Hydrogen energy development forecast

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Background

Hydrogen as the most frequent element in the nature is an energy carrier enabling to operate the most well known energy generators – stars of galaxies – for many billions of years. An example is the Sun providing energy for all living organisms on Earth. But hydrogen energy as a line of scientific and technical development was formed only in the middle of 70s in the last century. The problem is that the hydrogen doesn't exist in its elemental form on Earth and there are no hydrogen fields. The conducted researches on hydrogen generation, storage, transportation and utilization made obvious environmental advantages of hydrogen technologies in various fields of national economy. Carried engineering and economical researches has shown: despite the fact that hydrogen is the secondary energy carrier and is more expensive then natural fuels, its application in some cases is economically sound even now. So the hydrogen energy in many countries, especially industrially developed ones is considered to be a high-priority line of science and engineering development.

Aims

Hydrogen energy (hydrogen economy) allows to solve environmental, economical and social problems and at the same time ensures sustainable development and energy security of world community for a long-term perspective. This is the reason the hydrogen energy is acknowledged as a key-priority area (critical technology) almost in all developed countries, and intensive developments are underway in this sector with large-scale engagement of both budget financing in all developed and some developing countries and private investments. The global "green" movement fighting for conservation of climate and animal world on Earth also doesn't have any serious objections against development of hydrogen energy (hydrogen economy). Revealed nowadays advantages show that it has no alternative today and in foreseeable future.

Methods

The hydrogen differs from other energy resources both in terms of quality (energy intensity) and environmental cleanness. The last aspect gains more power as for the global climate change problem so for the local environmental problems: high concentration of toxic substances in the air of the large population centers, near stations of power and heat supply and large industrial enterprises.

The forecast of hydrogen energy development is based on the analysis of the history of hydrogen use knowledge and experience development with regard to different technologies, its application in various appliances and technologies of the hydrogen energy sector as well as on the analysis of the latest scientific achievements in promising areas of potential breakthrough technologies related to hydrogen energy.

When developing new hydrogen technologies in the USA, Germany, Canada and Russia there is applied the experience of rocket engineering, atomic and chemistry industry, special metallurgy, cryogenic and defenseindustry. Japan researches are based upon knowledge and experience of high technologies of electronic, electrical, metallurgic and metal-based manufacturing industries and cryogenic and aerospace engineering knowledge of foreign countries. To generalize all accumulated experience there is used opinions of experts engaged in different branches of science, engineering and ecology that are somehow associated with development of future energy technologies and which are closely related to the sustainable development of the mankind in the mid and long-term period, and the social responsibility of business.

The results

Depletion of conventional energy resources is not so critical yet and according to some estimations the oil and gas reserves will be sufficient for more than 100 years, coal – for 400 years, and nuclear fuel – for more than 1 000 years. However there is a decline in production of easily accessible energy carriers, consequently leading to an increase of oil and natural gas prices. This process is accompanied by the energy resource base changes (fig. 1).

