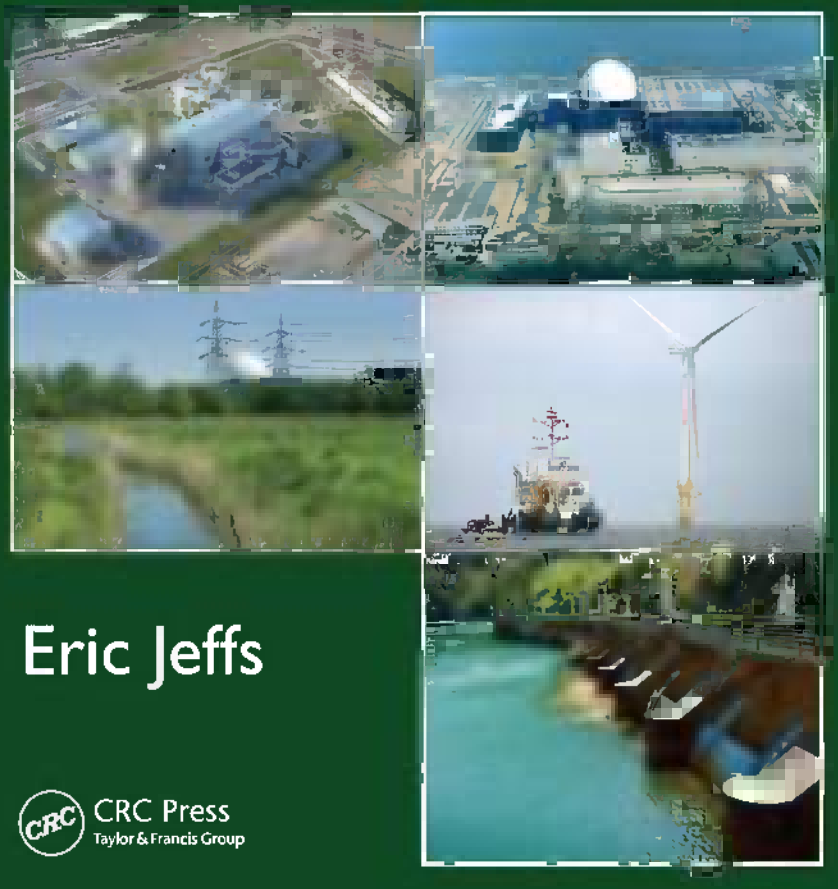
GREEN ENERGY

Sustainable Electricity Supply with Low Environmental Impact



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Dick Foster Pegg was born in the United Kingdom and served an apprenticeship at Rolls-Royce at the time of their early gas turbine models, before emigrating to the United States where he worked for Bechtel Corporation on power plant design, including some of the early combined cycle projects there. Later he joined Westinghouse to work on gas turbine reseach and development in Pennsylvania.

Louis Codogno was Managing Director of the Energy Division of Cockerill Mechanical Industries until his retirement in 2005. I thank him in particular for not only arranging site visits but also introducing me to many of his clients which gave me an insight into the energy policies of those countries, notably in the Middle and Far East.

Dr Maher Elmasri, was Professor of Mechanical Engineering at Massachusetts Institute of Technology until 1987, when he left to start his own company, Thermoflow Inc. It is now the leading company supplying a powerful suite of software for the design of combined cycle, and steam plants of different types including integrated gasifier combined cycles.

1
Introduction

For all but the last 250 years mankind has depended mainly on natural sources of energy. Today that would mean the sun, wind, water and biomass (fire). Where oil and coal had been found near the surface they had also been used but only as a basic source of heat, and there were fewer than 500 million people on the Earth.

The industrial revolution was founded on coal and coincided with advances in agriculture and medicine which, in little more than a century, transformed the way of life of the people of Europe and North America.

Before 1800, ships were built of wood and propelled by sails, wind and water mills ground corn and transport on land was on horseback, or in a horse-drawn carriage. As soon as coal was recognized as a fuel to generate steam the inventions followed that made it the fuel for transport and for powering industry.

