CHALLENGES FOR HYBRID RENEWABLE ENERGY SYSTEMS

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Part I. Renewables in UK and Europe

Our civilisation is totally dependent on its abundant energy supplies which have supported the exponential growth of populations, food, manufacturing, building and our mastery of the planet. Exponential growth now demands radical, managed rearrangements or it will lead to a crash of our civilisation within a century. ('Limits to Growth') The wealthy industrialised nations are responsible for the exponentials and have the means to make the corrections. The largest developing countries, China and India, have proved capable of restructuring themselves in a few decades to become the world leaders in rebalancing energy supplies. The developed world has become complacent and resistant to radical changes, as shown by the failed series of conferences on climate change. Global emissions of CO_2 and the more potent greenhouse gas, methane, have increased by 50% since these talks began. Strong changes to the climate are already in evidence around the world. Some effort is now needed to evaluate the impact of weather patterns till 2050 on all weather dependent components of our society including renewable energy, food production, and local ecologies. This has become a critical century for the human race.

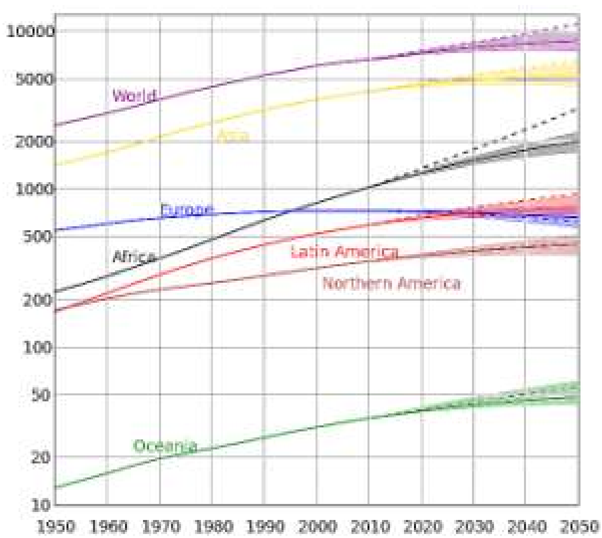


Figure 1. The exponential growth of world populations. Only Europe is predicted to decline, with healthier older populations, by 2050.

The limits to the cheapest fossil fuel energy supplies have become apparent and worse, emission of their wastes into the atmosphere is the driver for global warming. Cheap oil is in decline, though the effects are masked by the egregious crash of our financial systems. The use of fossil fuels must now to be curtailed as quickly as is practicable to avoid the catastrophic consequences of rapid climate change. There are two replacements: renewable sources driven by sunshine or nuclear sources for fission and fusion fuelled by stellar materials. Many proponents of renewables are anxious to deploy them, regardless of cost, to stop nuclear power which is seen as a threat to renewables and a historic threat to the fossil fuels industry. Energy agencies across the world find that Nuclear is the cheapest source of emissions free electricity.

The modularity of windmills and solar panels and lavish subsidies makes it easy for many companies to leap into this new energy market. Huge numbers of units are needed to meet any sizeable fraction of the global needs. They provide a low productivity, uncontrollable and erratic source of electricity which is widely separated from population centres. Wind and solar power cannot alone provide reliable electricity to match daily and seasonal load variations. They require closely coupled, 100% support from other energy partners or energy storage systems to level the power delivered and should be funded and managed as Hybrid Energy systems. The complete systems are indeed extremely expensive and, even for rich countries, deployment at any cost must have limits.

