

Remarks about ENERGY and ENERGY RESEARCH

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Ladies and Gentlemen,

A few months ago the President of the European Physical Society, Fritz Wagner, asked me to address the assembled participants of this anniversary event and their guests, because he felt that it required an Anglo-Saxon to make a witty speech during dinner! I have chosen, however, to say something more serious. This is not the result of my sense of humour having been blunted by living for many years in Germany (as Fritz immediately suggested!). No, I felt that you – my captive audience for the next 30 minutes – deserve something more intellectually challenging than a string of anecdotes or funny stories about physics and its European practitioners, or indeed about Europeans and their cultural differences, something for which we should actually be thankful!

I have therefore decided to discuss the concept of sustainable development and – in this context – to make some remarks about energy and energy research. The EPS has concerned itself particularly with this topic during the presidency of Fritz Wagner. Some of the things that I will say you have no doubt heard before. A few things may be new to you and some of them may be controversial.

I would like to begin by noting that the last four decades of the 20th century were characterised by an increasing concern about the degradation of the environment and the depletion of natural resources. Perhaps it was the book by Rachel Carson "Silent spring" in 1962 which first drew the attention of the general public to the problems of mankind's influence on its environment, in particular to pollution in the developed world and to the potential, now all too apparent, loss of bio-diversity. Moreover, the years that followed were characterised by a series of man-made environmental disasters which in the perception of the public probably began in Bhopal in India, but culminated in Chernobyl. The report of the Club of Rome, "Limits of Growth" written by Dennis Meadows in 1970 pointed out that prosperity was dependent on sufficient supplies of raw materials, and in particular on cheap sources of energy in the form of fossil fuels and that these were finite. The assumptions made by Meadows in his computer models were not all correct and the predictions, as it

turns out, were wholly incorrect. Nevertheless, the book forced scientists and economists to think about the use, or rather flagrant misuse, of the resources of the planet.

The onset of mankind's detrimental influence on the environment is generally thought to be the industrial revolution in Europe. But there are earlier examples. In his book "World Fire" the historian Stephen J. Pyne describes how the Australian aborigines radically changed the landscape of the continent by the use of fire when they settled there 40 thousand years ago. Laurion, where the Athenians mined their silver, was already regarded in the 4th century BC as an unhealthy area. Socrates remarks, in a conversation reported by Xenophon, that a young politician was not expected to pay a visit there. The condition of the slaves who actually worked in the mines was apparently not a matter with which the Athenians necessarily concerned themselves! In more modern times we can cite the destruction of hundreds of thousands of square kilometers of forest land between the 13th and 18th centuries in Europe in order to create more agricultural land to feed the growing population of the towns.

Thirteen years after the Club of Rome report the United Nations set up the World Commission on Environment and Development under the Chairmanship of the former Norwegian Prime Minister Gro Harlem Brundlandt. Its report "Our common future" in 1987 made the now accepted definition of sustainable development as development that "meets the needs of the present generation without compromising the ability of future generations to meet their own needs." The pillars on which it rests are environmental responsibility, economic sustainability and social development. Some sources would add "using sound science in a responsible way" and "promoting good governance". However, as the UK government has recently pointed out in one of its publications, "globally we are not even meeting the needs of the present let alone considering the needs of future generations. Unless we start to make real progress toward reconciling these contradictions we face a future that is less certain and less secure. We need to make a decisive move toward more sustainable development. Not just because it is the right thing to do, but also because it is in our own long-term best interests."

Whereas most of us are aware of what sustainable development means, it is true to say that in the last decade the concept has not played such an important role in the media and in political debate, as it did when it was first defined in the 1980's. Although the questions of energy supply and climate change now occupy the political stage, the underlying philosophy and the various other aspects of sustainable development are no longer so prominent. Who remembers the World Summit on Sustainable Development in Johannesburg in 2002? Who is aware, for example, that the first EU sustainable development strategy was launched at the Gothenburg summit in 2001 and that the European Council in

accepting a progress report from the Commission on the implementation of the strategy in December 2007 reiterated that "sustainable development is a fundamental objective of the European Union"? Does the British public still know that the Government launched its sustainable development strategy in 2005 under the slogan "Securing the future"? Is the German populace waiting with baited breath for the progress report on the national sustainability strategy this autumn? To confuse matters more, the media quite often use the word "sustainable", but not in the sense I have defined, but rather to mean "long-term" or "lasting".

