C O M I N O F O U N D A T I O N

Emission Free Electricity Generation

Background

Electricity's extraordinary versatility as a source of energy means it can be put to an almost limitless set of applications which include industrial processes, heating, lighting, transport, communications, and computation. The use of electrical power has become the backbone of modern industrial and domestic society. This will remain for the foreseeable future. Generation of electricity produced centrally and supplied by a grid system currently powers the economies of all developed and developing countries because of convenience and relatively low cost.

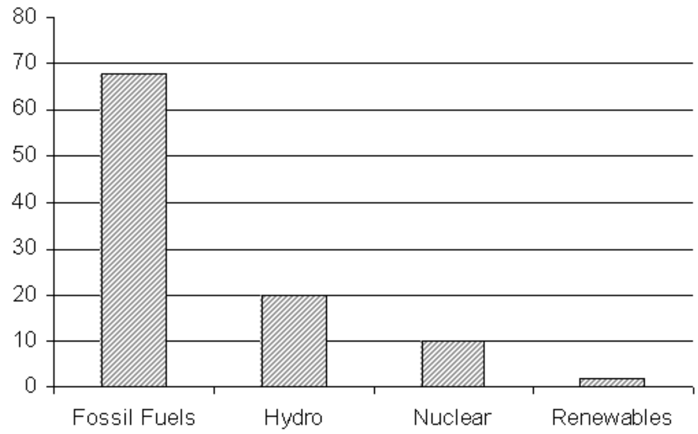
Because citizens rely extensively on electricity, energy generation and energy supply have become highly charged, politically. Perhaps only the defence of a nation is regarded as being more important. Just as humans must consume energy each day to live their lives, so must our modern high-tech society. Politicians know that if there is sustained failure in energy supply citizens may take to the streets. In 2008 this is illustrated by the constant power cuts in South Africa due to their failure to adequately plan to meet the demand for electricity as their economy expands. Since South Africa exports electricity to neighbouring countries this is also impacting on the Southern region of the African continent.

The management of energy generation is complex. Governments across the world seek to control the generation, import and supply of electricity to industry, business and consumers. The two main exceptions to national and semi-national monopolies are Britain and, to a lesser extent, the United States. This means that how energy is generated is to a large extent dependent on political considerations.

The cheapest, and most abundant, sources of fuel for generating electricity across the world are fossil fuels which are the largest source of greenhouse gas emissions; the burning of coal plus some oil and natural gas create 40% of all such emissions across the world.

Just under half of these emissions come from the fossil fuel generating plants in two countries – the United States and China. The extensive use of fossil fuels for electricity generation has released huge quantities of carbon dioxide and other greenhouse gases into the atmosphere over the last 100 years. The breakdown of fuel used for worldwide electricity generation is shown in fig. 3.1.

fig 3.1 Sources of fuel for worldwide electricity generation 2004



This shows that a third of worldwide electricity comes from sources that do not create greenhouse gases, except at their construction stage, with two thirds coming from fossil fuels. Worldwide these emissions come from a several thousand generating plants that are highly visible whilst other greenhouse gas emissions, other than water vapour and the occasional volcano, come from billions of small-scale local sources – cars, cows etc.

Over the last 10 years world demand for electricity has increased by 30%. This is due to the expanding population of the world and the expanding economies of the developing countries. The 20th century started with a world population of one billion people and closed with 6 billion with a further 4 billion estimated before the world population peaks towards the end of the 21st century. Currently, each person is using, on average, four times as much energy as the average person used 100 years ago.

Demand for energy across the world will probably double by 2030 and treble by 2040. The potential impact of greenhouse gases from electricity generation if fuel sources for it do not change is such that global warming could devastate the world as we know it today, and make it a very difficult place to inhabit in the 22nd century.

Clean energy that does not result in greenhouse gas emissions is abundant throughout the world in the form of energy released by the sun, the wind and waves, and nuclear power. Electricity can be generated in many ways that have near zero emissions. Until recently mankind had not realised the damage that greenhouse gases are doing to the world and politicians encouraged industry to take the easiest, the most convenient and the cheapest way to generate the electricity needed by society.

Most people in the world are now becoming concerned about climate change and the impact of global warming. Unexpectedly a recent survey showed that far more people in China are concerned about this issue than people in the United States. In developed economies the need for politicians to implement policies to combat climate change and global warming by reducing greenhouse gas emissions is rapidly climbing the political agenda. Politicians are aware of the need to change the fuel mix for electricity generation quickly, and action is being taken across the world to ensure that significant changes are made.

The range of current and imminent technologies for low-emission electricity generation is extensive. It is inevitable that a mix of existing and new technologies will progressively and substantially change how electricity is generated before 2050. Countries will use different technology mixes depending on their political considerations, their location in the world, their economic infrastructure and their available fuel reserves and resources.

The extent of the investment that will be needed to build new, emission free, power stations is very substantial. Government sources will only provide limited funding and therefore private sector companies will have to be stimulated to invest either by means of carbon trading schemes that transfer funds from those with high emissions to those with low emissions, by taxation of companies that have unacceptable emission levels or by subsidy.

It is instructive to review each of the existing and potential processes for generating electricity to understand the potential for changing the mix by increasing the contribution from renewable energy sources and by reducing emissions from using fossil fuels. It will take decades to progressively reduce and finally eliminate greenhouse gas emissions from energy generation.