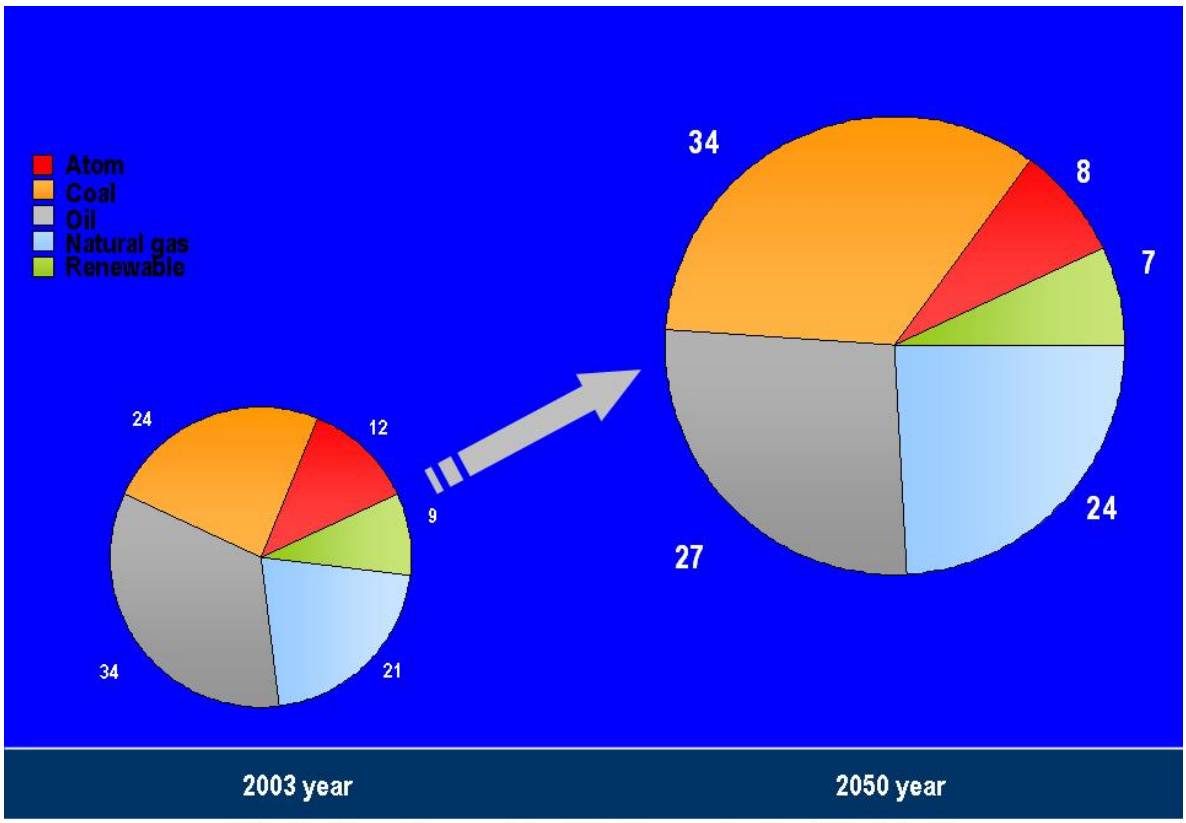

Fig.1. Structure of fuel balance in the World, %
(Under forecasts of International Energy Agency – IEA)

In particular, hydrogen production and consumption will grow (fig. 2, 3). The use of renewables, nuclear energy, coal and biomass will be significantly expanded. In the long term the energy of thermonuclear synthesis will receive substantial distribution. Carried out intensive scientific researches related to it are at the closing stage. The first semi industrial experimental energy installations must appear to the middle of this century. So then it will be possible to estimate real perspectives of essentially new World energy which at the same time represents one of the lines of the hydrogen energy development.

