Chapter 1

INTRODUCTION

1.1. WORLD ENERGY SITUATION

In 1996, the world's consumption of primary energy amounted to 8380 million TOE[1], which was 3 % more compared with the previous year. Most of the energy, 90 %, originated from fossil fuels (coal: 27 %, oil: 39.5 %, gas: 23.5 %) and the remainder from nuclear power (7.4 %) and renewable energies (hydro: 2.6 %) [8]. About 30 % of the primary energy consumed is used for electricity production. Currently hydro and nuclear are the only significant non-fossil contributors to electricity production with hydro representing about 20 % and nuclear about 17 % of global electricity. Other renewables have been able to penetrate only limited niche markets [5].

As described in a study by the European Commission, global energy supply is expected to increase by 1.6 % per year. Renewable energies are gaining mainstream acceptance with a 2.0 % increase per year, nuclear not more than 0.5 % per year. Natural gas is currently the fastest growing energy source with an annual increase of 2.7 %. The energy intensity of many products has fallen, but energy consumption is increasing: consumers have developed new needs, developing countries want to achieve higher economic and social levels. The energy trade is growing rapidly [7].

The future energy supply mix will depend on the magnitude of demand growth, changing objectives and social priorities, and the technologies to meet them [5]. The International Energy Agency (IEA) in Paris does not expect a significant change in the world's energy mix, because long time periods are required to develop new or improved energy technologies before they can be commercially deployed. What it does expect is a strong demand for more energy (1.6 %/yr) due to population increase and rapid economic growth in some regions of the world. The US Electric Power Research Institute (EPRI) does not anticipate primary fuel resources to be an economic constraint in the next century although their absolute and comparative cost might shift with time. A balanced and stable program without pursuing extreme policies has the best prospects of achieving lowest long-term social cost, therefore it recommends facing the future with an array of options and flexible strategies [5].

1.2. GLOBAL ENVIRONMENTAL IMPACT

Most of the world's fuel supply is some sort of hydrogen combined with carbon, hydrocarbons. Burning hydrocarbons means liberating carbon oxide gases with undesirable side effects: CO is toxic to life, CO_2 is currently labeled as one of the primary causes of the greenhouse effect. The other aspect of hydrocarbons is their limited supply on earth.

Although the problem of global warming has been recognized, there is still a discrepancy between the global trend of CO_2 emission and the global target of CO_2 reduction. The agreement of 154 countries at the Rio earth summit in 1992 was to pursue

[1] 1 TOE (= ton oil equivalent) = 1.428 TCE (= ton coal equivalent) = 41,868 MJ

"sustainable development" by reducing the emission of greenhouse gases to the 1990 level by the year 2000. Figures from 1996 revealed a new record high with CO_2 emissions increased by 2.8 % compared with 1995. According to a prediction by the PROGNOS AG in 1991, compared with 1989 global CO_2 emissions will be increased by 67 to 170 % in 2040. Even if the industrial countries were successful in achieving a CO_2 reduction of 80 %, total emissions would still increase by 30 to 100 % due to the enormous energy demand of the developing countries [4]. For the OECD, there is a predicted 13 % increase of CO_2 emission between 1990 and 2010 versus the declared goal of a 15 % decrease in the respective period [6]. CO_2 contributes 40 % to the anthropogenic greenhouse effect [1] with a long lifetime of up to 100 years in the atmosphere. More than half of the CO_2 emissions come from energy production. Traffic contributes a great deal to the environmental impact by using fossil fuels at low efficiency.

A recent analysis by EPRI expects that even with a favorable scenario, total carbon combustion will rise from the 5.5 gigatons of 1986 to at least 8.6 gigatons in 2060 despite the introduction of renewables and a relaunch of nuclear development [5]. In contrast, a reorientation has occurred in some sectors, in particular, in the automotive industry where low emissions of nitrogen oxides and hydrocarbons are mandatory.

The United Nations Convention on Climate Change has prompted initiatives by various countries to identify and implement methods for curbing the rise in greenhouse gas emissions. Studies by the International Panel on Climate Change (IPCC) have shown that a stabilization of the atmospheric CO_2 would be achieved in the second half of the next century, if CO_2 emissions are reduced by 60 % within the next few decades. In the short term, the desired reductions are likely to be achieved through energy savings combined with the deployment of more advanced, more efficient supply and utilization technologies. However, it is generally recognized that the longer-term targets will require substantial increases in the deployment of new and improved technologies.

Three conferences of parties to the **United Nations Framework Convention on Climate Change** have been held so far to discuss the global warming issue. The summit in Toronto in 1988 resulted in the promise of a 20 % CO_2 reduction by 2005; the reality today is a 16 % increase compared with the 1988 level. During the conference in Rio de Janeiro in 1992, it was decided to go back to the 1990 level by 2000; so far there has been an increase of 8 % in the OECD countries. At the third world summit in December 1997 in Kyoto, Japan, the 167 participating countries came to an agreement which, if finally accepted[2], will for the first time be an obligatory agreement according to international law. It includes the commitment by the 38 industrialized countries to reduce their overall emissions of the gases, which contribute to the global warming potential, by 5.2 % compared with 1990 and 1995[3] by the years 2008/2012, respectively. Emission change ranges between -8 % (EC) and +10 % (!) (Iceland) for the single countries. No goal has been specified for the developing countries. The introduction of new economic instruments such as the possiblities of trading emission permits and of taking so-called "phantom" emissions into

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[2] The draft protocol has legal effect 90 days after it has been ratified by 55 % of the parties of the convention, among them industrial nations with more than 55 % of all CO_2 emissions [2].
By midth of May 1998, 35 countries have signed the protocol including industrialized countries (among them Japan and Germany) with in total 39 % of the worldwide CO_2 emissions.

