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STATUS AND PROSPECTS OF HYDROGEN POWER ENGINEERING IN THE REPUBLIC OF BELARUS

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Consideration is given to modern problems of development of scientific research in the field of hydrogen power engineering in the Republic of Belarus, the lines of investigations, and the prospects and problems facing research organizations.

Hydrogen power engineering is a promising lead for modern power engineering and industry, which is based on the utilization of hydrogen as an environmentally clean energy carrier. Hydrogen power engineering involves the development of methods and processes of large-scale production of hydrogen, the technologies of storage, transportation, and utilization of hydrogen in power engineering, industry, and transport with the use of electrochemical current sources (fuel cells). In Byelorussia, the first investigations of hydrogen and oxygen production from water on the basis of utilization of nuclear-reactor power were organized in 1971–1972 by A. K. Krasin, Academician of the BSSR Academy of Sciences in the Hydrogen-Power Laboratory at the Institute of Nuclear Power of the BSSR Academy of Sciences. In 1977, this laboratory formed part of the Institute of Heat and Mass Transfer of the BSSR Academy of Sciences. In 2003–2005, large-scale basic research in the field of hydrogen power was performed within the framework of the "Vodorod" State Program of Oriented Basic Research under the supervision of Academician S. A. Zhdanok. Investigations on different lines associated with the production, storage, and utilization of hydrogen, on the methods of conversion of hydrocarbon fuel with the use of a nonequilibrium plasma and superadiabatic filtration combustion in porous media, on the synthesis of carbon nanomaterials for systems of bound storage of hydrogen, on creation of low-temperature and high-temperature fuel cells, and on metrological support of work in the field of hydrogen power engineering are carried out in the National Academy of Sciences of Belarus. A number of demonstration setups realizing new high-efficiency technologies of production and utilization of hydrogen from methane and natural gases using plasma-membrane technology have been created at present; domestic structures of fuel cells for direct conversion of chemical energy to electric energy are being developed and systems for bound hydrogen storage in metal-hydride accumulators are being designed.

The concept of hydrogen power engineering has been the priority line of scientific investigations in the field of production, storage, transport, and utilization of hydrogen [1–9]. The progress made in the development of such hydrogen technologies as fuel cells, transport systems operating on hydrogen, metal-hydride hydrogen accumulators, microturbines, and cogenerating power plants has demonstrated that the utilization of hydrogen leads to qualitatively new indices in the operation of systems or units and, despite the fact that hydrogen is the secondary energy carrier and is more expensive than natural fuel, in certain cases its use is economically expedient even now, in particular, in the aerospace, atomic, and chemical industries, special metallurgy, the cryogenic and defense industries, and in power engineering as an environmentally clean energy carrier in the near future.

The production of inexpensive hydrogen and hydrogen fuel can be ensured by systems of high-efficiency conversion of a hydrocarbon fuel to hydrogen with the use of a nonequilibrium plasma and superadiabatic filtration combustion in porous media, high-temperature water thermolysis in specialized new-generation nuclear reactors, in high-efficiency electrolyzers with proton-exchange membranes, with the utilization of the energy of renewable energy sources, biogas, etc. Among the most critical components of hydrogen power engineering are the technologies of creation of electrochemical current sources with direct conversion of chemical energy to electric energy, i.e., fuel cells, including low-temperature cells with a solid-polymer electrolyte (PEM FCs) and with direct methanol conversion

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(DMFCs), high-temperature ones with a solid-oxide electrolyte (SOFCs), alkaline fuel cells (AFCs), and molten-carbonate fuel cells (MC FCs). The activity of worldwide scientific investigations in the field of solid-polymer fuel cells allows prediction of a rapid reduction in the cost of power-generating plants based on them and a growth in the efficiency and unit power of the plants (to 65–85% and 50–100 US dollars/kW for a power to 100–300 kW with a predicted service life up to 40,000 h or longer). No expensive catalysts are used in solid-oxide fuel cells, and, for a unit power of the plants to 1 MW with an electrical efficiency up to 60% and 80–90% in utilization of heat (service life longer than 20,000 h), they are the most promising, as the technology of manufacture of high-temperature ceramics is improved. The development of environmentally clean automobile transport operating on hydrogen fuel involves the creation of cars with hybrid and hydrogen power-generating plants, including those based on methanol or ethanol, and the development of the infrastructure of gas stations. The storage of hydrogen is assumed in cryogenic and metal-hydride systems, in high-pressure cylinders manufactured from composite materials, and in bound-hydrogen-storage systems based on carbon nanomaterials; the creation of reversing metal-hydride systems for production of hydrogen of high purity is planned. The development of hydrogen power engineering is largely determined by the formation of international and national environmental programs and by the quest of the leading states to ensure their energy security by abandoning the monopoly orientation to hydrocarbon fuels.

