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The Next Economy in Ukraine: Developing Alternative Energy with the Help of Nbic-Technologies

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Authors' contributions

This work was carried out in collaboration between all authors. Author IM designed the study, wrote the protocol, and wrote the first draft of the manuscript. Author OK managed the literature searches, analyses of the study in alternative energy in the World and Ukraine and author IB managed the content analysis of classic papers and researches of modern economists-practitioners devoted to the peculiarities of the modern prospects of alternative energy in the World and Ukraine with using NBIC-technologie. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The next economy development is inseparably connected with alternative energy development in the world leading countries. However, each country elaborates its own the most prospective energy technologies. The main aim of the research is to find out, which technologies could be the foundation for Ukrainian energy independence in near future under conditions of new Nano-bio-info-cognitive (NBIC) technological revolution.
Study Design: The reviews were carried out in the period 2010–13 on the basis of studying the world countries alternative energy development trends as well as on the basis of the research results obtained by Ukrainian academic institutions.
Place and Duration of Study: Scientific research center for industrial development problems of

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the National academy of sciences of Ukraine, Department of Foreign Economic Relations and Touristic Business between June 2014 and December 2014.

Methodology: Content analysis has been used as the main method of research, which allowed making a meaningful analysis of classic papers and researches of modern economists-practitioners devoted to the peculiarities of the modern prospects of alternative energy in the World and Ukraine with using NBIC-technologies.

Results: It has been demonstrated that in connection with energy and environmental problems exacerbation the gradual exhaustion of fossil hydrocarbons would lead in ever increasing scale to wide attraction of renewable energy sources, to searching for new efficient and environmentally friendly energy carriers. It has been identified that Ukraine, which as of today struggles for its energy independence, carries out intensive research in creating alternative energy foundations using NBIC-technologies as a basis for the Next Technology development - highly efficient, environmentally friendly, independent from the whims of other countries that possess hydrocarbon resources. It has been proved that hydrogen could become the most prospective energy carrier capable to satisfy industrial consumers and private households' energy needs both in the world countries and in Ukraine. It has been ascertained that only inconsiderable part of the world produced hydrogen reaches high-technology industries, which could be attributed to the insufficient development of up-to-date technologies of hydrogen production, especially the ones with using alternative and renewable energy sources, technologies for hydrogen efficient and safe storage, technologies and materials to produce cheap and smooth-running Fuel cells as the most attractive end-element of the hydrogen-energy cycle. It has been discovered, that the development of up-to-date technologies using the potential of NBIC-technologies to generate hydrogen, creation of the corresponding materials and highly efficient processes could entail considerable costs decrease both in hydrogen generation and in supplementary systems build-up, especially the costs of fuel cells, that would provide for wide commercialization of the mentioned technologies, which are a component of hydrogen power engineering. It has been shown that the majority of the developed countries as well as Ukraine continue intensive fundamental and applied research along the identified directions. Moreover, the further development and wider application of hydrogen technology coincides with the general developmental trend of industrial countries energy parks, which rests on wider utilization of solar, wind, geo-thermal energy as well as on maximum possible decentralization of power supply capabilities. It has been proved that hydrogen technology, based on NBIC-technologies, being of universal character, environmentally friendly, being fit to utilize any primary energy sources would play a leading role in creating the next economy in Ukraine and could satisfy nearly 20% of the general national energy need with no environmental risks.

Conclusion: Alternative energy with NBIC-technologies utilization could become a basis for the Next Technology development – highly efficient, environmentally friendly, and independent from the whims of other countries that possess hydrocarbon resources. The spheres of NBIC-technologies utilization in Ukrainian power engineering sector, which consists of energy generation (transformation, production), storage, transfer and conservation, include: production of synthetic hydrocarbon fuel; solar energy conversion; ethanol production; oil products reprocessing; Fuel cells; batteries and other energy accumulators; energy transfer and distribution; hydrogen production; light emitting diodes (LED) production. Ukraine together with the majority of the developed countries continue intensive fundamental and applied research in the mentioned branches as well as in the sphere of hydrogen power engineering creation, which could satisfy nearly 20% of the general national energy resources need. With the application of NBIC-technologies the hydrogen power engineering, being of universal character, environmentally friendly, being fit to utilize any primary energy sources, could play a leading role in creating Ukrainian next economy.