At the beginning of the twentieth century, the basic elements of contemporary infrastructure were already in place. The first telephones were in use, coal-derived town gas was piped to homes, and electricity for lighting and urban transport was starting to appear on the scene in the major cities. The railway networks had been established; Charles Parsons had built the first steam turbine, which he demonstrated as the engine of a ship. Marconi had transmitted the first radio signal across the Atlantic. The first cars were on the roads. In Germany Rudolf Diesel had developed the engine which bears his name. The first powered flight was in December 1903.

The twentieth century will surely be remembered as the time when energy transformed human effort and understanding of the world as at no other time in history. But it has also been a century of war with two World Wars and several large regional conflicts. These accelerated technical developments and carried energy demand to higher levels so that in the years that followed the entire population of the developed

world could have secure access to heat, light and power, and in a growing number of new applications. All of these applications depended on there being a secure supply of electricity both to produce the equipment and to operate it.

In fact the whole period since the end of the war in 1945 has been one of considerable innovation. The first transistors were produced at the Bell Telephone Laboratories in the United States in 1948, just as the first computers were starting to appear in industry. From this beginning were developed the microcircuits which are the basis of modern computer systems and process controls. It was not until 1980 that the personal computer started to appear and computing power spread into the home.

Developments in aviation, particularly the wide-bodied aircraft with large turbofan engines encouraged tourism which saw the development of hotels and various places of entertainment around the world, which all added to the demand for electricity.

Larger and more efficient power plants were built to supply the increasing electricity demand at a rate which meant that it doubled in eight years. During that time the development of power generation sought to improve the efficiency of the process and raise the transmission voltage.

There was concern over pollution from coal-fired plants which led to the introduction of electrostatic precipitators to collect dust carried over in the flue gases. The height of the stacks, up to 200 metres on the largest stations, would ensure dispersal of the flue gases on the prevailing wind.

Nuclear power had started within this general development of electricity generation that was in progress up to 1970. The first nuclear power station is generally considered to be Calder Hall in northwest England, which was officially opened by HM Queen Elizabeth II in October 1957 and was closed down after 45 years of operation, in 2002. The first Pressurized Water Reactor (PWR) followed at Shippingport, PA, at the end of that year. The 68 MW unit ran for 25 years and was shut down at the end of 1982.

The twentieth century was also a time of social change and not just in greater sexual freedom, but in the questioning of the direction in which society was moving. If there is one event which started the Green movement, it was surely at Christmas 1968, with a dramatically emotional broadcast from the three-man crew of the Apollo 8 spacecraft who were then the first people to be orbiting the Moon. They chose to read the opening verses of Genesis, the first book of the Bible, to underline what they were seeing: the planet Earth, a blue and white ball

up in the lunar sky, which was the home of all mankind, and the only one that we had.

This broadcast set people talking about the environment and what effect their activities might have on the world. It was first realized that growth in demand for energy, if dependent on finite deposits of fossil fuels, could not continue indefinitely. It was then not long before new infrastructure developments such as a power station, motorway, or a large industrial site had to present an environmental impact statement as an integral part of the planning process. This would look at the use of the land, what effect it would have on the surrounding communities, and whether it threatened a wildlife habitat; did it impinge on an area of outstanding natural beauty, what sort of wastes did it produce, and how would it dispose of them.

Five years later, in the autumn of 1973 war broke out in the Middle East between Israel and its Arab neighbors, Egypt and Syria, who sought to recover land taken from them in 1967. At the same time the Organization of Petroleum Exporting Countries imposed a four-fold increase on the price of a barrel of oil.

At the time there were a large number of oil-fired power plants in Europe and much of the rest of the world which had suddenly become very expensive to operate. But since most of the oil used in Europe, and increasingly in North America, came from the Middle East, something had to be done. The other big market, transport, was also paying more for its fuel, and this was an easier target for governments to address. Speed limits were introduced and various other short-term measures to limit car use and supposedly to cut oil imports.