Water, coal, natural gas, and other kinds of fuel can be the basic raw materials for production of hydrogen and hydrogen fuel. As the primary energy source for production of hydrogen from water one can use solar energy, wind energy, or atomic energy. The existing technologies and technological units — internal-combustion engines, turbines, etc. — can be used for utilization of hydrogen and artificial fuels based on it. When electrochemical current sources are used, the efficiency of hydrogen as a fuel multiply increases. New energy-flow diagrams and hybrid power-generating plants enable one to abandon the traditional hydrocarbon fuel in power intensive industries. New technologies of hydrogen power engineering make it possible to produce, on a large-scale basis, inexpensive hydrogen as a valuable raw material and reactant. The resources of the raw material and the technologies (brought to a commercial level in large-tonnage chemistry) of synthesis of hydrogen-containing chemical compounds — ammonia, methanol, and some others — enable one to reduce the cost of the necessary infrastructure of delivery and filling with hydrogen and to use the optimum systems of its storage. Thus, methanol overperforms liquid hydrogen 1.5 times in volume density of hydrogen storage in the same manner as dimethyl ether (DME) produced from methanol for use on motor transport instead of diesel fuel, and, as the cost of natural gas increases 2 to 3 times, the hydrogen produced by methane steam conversion (MSC) will be a more inexpensive energy carrier than gasoline with the growing costs of hydrocarbon fuel. Hydrogen and hydrogen fuels (e.g., methanol) can be transported, stored, and accumulated in the same manner as traditional kinds of fuel. The supply of hydrogen bound in an organic substance and in water is virtually inexhaustible. The rupture of these bonds enables one to produce hydrogen and to subsequently utilize it as a fuel. Numerous processes on decomposition of water into the component parts have been developed. In heating above 2500^{o}C, water decomposes into hydrogen and oxygen (direct thermolysis). This high temperature can be obtained, e.g., using solar-energy concentrators.

Most of the hydrogen produced worldwide on industrial scale is formed in the process of MSC. Hydrogen produced in such a manner is utilized as the reactant for petroleum refining and as the component of nitrogen fertilizers and for rocketry. Steam and thermal energy at temperatures of $750–850^{o}$C are necessary for separating hydrogen from the carbon base in methane, which occurs in chemical steam reformers on catalytic surfaces. The first step of the MSC process splits methane and steam into hydrogen and carbon monoxide. In the second step, the "shift reaction" transforms carbon monoxide and water to carbon dioxide and hydrogen. This reaction occurs at temperatures of $200–250^{o}$C.

However, the main attention of researchers, development engineers, and investors is attracted to fuel cells. Fuel cells (electrochemical generators — ECGs) represent the type of technologies using the reaction of oxidation of hydrogen in a membrane electrochemical process which produces electricity, thermal energy, and water. Quite perfect ECGs have been used in space technologies. Fuel cells for cars and buses are being successfully developed for the next generation of transport facilities and for independent power-supply systems.

It is potentially efficient to store hydrogen in hydrides, i.e., chemical compounds of hydrogen with other chemical elements. Storage systems based on magnesium hydrides are currently being developed.

With the aim of developing hydrogen-power technologies, the State Program of Oriented Basic Research (SPOBR) "Investigation of the Physicochemical and Biological Processes of Production, Storage, Transport, and Utilization of Hydrogen in Power and Technological Systems" ("Vodorod") for 2003–2005 was formulated in the Republic of Belarus in 2003; the prime objective of the program was organization of large-scale basic research in the field of hydrogen power engineering and designing and manufacture of prototypes of power-generating plants that meet world standards. The State customer of the program was the National Academy of Sciences of Belarus; the leading organization was the State Scientific Institution "A. V. Luikov Heat and Mass Transfer Institute" of the National Academy of Sciences of Belarus. The participants of the program were 16 organizations, including 13 from the National Academy of Sciences of Belarus. The program of investigations was formulated according to the thematic sections:

1. Physicochemical and biological methods of production of hydrogen.
2. Scientific foundations and principles of creation of the promising methods of transportation and storage of hydrogen.
3. Development of hydrogen-utilization systems.
4. Development and production of fuel cells.
5. Economic aspects of hydrogen power engineering.

In the process of realization of the objectives of the program, the concept of development of hydrogen power engineering in the Republic of Belarus over the period from 2003 to 2020 has scientifically been substantiated; this concept was reflected in the concept of the National energy security of the Republic of Belarus.