Keywords: Energy efficient economy; Ukrainian energy issues; alternative power engineering; NBIC-technologies; nano-technologies; hydrogen power engineering.

1. INTRODUCTION

Modern civilization sustainable development and population life quality directly depend on the sufficient energy supply, which in its turn causes compelling necessity to solve the problem of resources exhaustion, which are utilized by the available technologies. To a large extent exactly energy issues cause periodic world crisis and stimulate searching for non-traditional ways of

satisfying energy requirements of any world country [1]. The last decade events review may drive us to a conclusion – the world is approaching the next global energy crisis. It can be attributed to the exhaustion of the prospected and accessible organic hydrocarbons' reserves. Conclusions of almost all analytical centers are the same: Oil and natural gas reserves may last for 50 years, coal reserves – 100 years (the data may vary, but not drastically). Severity of gas deficit issue could be alleviated by shale gas production, but it could hardly change the situation fundamentally taking into account the ever growing demand for hydrocarbons [2]. Therefore, practically all world countries carry out intensive research of the most efficient power engineering technologies that would become an alternative for hydrocarbon power engineering. Ukraine, which of today is extremely interested in finding ways of reaching energy independence, performs intensive research in creating foundation for alternative energy sources as a ground to develop the next economy – highly efficient, environmentally friendly, and independent from the whims of other countries that possess hydrocarbon resources.

The aims of the article are:

- To describe the most prospective energy technologies and main branches of NBIC-technologies implementation in power engineering sector for the Next Economy in the world;
- To show further development of fundamental research in Ukraine in three main directions: hydrogen generation, storage and utilization with the purpose of creating new highly efficient processes, materials and technologies for hydrogen power engineering with using NBIC-technologies.

2. METODOLOGY

Content analysis has been used as the main method of research, which allowed making a meaningful analysis of classic papers and researches of modern economists-practitioners devoted to the peculiarities of the modern prospects of alternative energy in the World and Ukraine with using of NBIC-technologies.

General scientific methods make up a methodological foundation of the research. They include: description, comparison, statistics review, system analysis and others, which help characterize this phenomenon development in a more comprehensive way. We also apply the methods of dialectic cognition, structural analysis and logic principles that provide for making authentic conclusions as regards the investigated topic.

Official statistical data of the state institutions and international organizations, publications of reference character, analytical monographs, annual statistical bulletins, Ukrainian National Academy of Science reports as well as annual Ukrainian State Statistical Bureau reports serve as an information grounds for our research.

3. RESULTS AND DISCUSSION

3.1 The Most Prospective Energy Technologies in the World

Fig. 1 presents an overview of the most prospective energy technologies [1].

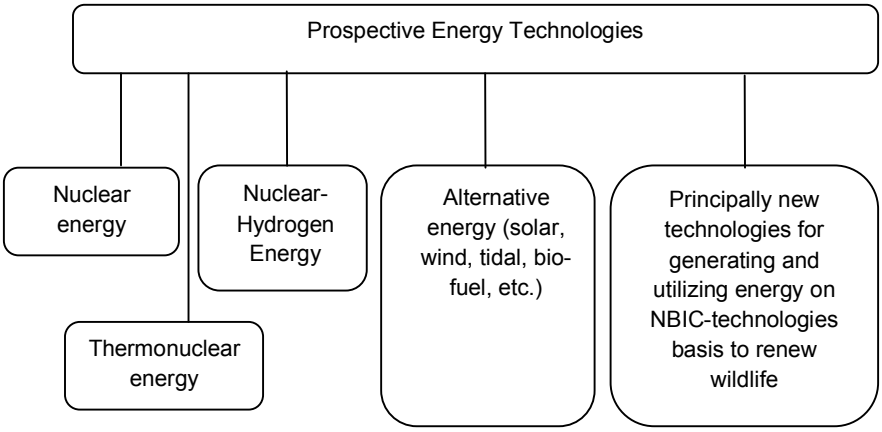

Fig. 1. The most prospective energy technologies [1]

As of today, new energy technologies actively develop together with traditional hydrocarbon energy technologies; nuclear power engineering experiences a renaissance (even after 2011 Fucushima NPP nuclear disaster); developed countries implement a global project to build up an international thermonuclear reactor. Solving the problems of LENR (low energy nuclear reactions) or *cold fusion* could serve as a quick move out of power engineering deadlock. In other words, there is a good prospect for creating and utilizing a real alternative for the traditional hydrocarbon fuel and not less traditional "uranium" nuclear power engineering – a process of implementing totally safe nuclear reactions at low energy, as, for example, on the basis of nickel and hydrogen Nano powder, implemented in the so-called Andrea Rossi heat generator E-Cat [2].