Geography plays an important role in the renewables story. Unlike the USA, Europe has no prairies or large deserts and is densely populated. Windmills work better the taller they are and in the highest spots with a long uninterrupted vista, meaning they will dominate the landscape in which they sit. England is the most densely populated country in Europe and only the countryside is possible for large windmills. Much of that was designated as farmland, National Parkland, nature sites, places of outstanding beauty, managed forests, and hill farms. Solar PV farms are now allowed to use many acres of farmland. Country residents across England have protested about every wind farm proposal and prevented almost 50% of them. They have now been met with the extreme response of new regulations which allow the Department of Energy to override all objections by citizens, councillors, MPs, Bishops and Lords of the realm. Wind farms can, in principle, be approved anywhere. Even Britain's premier seaside resort, Bournemouth, is threatened with a large offshore wind farm which will eventually stretch across the bay. Its 350 MW of net generation could easily be re-sited or an onshore CAES energy storage plant, as described in Part II. Many would prefer to have no windmills in England, but grid connections to high wind, low population density areas like the Scottish highlands, Ireland, or Normandy. England is set to accrue the most damaged rural amenities in Europe.

The UK, Germany and Denmark have made commitments to deploy large amounts of wind and solar energy over the next 15 years. This already provides us with real experience of their performance and a view of the oppressive legislation and uncontrolled spending needed to establish the technologies. The USA and Europe are exploring plans for renewable systems able to reduce greenhouse gas emissions from all sources by 80% by 2050. The US National Renewable Energy Laboratory (NREL) has published the largest, most careful study of such scenarios and this is examined in Part II. We will find that the expensive, elaborate, continent wide electricity system needs extremes of legislation and system control well beyond those envisaged in England.

The parts of this report which address just the UK story were submitted to the House of Commons subcommittee on Energy and Climate Change, 10/7/2012. All the ECC submissions are published here: (www.parliament.uk/eccpublications Submission 15). This committee chose not to hear oral evidence in opposition or critical of the UK renewables programme in previous hearings. No formal analysis of the evidence is to be found.

The great political challenge for Europe is to agree on continental scale management of renewable energy resources.

I.1.1 Renewables as Hybrid Energy Systems

Europe has considerable amounts of real data on the performance of wind farms and solar panels. A number of analyses have shown serious technical weaknesses in the case for overwhelming deployment of the systems.

The erratic nature of energy from windmills is now well known, though the renewables industry (RenewablesUK www.bwea.com), DECC, EIA, and other public agencies publish little or no complete data or analyses on performance. The following chart (Stuart Young Consulting, www.jmt.org) illustrates the behaviour for onshore wind power in the UK. Real data for December 2010 from 6 different wind farms across England and Scotland has been added and scaled up to represent the planned 30 GW (Gigawatt peak power rating) for the UK by 2020+.

DECEMBER 2010

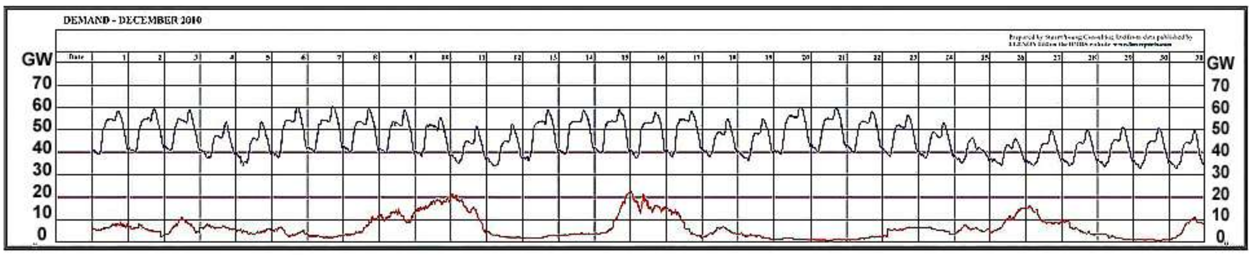


Figure 2. The upper curve shows the daily demand variation in December 2010, averaging some 50GW. The lower curve represents a group of existing wind farms around the UK, with the rated output scaled up to the planned UK peak capacity of 30GW. The wind energy output is completely uncorrelated with the daily demand variation but the wind farms are quite well correlated with each other. Output across the UK collapsed below a few percent of peak for some 12 days. The maximum output was under 70% of peak and charts showing more than 80% of peak are isolated examples of performance. The mean output for the whole of 2010 was around 21%,or 6.3 GW from 30GW, far short of the standard industry claim for 30-35%.

