston B	1190	1776-2011 - 2016
Hartlepool	1210	1989-2014
Heysham 1	1150	1989-2014
Dungeness B	1110	1985-2018
Heysham 2	1250	1989-2023
Torness	1250	1988-2023
Sizewell B	1188	1995-2035
Closed Nuclear Power Plants	**Capacity in MW**	**Lifetime**
Windscale	32	1963-1981
Berkeley	276	1962-1989
Hunterston A	300	1964-1989
Winfrith	92	1968-1990
Trawsfynydd	390	1965-1991
Dounreay	234	1976-1994
Hinkley Point A	470	1965-2000
Bradwell	246	1962-2002
Calder Hall	200	1956-2003
Chapelcross	200	1959-2004
Sizewell A	420	1966-2006 - 2008
Dungeness A	450	1965-2006

Appendix 4: Carbon Capture and Storage (CCS)

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[42] Source: http://www.dti.gov.uk/energy/sources/nucler/technology/generation/page17922.html)

This is an objective which if realised, its proponents believe, would allow fossil fuel boilers in electricity generating stations and elsewhere, to capture and then store their CO_2 emissions, thus allowing these boilers to continue into the “low carbon” era ahead of us.

It is important to recognise this is a proposal which were it to be realised, would contribute nothing to the over-riding necessity of reducing Britain’s dependence on imported fossil fuels with all that that means for our economic sustainability (Table 4).

The technical objections to CCS on any scale to significantly affect the UK’s current emissions reduction targets are quite insuperable however, so no full scale CCS system will ever be built, though about £20 million is currently being wasted on studies and laboratory-scale trials, principally by the Australian government (about £12 million).

The German company E.ON pulled out of its Kingsnorth 1.6 GW coal station in 2010 because the British Government insisted on it being built with CCS capability.

The Drax coal-fired 4 GW plant can stand as proxy for the rest of the 10 GW of coal stations capacity likely to remain after the other 14 GW are closed down by 2015 under the EU’s Large Combustion Plant Directive (LCPD). Air containing around 80% nitrogen and 20% oxygen, in round terms, is used to burn coal, so CCS involves 3 processes:

(i) Separation of nitrogen and steam from CO_2 in the boiler exhaust gases (steam is co-produced with CO_2 from the hydrogen in the coal).

(ii) Compressing CO_2 to the liquid state for transport to the storage vessels.

(iii) Pushing CO_2 into the storage vessels – the current idea is to use reservoirs under the North sea formerly occupied by oil and gas.

As with all things in an industrial economy serving millions of people, the numbers involved are all determining. Consider (i) to (iii) as applied to a 4 GW coal-fired electricity generating station. If it were natural gas-fired, the CO_2 figures would be reduced by about 60%.

Table 16: CCS at the Drax Scale

Electricity generated p.a. from 6 coal-air boilers	29 TWh (about 8% of UK production)
CO_2 co-generated p.a.	7.9 million tonnes (21,000 tonnes per day)
Nitrogen leaving boiler with CO_2	21 million tonnes (56,500 tonnes per day)
Separation of CO_2 from nitrogen and steam	Ethanolamine wash columns 77,500 tonnes per day (3,200 tonnes per hour)
Volume of gaseous CO_2 per day	10.5 million cubic metres per day
Pressure needed to compress CO_2 into liquid state:	
Temperature (summer day) 22 °C	60 bar (atmospheres)
15 °C	50 bar
6 °C	40 bar
Volume of liquid CO_2:	
per day	19,000 m^3
per year	7 million m^3

Seven million m^3 is about the volume contained in the living area (two floors) of 24,000 UK houses – not far short of all the houses in a town the size of Cambridge or York – *and this is each year*.

This huge volume of liquified CO_2 at 50 atmospheres could conceivably be contained in one metre diameter steel pipes and placed on the sea bed. Around 9,000 km of such pressure pipe would be needed, equivalent to twice round the British Isles *each year*. An even more fantastical idea has been mooted – namely to insert liquid CO_2 into the supposedly empty reservoirs 1,800 feet down under the North Sea, left by extracted oil and gas. Reservoirs are not "empty" volumes, but exceedingly complex porous limestone and sandstone structures of varying permeabilities, and most of the oil and gas pushed itself out under its own pressure of 50-100 bar. The proposal to try to fill these structures with liquid CO_2 is akin to trying to push the UK annual consumption of milk (5.5 million m^3) back into around 5 thousand million 1 litre cartons at least 1,800 feet down (to keep CO_2 liquid). If any CO_2 should escape in any quantity, it will bubble up to the surface creating a gigantic foam, suffocating large numbers of people in ships and on land. The figure above relates to just 8% (one twelfth) of UK electricity production.

The whole CCS proposition is in fact totally fanciful and all development work and projects should cease forthwith.

References

1 Maintenance of United Kingdom Electricity Supplies and Proposals for a Secure Energy Strategy to 2050, 12 August 2009, S F Bush and D R MacDonald, The National Grid Consultation, June-September 2009 (see www.britain-watch.com/energy-and-environment/secure-energy-strategy-ses/ (This reference is source of primary references available through this link.)

2 BBC Radio4 Today Programme, March 8 2011, Steve Halliday

3 Analysis of UK Wind Power Generation, November 2008 to December 2010, published May 2nd 2011, Stuart Young Consulting, Dunnet, Caithness, available from John Muir Trust www.jmt.org

4 Mike Hillard, http://tranquilityhouses.org.uk, 15 May 2010.