Hydrogen (nuclear-hydrogen) power engineering is one more potentially efficient future direction of power engineering development, which also includes metallic hydrogen and other exotic substances generation [1]. It means that at sufficiently high-ratio compression, when external nuclear outer shells get crushed, all the substances transfer to metallic condition. Water is also manifesting specific properties at high pressure. Usual Fullerene C_{60} as well as Fullerene C_{36} can also be treated as exotic substance, which after adding specific admixtures could have ultra-high temperature of superconductive transfer. Prospective directions of metallic hydrogen utilization: power engineering and micro-electronic engineering; safe storage of hydrogen fuel; research of different metallic hydrogen alloys with heavier elements.

High-temperature and room temperature superconductivity is one more prospective direction for alternative energy development and for solving the issue of power supply [1]. The main aim of the experimental research is to create materials with the capacity of transferring to super-conductivity condition at room temperature. And the main task for the theoreticians is to explain the mechanisms of high-temperature superconductivity to render assistance to experimentalists. Areas of using materials with room temperature superconductivity are as follows: 30% power engineering efficiency increase occurs at the expense of excluding costs of high-voltage power transmission lines heating (with this, the principle of power transmission will change); creation of super-power electric magnets in subatomic particles accelerators; creation of super-sensitive modern magnetometers on the basis of Superconducting Quantum Interference Device (SQUID), which have started to be used in super-sensitive systems of Magnetic Resonance Imagery (MRI) as of today. In other words, the main spheres of such principles implementation would be the ones, where advantages (high efficiency, small size and weight) would outscore the shortcomings (high price, additional cooling systems to reduce temperature to liquid nitrogen temperature, etc.). They include: highly efficient electric power supply lines; electromagnetic transformers; electric motors; transport of the future on the basis of magnetic levitation, etc [1].

Solar power engineering is distinguished among great versatility of *alternative power engineering* types. Despite the fact that renewable solar power engineering has been developing for many years and solar cells efficiency has considerably improved, presently solar energy has not yet become a powerful energy resource. According to scientists one of the main reasons for such a situation is the fact that in contrast to wildlife, where solar energy gets accumulated with the help of photosynthesis in green leaf biological structure, which is not yet achievable for artificial creation, humans model that natural process with the help of semi-conducting structure [1]. However, wildlife by itself is a very "economical" energy user; it is correctly self-organized, i.e., "photosynthesis low-power energy" is superfluously sufficient for it. Human community in modern life use artificially created machines and mechanisms that use huge amounts of energy. Their power supply is principally impossible with the help of economical, "nature-like" power engineering capacities.

Together with the similar global projects, there are several new (old) alternatives – hydro-power, bio-fuel, wind power, geo-thermal power. Each of them is capable to solve some part of the problem, but globally they can't ensure (so far) solving the power deficiency problem. Their aggregated contribution into global power engineering is nearly 20% [1].

3.2 Main Branches of NBIC-Technologies Implementation in Power Engineering Sector

Together with the present technologies development and improvement the humankind faces a complicated and ambitious challenge – creating *principally new technologies and*

systems for energy utilization, i.e., replacement of the present day energy end-user with the *systems that revive wild life.* Now we understand that such a replacement could be accomplished by way of "launching the future" on the basis of converging Nano (N)-, bio (B)-, info (I)- and cogno (C)- technologies together, or NBIC-technologies.