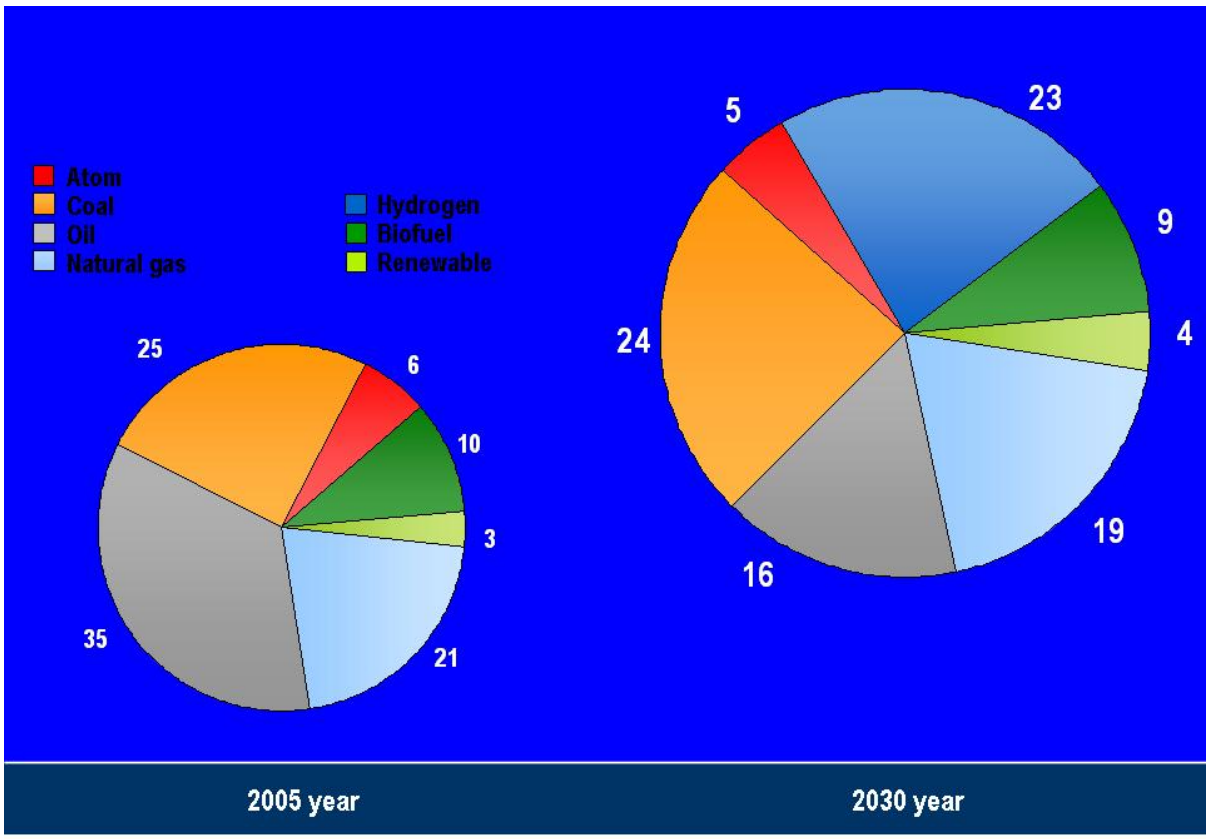

Fig. 2. Structure of the world power balance, %

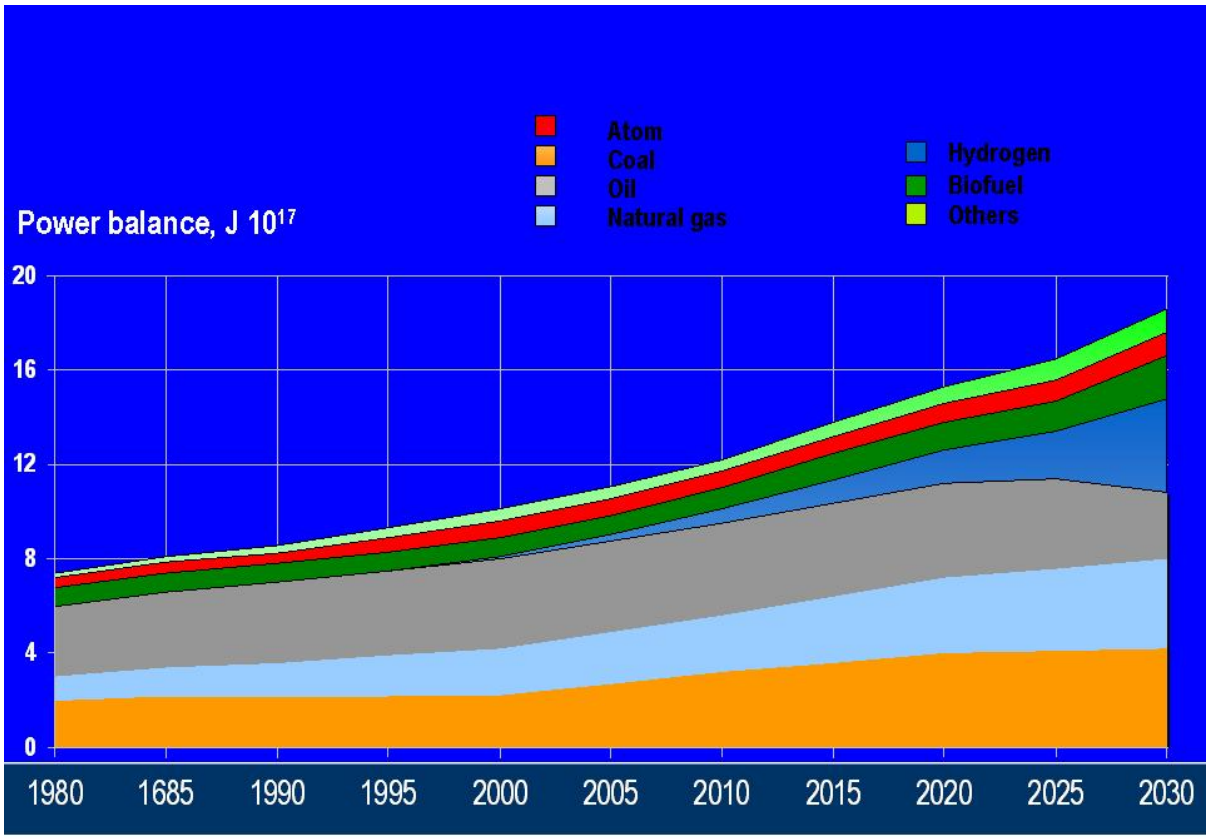

Fig. 3. Dynamics of the world power balance

However the growth of greenhouse gases emissions (fig.3) and global climate change along with a number of accompanying factors urgently demand transition to the hydrogen energy and economy.