Coal as an important, and continuing, source of fossil fuel

All the fossil fuels are used to generate electricity, but reserves of oil and gas are spread very unevenly across the planet and are beginning to show major problems of supply and price. This has given, and continues to give, the nations with the largest reserves of oil and gas great economic and political power. Coal, on the other hand, is widely distributed and abundant throughout the world. In consequence, has become the favourite fuel source for many governments, and is used to generate almost half the world's electricity. It is particularly the main source for today's leading developing countries with three quarter of China's and India's fast growing electricity needs being generated from coal.

The United States has not favoured coal for generating electricity in the last quarter of the 20th century, but coal is now poised to make a comeback since the prices of oil and gas have risen significantly as world supplies start to dwindle. The United States also wants to reduce dependence on energy imports. Approximately 100 coal-fired power plants were at the planning stage in the United States in 2007. Since world reserves of coal are many times higher than those of oil and gas, coal will remain a major source of fuel for electricity throughout the 21st century. Since coal is the most prolific source of greenhouse gas emissions the most immediate challenge is to deploy technology that will near eliminate carbon dioxide emissions from coal-fired electricity generation. What is this technology and is it available?

There are several ways of enhancing the performance of coal plants in a carbon-constrained world: higher efficiency in generation, mixed fuel intake, novel approaches to gasification, carbon capture and storage and other advances. These technologies are at various stages of development and use in 2008. The technology that is about to become an important commercial reality is carbon capture and storage, which has been developing for over 15 years. Europe, China and the United States are all producing demonstration plants to advance this technology.

Carbon capture and storage technology initially separates and captures the carbon dioxide that is produced in the generating process. The carbon dioxide is then transported by pipeline from a power plant either to deep saline aquifers, coal beds that cannot be mined, or depleted gas or oil reservoirs.

If carbon dioxide is stored in depleted oil fields there is an enhanced benefit in that up to 15% more oil can be recovered. Storing carbon dioxide in depleted oil reservoirs creates what is known as enhanced oil recovery, which has been used in the United States for several decades in the last half of the 20th century. With depleted gas and oil reserves in the North Sea the UK is well placed to use this technology. However, there are those who argue that the carbon dioxide stored in semi-depleted oil reservoirs will release oil that will produce 15 times more carbon dioxide when used as a fuel. For well-selected geological sites it is estimated that the carbon dioxide stored will remain sealed for over 500 years. Suitable storage sites are plentiful across the world.

Fully operative coal-fired plants fitted with carbon capture and storage technology are not, in 2008, a mainstream commercial reality although significant progress has been made. As a first stage some existing, and many newly built, coal-fired plants have been fitted with supercritical steam generators and more than 450 such plants are now operating in the US, Europe, Russia, Japan and China. These power plants have much higher efficiencies and improve on the one-third efficiency of sub critical plants. These new efficiencies save fuel and reduce emissions.

Many of these plants will be able to be fitted retrospectively with carbon capture and storage equipment in the future to enable emissions to be near zero. The UK and other countries are now requiring that new coal-fired power plants are built with supercritical technology and have the ability to upgrade to carbon capture and storage.

Existing and new coal-fired power stations that use supercritical technology will capture the carbon dioxide after combustion. There is, however, an alternative gasification technology, which captures the carbon dioxide from the chemical process before combustion, and has the advantage that it also generates hydrogen as a by-product which can be used as a transport fuel. Coal gasification converts coal to a gaseous fuel through partial oxidation, being fed into a high-temperature pressurized container along with steam and a limited amount of oxygen to produce a gas. The gas, known as syngas, mainly consists of carbon monoxide and hydrogen. The gas is cooled and undesirable components, such as carbon dioxide and sulphur, are removed. Syngas can then be used as a fuel or further processed and concentrated into a chemical or liquid fuel.

An integrated gasification combined-cycle system then combines the coal gasification process with a gas fired combined cycle power generation process. This second stage takes the cleaned gas and burns it in a conventional gas turbine to produce electrical energy. The hot exhaust gas is recovered and used to create steam for a turbine which also produces electrical energy. In typical plants, about two thirds of the electrical energy is produced by the gas turbine and one third by the steam turbine. None of the basic technologies used – coal gasification, gas turbines, and steam turbines – are new. At the start of the 21st century there were about 10 integrated gasification combined-cycle power plants operating in the world but none were fitted with carbon capture and storage.

In 2008 the most pressing technological need is for carbon capture and storage to become a mainstream commercial reality. The European Commission and a number of Governments have recognised the need for carbon capture and storage demonstration plants as soon as possible. The GreenGen project in Beijing, China is creating a 250MW integrated gasification combined-cycle plant with carbon capture and storage using a depleted oil well. It will be operational by 2010 and will be upgraded to a 650MW plant.

Although the United States has been leading the development of this technology, government funding for the development of demonstration plants using carbon capture and storage is currently restricted. A change of President in late 2008 is expected to open the way for renewed government funding. A demonstration carbon capture and storage plant in the UK will be on stream by 2014 and 12 such plants are the current objective of the European Commission by 2015.

Carbon capture and storage technology will be fully demonstrated in various parts of the world by 2015 and is expected to be used to progressively replace 'dirty' coal-fired power stations over the following decades.

Gas – an alternative fossil fuel source

Natural Gas is the cleanest of fossil fuels since it only produces approximately two thirds of the volume of greenhouse gases produced by coal. It is also a more efficient source of fuel with a quarter of world electricity being generated using natural gas.