The named problem was tackled by many renown scientists, including also M. Roco, W. Bainbridge, B. Tonn, G. Whitesides [3,4], who studied the issues of knowledge, technologies and society convergence; L. Foster [5] worked with the issues of using nano-technologies for power engineering and energy efficiency enhancing; A. Kazantsev, V. Kisilev, D. Rubvalter, O. Rudenskiy [6], P. Maltsev [7], F. Rahman [8], together with Ukrainian scientists M. Kizim, I. Matyushenko, I. Buntov, O Khanova [9-12] et al. dealt with the development and prospects for NBIC-civilization. At the same time implementation of energy saving hardware on the basis of NBIC-technologies into developed countries economies requires reviewing of the prospects for its utilization to develop the next economy in Ukraine – highly efficient, environmentally friendly, and independent from the whims of other countries that possess hydrocarbon resources.

The main branches that utilize NBIC-technologies in energy sector, which include energy generation (transformation, production), accumulation, transfer and storage, are as follows [13]: Production of synthetic hydrocarbon fuel; solar energy conversion; production of ethanol; oil products reprocessing; Fuel cells; batteries and other energy accumulators; energy transfer and distribution; hydrogen production; LED.

Table 1 presents a concise description of nanotechnologies market sectors and their products in the "Power engineering" sphere [13,p.52].

Photovoltaics (PV or solar cells), hydrogen conversion (Fuel cells), thermoelectric (thermoelectric devices), improvement of hydrocarbon energy (catalyzers, additives). As to "The Global Technology Revolution 2020, In-Depth Analyses 2006", international experts included only cheap solar energy into the list of the most prospective technologies for 2020.

Table 2 names some the most known world Nano-technological designs for PV, directed to solve the challenges of creating and improving new highly efficient materials and new devices, decreasing costs and increasing efficiency of solar cells [14,p.188–190].

The most prospective areas of using Nanomaterials and Nano-technologies in the sphere of energy distribution, transfer, accumulation and storage are highly efficient transfer systems (wires, transformers and other devices) as well as rechargeable batteries and super capacitors [9].

Development of Nano-structural new class electro technical wires for different power transfer lines with super-strength (at steel level, 1200-1500 MPa) and electric conductivity (at the level of 60–75% of pure copper conductivity) with Nano-metric level of microstructure dispersion is one of the Nano-technologies tasks. Such designs include Nano-compositional electric wires of high strength and conductivity, which are made of silver fiber, which are distributed in copper matrix, as well as super strong highly conductive cables on the basis of intermetallides [14].

Table 1. Main nanotechnologies market segments in the "Energy" sphere

Fuel cells	Oil products reprocessing	Solar energy conversion	Energy transfer and distribution	Other market segments
- Fuel cells on solid oxides SOFC; - Fuel cells on Nano horns; - Nano size thin films for PAFC & PEMFC; - Polymeric membranes for PEMFC & DMFC; - Nano-composites for PEMFC & DMFC	- Fluid cracking; - Hydrofining; - Heavy oil upgrading; - Nano-devices utilized in oil processing; - Other reprocessing processes	- Dye-sensibilized solar cells (DFFC); - Solar cells on quantum dots; - Hybrid metal-organic solar cells - Solar cells on polymers activated with carbon fullerenes	- Cryogenic pipelines and reservoirs; - Transformers; - Nano-devices participating in energy transfer and distribution	- Synthetic hydro-carbon fuel production; - Hydrogen production; - Ethanol production; - LED; - Batteries and other energy accumulators

Composed according to [1,9,13]