[3] The 1990 level is the baseline for the greenhouse gases CO_2, CH_4, N_2O. The 1995 level is the baseline for the greenhouse gases sulfur hexafluoride (SF_6), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs).

account meaning that the creation of CO_2 sinks (e.g., reforestation) could be balanced with emissions, was a matter of controversy and needs further elaboration.

1.3. WHY NUCLEAR POWER?

Limited fossil energy resources and pending environmental issues are likely to increase the significance of non-fossil energy forms – hydro, nuclear, solar, wind, geothermal, tidal – in the long run. Despite its low growth at present, nuclear power is foreseen by the World Energy Council as gaining importance in the future representing, besides renewables, a serious option for decoupling the existing energy demand from CO_2 emissions.

Usually the sites of high energy potentials are not identical with the sites of energy consumption. This situation offers the following options:

- on-site generation of energy-intensive products
- generation of electricity and transport via grid
- transformation of electricity into chemical energy carriers, e.g., hydrogen, methanol
- direct generation of hydrogen and transport via pipeline.

Nuclear power is considered by many to be the most promising CO_2-free energy technology with long-term fuel supply security. According to a statement by IAEA, in 1996 the nuclear power installed worldwide saved an additional impact on the atmosphere of 2.3 billion tons of CO_2 per year corresponding to 8 % of additional release [3]. Principally used as base load power plants, nuclear off-peak electricity could be applied for hydrogen production.

The operation of nuclear power plants in the "Combined Heat and Power" (CHP) mode, i.e., cogeneration of electricity plus heat including the production of process heat is a means of significantly raising energy conversion efficiencies. Furthermore the refinement of fossil fuels, e.g., coal, by nuclear power contributes to the fundamental objectives of energy policy: (i) energy security, (ii) saving of resources, (iii) protection of the environment. Cost is a major concern, but nuclear power seems to be competitive in the long term.

1.4. WHY HYDROGEN?

Hydrogen, the most abundant element in the universe, is – as a fuel – clean, powerful, renewable, and environmentally benign. It can be burnt to water vapor at a very low level of pollution releasing its chemical energy as heat. It can be stored directly or transported for later usage. Most of the hydrogen is bound in chemical compounds, i.e., it must be extracted prior to its use by means of a primary energy resource. The introduction of hydrogen as a significant contributor to meet the world's energy demand in the future requires an infrastructure, economy, and last but not least, safety.

An important driving force for development work on hydrogen has always been developing a further secondary energy carrier, in addition to electricity, for the non-electric market. Economic solutions for generation, storage, transport, distribution, and application may help to introduce a new energy concept with hydrogen playing an essential role as a secondary energy carrier.

The fact is that billions of cubic meters of hydrogen are produced every year, but unfortunately mostly converted from fossil fuels and only to a small extend used for energy purposes. In a future low-emission energy economy, the hydrogen energy carrier could play a pertinent role using its advantages compared with other alternatives. With the energy carrier hydrogen, all the subtasks of an energy transmission can be performed in a safe and appropriate way. A major drawback of hydrogen is its hazard potential if inadvertantly released and mixed with the ambient air to form a flammable gas mixture. Therefore it is necessary to assess its risks to society.

1.5. OVERVIEW

The report covers all main issues concerning hydrogen and its potential connection to nuclear power. It presents for either area goals achieved so far and ongoing research activities. Also secondary areas are described including processes with hydrogen as an intermediate step.

The first part comprising three chapters deals with nuclear power as the primary energy source for producing electricity and process heat / steam which could be utilized for hydrogen production. Chapter 2 treats the design of nuclear power plants for process heat application and the components required. Safety considerations described in chapter 3 concentrate on the aspects that are peculiar to nuclear process heat plants. International activities on using nuclear power to be utilized in process heat applications, for example for hydrogen production in the past, present, and future are listed in chapter 4.

The second part of the report focuses on key technologies as the basic elements of an economy with hydrogen as an energy carrier. Chapter 5 (plus appendix A) describes the production methods for hydrogen including those which are still at an early research stage. Chapter 6 (and appendices B and C) contains the description of methods and components for the storage, transportation, and distribution of hydrogen. In chapter 7, both major and minor areas of applications of hydrogen as a feedstock for (petro)chemical processes and, in particular, as a fuel are presented. The safety aspects which have to be considered in a hydrogen energy economy including some examples of a safety and risk assessment are given in chapter 8. This part on hydrogen is terminated by giving a – most probably incomplete – list of international activities for promoting the use of hydrogen including a more detailed description of some examples of an autonomous hydrogen energy system or subsystem, some in operation, others still at the design stage.

The report ends with a rough description of a future large-scale hydrogen energy economy, in which nuclear power may play a significant role, and the efforts needed to reach this goal.

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