# NUCLEAR ENERGY REVIVAL – BASIS FOR HYDROGEN ECONOMY

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## ABSTRACT

We live in the world, which is just starting to consume more and more energy. In the next 50 years human population will increase from 6 to 9 billions and mankind will consume so much energy, as it was consummated in all history before. Increasing energy dependence and global warming become emblematic of the new century. The most analysts put them on the first place in the long list of main problems of the mankind future. Nuclear energy used for electricity and hydrogen production has the biggest technological potential for mitigating the consequences of the main energy outstanding issues of the new century:

1. increasing of energy dependence;
2. global warming and particular evidence of abrupt climate change.

Because of good technical and market position the political basis should be assured for fast development of new generation nuclear reactors and fuel cycles which can satisfy vigorously increasing needs of affordable and clean energy. Environmental conditions require immediate action for quick increasing of nuclear energy share in the global energy mix. Politicians must give chance to the nuclear industry to take adequate part in the fight for conservation of Earth natural biosphere and biodiversity for future generations.

## 1 FORECASTS FOR ENERGY DEMAND

To the year 2050 the world consumption of energy will be twice higher or more ,even by average rate of economical growth. World power generation capacity will exceed 7 000 GW (Fig.1).

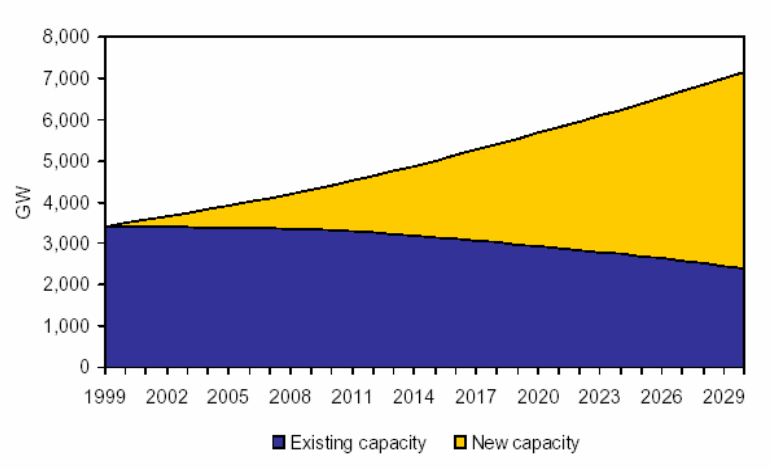



*Figure 1* World Installed Power-Generation Capacity [1]

Electricity, as a universal energy source, will stay “the fuel of the economic growth”. Increasing of population, volume of gross domestic product and electricity sales in USA (Fig.2) has firm interrelation. Energy consumption is increased faster than population growth. This trend is essential not only for USA, but for all countries in their way to industrial development.

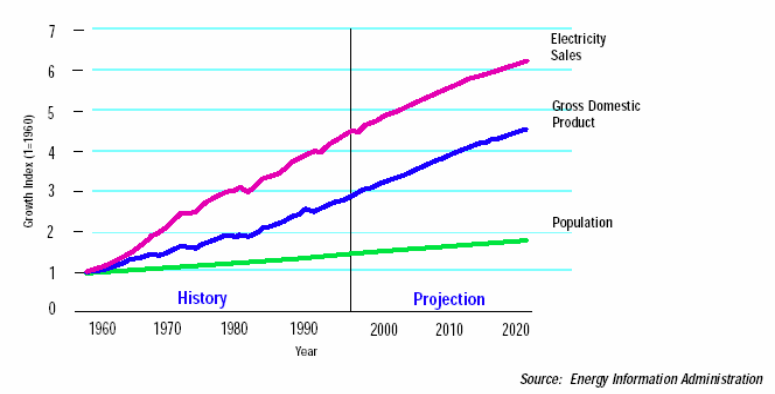



*Figure 2* Electricity:The Fuel of Economic Growth [2]

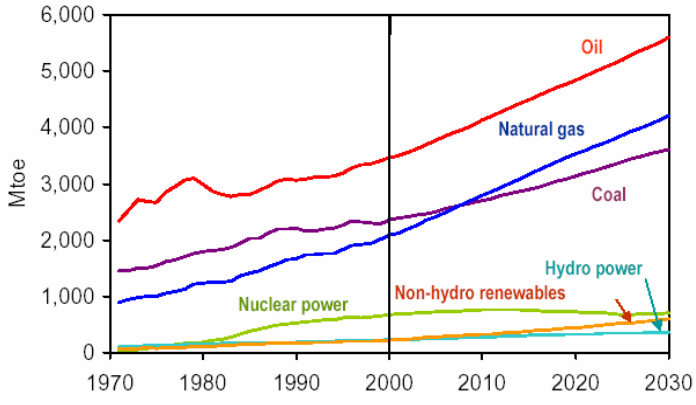



*Figure 3* World Primary Energy Demand [1]

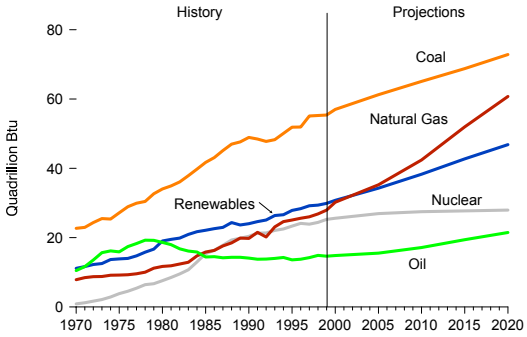



*Figure 4* Energy Used for Electricity Generation by Fuel [3].

Forecasts of energy demand of the world increase the use of fossil fuels (Fig.3), insignificant increase of renewable and decreasing of nuclear energy share in the world energy mix. The picture is similar in the electricity production (Fig.4). Consumption of oil increase, despite its share is least, by the total energy mix is the main energy source. The consumption of natural gas will increase faster. It is expected that the electricity production by gas stations will exceed this from renewable (including hydro) in the next 5 years.

