Future Energy Supply and Environment Protection - a Challenge for Large Scale Power Generation

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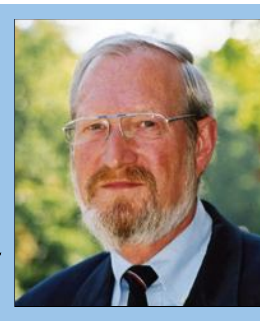

1. Introduction

The technology of fossil fuel conversion for heat and electricity production experienced major distinct development periods based upon external driving forces as a consequence of changing requirements of our industrialized surrounding. Therefore, a strongly expanding economy with a corresponding demand for increasing capacities and plant availabilities was observed during the beginning of the second half of the last century. More recently the awareness of negative effects of environment pollution resulted in the development and application of emission control measures which were successfully implemented during the previous decades.

Furthermore, the discussion of energy utilization in connection with the global climate issue resulted in a reconsideration of the use of fossil fuels, and in particular in a diversification of the primary energy sources which opened a new field for research and development. In particular, the Kyoto Protocol concerning CO_2-abatement and the resulting obligations, especially for those countries who adopted this agreement such as the members of the European Union, have initiated extensive research and development efforts towards efficiency improvements of large scale fuel conversion processes as well as capture and storage of CO_2.

The presentation will, after a review of the achievements in research and development in the area of heat and electricity generation, deal with the new requirements as a consequence of the changing needs of our society and of the increasing concern about local and global environment protection, followed by a detailed discussion of strategies and of technological options in order to satisfy the future energy demands of our society.

2. Key Features

2.1 Society and energy

During the last century and, in particular, in the previous few decades considerable changes took place in our world which is essentially a result of a growing population and the corresponding needs. After a hardly recognizable increase of the world population from the first recorded food prints of mankind about 3.5 million years ago up to the middle ages – statistical data estimate the number of inhabitants in 1600 to be less than half a billion – it took about 200 more years to complete the first billion by approximately 1820. Only 110 years later in the early 40ies of the last century the second billion was reached followed by a rapid growth to the third, fourth and fifth billion in only 30, 20 and 10 more years respectively. In fact, the human population quadrupled in the 20th century, and doubled in only little more than 45 years from 1960 up to today. This trend is particularly noticeable for regions in transition such as Africa and certain areas of Asia and, among those, for most of the poorest countries.

The evolution of mankind up to our present society required not only human potential, knowledge and experience but also natural resources such as raw materials and energy. Whilst the distribution of raw materials is highly localized, energy in its usable forms can be converted almost everywhere from different primary energy sources such as natural power or from e.g. bio-organic material and especially their fossil remnants. From the early days of mankind up to the pre-industrialization period the energy requirements were predominantly in the form of food and fuels for domestic purposes and were, thus, in comparison with today, fairly low with a growth rate almost in parallel to the population expansion. With the beginning of the industrialization age the energy utilization increased and continued to rise rapidly, in particular, during the previous 5 decades as a consequence of the advances in productivity, mobility and living standard. In fact, the worldwide consumption of usable forms of energy increased in the 20th century 13 times, tripled since 1960 up to today and, thus, rose much faster than the population.

The most important primary energy sources are of fossil origin, namely coal, gas and oil, which are– apart from transport fuels and chemicals – predominantly converted by combustion into heat and pressure and eventually into the most versatile electricity. Driven by a rapidly growing demand, the electricity generation technology, in particular based on solid fossil fuels, developed during the previous 100 years with a drastic increase of unit sizes, whilst in parallel reducing the specific fuel consumption and consequently improving the efficiency of the energy conversion process. Modern large power stations have capacities up to 1000 MWe and operate with net efficiencies of more than 40%.

2.1 Environmental considerations

Triggered by the increasing awareness in our society of harmful influences of various by-products of fossil fuel utilization like the emission of particulate matter and of gases such as the oxides sulfur and nitrogen, many countries enforced emission control by legislative actions over the past decades. As a consequence, effective technological solutions for the modification of the fuel conversion process and for the cleaning of the effluents of power stations had to be developed and are applied today for environment protection in full compliance with local and regional emission control standards.

A new challenge for the power station technology arose due to the worldwide discussion about the emission of carbon dioxide and its predicted influence on the global climate (the s.c. "green house effect") which is related to the utilization of carbon-containing fuels, predominantly of fossil origin. In order to minimize such potentially negative effects and its regional and local consequences, the Kyoto Protocol on greenhouse gas emission control was agreed upon in 1997 and has been adopted since then by most countries via transfer into own regulations. As a consequence, considerable efforts were initiated to develop technological alternatives and process solutions in order to ensure a sustainable energy supply at greatly reduced CO_2-emissions.

Obviously carbon-free fuels would be the preferred alternative for the future. Among these options the nuclear fuel utilization is a worldwide well experienced option but meets at present - at least in various countries - problems of public acceptance. Furthermore, hydropower as one of the regenerable energy sources is already extensively in use and a substantial increase is unlikely. Other regenerable sources, such as wind and solar energy are very much favored in public. However, area requirements, energy density, local and time availability as well as investment costs - in particular for the latter - still restrict their application. Therefore, unless considerable cost reductions can be obtained in future, only a limited contribution to the overall electricity supply is expected, even in regions with beneficial natural conditions.