Who is concerned about the consumption of precious natural resources, anyway? Assuming Europeans were to know that in 2006 only 11% of the platinum contained in automotive catalytic convertors was actually recovered, would they actually worry about it?

A short aside: The word "sustainability" was not part of the English language before 1987. A German translation, namely, "Nachhaltigkeit" was, however, readily found: it describes the principle on which forest management has been based in Central Europe for over two hundred years. Indeed, the concept, and the word "nachhaltig", are used by Oberberghauptmann von Carlowitz in his "Sylvicultura Oeconomica" in the year 1713. In other words, the Germans had a word for it; the Anglo-Saxons had to invent one! (Most of this information is available in Wikipedia. However, since I used some of these ideas in a similar lecture given some years ago, it is not I who is guilty of plagiarism. Anyway, as Alfred Polgar the Austrian theatre critic once said "Plagiarism was always the most honest way of expressing admiration".)

Now some more fundamental thoughts: The realisation of sustainable development depends on the availability of sufficient energy. Matter and energy are subject to laws of conservation. In natural, non-radioactive processes the total number of atoms of each element remains constant. An element can of course be degraded in that it may form a less valuable chemical compound, for example an oxide from a pure metal, but the process is reversible. We can recover the pure metal. Energy, on the other hand, regardless of its origin – solar, fossil fuel, a nuclear process - is irreversibly degraded by its use. The total quantity of energy remains, but the result of any conversion process (whether it is for electricity generation, heating or transport) is that high grade energy is changed into low-grade heat. The petrol in a car, for example, produces heat and mechanical energy which drives it. The motion of the car is only possible against the various forces of friction. The friction of the tyres on the road and of the car in the air leads to a heating of the environment.

The so-called degradation of the elements, on the other hand, can be reversed, but *only if sufficient energy is available*. Oxidised or corroded metals can be

reconstituted, water can be purified or desalinated, consumer products can be recycled, but the crucial factor in closing such material cycles is the input of energy. Even achieving so-called "soft" sustainable development requires considerably more energy than is realised and certainly more than is normally allowed for in predictions of future world energy consumption, at least on the basis of present assumptions concerning population and economic growth.

In a further aside, this time on the Second Law, which I have not yet mentioned by name: One remembers the statement by the novelist and physicist Sir Charles Snow in a much-quoted lecture in 1957 that it was just as important for the student of the humanities to appreciate the Second Law of Thermodynamics as it was for the scientist to be familiar with the works of Shakespeare. The problem was that a whole generation of non-scientists – at least in the Anglo-Saxon world – tried to follow Snow's advice and were understandably left frustrated and disappointed by their attempts to master the Second Law. When the public understanding of science movement actually took root, it was not as a result of the adage of Snow. On the contrary, the initiators were biologists who realised that there was a direct way of tackling the problem!