## 2 MAIN OUTSTANDING ISSUES OF PRESENT ENERGY MIX

There are currently two problems which are insuperable in the present energy mix. They are:

- **Increasing energy dependence**. This problem is determined by permanent increase of oil and gas consumption from one side and by exhaustion of the profitable reserves - from another.
- **Global warming and climate change**. They are determined by using fossil fuels, which are main energy sources now and are projected to be the same in the new century.

**It is clear now, that the environmental crash caused by global warming can not be avoided but we could only mitigate the consequences to the Earth. Their solution can`t be postponed any more.**

Independent international analysis is necessary to be made for adequate and in time solution.

## 3 INCREASING OF ENERGY DEPENDENCE AND NUCLEAR ENERGY AS POSSIBLE SOLUTION

### 3.1 Exhausting of world energy reserves and possibilities for enlarge of energy base

The energy sources, used to that moment, are exhausting with increasing rate. To the end of this century the main of them – oil and natural gas will be totally exhausted. The coal and uranium will be exhausted in the next century. Renewables were at the center of the energy discussion at the World Summit on Sustainable Development in Johannesburg (26 August – 4 September 2002). In 2000, renewables accounted for 13.8% of the 9958 Mtoe of World Total Primary Energy Supply (TPES). Combustible renewables and waste (97% of which is biomass, both commercial and non-commercial) represented almost 80% of total renewables followed by hydro (16.5%) [4].

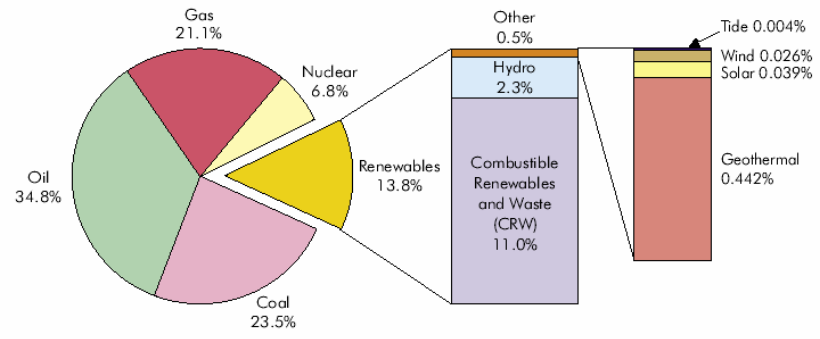



*Figure 5* 2000 Fuel Shares of World Total Primary Energy Supply [4]

Including Combustible Renewables and Waste (CRW), in a scenario assuming the continuation of present government policies and no major breakthrough in technologies, renewables would grow by 1.3% per year (below the 1.7% overall growth of the total energy demand) over the next 30 years.

In this scenario, the world share of renewable energy would decline from 13.8% in 2000 to 12.5% in 2030. This is principally due to a slowdown in the growth of CRW (to 0.8% p. a.), caused by the shift from traditional biomass to modern forms of energy in developing countries, and some reduction in the growth of hydropower (to 1.6% p. a.). Other (or "new") renewables will show the fastest growth (at 4.1% p. a.), but because their very low start they still will remain the smallest component of renewable energy in 2030.

Total renewables supply experienced an annual growth of 2% over the last 30 years, almost identical to the annual growth in TPES. However, the "other"category in the chart above (also referred to as "new" renewables and including geothermal, solar, wind, etc.)had recorded much higher annual growth of 9%. Due to the very low base in 1971 and up to the recent fast growing development, wind had experienced the highest increase (+52% p.a.)and is followed by the solar (+32% p.a.).

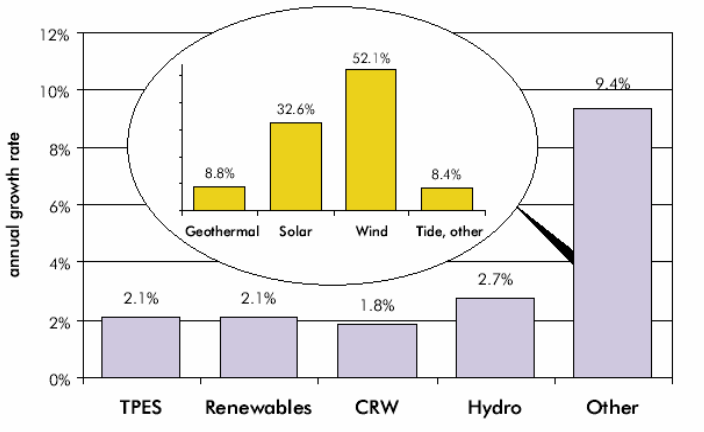



*Figure 6* Annual Growth of Renewables Supply from 1971 to 2000 [4]

World capacity of the main share of renewable – hydro, is limited and will be assimilated totally soon in this century. World capacity of another renewable are limited too and may be assimilated after some centuries.

**The most abundant renewable - wind and solar energy - can not be basic for reliable energy system in national, regional and global measure because of their natural variability and very low capacity factors and some ecological issues such as needs of huge areas for their set up**. For this reason, the renewable will have only a little share in total energy production.

Energy reserve of fission nuclear energy can be increased many times by using of breeder reactors and closed fuel cycle (Fig.7).

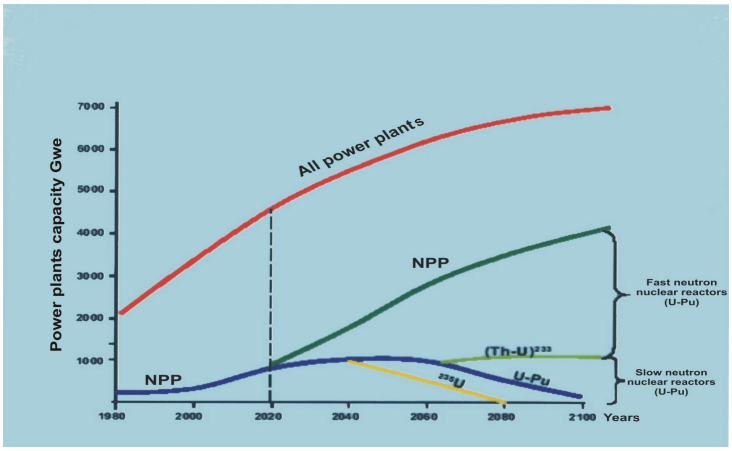



*Figure 7* Energy reserves for development of nuclear energy with fast neutron reactors [5]

Fission nuclear energy on breeder reactors technology can ensure the main share of energy needs of mankind for many centuries ahead.