In the first decade of the 21st century some electricity generators, particularly in the United States, are switching from coal fired to gas fired plants to reduce emissions and take advantage of lower capital investment costs. But, as previously mentioned, natural gas reserves are located in parts of the world that are politically sensitive, for example Russia and the Middle East. A few pipeline networks transport natural gas across continents to many counties, particularly in Europe, but there is concern that these pipelines are particularly vulnerable to terrorist attack in the modern world of the early 21st century. Increasingly natural gas is being transported in liquefied form by sea in tankers to overcome the supply continuity risks.

Provided that the political situation remains stable and pipeline supply is not disrupted, the proportion of electricity generated from this fuel source is expected to remain constant until 2025, although worldwide natural gas reserves will become increasingly scarce and prices will rise. As countries seek to ensure security of energy supply and with increased investment in clean coal power stations, nuclear power stations and renewable energy sources, it is likely that the proportion of electricity generated from natural gas will reduce significantly by 2050.

It is possible to apply carbon capture and storage technology to natural gas power generation and this may be encouraged by governments through carbon emission trading schemes. Since natural gas is considerably cleaner that coal, environmentally, carbon capture and storage will only be adopted by generators using gas if the financial incentives provided through carbon trading mechanisms offer adequate returns. It is likely that gas-fired power stations will remain in use in the countries with large indigenous supplies.

Oil – the least used fossil fuel source

Oil is predominantly refined to provide fuel for transport and chemicals for plastics manufacture. Where oil is used as a fuel for electricity generation it produces about three quarters of the greenhouse gas emissions when compared to coal. Four factors - the continued high price of oil, the locations of the main reserves of oil in the world, the need to continue to fuel transport in the medium term and the increasing need for plastics - are steadily eliminating oil as a fuel source for electricity generation although some oil-fired power stations may remain in use in the countries with large indigenous supplies.

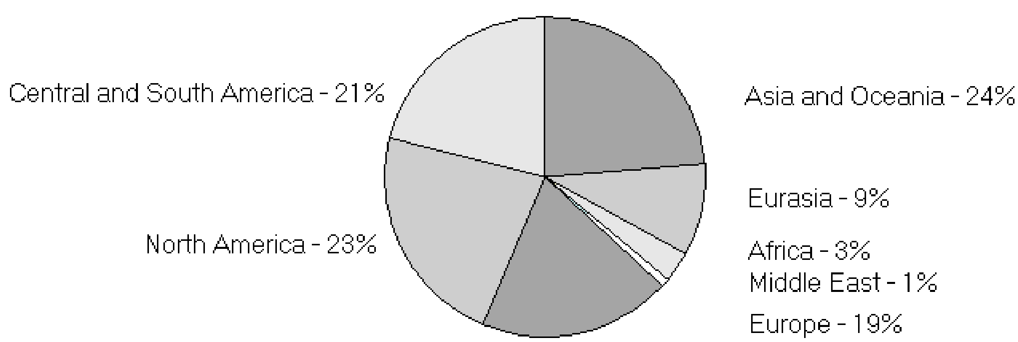
Hydro-electric power – the oldest renewable energy source

Hydro-electric power is the most long-established renewable energy technology. The first water wheels - used for irrigation - were developed in the Far-East over two thousand years ago and in Roman times waterwheels were applied to milling (hence watermills) and by the time of the Industrial Revolution in the 18th Century waterwheels were used extensively to work the bellows in foundries and hammers in forges, and drive the machinery of factories.

Towards the middle of the 19th Century the first water turbines were developed. The turbine was distinct from the water wheel in that it was smaller, more compact, more efficient, and ran at a higher speed. The latter qualities made the water turbine particularly suited to use for electricity generation.

In 2005, 20% of world electricity generation used water power as its fuel source. Figure 2 shows that the world-wide location of this form of generation is evenly balanced across continents with mountainous regions.

fig 3.2 – World-wide locations of hydro power for electricity generation 2005



Many of the best locations for using hydro power have seen dams constructed during the 20th century and the availability of new locations is limited. Some new dams will be built in the 21st century but as past investment in dams for hydro generation has caused displacement of populations this will be an increasing problem. This is currently a major issue in China where the building of a dam across the Yangtze river is displacing 3 million people.

Initially, generating electricity from hydro power would appear to be completely free of greenhouse gas emissions. This is true where generation is from fast flowing river locations, but where there is an extensive build up of water behind a dam methane builds up at the bottom of the reservoir created by the dam and, when the water is used to drive turbines to produce electricity, this methane is released into the atmosphere. This is a greenhouse gas that is 21 times more powerful than carbon dioxide. Although technology exists to capture this methane from the bottom of dam basins and use it for power generation it has not been economic to apply this technology. Blocking a river also stops the movement of fish to spawn upstream and slows the formation and distribution of silt downstream to fertilize fields.

To counter these problems scientists have been seeking to develop freestanding turbines that can be placed underwater to generate electricity. For several decades prototype turbines have proved relatively inefficient and difficult to reach for maintenance, a major issue given the high level of wear and tear. New designs now use computers to align turbines with the water flow so that that 35% of the energy is extracted and enable the electric generator to be located above the surface.

Several designs have been developed and are now being deployed, commercially. Investment in freestanding turbines has increased from $13m in 2004 to $156m in 2007 with a wide variety of projects. Proponents of the technology believe this is the beginning of a new industry which may make a significant impact on the generation of electricity from renewable sources.

Large scale centralised generation of electricity from existing and new hydro plants will remain throughout the 21st century together with some generation from new technology sources, but the proportion of electricity generated from hydro overall may decrease.