The crisis had three long-term effects. First there was a concerted effort to find new fuel resources outside the orbit of OPEC. Immediately this meant development of the oil and gas fields, in the North Sea and Alaska, while elsewhere gas fields were being discovered and developed in the Indian Ocean off Mumbai, in the Gulf of Thailand, in South America, in and around Australia, and in the northern North Sea off Norway. Gas was coming into Europe from North Africa and Siberia, but as natural gas entered the market it first replaced coal gas in the domestic market. In Europe at least, natural gas did not become a mainstream fuel for power generation until about 1990.

Second, a large nuclear power programme had, by the end of the century, installed some 450 units around the world. Some of the earliest nuclear plants have now been closed, but there are still 439 in operation and 35 under construction, including three in Europe and one in the United States.

Work on the development of more efficient energy systems led to the introduction of larger coal-fired power plants with supercritical steam conditions and compulsory environmental additions of Flue Gas Desulphurization (FGD), and more efficient burners to further reduce emissions. Larger gas turbines running at synchronous speed led the development of the gas-fired combined cycle to the point where, since 1990, over much of the world, it has become the preferred choice of power plant for system expansion.

Third was the arrival on the scene of a global protest movement which began to attract public attention. The Green argument was that governments had got us into this mess in 1973, and we couldn't trust them to find the answers.

The first nuclear power plants had come into service and were seen to be reliable in operation and with low fuel costs. Furthermore the uranium fuel came from politically friendly countries, mainly Australia, Canada, and the United States. By 1973 there were forty seven nuclear power reactors in operation in Europe, twenty eight in the United States, five in Canada and five in Japan. But a look at the records of nuclear power in these areas shows that governments had already made plans for more nuclear stations, and a large number went into operation up to 1990. Construction of some of these, having started before 1973, it cannot be considered to be a reaction to the oil crisis as such.

Although the Green movements came to the fore in the early 1970's they were first interested in the influence of energy technology on people and the environment. Los Angeles was known around the world as a city totally dependent on cars, and with an almost permanent smog in the daytime. But it was not the only city so afflicted: flying around the United States at the time, as the aircraft descended there would come a point where it would suddenly shudder as it passed through a temperature inversion.

There began a series of actions which aimed at improving the environment and human health particularly in the cities. Fifty years ago lead tetra-ethyl was used as an anti-knock agent in gasoline until it was claimed that airborne lead from car exhausts in the city environment could retard brain development in children.

After 1970, at about the same time catalysts were developed to remove nitrogen oxides from vehicle exhausts, which were claimed to be responsible for increased incidence of asthma in the population, and because lead would poison the catalyst, unleaded gasoline was introduced first in the United States and later in the rest of the world.

Acid rain also began to be noticed after 1970 and was attributed to the

presence of sulphur in coal, which when burned in power station boilers would produce sulphur trioxide, which on contact with moisture in the air would form sulphuric acid. Sweden, in particular, complained of the acidification of lakes in the south of the country, which were downwind of large coal-fired power plants in Denmark and the UK.

Many of the older plants which had originally been designed for coal firing had later been converted to burn oil, which often had relatively high sulphur content and many of these older, less efficient power plants would be replaced by the new nuclear and coal-fired stations. So the first move was to develop FGD systems and fit them to all new coal-fired plants. The first installations appeared at the end of the decade on power plants in Germany and the United States. Unlike coal, those power plants which still burned oil could have the sulphur content reduced in the refining process.

So there was the beginning of an environmental clean up which has continued to the present time, and which has not significantly altered our way of life. But it has not proceeded as fast as it might have done. Improved combustion systems and exhaust cleaning have resulted in the reduction of nitrogen and sulphur oxides from power plants and cars.

Although the efficiency of power generation has improved, there are still in service many coal and oil-fired power plants from earlier times, which have lower steam conditions and few if any of the environmental measures which are now required for all new coal-fired plants. The combined cycle, gas-fired, with high efficiency, and low environmental impact, was by the end of the century accounting for the majority of capacity additions over much of the world, and particularly in the developing countries of southeast Asia

In 1975 only 30 years had passed since the bombing of Hiroshima and Nagasaki had brought to an abrupt end the Second World War in the Far East. There were many people alive then who would remember newsreels, and had read reports of the aftermath of these events, and enough were ready to believe from a position of ignorance that if anything went wrong in a nuclear power station there would be similarly a huge explosion that would kill them all if they lived anywhere near it; after all the fuel was the same material that had beeen used in the atomic bombs

But there was another issue which was even more potent and that was the use of plutonium. This is a transuranic element which does not occur naturally. It is a product of the nuclear reaction and reprocessing separates it from the spent fuel. The only thing that is widely known about it is that it was the material used for the Nagasaki bomb, and that

one of its isotopes has a half life of 24 000 years. Yet it is a valuable fuel material in its own right, is responsible for about one third of the output of any nuclear power station, and has been used in the generating units for the long range spacecraft to the distant planets and beyond.