Fusion energy based on the nuclear synthesis can ensure energy needs of human civilization for hundred centuries ahead.

## 3.2 Increasing of world energy dependence

The world`s oil import dependence increases fast and is one of the most important issues of the global policy now (Fig.8). Dependence from oil import is the highest for OECD Pacific countries – above 90%. We could expect the same for South Asia and OECD Europe countries in the next 30 years. This terrible dependence of developed and fast developing countries as China from a few countries in which territories

world`s oil and gas reserves are concentrated, lead to more and more conflicts among them. But these conflicts could not solve the problems. They will make them deeper. Energy supplies will become more and more insecure.

Nuclear power plants operate with significant less fuel than any other. The nuclear fuel is being refueled once in a year or in several years. Because of the comparatively low price and volume we can ensure reserves for many years ahead. This possibility made nuclear power plants guarantor for the high national and regional energy security.

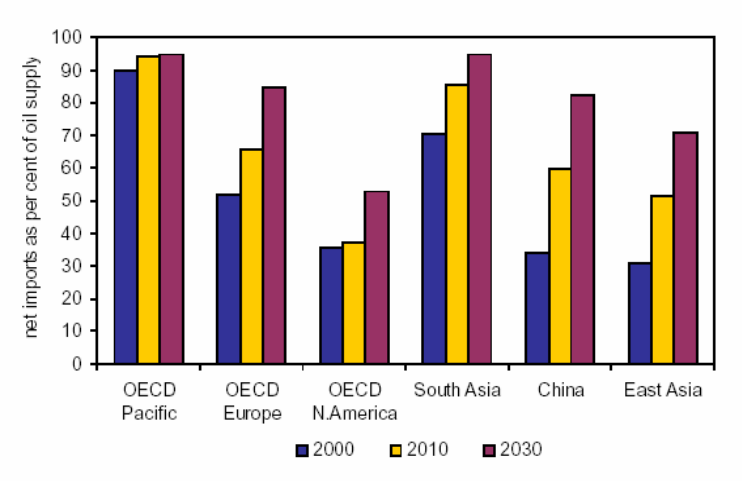



*Figure 8* Oil-Import Dependence [1]

## 3.3 Utilization of different energy sources

The main performance of any energy production system is its level of utilization – average annual capacity factor (Fig.9). For NPP this factor permanently grows up. It reached 80% in the 1999 in OECD countries (Fig.10). For some countries it reached 90% (USA for example). For renewable it is about 30%. Its capacity factor is about 3 times less than NPP and coal plants capacity factor. Renewable can achieve higher capacity factor by more broad local application in the near future by hydrogen production. Hydrogen can be used as energy source in fuel cells for transport purposes and for electricity production in selected time or as heating generation secondary energy source.

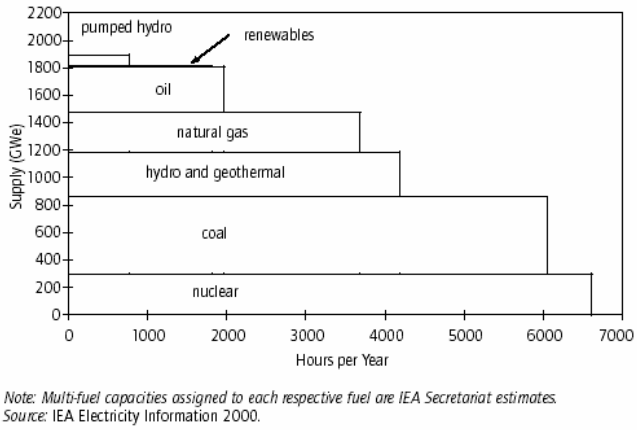



*Figure 9* OECD Electricity Supply Curve, 1998 [6]

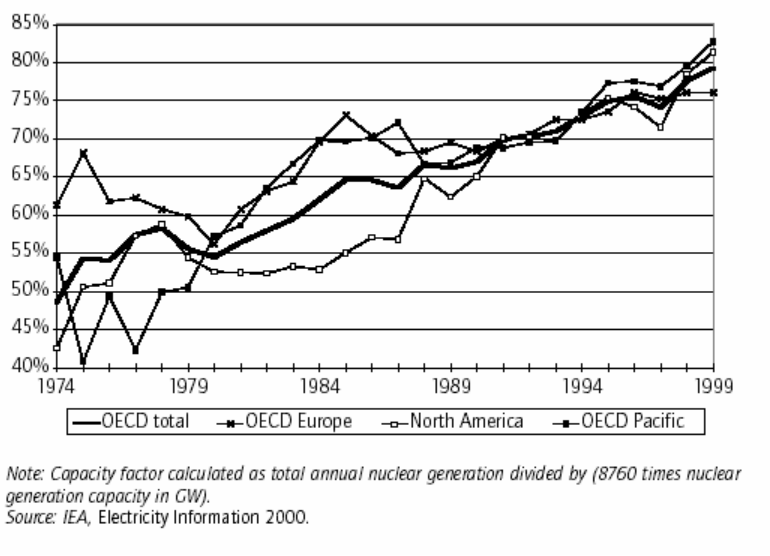



*Figure 10* Nuclear Plant Gross Capacity Factors, OECD Regions,1974 to 1999 [6]

## 3.4 Production cost of electricity from different energy sources

Another extremely important energy source performance is the production cost of the electricity produced by them (Fig.11). There is a stable decrease of production cost of electricity by NPP and coal plants. The production cost of electricity by plants using oil and natural gas has increased in the last years. This increase can be explained with (Fig.12) higher production cost sensitivity connected with increasing of the fuel price for plants using oil and gas than this of NPP and coal plants.