Table 2. World Nano-technological designs for PV

Name	Main nanomaterials	Positive effect
Flexible organic solar batteries	Fullerenes (C_{60}) & hetero-structures C_{60} / p-Si	High adsorptive capacity of solar spectrum shortwave region
Solar batteries	Non-organic and organic materials with Nano layer and cluster structure	Energy accumulation and transfer
Solar batteries organic photo cells	Polymer-fullerene Nano-structures	Charge carriers are transported by nanocrystals and organic molecules network
Solar batteries	Quantum dots	Efficiency ratio increases up to 42% (theoretically - up to 86%) at the expense of generating three electrons per one falling photon
Multi-layered hetero-structures: – InGaAs/AlGaAs, InAs/InGaSb; – GeSi	Quantum wells; Quantum dots	Industrial technology to produce IR-range photo receiving modules
Multi-cascade photo-electric converters	Nano-hetero-structures	Efficiency factor is up to 35% at 1000-fold concentration of ground solar radiation (2-times cheaper than the available ones) for concentrating solar power plants
Solar batteries	Ceramic nanomaterials of titan-dioxide and silicon layers 50–100 nm thick	Electric energy production increases 1/3 times without increasing solar cells area
Solar batteries	Metal nanomaterials (Ag, Cu, Co, Mn, Mg, Zn, Mo, Fe), their oxides and hydroxides	Cheap batteries, physical phenomena are used in those materials
3-D solar cells	Carbon nanotubes	Solar energy silicon batteries adsorption ratio increases from 67.4% up to 96.21%
Solar batteries	Nano-antennas arrays with 2-4 μm diameter	92% of light energy is converted into electricity (against 80% of the available ones). They can work at night at the expense of IR range utilizing (heat from electronics)
Solar batteries	Polycrystal silicon (c-Si), highly pure silicon-trapping materials	Devices for microelectronics and photo-cells
Solar cells	Amorphous silicon (a-Si)	Solar batteries thickness decrease at the 10% efficiency increase
Aerogels	Nanoparticles united in clusters (up to 5 nm) with hollownesses (up to 100 nm), that occupy up to 99% of the volume	For solar collectors; they have the required mechanical strength
Solar energy sources	Nanostructures sensibilized by absorbing dyes	Potential of cheap production

Composed according to [1,9,13,14]

Development and production of special conducting materials for radio electronic equipment and future manometer devices is one more task to perform. Such designs include: nanowire on the basis of indium oxide; ultra-thin wire on golden particles basis; nanostructure compositional superconductors NbTi with low energy consumption in quick changing magnetic fields for synchrotrons magnetic systems SIS-100 and SIS-300 of the FAIR international project; thermocouple wire for high-sensitive temperature measurements on the basis of nanostructure nickel alloy, etc [13].

When developing electric batteries and super conductors new designs it is expected that

nanomaterials will play a decisive role in solving the following main tasks: increasing energy density and capacity, including also classical electric batteries; increasing the indicators of life and efficiency after batteries recharging; increasing the general service life (cycles "charging–discharging"); decreasing the used materials toxicity; decreasing explosion hazards and fire hazards [14].

Batteries on the basis of Nano-wires, which became known in 2007, provided for size considerable decrease, energy density and capacity considerable increase, service life increase. Very soon such batteries may replace lithium-ion batteries used in laptops, cell phones and other electronic devices. Even today the scientists of Tulsa institute (USA) have designed batteries of 1 μm size, which could suitably be used for small robots' electric power supply. Now, developed countries research institutions conduct the final stages experiments in creating carbon electrodes on the basis of one-wall Nano horns (special type of Nano-tubes) for methanol fuel elements, capable of ensuring dozens of hours of mobile Nano-devices continuous work [15,p.260].

Energy conservation can boast of the most important and highly efficient Nano-technologies application for materials and devices production to improve thermoinsulation (aerogels, "smart window glass"), to provide for more efficient and economic lighting (light diodes on the basis of polymer organics OLED), or for more efficient utilization of traditional hydrocarbon fuel (catalyzers) as well as for creating lighter materials for machine engineering and for transport [9].

The main purpose of heat insulation is to decrease the speed of heat transfer (actually, heat costs) occurring due to heat conductivity, convection and heat radiation as well as due to any combination of those energy processes. Heat costs could be reduced in two ways: by utilization of high-porous materials that retain gaseous substances (air or other environment) and thus preventing convection; by utilizing coating to reflect radiation of different origin (mainly, it's infrared spectrum) both outside and inside premises. Today we have developed new transparent aerogels that could be used as light permeable material and simultaneously as insulation material to coat solar collectors. For example, aero-glass (Nano composite silicon aerogels) has low conductivity, low hard particles density and high dielectric permittivity that make aero-glass to be one of the best light-permeable insulation materials [9].

Moreover, to increase energy conservation we may use "smart window glass" within premises that can react to changes in lighting and temperature patterns of the environment according to changes in transparency and heat conductivity.

Total transfer to gas discharge daytime fluorescent lamps especially to LED equipment may ensure considerable electric energy saving. Organic light diodes OLED, based on different forms of green fluorescent proteins (GFD), present a considerable interest. In future GFD could be also used when building monitors, TV-sets, different displays etc. GFD are totally safe for environment and require very inconsiderable energy volume [14].