To return to our theme: We have a paradoxical situation: achieving sustainable development requires more energy, but our energy system itself is far removed from satisfying sustainability criteria. Over 80% of the world primary energy supply of 477 EJ (in the year 2005), or 11.4 Gtoe, is provided by fossil fuels. The percentage is actually rising. A very small proportion of the energy of the sun incident on the Earth over millions of years has been stored in the form of coal, oil and natural gas. Mankind is currently squandering these precious natural resources over a period of a few centuries and, at the same time, increasing the CO₂ concentration of the atmosphere in an alarming way. Global warming and serious climate change are known to result. Conventional oil reserves are expected to last about 50 – 70 years at the present rate of use. The "Trendlines" peak oil production forecast is 91 million barrels per day (mbd) in 2013, staying constant for several years, before declining. (In 2008 we will already reach 87 mbd). Oil shales and natural gas will be with us somewhat longer. World coal reserves are sufficiently large to supply us for two to three further centuries. The same is true for the uranium fuel of conventional fission reactors, which – although they do not produce CO₂ – are subject to critical scrutiny in many countries because of the safety issue and the sustainability problem posed by the unavoidable production of highly radiotoxic waste, a point to which I will return. Moreover, world energy demand is likely to increase drastically in the course of this century: the present world population of 6 billion could double by the year 2100. Finally, we note that emerging economies have already begun to benefit from the fruits of stronger economic growth and thereby increase their demand for energy. The thirst for energy in China, and the construction rate of new coal-fired power stations are phenomenal. *The*

Economist reported recently that in the two years 2006 and 2007 China created a total extra generating capacity larger than that currently available in the whole of France!

I would submit that the answer to the problem is an apparently simple “energy agenda“ which proves to be very difficult in practice to realise: In order to drastically reduce the use of fossil fuels it is necessary

1. to promote the use of renewable energy forms (provided they fulfil sustainability criteria)
2. to achieve a more rational use of energy,
3. to improve the efficiency of energy conversion processes and
4. to explore fully all future options even if some of them do not necessarily fulfill the strict definition of sustainability.

These measures require that the fraction of GDP spent on energy research and development be drastically increased, because here we are doing very badly. And there are substantial differences between European countries. Germany spends – according to the statistics of the International Energy Agency (IEA) in Paris – 0.016% of GDP on energy R&D, whereas the energy sector share of GDP is about 10%. However, France, Finland, the US and Japan all spend more – again as a percentage of GDP. Japan actually spends four times as much! Germany, however, is known for its very high subsidies for solar energy and wind, although – as a result of a decision of the European Court in Luxemburg they are not officially regarded as subsidies and enjoy the description “feed-in tariffs”. Just on a point of interest, Germany actually spends even more on subsidising its national coal industry, a sum last year of no less than 3.5 billion Euros! But energy research is bound to become more important as the situation worsens, since it offers one of the very few hopes for the future. Perhaps most important of all for us gathered here to celebrate 40 years European Physical Society is to reflect upon the fact that physics may soon return to the top of the research agenda! With an oil price over 80 \$ per barrel and G8 summits dominated by energy and climate issues, physics, but also chemistry and engineering, which provide the bases for new technologies, should come into their own.

All four points on the agenda I have just mentioned are expensive and in themselves will cause the price of energy to rise. It will of course rise steeply anyway when supplies of fossil fuels dwindle in the second half of the century, but by then billions of tons of valuable raw materials will have been exhausted and there will probably have been irreparable damage to our environment.

Time does not permit me to discuss all the points on the agenda but I am going to look briefly at two options under the fourth point, namely, nuclear fission and nuclear fusion.

The IEA forecasts that the percentage of nuclear power in world energy supply is likely to remain constant at 5% until 2020, despite the fact that this is hardly a sustainable solution to our energy problem. The 5% means that 10,000 tons of spent nuclear fuel are produced per annum with the concomitant problem of final storage. It is therefore strange that research into partitioning and transmutation, which is the process of degradation of highly radioactive actinides into stable or short-lived isotopes, is not carried out with more decisiveness. The accelerator-driven sub-critical reactor-based system MYRRHA has still not been funded. The much-discussed Generation IV, which is still on the drawing board, contains power plant designs based not only on the high-temperature reactor but also on the fast reactor principle which uses a minimum of nuclear fuel and above all can substantially reduce the amount of radiotoxic waste. The potential problems of the fast reactor are well-known, and proliferation is always cited as a major one, but they could give us some respite, enabling us to win time, so that more sustainable solutions to the energy crisis can be found. Generation IV contains enormous challenges for physicists and engineers.