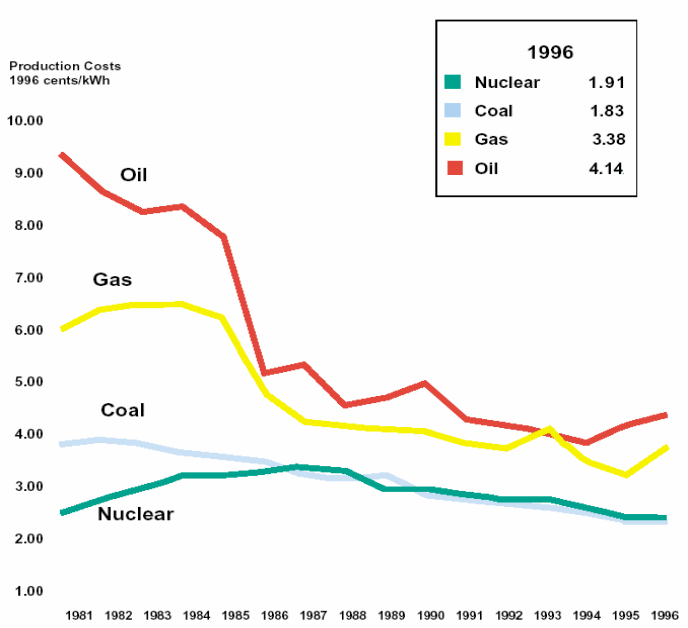
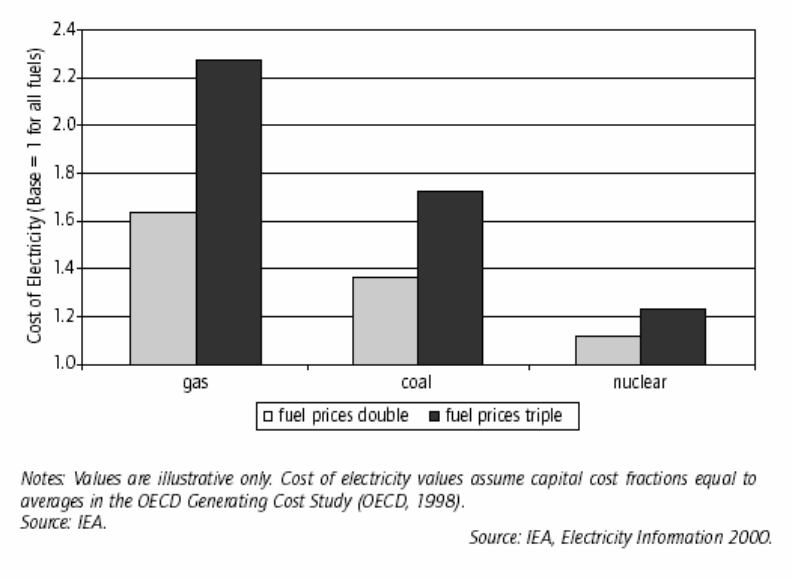



*Figure 11* U.S. electricity production cost [7]




*Notes: Values are illustrative only. Cost of electricity values assume capital cost fractions equal to averages in the OECD Generating Cost Study (OECD, 1998).*
*Source: IEA.*

*Source: IEA, Electricity Information 2000.*

*Figure 12* Sensitivity of Generation Cost to Fuel Price Increases [6]

**Future exhausting of oil and gas reserves will lead to firm increasing of production cost of electricity in plants operated with these fuels.**

The last research of the International Energy Agency is to confirm the above statement (Fig.13). **Forecasts for the near future are that the production cost of electricity energy from NPP will be similar to this from coal plants and in some cases it will be lower. This price in all cases is about double times lower compared to this from gas plants.**

| | Nuclear | Coal | Gas |
|---|---|---|---|
| Canada | 0.8 | 1.9 | 2.2 |
| Finland | 1.5 | 2.3 | 3.0 |
| France | 1.5 | 3.3 | 3.9 |
| Japan (1) | 3.2 | 3.2 | 4.0 |
| Korea | 1.4 | 2.3 | 3.7 |
| Spain | 1.9 | 2.9 | 4.1 |
| Turkey (2) | 1.3 | 0.9 | 2.7 |
| United States (3) | 1.5 | 1.4 | 2.0 . |

*(1) Japanese costs for gas-fired plants assume zero natural gas price escalation.*
*(2) Turkey has no operating nuclear power plants.*
*(3) US nuclear plant costs are based upon a design expected to be available by 2005.*
*Notes: Costs are projected for commercially available power plant designs entering service in 2005. These costs include O&M and fuel cost.*
*Source: OECD, 1998.*

*Figure 13* Projected Operating Costs of Power Plants (US cents/kWh) [6]

# 4 GLOBAL WARMING

## 4.1 Global warming related to human activities

The global warming of the Earth becomes more and more evident (Fig.14). It is very well known that carbon dioxide is the main one. It is emitted by burning of fossil fuel in transport vehicles, heat and electricity generation plants (Fig.15).