Another alternative is the use of s.c. "CO_2-neutral" fuels like biomass, both grown or as waste from various industrial processes. The potential of such fuels as a part-replacement is remarkable considering the availability of such fuels, the positive effect on alleviating disposal problems, and the attraction of co-utilization in existing fossil fuel fired plants as a technically feasible and cost-effective solution. It should also be noticed that in case of the utilization of biomass an additional requirement, namely the preservation of primary energy resources, is also well covered. Based upon the positive experience on large scale in Europe and beyond, the bio-fuel alternative seems promising although in the energy sector a share of only 5-10 % may be possible in certain favored regions.

2.2 Technological options

As a consequence of the above and considering the predicted worldwide increase of the future energy demand despite of dwindling natural resources, it becomes obvious that the energy supply for foreseeable future decades will be based predominantly on fossil fuels with the unavoidable production of carbon dioxide. Therefore, the future technology of energy conversion must meet the following three crucial criteria, namely a sustainable energy supply to satisfy an increasing demand at economically acceptable costs and with global and local environment protection by stringent emission control.

Whilst the first two criteria are essentially a matter of availability of both, resources and optimized technology, the third criteria requires, besides well established local emission control, two sets of new measures, such as a further reduction of the specific CO_2-production during the fuel conversion on one hand and/or the capture of CO_2 prior to the emission to the ambient surrounding and its subsequent use or disposal.

The first set of measures implies a consequent continuation of the ongoing efforts of improving the present power station technology with regard to efficiency and environmental performance, which will also result in a corresponding reduction of the required fuel input and inconsiderable savings of our natural resources.

The second set of measures asks for new considerations regarding the removal of CO_2 before or after the fuel conversion or even new processes with enriching the CO_2 in the flue gas prior to its capture. Such ongoing research and development activities have to be paralleled with efforts to select sites for CO_2-storage and to develop the corresponding transport infrastructure and disposal technology.

2.3 The way forward

Efficiency improvements of the fuel conversion process can be realized with advanced steam cycle parameters by a variety of measures which are all aiming at a widening of the upper and lower thermodynamic boundary limits such as the development and application of high temperature/high pressure steel materials, as well as at a cost-effective reduction of internal process losses on both the combustion and the steam raising side. In addition, such measures will result in a reduction of the specific fuel consumption and, thus, will lead to lower local emissions and less CO_2 production.

Experience with new large capacity coal fired plants has shown a successful operation of supercritical boilers with net efficiencies of 43 - 44 % (with cooling tower) and above 45 % (with sea water cooling). In addition, the advanced steam cycle power stations have at present the important advantage of known high availabilities and comparatively low electricity production costs. Based on the state of the art and, in particular, on new advances in material technology, the first ultra-supercritical steam cycles (USC) with expected net efficiencies of 45 % and higher are presently under demonstration in Europe in an operating boiler.

With regard to the second set of measures various large multi-discipline/multi-partner projects with a duration of up to 5 years are under way in Europe since early 2004. Highlights of these activities are the research and development of enhanced CO_2 capture processes in both post- and pre-combustion mode as well as of the corresponding storage requirements for on- and off-shore locations. All these projects are aiming at results applicable for demonstration as the next step.

Furthermore, the European Commission is presently preparing a new program for co-financing research and development actions for a duration of at least 5 years and to be started in 2007. Considerable funds are expected to be devoted to the issue of energy supply at near zero emission. In addition, a European Technology Platform for "Zero Emission Fossil Fuel Power Plants" (ZEP) was recently formed in which the European energy industry, research community, Non-Government Organizations, Member States and the European Commission expressed their joint commitment to the use of fossil fuels in a sustainable way. An effective Europe-wide program will be developed, leading to the successful deployment of Zero Emission Fossil Fuel Power Plants over the next fifteen years.

As part of this responsibility, the European industry already announced several large scale demonstration plants: an oxyfuel process pilot plant with a capacity of 30 MWth is due to be commissioned in 2008, the post-combustion CO_2-capture alternative is under way at various sites and a 450 MWe integrated coal gasification combined cycle project with CO_2 capture and storage was recently announced to start operation in 2014.

3. Conclusions

In order to combat the potential negative effects on the global climate as a consequence of the strongly increasing energy demand and its continuing dependency on carbon-containing fuels of predominantly fossil origin, Europe has itself committed to a strategy of providing a future sustainable energy supply scenario based upon an optimal mix of all available primary energy sources in order to alleviate the CO_2 problem. In line with this, research and development is directed towards zero-emission fossil fuel plant concepts to become available within the next 15 years; an important aim, because a 35% increase of power demand by 2030 is expected for the European Union which implies about 130 GW in replacement and new power station capacity. However, in order to reach this ambitious goal, apart from technology development, hurdles and barriers have to be overcome, such as a broad convincement of the public that energy is a vital but costly commodity and saving is a pertinent requirement. Finally, there is a definite need for long term binding political directives.

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