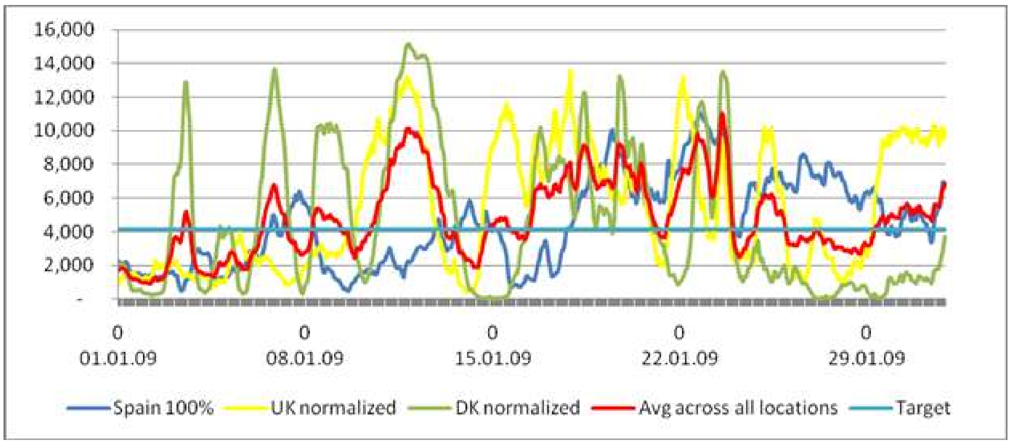
This one diagram has introduced most of the delivery problems for wind farms. Offshore wind farms perform better and, in a good year, produce over 30% of rated capacity, but only rarely the 35-45% claimed by industry. This ragged output of a net 10GW requires rapid responses from the National Grid to start or constrain up to 20GW of other power generators, mainly gas power stations, to match the total output to demand. A steady output of 20GW therefore comes from 10GW of wind and 10GW of gas, tightly coupled by the wind variations, in what is clearly a **Wind-Gas Hybrid** power system. This is a useful shift in the viewpoint for wind and solar energy. Other Hybrid partners like coal and energy storage systems will be discussed.

The operators of the 20GW of gas stations can only run half the time at extra cost in fuel, 20% higher emissions when running in on off mode, and higher staff and maintenance costs. The renewables industry claims that no new gas fired power stations need be built and that the existing fleet can be constrained off when the wind blows. Compensation to operators for the financial penalties of this are being negotiated in the UK in 2012. Future replacement gas stations will have to be built on a business plan of running only half the time.

I.1.2 Trans-Continental Energy Balancing

Could the erratic performance of wind farms be smoothed out better by averaging across several or all countries in the EU? The largest wind energy programs are currently in Denmark, UK, Germany, Holland and Spain, and the industry claims this will surely average out with new high power transmission lines connecting them all. Wind data from UK, Denmark and Spain (Kunz et al., www.theoildrum.com/node/7159 , www.theoildrum.com/node/6957) are enough to answer the question:

Figure 3. Real wind energy data from Denmark and simulated output based on real wind speed data for Spain and UK for January 2009, taken on 20 min. intervals (Kunz). The UK and Spanish data are simulated from recorded wind levels and normalised to the real Danish level of 36Twh/year, or 12GW peak power generation. The red curve shows the sum of all three and the blue line is the annual average for each. The highest peaks at 10GW are 2½ times the average and lows of several days at 1-2 GW exist across the group.



It remains to see how and when excess power in one country can be transmitted to those with not enough. Plans for high voltage cables to from UK Norway and other countries are already in progress. When all regions have excess power the alternatives are to constrain (dump) the energy or send it to some energy storage. Transmission losses are about 10% and round trip storage losses are about 20%.

Figure 4. High Voltage DC transmission lines, by land and sea could link the UK, Denmark, and Spain to swap or store renewable energy. Systems with a 20GW peak would need transmission capacity of 4GW on each line.