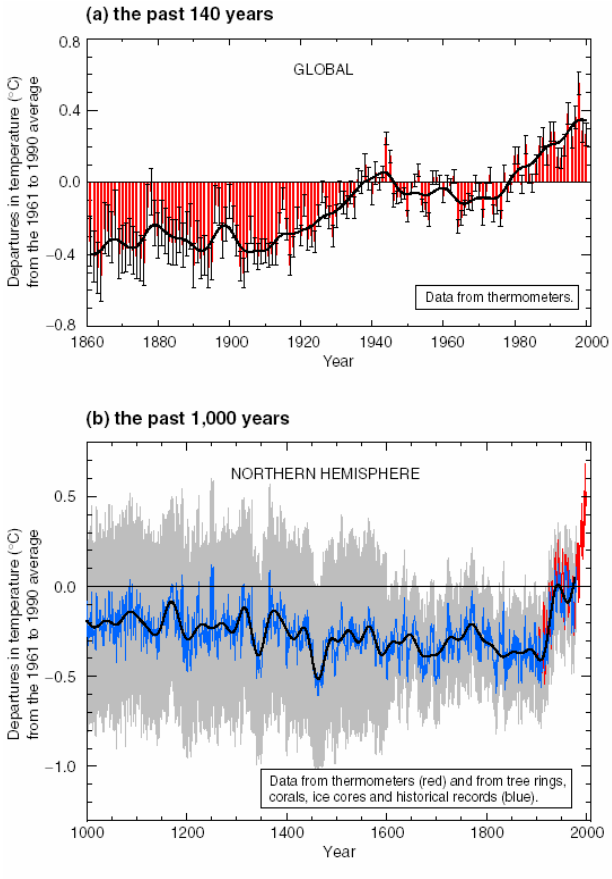



*Figure 14* Variations of the Earth's surface temperature for [8]

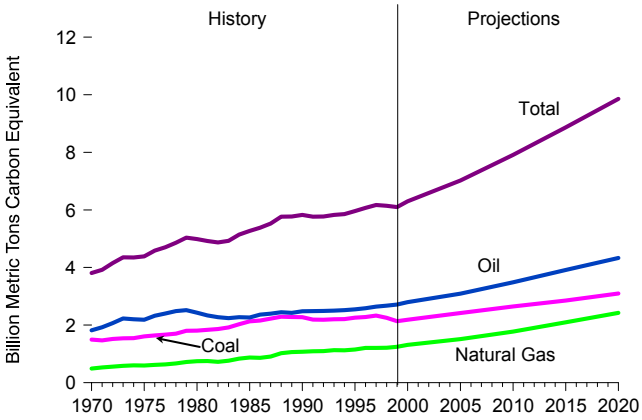



*Figure 15* World Energy-Related Carbon Emissions by Fossil Fuel Type [3]

Six billion tones carbon dioxide have been emitted in 2000. 2.3 billion tones are due to the burned liquid fuels, 2 billion tones – to the burned coal and about 1.7 billion tones – to the burned natural gas.We have witnessed catastrophic floods in Europe in the last years and unrecorded severe swelter. This, at least, must change the view of some scientists that these climate changes in the last 15-20 years are not related to the human activities..

## 4.2 Expectations for future carbon dioxide emissions

The trends are terrible. It is expected carbon dioxide emissions to increase with above 60% to 2020 and to exceed 10 billion tones per year.

The global warming has just started. But carbon dioxide emissions exceed several times accepted for sustainable levels for annual emissions (Fig.16):

- the level of sustainable development in 2050 must be 0.27 tones per capita;
- present world average emission is more than 4 times sustainable level – 1.21 tones per capita;
- currently USA exceeds 30 times sustainable level.

The expectations are that China and India will emit huge amount of carbon dioxide when they achieve the USA level of power consumption per capita. This will happen because Kyoto protocol does not obligate them to mitigate their harmful emissions.

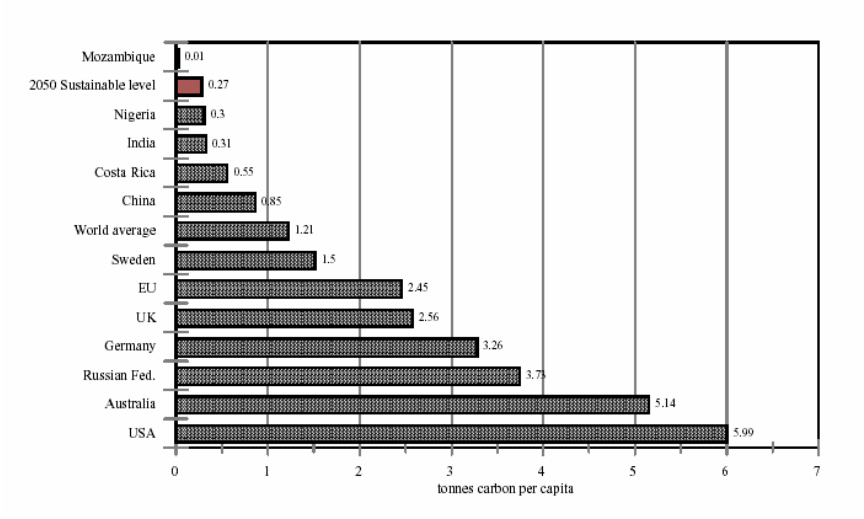
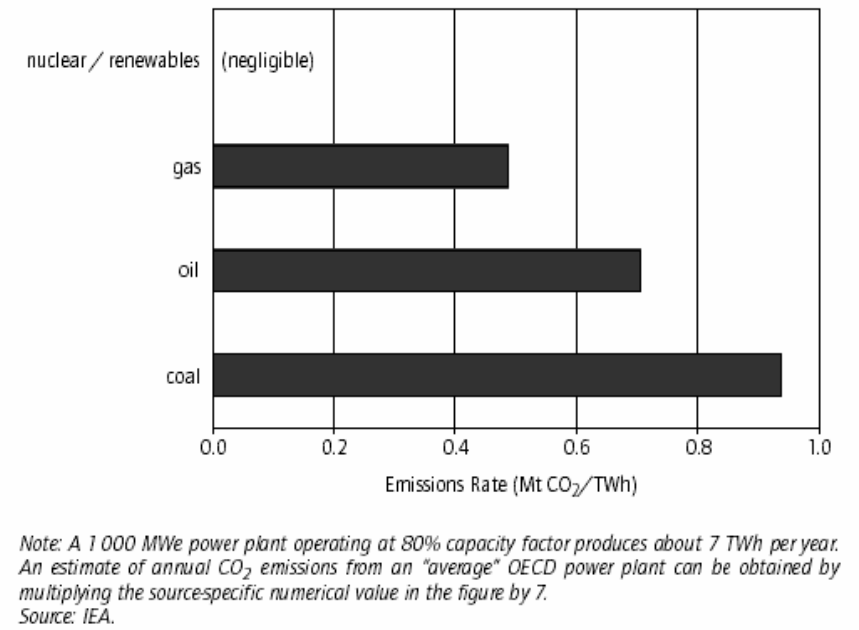