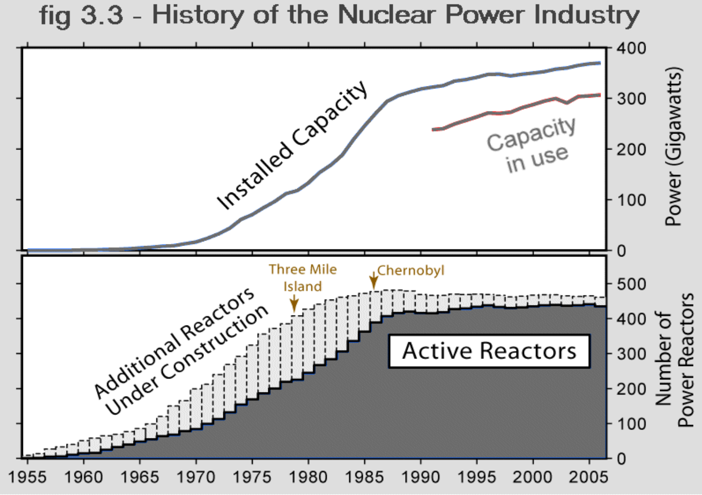
There is, however, significant renewed interest in micro hydro generation at the local level. Electrical power generation in developed nations from water mills waned as electricity from the grid became abundant, but the current drive to use electricity from renewable sources has revitalised this form of generation. In remote, mountainous regions across the world micro hydro generation is now well developed. It is being actively encouraged in some developed nations.

Nuclear power generation – a controversial source of energy

Nuclear power was generated for the first time at an experimental plant in Idaho in 1951. The first commercial generating plants became operational in 1956. In the 1950s there was considerable international discussion about this technology and the International Atomic Energy Agency was formed in 1957. Installed nuclear capacity rose quickly through the 1960s, '70s and '80s but then stabilised.

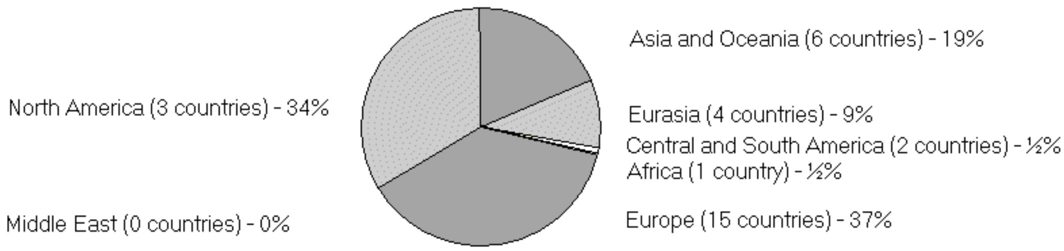
The reason for reduced investment was that generating electricity from nuclear sources became divisive both with politicians and with environmentalists. Whilst it is true that nuclear power generation is free of carbon emissions there are other impacts on the environment. The main problem, which is yet to be solved satisfactorily, is finding safe ways to dispose of nuclear waste. In addition there is the risk of catastrophic accident; two occurred in the 20th century – one at Three Mile Island in the United States and the other at Chernobyl in Russia. It is also considered that the costs of nuclear power generation over the lifetime of a plant could be significantly higher than those of a fossil fuel power station.

fig 3.3 - History of the Nuclear Power Industry



In 2007 nuclear power provided 10% of worldwide electricity from approximately 440 reactors in the world in 31 countries. The United States has the highest capacity producing just less than one quarter of its electricity from this source. France is the highest proportionate user with 80% of its electricity coming from nuclear. A number of countries, notably Ireland, Poland, New Zealand, Austria, Sweden and Italy, have passed referendums to oppose or phase out nuclear power.

fig 3.4 - World-wide nuclear power electricity generation - 2004



Since the reduction of greenhouse gas emissions has become an issue of major international importance many countries are reviewing their policies on nuclear power generation. As the world starts to set targets for emission reductions, some countries see nuclear power as a means to meet their expanding energy requirements whilst reducing emissions by closing end-of-life fossil fuel powered plants.

Although the rate of expansion of nuclear power across the world stagnated towards the end of the 20th century, management in the nuclear industry believed that nuclear power would remain a major source of electricity generation in the future. They ensured that nuclear technology was refined and developed. Nuclear power stations that are being built in 2008 use several more advanced technologies - they are larger in size, more efficient, have better design in terms of safety features and can be built more quickly. New plants have less than half the number of components and are being constructed to time in 36 months.

These improvements have reduced operating costs and give higher plant reliability. Most importantly the amount of waste from the generation process has been reduced by about 90%. At the end of 2007 there were about 30 new nuclear plants under construction, 65 plants planned and 160 plants proposed. Although some older plants may be de-commissioned this will increase the electricity generated from nuclear power by 40% by 2017. Significant further increases are likely and the proportion of electricity generated from nuclear power is likely to double by 2025. China is leading this expansion with generation from nuclear power planned to increase from the current 4GW to over 100GW by 2020, which represents 10% of China's generating capacity. This could increase to 30% by 2050.