Energy swaps make no sense if all countries have low or very high output relative to their demands. When 1-2 countries are low and the others are high, or willing to sell their electricity at a premium, then a swap makes sense. With only one time zone between these three the demands are similar. Making a swap to a country with low wind energy and low demand – during the night - is also unnecessary. A simple analysis of this three way scenario with the data in Fig. 3 shows that, on average, <u>no more than 10% of this expensive transmission capability would be used</u>. High power transmission lines are expensive. Between 20-30% of the cost of every offshore UK wind farm will be the connections to the onshore links and DC/AC conversion to the National Grid.

Perhaps the averaging of power sources across a much larger region would use equipment and resources more efficiently. The ultimate step is promoted by the project, DESERTEC, which extends from Iceland to Saudi Arabia and Norway to Mali, Figure 5. Every power source is connected to a high power, high voltage grid spanning the region. It is only on this scale that renewable electricity might be made available on demand to homes, industry, and commerce across Europe. The political problems appear greater than the financial ones for this scheme as every generator must respond on an hourly basis, a level of international cooperation never seen on any issue before.

Figure 5. DESERTEC: An Intercontinental super grid system connects Geothermal power in Iceland with solar energy in North Africa and Saudi Arabia. Storage and power is listed as hydro-electricity and molten salt thermal stores for solar installations. Biomass, Hydro, Gas, and storage are all modest compared to wind and solar and serve as their Hybrid partners.

Not surprisingly, the simple study by Kunz et al. is almost the only one which examines distributed performance using real data on the time scales of wind energy variations. The German Advisory Council on the Environment published a study on 'Pathways towards a 100% renewable electric system', 2011. No solution was offered to the problem of large excess production in a purely German system. The remarkable idea that offshore wind capital costs will drop from EU13/MWh to EU4/MWh by 2050 should be most attractive to investors. The UK DECC does not offer any analysis of a widely distributed system.

<u>A challenge to the EU renewables movement to model integrated EU-wide systems using real data wherever possible.</u>

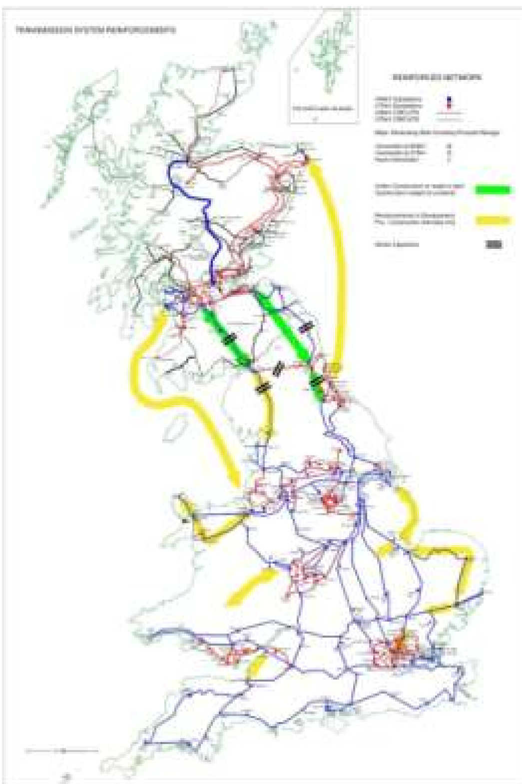
I.2.1 Renewables Experience in the EU

The current realities are that the drive to suppress nuclear energy has led to increases in the use of coal and gas and the investments in wind and solar have dramatically increased electricity prices. British nuclear power was bankrupted by the Labour government and all the nuclear laboratories, except for the Aldermaston nuclear weapons lab, have been closed. Only the Fusion laboratory and its EU JET programme, survive in reduced circumstances. The UK coalition government has returned to support of new Nuclear power but has moved first on legislation and regulation to pre-empt endless legal challenges by the renewables movement. Nuclear power is seen in the UK as an important part of a balanced energy mix.