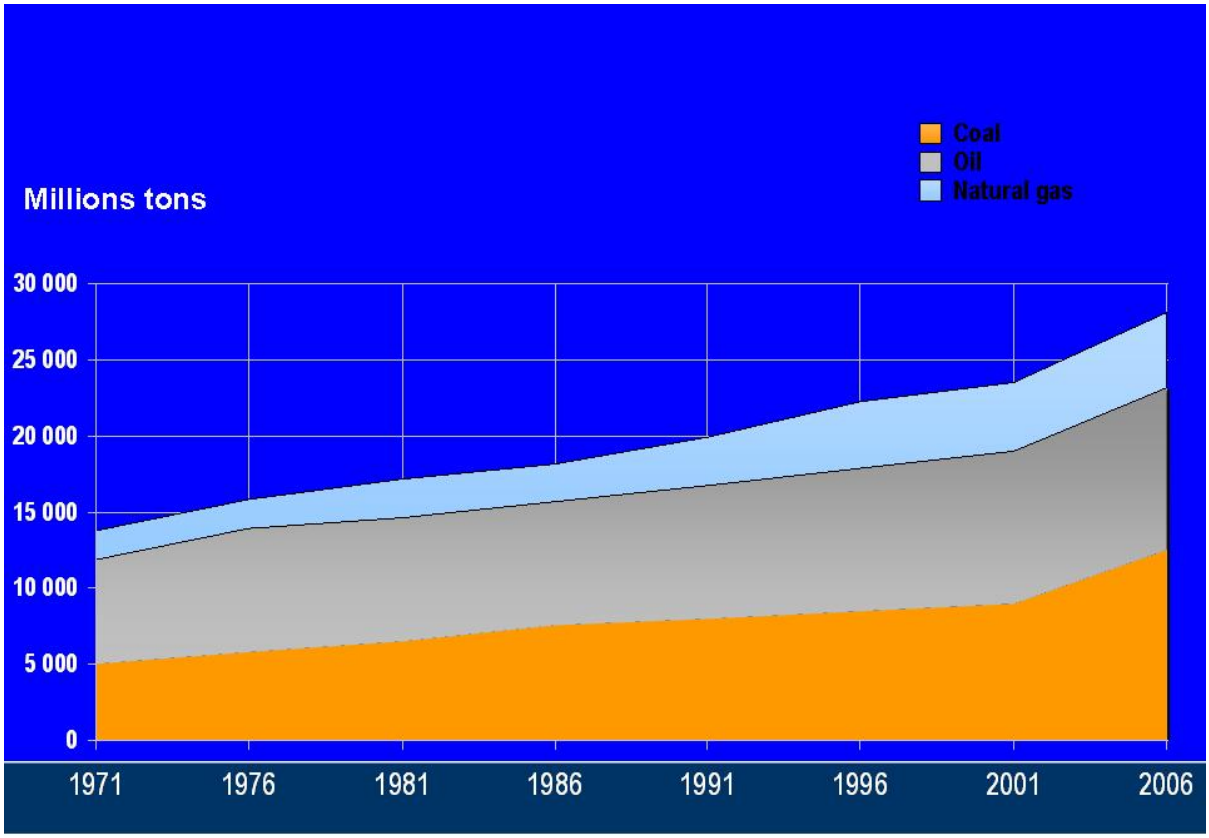

Fig. 4. CO_2 emission and its sources

The development of hydrogen energy and fuel cells – the foundation of hydrogen economy - propose to create new effective technologies and facilities for hydrogen production; its storage, transportation and distribution (generation of hydrogen infrastructure). Their foundations are being built up already now. Example – equipping highway at the border of the USA and Canada by hydrogen filling stations. And in the future we ought to solve a number of problems:

- providing hydrogen security (development of codes and standards)
- human resource development and retraining
- formation of public opinion (popularization of hydrogen energy)

At present the principle method of commercial hydrogen production is steam methane reforming (fig.4). This technology as well as other methods of production of hydrogen from organic fuel (partial oxidation, thermal destruction) is being successfully improved. But production of such energy-intensive and environmentally-clean fuel, as hydrogen, from other fuels cannot be considered as a successful scenario for a long term perspective.

Economic production of hydrogen from bioethanol (biomass) requires generation of new technologies and will meet hydrogen demand only in the small extent.

In the future the primary hydrogen method production will be associated with its production from water – indispensable source of hydrogen. We are talking about electrolysis, thermochemical and thermoelectrical cycles. Technologies with application of heat from reactors of different types and some other production facilities are very promising. These areas are the key ones in the programs of the USA, the European also Union, Russia and other developers of the hydrogen energy and economy.Intensive researches and development focused on hydrogen use as a fuel is in progress as well. Today we have extra power hydrogen fueled rockets designed to take up to 100 tons of cargo into space. There are actively upgraded and applied fuel cells capable to generate electrical and thermal power of high efficiency from compact installations.

The USA has appropriated 1 bln. dollars to develop a program of hydrogen fuel cell cars. The Europe's expenditures for development of hydrogen technologies and fuel cells exceeded 300 mln EURO and up to 2017 it is planned to spend 1 bln EURO. Russia still didn't clarify the extent of finances for similar researches on the mentioned period.