*Figure 16* Per capita emissions in 2000 and 2050 sustainable level [9]




*Note: A 1 000 MWe power plant operating at 80% capacity factor produces about 7 TWh per year. An estimate of annual $CO_2$ emissions from an "average" OECD power plant can be obtained by multiplying the source-specific numerical value in the figure by 7.*
*Source: IEA.*

*Figure 17* $CO_2$ Emissions by Electricity Generation Source in the OECD, 1998 [6]

Coal plants are emitting about 950 000 kg carbon dioxide by a TWh electricity production(Fig.17). Liquid fuels – 700 000 kg and natural gas – 500 000 kg. **Nuclear energy emits almost nothing in its life circle.**

## 4.3 The good practices and proposals

It is necessary to undertake urgent global actions for mitigation and elimination of the agents of global warming. **World needs fast and aggregate implementation of clean energies**. These energies are the nuclear and renewable.

France has showed the largest world experience on this way, changing fossil fuels with clean energy (Fig.18). Carbon dioxide emissions are so less as the share of nuclear energy in the total energy mix is broader. French experience has been proposed to all over the world. The USA Government had made series of analysis, which define the main directions of the new American energy policy.

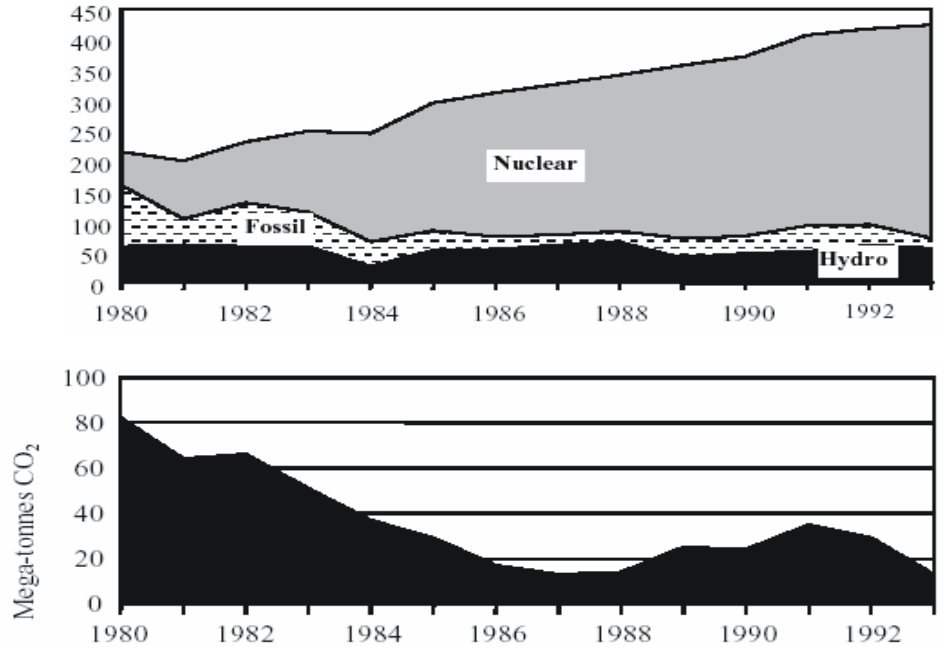



*Figure 18* Electricity generation by different fuels and carbon dioxide emissions by EdF [10]

**The main opportunities for reduction of carbon dioxide is by increasing the usage of clean energies, such as nuclear energy, renewable and "clean" coal for electricity production and changing transport fuels with hydrogen.**

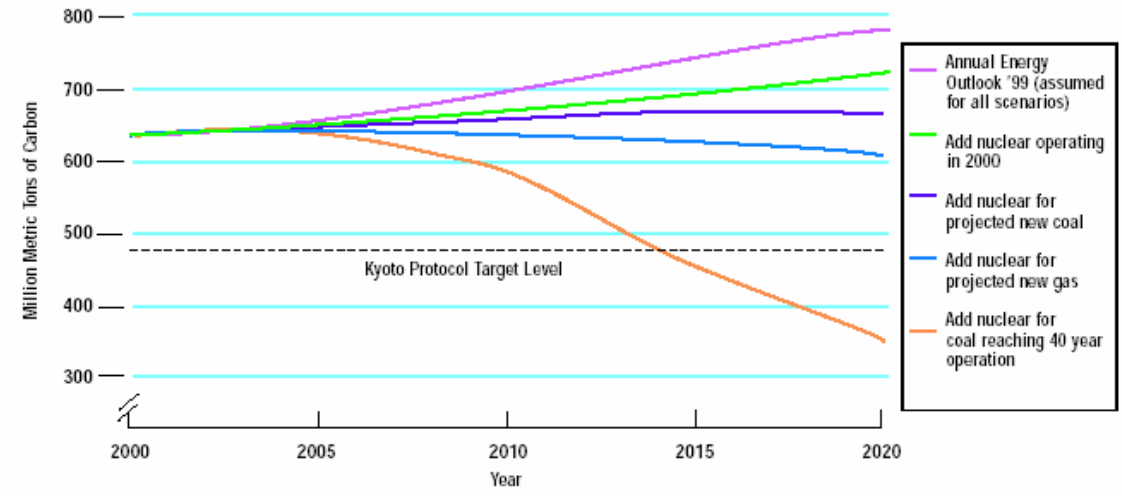



*Figure 19* Reducing Carbon Emissions Through Increased Reliability on Nuclear Energy [2]

The most effective activity is the replacement of the old coal plants (more than 40 years old) with new nuclear capacities (Fig.19). In the USA the age of coal plants is twice bigger than that of the nuclear plants (Fig. 20). The other countries, using nuclear energy are in the same position

**Such strategy is very useful for countries, where the production cost of electricity from coal plants is higher or similar to this from NPP (Fig.11).**