Last but not least, I come to nuclear fusion. Recent advances in high energy plasma physics show that fusion – the energy source of the sun and other stars – could provide the cornerstone of a sustainable, or almost sustainable energy system. Such power plants would be safe and environmentally friendly. In particular, one of the main problems of fission reactors, namely that of a possible uncontrollable nuclear reaction is banished; also the problem of radiotoxic waste is reduced by many orders of magnitude compared to present fission reactors. Fusion reactors would have almost limitless supplies of fuel and could be sited anywhere in the world. Fusion is, however, still in the development stage and it is not expected that commercial power plants will start operation before the middle of this century.

The fuel in a future fusion power station will be a mixture of deuterium and tritium. The reaction produces an alpha particle, a neutron and a considerable quantity of energy which is distributed between the two particles. The aim of fusion research is to produce schemes in which the deuterium and tritium nuclei approach each other sufficiently often and with sufficient energy that the reaction takes place. At present, the most successful scheme is to contain the hot, ionised gas – the plasma – in a toroidal magnetic field cage and to heat it with microwaves. This, however, requires the input of energy. A successful fusion power plant requires that the power amplification factor, i.e. the ratio of the power produced by the fusion reaction to the power required to heat and control the plasma, lies ideally between 20 and 40. Of the reaction products, the alpha particles lose their energy to the plasma and thus serve as heating; the neutrons leave the plasma and are stopped in the so-called blanket, where they

deposit their kinetic energy as heat, which in turn produces electricity via steam generation in the conventional way.

It is one of the success stories of European science that the EURATOM fusion programme has taken research in this field the farthest. The break-even point, i.e., a power amplification factor of unity, was all but reached on the joint European experiment JET in Culham, UK in 1997. 16 MW of fusion power were achieved for about a second and about 4 MW for a few seconds. JET is operated not as an institutionalised international research centre, but rather jointly by the national fusion research laboratories. These also have their own programmes, but they are in turn co-ordinated and linked within the European fusion programme. As was remarked by the last external panel which evaluated the European fusion programme, there is no better example for the European Research Area.

The next step in the fusion programme is the construction of the international experiment ITER in Cadarache in the South of France which will demonstrate that a plasma can burn under energy-producing, power-plant conditions for periods of up to many minutes. A power amplification factor of at least 10 is the aim. The following step will then be the construction of a demonstration power plant which will actually produce electricity. Unfortunately, the process of building and testing these two devices and the accompanying technology programmes are likely to take another forty years, so that fusion could only play a significant role in energy supply in the second half of this century. Nuclear fusion as an energy source is often referred to derogatorily as a "moving target": back in 1960 it was 40 years in the future, and now it is still 40 years away! The early fusion physicists were of course too optimistic in their predictions, but this particular criticism neglects the enormous progress that has been made, particularly in the last two decades, and the long waiting time for projects to be approved. Exactly 20 years elapsed between the setting up of the initial ITER planning group in Garching and the signing of the ITER agreement!

Why do I describe fusion as a sustainable, or almost sustainable energy source? Of the fusion fuels, tritium has to be bred *in situ* from lithium in the reactor itself, but sufficient lithium is available in the Earth's crust for tens of thousands of years and in sea water for at least a million years. There is sufficient deuterium in sea-water for an even longer period. Indeed, if it were possible to improve the energy confinement of fusion reactors such that the lower cross section deuterium-deuterium reaction, instead of the deuterium-tritium reaction, could be used the available fusion fuel would last for billions of years, in any case longer than the lifetime of the sun. A truly sustainable solution!

As physicists, I feel we have the responsibility to develop the option "fusion" to a point, such that future generations – it may not be our children or even

grandchildren – can make a decision based on economic, social and environmental factors relevant at the time. The Göttinger physicist Friedrich Hund was, as far as I am aware, one of the first to discuss the physical basis of the supply and use of energy in an essay entitled *Die physikalischen Rahmenbedingungen unseres Daseins* written in 1975. He noted "If we are not successful in getting fusion to work, then mankind will soon have to manage with the sun alone".