It is clear that nanomaterials are produced and sold to manufacturers of final products in all industrial sectors. Present and future in the application of nanoparticles in the sector "Energy" nano world market can be represented as follows [9,p.88]:

- In development - and nickel metal hydride battery;
- The market - organic catalysts, cerium dioxide in diesel engines;
- Well studied - catalysts for internal combustion engines.

Table 3 shows the comparative structure and dynamics of the sector "Energy" in the context of market segments nano world market in 2009 and in 2014 (as estimated) [9,p.156].

From Table 3 shows that in the forecast period from 2009 to 2014 in the sector "Energy" nano world market during the forecast period priorities may change. Record growth rates demonstrates segment "Solar Photovoltaics' (359.2%), but the bulk of the market will remain for refining (75%). Segments will grow significantly "Production of synthetic hydrocarbon fuels", "battery", "LED" and "Hydrogen Production." The average growth rate in the sector of compound interest will amount 9.2% [9,p.157].

Table 3. Structure and dynamics of the sector "Energy" in the context of market segments nano world market in 2009 and 2014

Segment	Scope in 2009, million dollars	Scope in 2014, million dollars	Average annual growth in 2008 – 2014, %
Total, including	3878,6	6028,6	9,2
Production of synthetic carbohydrate fuel	0,0	8,0	-
Converting solar energy	0,01	16,9	359,2
Production of ethanol	716,0	1265,1	11,8
Oil recycling	3003,0	3930,6	6,0
Fuel cells	63,97	187,8	23,3
Batteries and other power batteries	0,0	405,0	-
Transfer and Distribution	95,5	179,03	13,4
Light-emitting diodes	0,0	36,0	-
Production of hydrogen	*0,09*	*0,2*	*14,4*

Composed according to [9]

3.3 Prospects for Hydrogen Energy Development in the World and in Ukraine

In connection with aggravation of environmental and energy problems as well as the available prospects of gradual exhaustion of fossiliferous hydrocarbons, the issue of renewable energy sources wide involvement together with the search for new efficient and environmentally friendly energy carriers, including also hydrogen, are becoming more and more important.

Exactly hydrogen occupies a special place in tackling the mentioned challenges both from the point of view of the contained energy density and zero negative impact on the environment, because during its combustion only water is formed. Exactly those unique hydrogen properties underlay the principles of the so-called hydrogen power engineering, to be regarded as the most real alternative to the modern power engineering, which mainly is based on combusting hydrocarbons [16].

Hydrogen power engineering is considered to provide not only for involving new non-traditional energy resources (wind energy, solar energy, versatile biological waste energy, geothermal energy, secondary waste heat energy, etc.), but also will help improve consumption qualitative structure of traditional fossiliferous fuels, will increase the share of electric energy as an end-product of the whole energy chain. Hydrogen could be generated from natural gas with utilizing coal, biomass, practically all renewable and non-traditional energy resources types. Development of fuel cells (FC) modern technology helps convert hydrogen to electricity with unattainable for heat machines efficiency practically without environmental pollution.

The majority of experts consider that to solve the problem of hydrogen energy development based on full-scale utilization of hydrogen technologies, we require principally new decisions in three directions: hydrogen generation, storage and utilization.

Scientific, technological and economic tasks, faced by experts as regards the mentioned three directions, were declared in the US President G. Bush Initiative regarding hydrogen economy: considerably decrease cost of hydrogen generation from natural gas, biomass and through direct photo-electro-chemical water splitting; decrease cost of water-hydrogen fuel cells with polymer membrane for cars; develop efficient systems for storing hydrogen to be used in transport [16].

The set goals could be achieved only with further intensive development of fundamental knowledge in all the adjacent cognitive domains, like, for example, catalysis, hydrogen interaction with solid bodies including also Nano- and new carbon materials, physics-chemistry of the surface, new metal-hydride materials and membranes, safety and environmental challenges.