The results of investigations on the majority of sections actively influence the creation of new high-efficiency power technologies and technologies of synthesis of new materials, primarily nanocatalysts, the creation of new measuring systems, and the metrological support of scientific investigations.

Further development of scientific investigations and the introduction of results obtained in carrying out the "Vodorod" SPOBR are allowed in carrying out the State Program of Applied Scientific Research (SPASR) "Investigation of the Physicochemical Processes of Production, Storage, and Utilization of Hydrogen in Power and Technological Systems" ("Vodorod") in 2006–2010 (leading organization A. V. Luikov Heat and Mass Transfer Institute of the National Academy of Sciences of Belarus, scientific coordinator Academician S. A. Zhdanok, State customer the National Academy of Sciences of Belarus).

With the aim of ensuring the energy security of the Republic of Belarus and within the framework of the "Vodorod" SPASR, basic scientific research and the development of prototypes and design plans and specification proceed along in the following lines:

(1) development of prototypes of high-efficiency industrial reactors for production of synthesis gas;

(2) creation of high-efficiency systems for production of hydrogen of high purity;

(3) development of promising nanostructured catalysts for the needs of hydrogen power engineering and the chemical industry of the Republic of Belarus;

(4) creation of prototypes of low-temperature and high-temperature fuel elements;

(5) development of prototypes of high-efficiency electrolyzers utilizing the energy of renewable and low-potential energy sources;

(6) development of bound-hydrogen-storage systems based on metal-hydride accumulators and carbon nanomaterials.

Realization of the objectives of the "Vodorod" SPASR in 2006–2010 will make it possible to:

(1) create prerequisites for ensuring the energy security of the Republic of Belarus due to the possibility of high-efficiency utilization of all kinds of domestic natural fuel and renewable energy sources according to a unified technology;

(2) organize, in the Republic of Belarus, a high-tech infrastructure for distributed environmentally clean generation of electric and thermal energy directly at the sites of its consumption with the use of local raw-material and fuel resources;

(3) create high-efficiency import-substitution technologies and high-tech export-oriented industries.

The "Vodorod" SPASR is aimed at creating new scientific and technical decisions and the latest power technologies capable of ensuring the world standards of the national power engineering in the process of complex development of related industries: machine construction, instrument manufacture, and the chemical industry.

A distinctive feature of the program is realization of a number of objectives involving large international research teams from France, Bulgaria, Ukraine, and Russia within the framework of developing scientific cooperation of the 7th Framework Program of the European Council and bilateral programs of collaboration with the academies of science of the CIS countries.

Today, in Russia, the problems of development of hydrogen power engineering are taken up, along with organizations of the Russian Academy of Sciences, by such companies and organizations as the "UES of Russia" Russian Joint-Stock Company, the "Gazprom" Public Corporation, the Russian Union of Entrepreneurs and Industrialists, the Global Energy Fund, and other major research-and-production companies and institutes. To a great extent, this is determined by the understanding, among the society, of the inevitability of transition to hydrogen power.

The prime objectives formulated in the European Technological Platform on hydrogen and fuel cells are as follows:

1) political decisions that will favor the development of hydrogen technologies in power engineering and transport;

2) substantial increase in financing fundamental and applied research work on hydrogen energy;

3) creation of a system for demonstration of the advantages of hydrogen energy and raising awareness of the success of pilot projects in this field;

4) work with entrepreneurs to bring financing organizations closer to technology development engineers;

5) organization of an all-European educational program due to which the results of the latest investigations on hydrogen will be incorporated into the secondary-school curriculum;

6) setting up a center to raise awareness of these initiatives.

Under this plan of introduction of hydrogen power engineering in the European continent, we are expect to see, already by 2010, the beginning of commercial production of cars using hydrogen (it is acceptable to generate it directly on board in the first step), and the appearance of hydrogen gas stations in some areas. By 2020, it is planned to create inexpensive fuel cells and competitive hydrogen cars and local hydrogen-distribution networks. In 2030, there will appear devices for long-term storage of hydrogen which will become the main fuel for cars, and the heat and electricity for houses will be generated on the spot using fuel cells. In 2040, hydrogen power engineering will become dominant, and all the hydrogen will be generated from renewable sources, not from fossil hydrocarbon. By 2050, aircraft using hydrogen fuel are expected to appear.

The Republic of Belarus meets all conditions for successful development of hydrogen power engineering and fuel-cell technologies; the most important of them are the highly-skilled research and engineering personnel and the production base (enterprises of the electronic industry and machine construction).

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