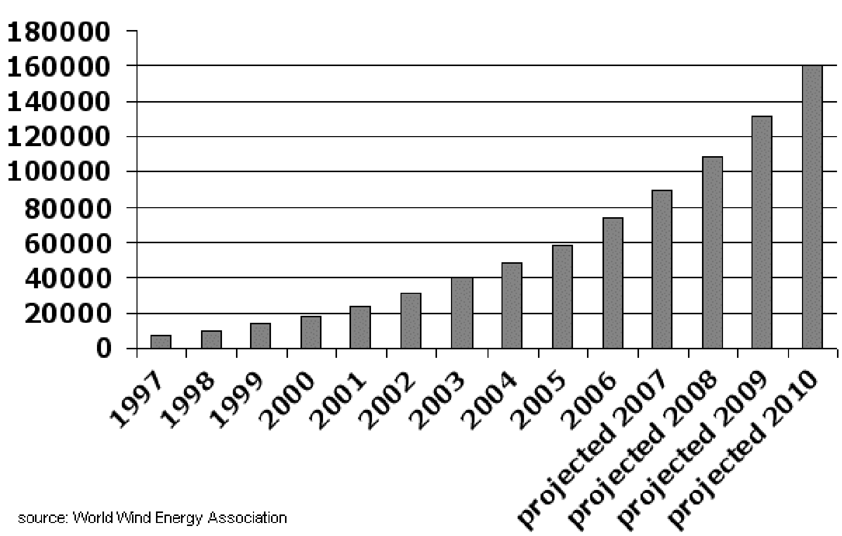
Uranium, the fuel source for nuclear reactors, is mainly produced in Canada and Australia. Estimates of world-wide uranium reserves indicate that these will be adequate to meet demand from increased generating capacity during the 21st century and this will be helped by continuing development of nuclear technology to further increase fuel efficiency.

A possible development in nuclear technology is that scientists at Sellafield, in the United Kingdom, demonstrated in 2007 that it is possible to turn high-level existing nuclear waste into a second-generation nuclear fuel. Recycling nuclear waste would clearly be much better than trying to bury it, since the latter is causing so much concern and expense. The development of this technology, however, requires funding from the United Kingdom Government.

Wind - a renewable source of energy with extensive potential

Windmills have been used to crush grain or to pump water for centuries but it is only recently that the need to generate electricity from renewable energy sources has sparked a new world-wide industry. At the end of 2006, worldwide capacity of wind-powered generators was 73.9 gigawatts. Although wind currently produces just over 2% of world-wide electricity, it accounted, according to 2007 data, for approximately 19% of electricity production in Denmark, 9% in Spain and Portugal, and 6% in Germany and the Republic of Ireland. Globally, wind power generation more than quadrupled between 2000 and 2006.

fig 3.5 - World Wind Energy - Total installed capacity (MW) and projection 1997 - 2010



source: World Wind Energy Association

Wind power for central generation is produced in wind farms which comprise a number of large, wind facing, turbine generators connected to electrical grids. In addition, individual turbines of various sizes are used to generate electricity for dwellings, farms or commercial use, particularly in isolated locations. Wind energy is plentiful, renewable, widely available in many parts of the world, and is free of greenhouse gas emissions. Wind farms can be located both onshore or, increasingly, offshore in shallow water. However, the intermittency of wind presents challenges and these are exacerbated when wind power is to be used to meet demand which is in excess of 10% of total electrical demand.

The intermittent nature of wind generation has caused problems in connection to a grid which are progressively being solved. In some countries people are delaying, or even rejecting, planning applications for wind farms since many people believe they spoil the environment. Also many potential sites for wind farms are far from demand centres, requiring high investment in the construction of new transmission lines and substations. Since the primary cost of producing wind energy is construction and there are no fuel costs, the prospective cost of wind energy is primarily dependent on the initial capital cost, including grid connection, and the lifespan of the turbines .

The commercial viability of wind power often depends on the pricing regime for power producers. Electricity prices are highly regulated worldwide, and in many countries may not reflect the full cost of production or various forms of subsidy. Producers may enter into long-term pricing contracts for wind to reduce the risk of future pricing changes, thereby ensuring more stable returns for projects at the development stage. Although the costs of wind generated power are reducing, the comparative cost is still above the generating cost using conventional coal, gas, or even nuclear fuel.

The potential for generating electricity using wind world-wide exceeds projected world-wide demand for electricity. Practical exploitation, however, depends upon economic factors and the impact of intermittent generation. Consequently many countries in the world are targetting that only 15 – 20% of their electricity will come from wind as a renewable energy source, excluding nuclear, by 2020. This drive to use renewable energy is being led by countries within the European Commission, the United States and Canada, and China, India and Japan.

Wave and Tidal Power – an emerging source of renewable energy

Wave power comes from the capture of the energy of ocean surface waves to generate electricity. Prior to 2007 there had been little interest in this as a source of electricity generation. The embryo technology is not yet widely employed and no commercial wave farm has been established. During 2007 companies in the United States and the United Kingdom announced plans to develop demonstration wave farms using different types of wave power plant and this is a technology that may well emerge over the next decade.

Tidal power, which exploits the movement of water caused by tidal currents or the rise and fall in sea levels due to the tides, also has the potential for future electricity generation. It is more predictable than wind energy. In Europe, mills driven by the tide have been used for over a thousand years, mainly for grinding grain.

This is the only form of energy whose source is the moon. Some other energy sources, nuclear power and geothermal, for instance, have the Earth as their source. The remainder, fossil fuels, wind, biofuels, solar, hydro etc. have the Sun as their source, either directly or indirectly.

Tidal power is generated by the gravitational pull of the Moon, and to some extent the Sun, on water. Due to these gravitational forces, water levels follow periodic highs and lows. The height of the tide produced at a given location is the result of the changing positions of the Moon and Sun relative to the Earth coupled with the effects of Earth rotation and the local shape of the sea floor. The greater the height of the tide the more promising it is to harness tidal energy.

Tidal power can be either a tidal stream systems that make use of the energy from the moving water currents to power turbines, in a similar way to wind turbines. This method is gaining in popularity because of the lower cost and lower ecological impact.