I.2.2 Scotland

Scottish politicians claim that Scotland will generate 100% of its electricity from wind by 2020. This is a misrepresentation as it omits the emissions from English gas fired power stations that are its Hybrid partner. On days with no wind they will be supported by this gas power. The load factor for the wind farms is claimed to be over 40%, but offshore wind farms in Denmark deliver no better than 30%.

Scotland gets 30% of its electricity from coal and 20% from the nuclear stations at Hunterston and Torness. The 1200MW coal station at Cockenzie breaches EU regulations on other emissions and will close in 2013, but Scotland plans to replace this with 2400MW of new coal stations, 800MW at Grangemouth and 1600 MW next to the nuclear power station at Hunterston. The old Longannet 2400MW coal station now meets EU regulations and has had its life extended to 2025. The emissions from Scotland are set to increase.



Their one large gas fired power station at Peterhead is a highly efficient closed cycle system unsuited to the leveling task, so all the leveling is done from England over the main 400kV grid connector. This connector has a 1.9GW capacity which covers the current levels. It is to be expanded to 4GW and a new High Voltage DC (HVDC) undersea line is to be installed between Flintshire and Hunterston. The investment, running costs and emissions for gas leveling in England simply do not appear in Scottish budgets or energy plans. This raises the general question of who should pay for the various elements of a widely distributed energy system.

Figure 6. The current and planned National Grid of 275kV and 400kV lines required to deliver offshore wind energy from Scotland, mainly the East coast. Most of the costs for new and upgraded lines should be included in the total cost of wind energy.

A challenge for Scotland is to quantify the real costs of their wind energy programme and the necessary support contracts and contribution to grid connections with England and others after independence. The Danish experience should provide the data.

A challenge for England is to eventually give up its sovereignty over UK energy sources, including any nuclear plants, and cede control to the EU.

I.2.3 German Wind and Solar

How do different types of erratic renewables affect the electricity supply and grid stability? A recent analysis (Euan Mearns, www.theOildrum.com) of German wind and solar output in the sunny month of March 2012 showed that rooftop solar photovoltaic (PV) energy on a large scale must also be partnered with gas or substantial energy storage.

The daytime solar feed of up to 15GW could not be suppressed by the grid operators. The 30GW of wind power did not get above 20GW and was below 3GW for 14 days. The mismatch of solar in the south and wind in the north, and the lack of 8GW of closed nuclear power, came close to crashing the grid. This exposed their failure to plan an integrated set of Hybrid wind-solar-gas systems with appropriate grid capabilities.