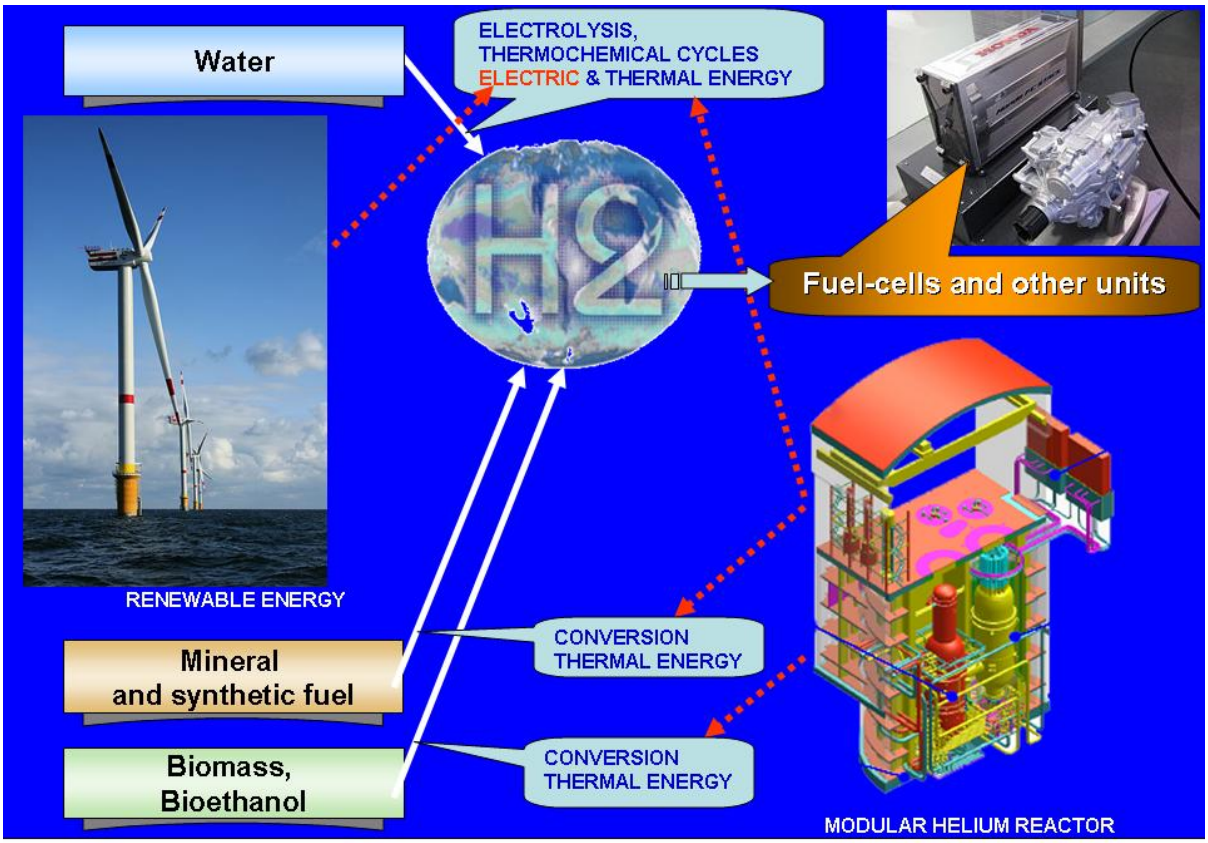

Fig. 5. The basic modern "know-how" of hydrogen

The USA National Hydrogen Energy Program *(National Hydrogen Energy Roadmap, November 2002)* contains the basic factors defining development of hydrogen energy (table 1)

Table 1

The main factors influencing the hydrogen energy development

Contributing factors	Obstructing factors	Contributing and obstructing factors
National energy security and the necessity to reduce oil import	Difficulties in creating and maintaining a national consensus on long-term priorities of the energy policies.	Rapid development of hydrogen and other competitive energy carriers.
Global climate change, the need to reduce and stabilize greenhouse gas and pollutant emissions.	Lack of hydrogen infrastructure and high cost of its development	Availability of relatively inexpensive fossil fuels and inevitable resource depletion
Global growth of population and economy	The lack of commercially available inexpensive systems for hydrogen production, storage and usage.	Consumers give preference to green and inexpensive energy supply
The need in new green energy at budget-conscious price	Hydrogen safety problems	
Air quality and the necessity to reduce pollutant emissions from transport and power plants	The demand in additional demonstration of carbon sequestration and inexpensive sequestration methods	

Reduction of hydrogen production costs is expected in 2015 and it will make up 2-3 dollars per kilogram (the objective of the USA Department of Energy). The mentioned price stems from the cost of one gallon of gasoline, which as energy carrier is equivalent to 1 kg of hydrogen. However the gasoline cost increase and higher efficiency of hydrogen production installations makes its production economically sound even today.