The misrepresentation of plutonium was put at the heart of the anti-nuclear case. We could not have a fast breeder reactor with a plutonium fuel cycle and we could not have mixed oxide fuel in the present reactors, because in both cases more plutonium would be produced. It must not be allowed to develop an industry based on bomb material because it could not be trusted to keep a proper inventory of all the material and account for any losses that might occur. Could not some of the material be leaked out to terrorists who could make their own bomb?

Opposition to nuclear energy grew first in the United States where there were plans to build another eighty reactors, to replace oil-fired power stations which were mainly in the southern and western states. Growth in electricity demand had slowed down and Green opposition at the various licensing stages had managed to extend the proceedings so much that the costs of the hearings were getting out of hand and many applications were abandoned.

Green protest had been seen to work, and the increasing presence of the leaders on the news media who regarded them as expert commentators on nuclear technology and development plans, ensured that there would be public exposure to their views. Their particular view on energy was that conservation would reduce demand which could then be met by renewables. But this is a contradiction in terms. There is nothing wrong with conservation in terms of having adequate insulation and more efficient electric machines and lighting; this has been at the heart of industrial development over the years.

It is the renewable energy which is the problem: large numbers of small units spread out over a large area. The heavy carbon footprint of production of all this equipment, and the much greater demand for steel and copper compared with a traditional thermal power station of the same output, has been conveniently overlooked by the advocates of renewables. But in reality what this view advocates is the construction of generating plant with no emissions, but unable to meet the demand placed on it for 24 hours a day and 365 days a year.

A consequence of Green activity has been a general extension of the planning process for all large infrastructure developments which has now got to the point that governments are starting to react to change the law governing the licensing of important national projects and curb the political infiltration which has seen many, particularly

European countries, adopt the Green energy prejudices. The result is less construction of new plant and great proclamations of faith in renewables.

Awareness of global warming developed at a time in some countries of government by one party that had been in power over several terms for a long time: Conservatives in the UK, Christian Democrats in Germany, and Republicans in the United States. Opposition parties in desperation sought support from groups of single-issue fanatics who opposed a particular government policy and found in the Greens willing supporters.

Thirty years after the 1973 oil shock, the world is again at a time when we are considering the way we generate electricity. Then the main concern was to take oil out of power generation. Today it is the removal of carbon dioxide out of flue gases and the introduction of other carbon-free technologies.

In about 1990 global warming started to come to public attention. At least much was said but very little was done. In the beginning the question was whether it was due to human activity or a natural phenomenon. Global warming has happened in the past and been followed by cold periods which suggests that it may have more to do with perturbations of the earth's orbit around the sun than any activity on earth. But if this is happening again then there is a ready explanation.

In the sixty years since the end of the Second World War, global population has trebled from 2 to 6 billion. It has happened in a period marked by great economic development, not only in industry but in agriculture and medicine. People are living longer and are eating better than in the past. All of this has led to growth in the production of electricity, and in the transport of goods and people around the world.

In 2000 there were 172 nuclear power plants operating in the then European Union. If these had not been built, coal- and gas-fired power stations would be supplying this energy, and emitting 500 million t/year of greenhouse gases. For the 450 operating plants in the world, then the savings of emissions would be about 1.4 billion t/year.

But while these plants were being built between 1970 and 2003 the population doubled. We live on a sphere approximately12800 km in diameter covered in an atmosphere more than 30 km thick, which is a lot of gas and almost everything that we do happens in the bottom 10 km of it. The claim for global warming is that carbon dioxide and other greenhouse gases collect in the upper atmosphere and trap heat which would otherwise be reflected into space. This might explain a succession of warmer summers and other unusual weather patterns.