Alternativvely barrages that make use of the potential energy from the difference in height between high and low tides. Barrages are usually considered for large estuaries but they have problems of very high construction costs, few viable sites globally and environmental issues.

Modern advances in turbine technology may eventually see significant amounts of power generated from the ocean, especially from tidal currents using the tidal stream designs. There are a number of high velocity areas where natural flows become concentrated, such as the west coast of Canada, the Strait of Gibraltar, the Bosporus, the Severn estuary in England and sites in south east Asia and Australia. Such flows occur almost anywhere where there are entrances to bays and rivers, or between land masses where water currents are concentrated.

A number of tidal power protoypes have been built and more are under construction in 2008. A barrage across the River Severn estuary, the Bristol Channel, in England is being reviewed by the United Kingdom Government. If built it would provide 5% of the electricity required by the United Kingdom, but the estimated cost of £23billion is three times the cost of coal fired power stations fitted with carbon capture and storage. However the Severn Barrage, if built would have a life of well over 100 years or three times the normal lifespan of a coal fired plant.

Given the interest in using renewable energy sources it is probable that wave and tidal power will become part of the energy mix from renewables in the future, but these sources are unlikely to play a major role.

Solar Energy – a renewable source of energy with huge potential

Solar energy is the energy that comes directly from the Sun. This energy drives the climate and weather and supports virtually all life on Earth. Over hundreds of millions of years it has nurtured vegetation on Earth which through the ages has created the fossil fuels that man has ravaged extensively in the last 200 years. Heat and light from the sun, along with solar-based resources such as wind and wave power, hydroelectricity and biomass, provide most of the available sources of renewable energy. The energy currently used to service the needs of man is only a minute proportion of the energy that is absorbed by the Earth each day from the sun.

Using the sun as a source of energy dates from the time of the early Greeks, native Americans and the Chinese, who warmed their buildings by orienting them toward the sun.

Solar power more specifically refers to the conversion of sunlight into electricity. This can be done either through the photovoltaic effect or by heating a transfer fluid to produce steam to run a generator.

In 2007 solar photovoltaics, often called solar cells, only provided 0.04% of the world's energy. Photovoltaic technology has advanced steadily since it was discovered for commercial use by Bell Laboratories in 1954 and is now at a critical stage of development since the expensive crystalline cell structures that have been used as solar panels for energy generation on buildings are about to be replaced by a variety of thin film panels. These thin film panels are moving towards offering increased efficiency, the ability to work in daylight as well as sunlight and much lower cost. The solar panel technology that will emerge in the 2008 to 2010 period will start to revolutionize this area of electricity generation.

Domestic houses and commercial premises across the world consume about half of the electricity generated. Due to convenience and cost a very high proportion of this electricity is provided by connection to electricity grids that draw their power from central power stations. It is probable that the emerging low cost of the new generation of solar panels will make the cost of electricity using local microgeneration very competitive with electricity provided from the grid. Many governments may follow the example of Germany and provide incentives to invest in microgeneration to help meet emission targets.

Both investment incentives and market forces will progressively drive investment in microgeneration solar power for for domestic houses and commercial premises. A large switch to de-centralised power generation will reduce the need for new central electricity plants and the need to increase transmission grids. The overall profile of electricity generation in 2050 could be significantly different.

In addition to photovoltaic microgeneration there have been a variety of power plants constructed to harness and concentrate the sun’s rays using mirror arrangements. Power plants in the United States and Spain demonstrate the use of this technology and consideration is being given building further plants in desert locations. Currently central electricity generation from large complexes of mirrors or other solar reception devices is not forecast to be a major area of development in coming years.

Geothermal Power – an under-used source of renewable energy

Geothermal power is the energy that can be generated by the heat stored beneath the Earth's surface or from the heat absorbed in the atmosphere and oceans. The first geothermal generator was developed in 1904 at the Larderello dry steam field in Italy. The largest group of geothermal power plants in the world are located in a geothermal field in California and quite a number of countries use this form of energy for electricity generation, although most geothermal power is used only for heating.

Geothermal energy offers a number of advantages over traditional fossil fuel based sources. From an environmental standpoint, the energy harnessed is clean and safe for the surrounding environment. In addition, geothermal power plants are unaffected by changing weather conditions. Geothermal power plants work continually, day and night, making them suitable as base load power plants.

From an economic view, geothermal energy can be extremely price competitive. Given excess capacity, geothermal energy can also be sold to neighboring countries. Iceland, for example, exports geothermal energy to Norway and is considering export to the United Kingdom. It also offers a degree of scalability in that entire cities can be powered by a large geothermal plant while more remote sites such as rural villages can be supplied by smaller power plants.

With increasing interest in renewable energy sources those countries having geothermal generation potential are reseaching possibilities. The United States, China and Australia have all got significant potential. If you dig deep geothermal energy is everywhere since the temperature increases by 25^0C to 30^0C for every kilometre you go down. This has stimulated The National Research Centre for Geosciences at Potsdam to drill two 4.4km holes at 400 meters apart. In one hole cold water is introduced under high pressure to secure steam at ground level from the other hole to drive turbines to generate electricity. It is estimated that there would be enough energy from the two holes to power a generating plant for 30 years. Since you can drill as many holes as you like, this source of potential power to generate electricity is virtually inexhaustible. As of 2007, geothermal power supplied less than 1% of the world's energy but this source of renewable energy, which is attracting venture capital, is likely to increase.