Europe has developed a program of transition to the hydrogen economy for the period up to 2015, this program in great part matches with the roadmap of the USA. One of its main priorities is to reduce consumption of hydrocarbon energy carriers in the total energy balance up to 50 % by 2020. Hydrogen price forecast according to the leading – edge technologies is shown in the table 2.

Table 2

The hydrogen production cost for different technologies

Resources	Technologies	Hydrogen prices (dollar/GJ)/ (dollar/kg)	Technology adoption year
Natural gas	Steam methane reforming, pressure swing adsorption (without sequestration)	5,54/0,75	Current
	Synthetic gas production using ion-conducting membrane, additional membrane separation, CO_2 sequestration	4,15/0,56	2013
Coal	Gasification, pressure swing adsorption (without sequestration)	6,83/0,92	Current
	Advanced gasification, membrane separation, CO_2 sequestration	5,89/0,79	2015
	Advanced gasification, membrane separation, energy production, CO_2 sequestration	3,98/0/54	
Biomass	Bio-oil pyrolysis by steam reforming	(9-16)/ (1,21-2,16)	
Nuclear	S-I cycle (thermochemical process)	9,70/1,31	2020
Electrolysis	At electricity cost – 4 cents/KWh	(19-22)/ (2,56-2,97)	Current

For Russia the hydrogen economy development (despite large natural gas and oil reserves) is crucial as well. According to energy consumption forecast for the period up to 2030 (fig. 5.) natural gas will play the leading role. The use of coal, nuclear and renewables, i.e. of all primary energy sources used for hydrogen production will be expanded. And at the same time the recognized idea that the gas is a transition fuel towards future hydrogen energy and economy will be actual.

This point of view generated by IGU and the leading world energy scientists is based on the fact that hydrogen energy is inherently tied with world gas industry and it forms the basis for transition towards world carbon free economy. The model of this transition has been partially worked at and was named hidricity.