The two forms of life on earth, animals and plants, play complimentary roles in sustaining each other. Animals inhale oxygen and exhale carbon dioxide which plants absorb and give out oxygen. Carbon dioxide emitted close to the ground by people and car exhausts is surely absorbed by trees and plants around us.

Global warming can be said to be the result of growth in population, and the increased use of energy that results from it. But we must be careful not to confuse two distinct issues: natural changes in global climate resulting from perturbations of the earth's orbit causing it to move nearer to or further from the sun, volcanic eruptions, sunspots, or other long period cyclic effects; and emissions of greenhouse gases from combustion of fossil fuels, and the increased poulation.

Emissions can be controlled or eliminated, and it is desirable that they should be. Burning coal or oil to produce process steam or to generate electricity has resulted in factories and power plants having tall chimnies to carry the smoke away on the prevailing wind.

Nuclear power came on the scene when there was growing concern over the efficiency of electricity generation at a time of rapidly growing demand. The completion of Calder Hall solved one of the problems in that it was 200 MW of generating capacity with no emissions to affect public health. It had come into operation two years after the British Govenment passed the Clean Air Act and four years before the first combined cycle was completed at Korneuburg, Austria.

But with the oil crisis, public opinion became more outspoken as measures were introduced to reduce consumption of oil. The environmental concerns which had developed at the end of the sixties were more in evidence, and confidence in government was diminishing.

While the first technology protests were environmental, it was the protests against nuclear power plans which came to the fore at the end of the 1970's and by 1990 had all but brought nuclear construction to a halt in North America and Western Europe, but not in the rest of the world, and notably in China, Japan, Korea, and Taiwan.

The Green argument was that we were wasting energy and therefore did not need to use so much. Were these new power plants really necessary? Should we not do more to insulate our homes, and turn down the thermostats and drive smaller cars. But even when you have done all that you still need electricity for lighting and cooking and the industrial controls and processes, so power plants have still to be built.

During this period there were many countries around the world with monolithic, state-owned, electric power utilities who saw it as their duty

to provide an affordable and reliable supply of electricity to everybody. In Europe that was the Central Electricity Generating Board in the UK, Electricité de France in France and ENEL in Italy, who although they were perceived as leaders in electricity generation and transmission technologies turned their backs on combined heat and power, the one measure that would have contributed to a significant energy saving.

In northern Europe, particularly Scandinavia, Germany and the Netherlands, district heating had been developed in many cities based initially on coal- and oil-fired steam turbines and later gas turbines. Sweden in the early 1970's even proposed nuclear plants for district heating, but it was not followed through. But they did replace some oil-fired package boilers on their district heating networks with electric heat pumps.

The objection to any form of combined heat and power was that it reduced the production of electricity, which was the prime purpose of the utility. If they bled steam off the turbine for district heating or industrial process supply, less electricity would be produced and they could not earn as much from the sale of heat as they could from the sale of electricity.

There was no such objection to a gas turbine with a heat recovery boiler. So it was no surprise that the United States took the first step with the Public Utilities Regulatory Powers Act (PURPA) of 1979. This created a market for combined heat and power which, since it was largely gas turbine based, played an important role in the development of gas turbines and low emission combustor systems across the industry. But it also promoted energy economy through combined heat and power, at least for industries which were naturally big energy users.

Why not renewable energy? These were all options being considered. Renewables, of which wind power is the most widely developed of the new technologies, are small scale systems and not available all of the time. Tidal energy, is only available for a few hours either side of high tide, and hence the availability of the power plant changes as the moon rotates around the Earth. Solar plants only work during the daylight hours, which in more northerly latitudes varies with the time of year. Wind generators, both on and off shore, can only operate within a range of critical wind speeds, which can occur at any time.

If other countries had followed the PURPA legislation in the United States it might have been different because what PURPA did was define what industrial electricity generators could do and also how they could trade electricity at a fair price. Although is was not obvious at the time it effectively started the separation of transmission and distribution from

generation, and for a large number of combined heat and power schemes this reduced the cost and increased the efficiency of energy production in a wide range of industrial processes.