Fusion power – a longer term potential source of energy

Fusion, which is said to be the holy grail of electricity generation, may be within reach before 2050 and may be the energy source that eventually provides limitless, safe energy. Fusion is the way that the sun and other stars create energy. Stars are huge fusion reactors, squeezing and heating light atoms like hydrogen, to produce heavier atoms like helium. Earth-bound fusion plants will imitate the Sun with atomic nuclei being driven into each other to fuse and release energy that can be used for a variety of applications, including the generation of electricity. Scientific progress in fusion research indicates that this new and potentially abundant energy source could become commercial in the 21st Century.

There has been large scale international collaboration to fund scientists and plant to refine fusion technology for 50 years. The main project is focused on the International Thermonuclear Experimental Reactor (ITER) where the final stage is to produce a nuclear fusion reactor. The partners in this project are The European Union, the United States, Russia, Japan, South Korea and China who agreed, in 2005, to locate this final stage at the Cadarache site in southern France.

In terms of the physics and the huge amounts of energy involved, the ITER project is akin to building a star on Earth. It will be the first fusion device to produce thermal energy at the level of conventional electricity-producing power stations, and will pave the way for the first prototype commercial power station. Making fusion a viable energy source for mankind is seen as a major scientific and technological challenge. The ITER project is the final step in making energy from fusion a reality and a commercial possibility.

Scientists at The United Kingdom Atomic Energy Authority (UKAEA) are making smaller versions of the same equipment which they believe may be technically easier, cheaper and swifter to develop. Their equipment is a leaner version of a prototype fusion reactor that has already solved many technical problems.

Those developing this technology recognise that there are still many difficulties to overcome but they believe that in a few decades commercial fusion reactors that provide cheap pollution-free electricity will be a reality.

An estimate of how electricity generation will be changed to eliminate greenhouse gas emissions

It is inevitable that politicians across the world will decide to take action in the early part of the 21st century to ensure that electricity is progressively generated with zero, or near zero, greenhouse gas emissions and that adequate 'clean' energy is available to meet continued worldwide economic development. The availability of current and near future generation technologies will ensure that change takes place to progressively eliminate greenhouse gas emissions.

Generation of electricity from renewable sources such as solar, wind, tides, waves and geothermal will increase significantly and microgeneration, which will be based on solar power, but supported by other forms of renewable energy, will become the cheapest form of energy for heating domestic homes and commercial premises. Microgeneration will significantly reduce demand on electricity supply from grids and will become a major source of future electricity generation. In developing countries where electricity grid systems are not in place microgeneration, mainly solar power, will be a major factor in developing the economies and lifestyles of people in these countries

Generation from nuclear power stations will increase significantly in the period to 2030 to accelerate the reduction in greenhouse gases in the short term. This form of generation may stabilise and start to reduce for political reasons, and availability of uranium thereafter. Fusion reactors in the second half of the 21st century may progressively replace nuclear power plants.

Fossil-fuelled power plants with high greenhouse gas emissions will be progressively replaced with plants with 'clean' technology. Coal will remain a major fuel source for much of the century and as oil and gas become increasingly scarce and expensive their use for generating electricity will decrease.

Hydro power will increase gradually as the limited number of remaining locations are brought into use and new technologies are developed, although its percentage contribution will slowly fall.

Change will not occur, however, without stimulus. The main driver of change in central generating plants will be effective use of emission trading schemes by governments to create the market forces that will encourage private sector companies to replace generating plants that emit greenhouse gases. Governments will also use incentives to encourage industry to invest in electricity generating plants that use renewable sources of energy.

Governments will also provide incentives to encourage their people to invest in microgeneration plant for domestic and commercial premises. World Bank funding for developing countries will be maintained to support investment in hydro generation and generation from renewable sources.

With the knowledge of past trends in electricity generation and an understanding of what is likely to happen across the world due to technological change in the future, it possible to make an estimate of how electricity generation will change over the next 40 years to 2050. It is also possible to forecast the likely change in greenhouse gas emissions.

The key factor in these estimates is to estimate the average annual increase in electricity demand through to 2050. Looking back, installed worldwide electricity generating capacity increased on average by just over 3% per annum for the 25 year period 1980 to 2005.

There is extensive potential to make the use of electricity more efficient, and the increasing cost of electricity and the many energy saving initiatives being implemented by industry, commerce, governments and consumers will combine to reduce demand for electricity in developed nations. The continued rapid increase in the economies of developing nations and the increased use of electricity in transport will, however, act as a counter-balance. It is, therefore, prudent to forecast that demand for electricity will continue to increase, on average, at 3% per annum for the 40 years to 2050.

Against this forecast for demand and the most likely use of technology, the projection of installed worldwide electricity generating capacity by type of installation is shown at figure 3.6. Carbon capture and storage is assumed to capture 95% of greenhouse gas emissions from fossil fuel power plants.

fig 3.6: Estimate of Worldwide Installed Electricity Generating Capacity by type of Installation 2004 - 2050

Type of Generating Capacity	Installed Generating Capacity (Million Megawatts)				% Share Installed Generating Capacity			
	2004	**2020**	**2030**	**2050**	**2004**	**2020**	**2030**	**2050**
Total capacity (3% p.a. increase)	**3872**	**6213**	**8350**	**15082**				
Period Increase		**+60%**	**+34%**	**+81%**				
Fossil Fuels	2652	2810	1749	409	68%	45%	21%	3%
Fossil Fuels (CCS)		400	902	3298		6%	11%	22%
Large Hydro	762	967	1042	1272	20%	16%	12%	8%
Nuclear	374	700	1037	1699	10%	11%	12%	11%
Large Renewables	84	1036	2607	5713	2%	17%	31%	38%
Microgeneration		300	1014	2691		5%	12%	18%
% emitting Greenhouse Gases and reduction from 2004	68.5	45.5 **+7%**	21.5 **-32%**	3.8 **-78%**				

This projection from 2004 through to 2050 shows that whilst electricity generation from renewable sources, including microgeneration, will increase substantially over the period the installed capacity of fossil fuel plants will remain an important part of the mix with carbon capture and storage taking an increasing role after 2020. Although the proportion of generation from nuclear power plants is estimated to remain constant the number of plants will increase fivefold.