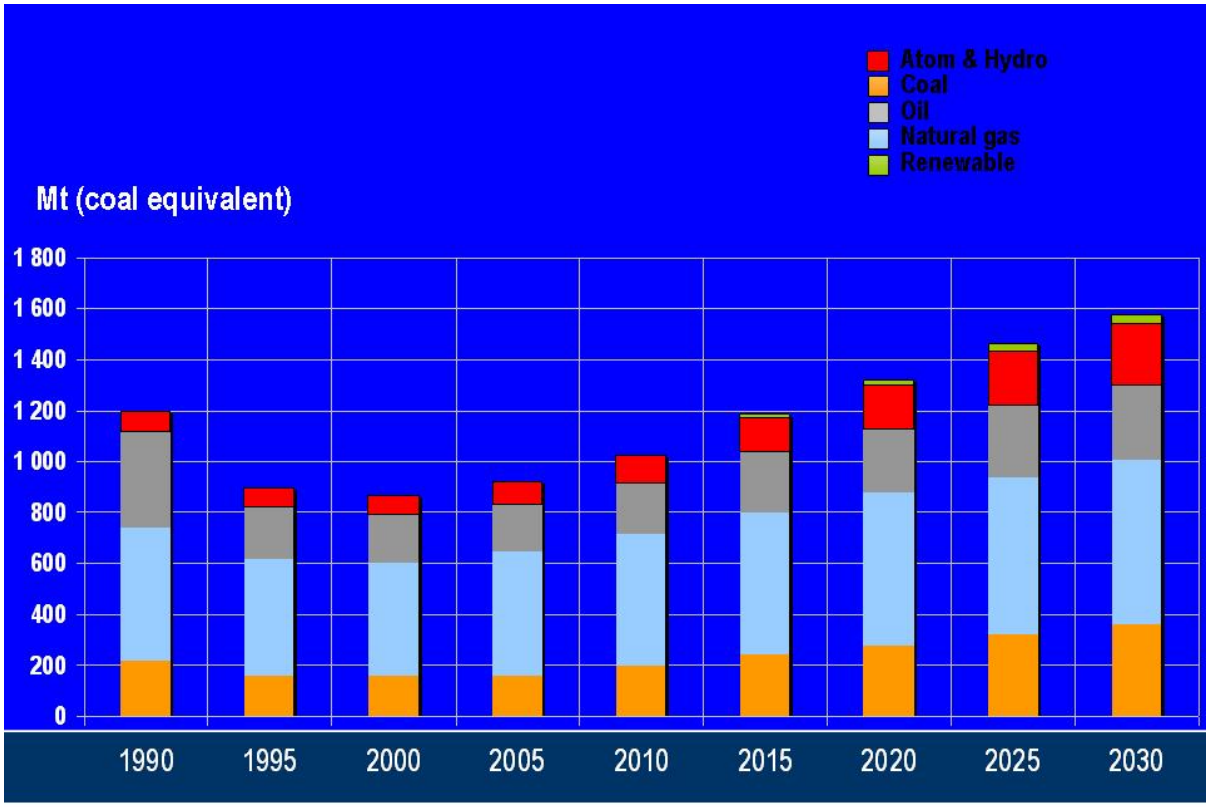

Fig. 6. Energy consumption in Russia
Rosstat data up to 2008 and the forecast of Russian Academy of Science

Interrelation of hydrogen and gas energy sectors

The hidricity model is:

1) production of hydrogen from methane;
2) gradual replacement of natural gas by hydrogen in existing distribution nets.

Commercial production of hydrogen is one of the requirements for the transition towards hydrogen energy – widespread use of hydrogen instead of hydrocarbons. Hydrogen combustion produces water and it makes new energy much safer for the environment. The transition to the new energy will be accomplished according to the hidricity model including hydrogen production from methane, underground disposal of carbon dioxide and use of hydrogen to produce energy free of GNG emission.

Hydrogen production from methane will certainly require significant amounts of energy, as far as it is an endothermic process. About half of this energy is preserved in the form of hydrogen as an energy carrier, and the same amount of energy is required for reaction itself. To eliminate greenhouse gas emission the energy required for this reaction may be produced by thermonuclear installations or by sun. But it will demand significant technological efforts and in fact may be provided only in the long-term perspective. The other energies including renewables will provide initial period for gradual transition to the hydrogen energy and development of its safe technologies.

The hydrogen produced from methane can be transported by existing pipelines or in the form of super refrigerated liquid. In addition today the option of hydrogen mixing with natural gas in pipelines with further separation is also considered. But the problem of hydrogen transportation still requires development due to the peculiarities of separation technologies or combined use. The economically attractive technologies for hydrogen separation from its mixture with natural gas (low-temperature, membrane or other economic separation technologies) are not completely finished.

When combusting mixture of hydrogen and methane with zero carbon dioxide emissions in the atmosphere we need a technology separating water vapors from carbon dioxide and further storage of the last one either in geological horizons or deep oceanic waters.

It is expected that the hidricity era may began in the mid-late XXI century due to a world energy lag effect. The shift towards hydrogen energy will require changes not only in technological processes but also in the way of thinking of the mankind in whole. The last objective is the goal of this paper.

Conclusion

So the hydrogen energy era is mostly achievable only in combination with gas energy which will provide time for technological breakthroughs related to production of economic hydrogen sources and will assure long-term energy production with minimal environmental impacts.

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