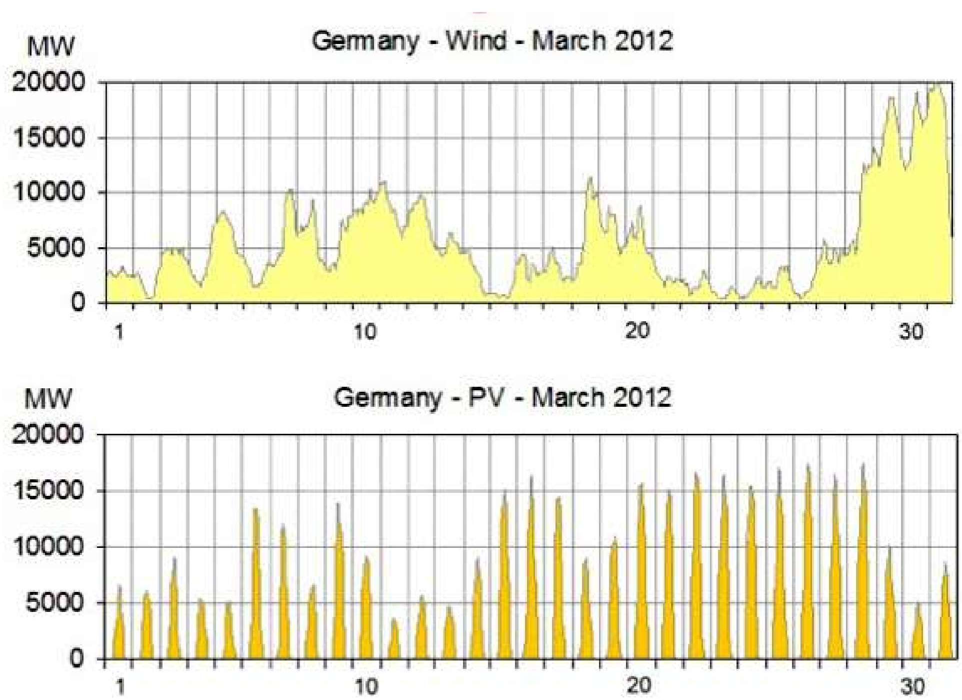


Figure 7. German Wind and Solar power, each peaking at 15-20GW. The solar power does not cover the evening maximum demands. The wind power is below 10% of its peak for 5 days. Leveling power of up to 30GW peak is needed from Hybrid partners to provide stable electricity on the grid.

Rooftop Solar PV is inevitably sited far from any large scale energy storage and will require very high capacity grid lines to divert the peak energy there. An alternative is for the grid to signal rooftop installations to cease production or use in-house storage. The German rooftop solar is easily the world's most expensive electricity as it operates at a 10% load factor and was mostly bought through subsidies at the high early prices for solar panels.

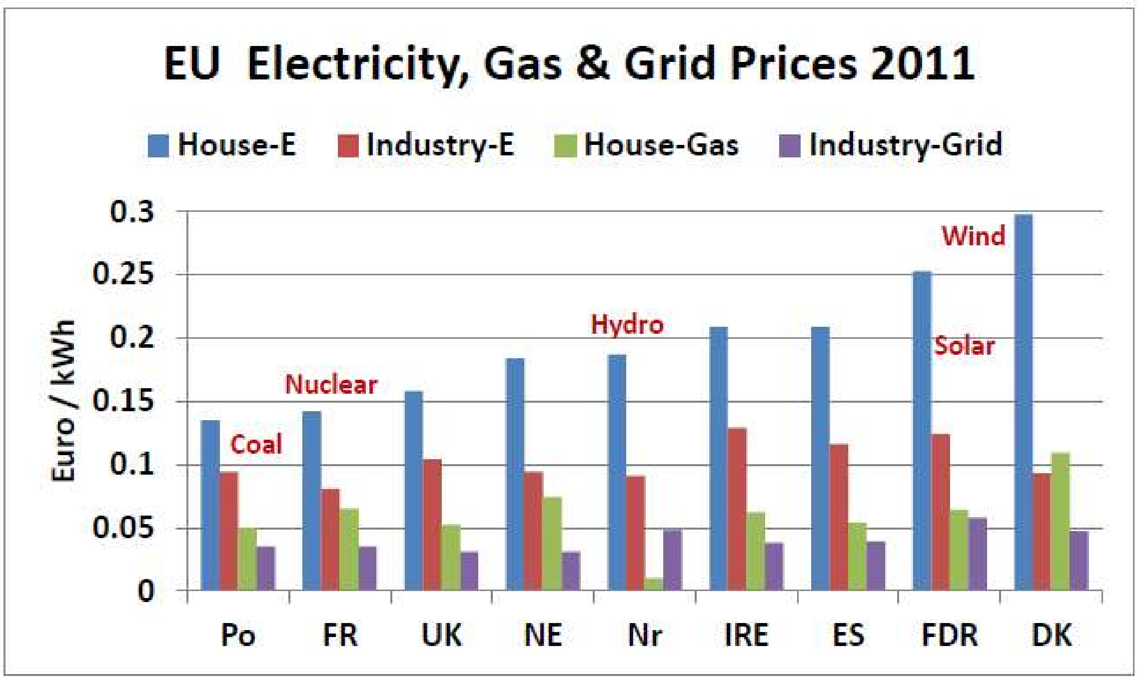
Renewables can often peak together and their total output can exceed the total desired load. Thus, thehigh German solar PV capacity would limit wind energy to a maximum of about 70GW today, or require substantial curtailment. The German desire to increase solar capacity to 40GW limits wind capacity to the current level, or needs grid connections to export it somewhere else.