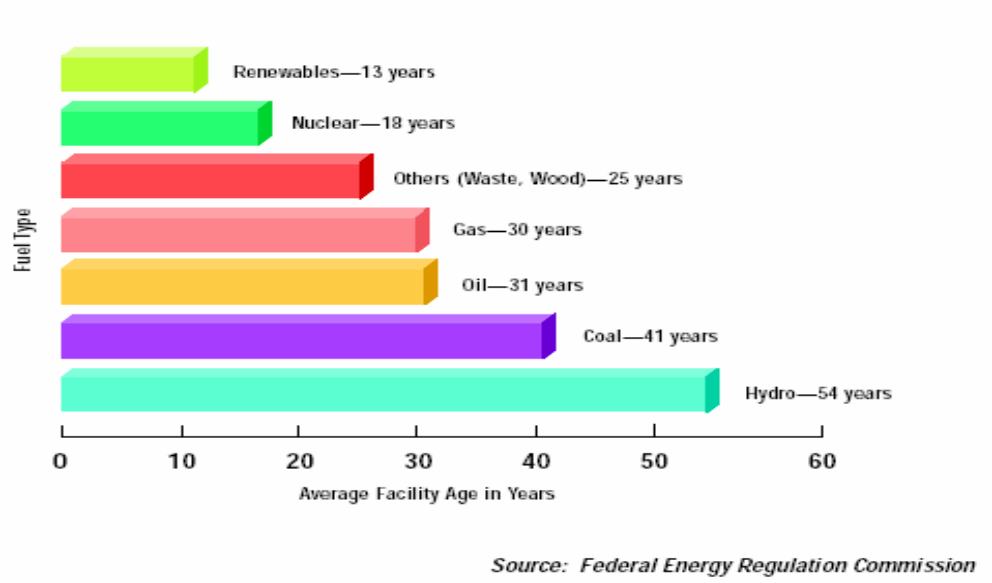



*Figure 20* Average Power Plant Age by Fuel Type [2]

## 4.4 From Sahara to Siberia climate and reverse

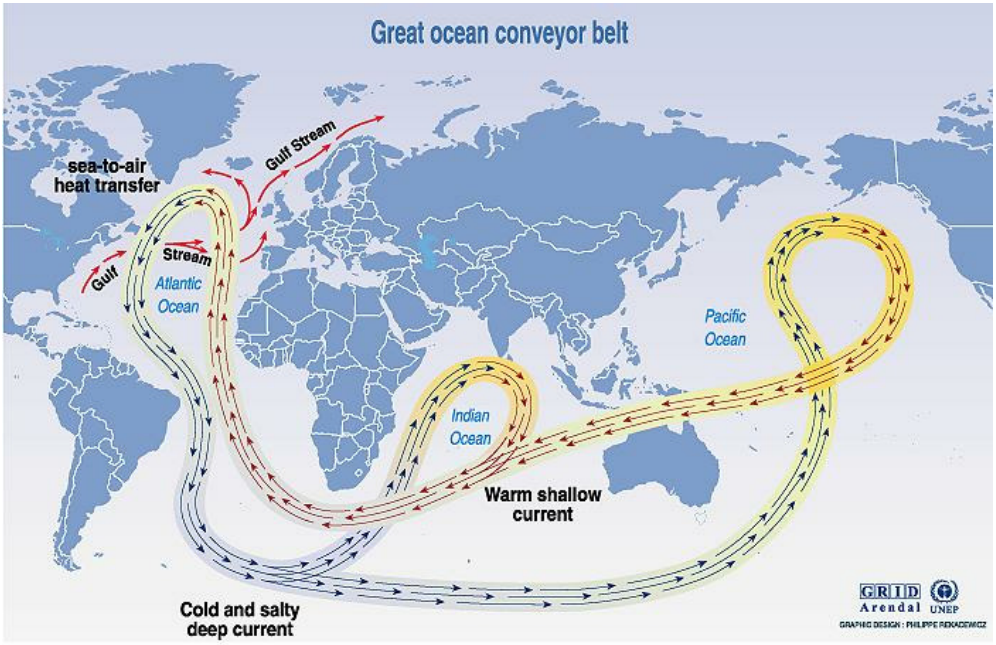
Most of the studies and debates on the potential climate change, along with its ecological and economic impacts, have focused on the ongoing buildup of industrial greenhouse gases in the atmosphere and a *gradual* increase in global temperatures. This way of thinking, however, fails to consider another potentially disruptive climate scenario. It ignores recent and rapidly advancing evidence that Earth's climate repeatedly has shifted *abruptly* and *dramatically* in the past, and is capable of doing so in the future.

A 2002 report by the US National Academy of Sciences (NAS) said, "available evidence suggests that abrupt climate changes are not only possible but likely in the future, potentially with large impacts on ecosystems and societies" [11].

The oceans also play a pivotal role in the distribution and availability of life-sustaining water throughout our planet. Changes in ocean circulation or water properties can disrupt this hydrological cycle on a global scale, causing flooding and long-term droughts in various regions.

The global conveyor belt thermohaline circulation (Fig.21) is driven primarily by the formation and sinking of deep water (from around 1500m to the Antarctic bottom water overlying the bottom of the ocean) in the Norwegian Sea. This circulation is thought to be responsible for the large flow of upper ocean water from the tropical Pacific to the Indian Ocean through the Indonesian Archipelogo. The two counteracting forcings operating in the North Atlantic control the conveyor belt circulation: (1) the thermal forcing (high-latitude cooling and the low-latitude heating) which drives a polar southward flow; and (2) haline forcing (net high-latitude freshwater gain and low-latitude evaporation) which moves in the opposite direction. In today's Atlantic the thermal forcing dominates, hence, the flow of upper current from south to north.

When the strength of the haline forcing increases due to excess precipitation, runoff, or ice melt the conveyor belt will weaken or even shut down. The variability in the strength of the conveyor belt will lead to climate change in Europe and it could also influence in other areas of the global ocean.