When, ten years later, privatization of electricity supply in the UK created the functional separation of generation and transmission, it kick-started a global expansion in combined heat and power. If anybody could generate electricity and guarantee availability, and sell it at a fair maket price, then how it was generated was irrelevant. Investors wanted a plant which was quick to build and operate, and could offer a rapid rate of return on the investment; which all pointed to the combined cycle, with its speed of construction, low environmental impact, and high thermal efficiency.

All during the 1980's, as Green influence infiltrated public opinion, the electricity generators saw no future in, particularly, wind power which was expensive to build and intermittent in operation. They could improve efficiency and cut emissions of thermal plants, but wind had a bigger environmental impact with dozens of units of low capacity.

The object of the Kyoto conference at the end of 1997 was to discuss how global warming could be reduced through cutting emissions from electricity production and energy use, and developing environmentally friendly systems of electricity generation. This was considered to be so important that targets should be applied to define progress, which were set up in a follow-up conference, in the Netherlands in 2001. This set targets for emission reductions to 1990 levels by 2012, when a second stage would be defined, with more countries, to carry through to 2020.

It was this conference which effectively pushed the Green Movement's agenda in support of renewable energy. By 1997 the deregulation of electricity supply around the world was well advanced, which set the conditions for small generating sets to be installed by industry and the new generating companies. Wind farms started to appear across Europe and North America, initially units of up to 2 MW on land, and later in response to public objections, at 3.7 MW and upwards offshore.

The countries in the initial phase of Kyoto are chiefly in Europe and North America, allegedly the most polluting countries, which should show the rest of the world what to do. But this is a relative term, the Green activists are fond of pointing to the United States as the biggest polluter of the lot. Yet for more than forty years that country has worked hard to improve its own environment and received no credit for it at all. The result is that across the country there has been a marked reduction in emissions, particularly of sulphur and nitrogen oxides both from vehicles and power plants.

The United States has always relied on technology to reduce emissions, and it is technology which will reduce electricity demand. At present the nuclear fleet is having its steam turbines upgraded and an increasing number of stations are getting the license extensions to sixty years. If each one of 104 operating reactors receives an upgrade of 50 MW, that is equivalent to five additional reactors being added to the system. Four new reactor designs have been licensed by the Department of Energy, and several generating companies are now actively planning new nuclear plants for service after 2015. The Electric Power Research Institute (EPRI) is even looking at what would be needed to license the existing nuclear plants for longer than sixty years.

There is a continuing market for wind generators across the 48 contiguous States. But it is not for this alone that emissions are falling. The American view was that targets and taxes, were not the way to produce results and it seems to have had some effect. Net greenhouse gas emissions fell by 1.5% from 2005 to 2006.

The European Large Combustion Plant Directive (LCPD) which was announced in 2001 requires all coal- and oil-fired power plants built before 1987 to be shut down by the end of 2015, unless they have opted in by fitting FGD systems and other environmental measures before the end of 2007.

LCPD is among the more sensible post-Kyoto decisions which has been accepted by the now 27 European Union countries. which are required to achieve a 20% cut in greenhouse gas emissions by 2020. It amounts to a timetable for cutting pollution, because more efficient and environmentally friendly power plants that replace the old stations will have lower and cleaner emissions, and must be of an equivalent capacity. If not, then severe power cuts may follow, which will require serious load shedding day after day to control the frequency.

So before we consider the energy system of the future, if we are to use less then it is down to us as individuals to play our part. Low-energy fluorescent lights are gradually replacing incandescent bulbs, but more for the sake of economy. An 18W low energy unit costs more but will give out as much light as a 100W incandescent bulb and last up to ten years. Around the world utilities and some supermarkets have been offering attractive prices for bulk purchases of the fluorescent units.

If a housholder with 100 W light bulbs, in each of the five major rooms of a typical three-bedroom house, were to change only these bulbs for low energy units, the load would drop by 410 W. Repeat this in a million homes and the total reduction of 410 MW is the equivalent capacity of a single-shaft combined cycle plant in the 50 Hz market.