Germany is in the process of closing its nuclear base load power stations which has damaged the finances of their principal energy companies. It should be clear from the previous discussion that no amount of new wind power in the UK or Denmark will guarantee electricity on demand for Germany.

I.2.4 EU Electricity Costs

Households incur higher taxes and pay more for electricity than industry. Large industrial plants may pay extra for their special grid connections. The cheapest form of energy is Natural Gas burned for heating. Clearly, the emissions from gas heating will not be captured, so good insulation is needed to make heating with low emissions electricity affordable. Unfortunately, Figure 8 shows just how high electricity prices are being driven by renewable subsidies.

Figure 8. EuStat data compares domestic and industrial electricity prices between countries with various energy mixes. Consumers pay much higher prices than industry due to taxation. The grid connections are a large component of the price to industry. Dominant electricity sources are noted for several countries. Poland runs mainly on its coal, France on nuclear, and Norway on Hydro. The wind and solar renewables make electricity 40% more expensive in Germany than in UK.



I.2.5 Carbon Capture & Storage

This technology is mandatory if coal and gas are to continue as Hybrid partners to Wind and Solar renewables. However, it remains a rather distant prospect. Carbon capture adds up to 30% to generating costs and 20% to fuel consumption so operators will not even attempt to do it without legislation. Storage is equally expensive as the captured CO2 must be compressed and pumped to a suitable burial site. The best choice is to an existing oil field where the gas may aid extraction of more oil and provide some revenue. The worst is to some distant oilfield in the North Sea where 500 year containment may be difficult to check or repair.

It is clear in the briefings from DECC on CO_2 storage in offshore wells or saline deposits, gastight for 500 years, that this presents the highest risk and cost for every UK CC&S system. BP withdrew its own trial of a complete CC&S system at Peterhead on this basis. The best UK scheme, which has not been considered, would be to design, build and test offshore storage as a project integrated with a proven gas fired unit using Carbon Capture. The gas power station would be a Hybrid partner to wind energy in Scotland.

There are now 18 CC&S power projects approved around the world, though none are built (sequestration.mit.edu). Twelve will be built on existing oil fields, gaining revenue from enhanced oil recovery (EOR). Only 10 of 17 pilot plants are actually running. Only one pilot is storing CO_2 in an offshore gas field. Only Norway is testing capture for gas fired units. It will take several years for the engineering and operating practices to be established.

It is a premature expense for the UK to duplicate existing trials in other countries by building new coal fired power stations with experimental Carbon Capture at Grangemouth (2X400MW) and Hunterston (1600MW). This can be nothing more than a gamble, with no consequence for the coal burners, if CC&S fails to materialise here.

Germany has no current CC&S pilot projects and two full scale CC&S power stations have so far been rejected by local communities.

A challenge for Germany is to produce a plan to close its coal mines and coal power stations keeping only sufficient coal for those using a CC&S system.

Concluding Observations, Part I

There is little doubt that wind and solar energy alone on any scale cannot meet the electricity needs of an industrial civilisation like Europe. These sources must be partnered with dams and lakes and river runs and biomass fuels from forests and farms, but are currently partnered with the familiar fossil fuels. The Wind-Gas Hybrid combination can never be part of a scenario of 80% electricity from carbon free sources.

Climate change scientists have pressed for urgent action in reducing emissions, but this urgency has merely stimulated a very fast build of systems without a clear view of how they are to grow and integrate with society. As the unforeseen problems emerge we are compelled to fall back on the fully matured engineering of new coal and gas stations. Greenhouse gas emissions continue to increase.

Part II discusses the more coherent US plan for the development of an 80% Renewable electricity supply by 2050.