Source: Broecker, 1991, in Climate change 1995, Impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

*Figure 21* The Global Ocean Conveyor

A report [12] prepared by the Pentagon (headquarters of the US Department of Defence) warns **that climate change may lead to global catastrophe costing millions of lives and is a far greater threat to the US than terrorism**. Most significantly, it says climate change should be considered "immediately" as a top political and military issue that "should be elevated beyond a scientific debate to a US national security concern." "Future wars will be fought over the issue of survival rather than religion, ideology or national honor" And it envisions the need to turn the US and other rich western countries into "fortresses," armed against an angry tide of people displaced by rising sea levels or unable to grow food..

# 5 TECHNICAL AND POLITICAL BASE FOR NUCLEAR ENERGY AND SUPPORT OF HYDROGEN ECONOMY

As a result of the analysis of increasing energy dependence, global warming, particular the terrible consequences from expected abrupt climate changes, the politicians were forced to accept the fundamental conclusion for world energy system as that:

**In structuring of new global energy mix the nuclear energy has not alternative, which can meanwhile ensure energy secure and sustainable development. It is only basis for wide production of hydrogen by electrolysis and thermo chemical processes.**

This conclusion was under review by the world`s political leadrs . The consecution of the initiatives and decisions follows, which has been established as a base for revival of world`s nuclear energy and the start up of the hydrogen economy.

## 5.1 IAEA report for hydrogen as energy carrier and its production by nuclear power

In 1999 the International Atomic Energy Agency (IAEA) issued a fundamental report on hydrogen production by nuclear power [13].

Nuclear power is considered to be most promising $CO_2$-free energy technology with long-term fuel supply security. In 1996 the nuclear power plant installed worldwide saved impact on the atmosphere of 2.3 billion tons $CO_2$ corresponding to 8% of caused by human activities release. Principally used as base load power plants, nuclear off-peak electricity could be applied for hydrogen production. Other possibility is hydrogen production by new generation high temperature nuclear reactors by using of different thermochemical cycles.

The report describe a future large-scale hydrogen energy economy, in which nuclear power may play a significant role.

## 5.2 USA Vision for hydrogen economy

A plan for transition of USA to hydrogen economy [14], which foresee after 2010 wide hydrogen production through electrolysis by using of renewable and nuclear energy, and later – through water thermochemical dissociation with using nuclear energy (Fig.22).

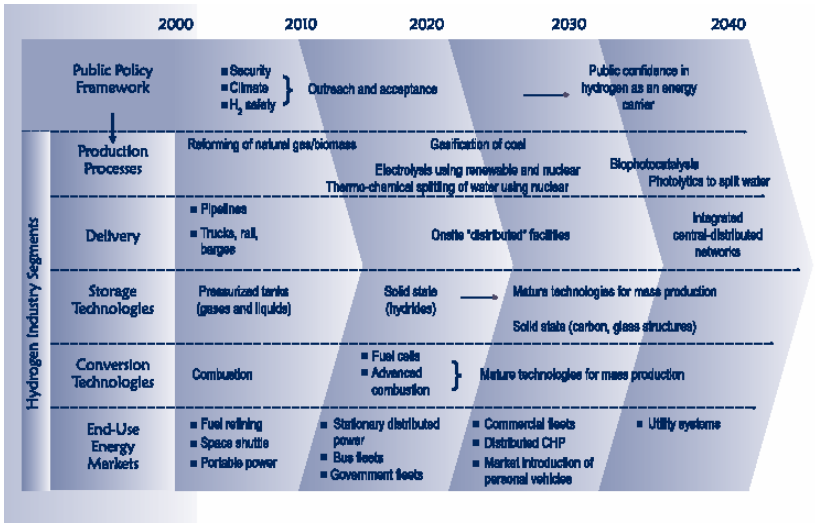



*Figure 22* Transition to the Hydrogen Economy [14]

## 5.3 European technology platform on hydrogen and fuel cells

On 20th of January 2004 President of the European Commission Romano Prodi launch The European technology platform on hydrogen and fuel cells [15]. It is projected nuclear power to play essential role in the production of hydrogen in the close future (Fig.23).

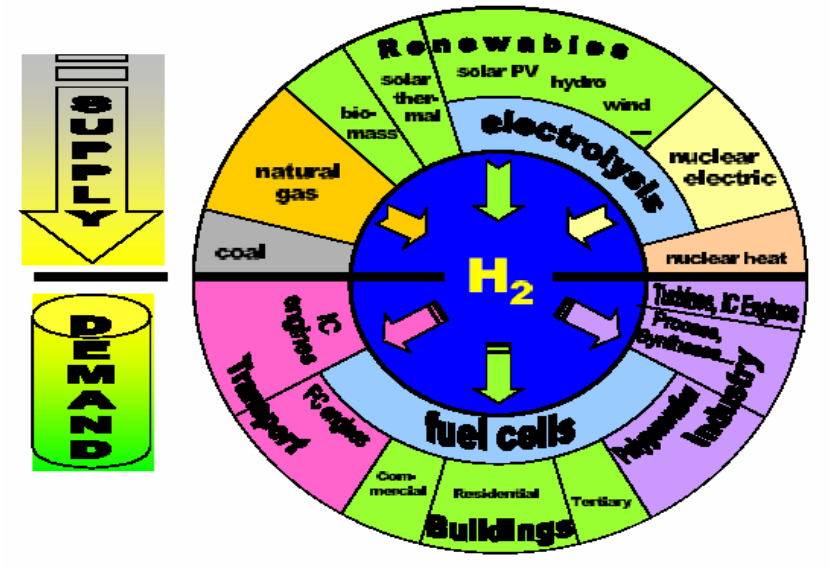



*Figure 23* European Commission vision for future hydrogen production and use

## 6 CONCLUSIONS

Nuclear energy used for electricity and hydrogen production has the biggest technological potential for solving of the main energy outstanding issues of the new century:

1. increasing of energy dependence;
2. global warming.

Because of good technological and economical performance political conditions must be created for adequate participation of nuclear energy in the future global energy mix.

Society must give chance to the nuclear industry to mitigate the catastrophic effects of climate changes caused by human activity.

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