These projections also show that the continued appetite for electricity worldwide will outstrip international efforts to reduce greenhouse gases from electricity generation until after 2022. Thereafter continued high investment in renewable energy sources, including microgeneration, nuclear power plants and ‘clean coal’ plants will enable emissions to fall until they are at least 78% below 2004 levels in 2050. The percentage of plants emitting greenhouse gases in 2050 could be as low as about 4%.

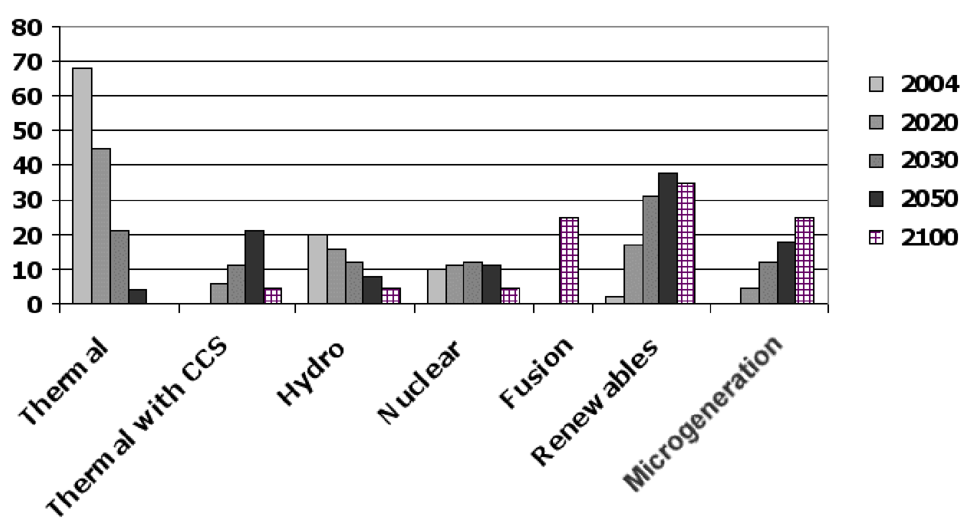
It should be emphasised that this will only occur if the nations of the world unite in the near future to stimulate progressive investment in 'clean coal' carbon capture and storage power stations through effective worldwide emission trading schemes. This will also help ensure continued investment in other emission free generation plants. It is also dependent on the anticipated low cost of solar panels driving the formation of a major new worldwide industry in solar panel microgeneration for domestic homes and commercial premises. This new industry could quickly become as large as the vehicle manufacturing industries.

The changing mix of electricity generation during the 21st century

In 2004 greenhouse gas emissions from fossil fuels from energy generation are 40% of total world emissions, with traditional fossil fuel power stations still being built to meet ever-increasing world demand for electricity. If the global warming problem is to be overcome it is imperative that the technologies that are now available for clean electricity generation are put to use quickly; this source of greenhouse gases offers by far the best opportunity for substantial short/medium-term reductions.

The share percentage for the mix of fuel changing from 2004 to 2050 is shown in the figure 3.6. Building on these estimates figure 3.7 shows how the technology mix for generating electricity will probably change over the rest of the 21st century. If the nations of the world work together it should be possible to nearly eliminate greenhouse gas emissions by 2050 and secure nearly complete elimination by the end of the 21st century.

fig 3.7 - % Share of World Electricity Generating Capacity 2004 - 2100



It is difficult to project exactly how the mix of electricity generation will change from 2050 to 2100 not least because there will probably be advances in technology, or market forces, that are totally unforeseen. The massive impact of computer networking was not predicted in 1960.

The change in technology to generate electricity will be dramatic in the first half of the 21st century. The second half of the 21st century may be more progressive and not see the same extent of change although fusion reactors may become a commercial reality. If fusion reactors are competitive in commercial terms they may progressively eliminate electricity generation from fossil fuels and nuclear power.

The 20th century has seen mankind use ever-increasing amounts of electrical power to support the advanced technologies that have been developed to support many aspects of human life. Unfortunately the majority of the fuel used to generate this power has created, and continues to create, huge quantities of greenhouse gases that threaten to cause the temperature of the world to increase to levels that could make parts of the world uninhabitable.

In 2008 the generation of electricity, worldwide, is responsible for 40% of these greenhouse gases through the use of fossil fuels. The technology already exists to enable the nations of the world to unite to generate electricity in ways that do not produce greenhouse gases and it is hoped that this will become an international reality.

Although worldwide demand will increase electricity generation year on year by 3% it should be possible by investment in alternative technology to near eliminate greenhouse gas emissions from electricity generation by 2050 and totally eliminate them by 2100. This is the major, and most important, component in stabilising and reducing the level of worldwide greenhouse gas emissions and keeping cool.

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The intention of this article is to advance knowledge and understanding of some issues associated with climate change. The views expressed are those of the author and do not, necessarily, represent the views of the Comino Foundation.