Exactly to solve those issues and involve wide scientific community into such type research a set of international and national hydrogen energy programs was created in the period 1995–2005. First of all, those were hydrogen initiatives of International Energy Agency (IEA), which has

been supporting nearly 40 corresponding international programs. Such international organizations as Organization for Economic Cooperation and Development (OECD), International Partnership for Hydrogen Energy (IPHE), World Energy Net (WE-NET), etc. provide for the development of hydrogen power engineering. Moreover, in 2003 European Commission created "Technological platform for hydrogen and fuel cells», which started to function in January 2004. A set of projects, dedicated to hydrogen, was financed by EU under the auspices of the 6th and 7th Framework Programs as well as the program "Horizon 2020" [16,17].

The majority of the industrially developed countries including Russia have their national hydrogen energy programs. Together with fundamental research development in hydrogen energy sphere the developed countries also implement a number of the so-called demonstrational projects, which aim to demonstrate to the community the capacities and advantages of hydrogen energy and prepare grounds for its wide implementation in future [17].

As of today, world annual production of hydrogen equals by different estimations to 50-80 mln.tons, and its main share is taken by methane vapor-phase conversion, i.e., it is anyway connected with consumption of fossiliferous energy carrier. The same sad situation pertains to hydrogen utilization, the major part of which is used in chemical, metallurgic, nuclear industries, etc. Only a small portion of the generated hydrogen is used in highly technological branches, as, for example, in small-scale power engineering, motor transport, instrumentation, etc. This could be attributed to the insufficient development of innovative technologies for hydrogen generation, especially with utilizing alternative and renewable energy sources, technologies of its efficient and safe storage, technologies and materials to produce cheap and reliable working fuel cells as the most attractive end-product of hydrogen-energy cycle [16,17].

Exactly the development of those technologies, creation of the corresponding materials and highly efficient processes could lead to a considerable decrease in the hydrogen cost, costs of supplementary systems, especially fuel cells, which would provide for wide commercialization of the indicated technologies, which are a component of the so-called hydrogen technology.

In Ukraine research, dedicated to the development of hydrogen technologies and hydrogen energy, has been carried out since1970-s. The following research institutes of the Ukrainian National Academy of Science have been actively working in that direction: Institute for the problems of machines engineering named after A. M. Pidgornyi, Institute for the problems of materials engineering named after I. M. Frantsevich, Physical-mechanical institute named after G. V. Karpenko, Institute of gas, Institute for electric welding named after E.O Paton, Institute for general and non-organic chemistry named after V. I. Vernadskiy, Institute for chemistry of high-molecular compounds, Institute for physical chemistry named after L. V. Pisarzhevskiy, Institute for bio-organic chemistry and petro-chemistry, etc. The majority of the indicated institutions participate in international projects in the field of hydrogen technologies or alternative energy, including the ones that are financed by Science and Technology Center of Ukraine, CDRF, NATO programs Science for peace and security, etc [16,17].

Important results were received in the direction of developing innovative hydrogen technologies, including: a number of prospective technologies of hydrogen generation were developed, including also highly efficient water electrolysis processes, different catalytic and biological processes to generate hydrogen from waste, non-conditional fuel, etc.; electronic build-up of hydride phases was researched and physical-chemical principles for creating materials-accumulators for hydrogen on the basis of intermetallides and carbon nanostructured phases were proposed; scientific grounds were underlain to create modern fuel cell technologies both on the basis of low-temperature proton conductors and on the basis of high-temperature oxide ceramics [16].

At the same time, regardless of the great volume of work done and its high scientific level it was necessary to coordinate fundamental research of Ukrainian hydrogen energy issues at the integrated methodological basis.

Target comprehensive program for the National Academy of Science of Ukraine (NASU) scientific research "Fundamental problems of hydrogen energy (2006-2010)" was started by NASU Presidium decree No.152, dated 13.06.2006. The NASU Presidium Resolution No.183 dated 13.03.2006 approved the Program Concept [16].

The aim of the program was to: create scientific grounding and propose new highly efficient processes, materials and technologies in the sphere of three major components for hydrogen energy: generation, storage and utilization of hydrogen; provide for utilization of hydrogen-energy technologies in Ukrainian economy having the purpose of improving the power balance, their fuller implementation to solve energy issues of Ukraine as regards renewable energy sources and non-traditional energy carriers; considerably improve ecologic situation in Ukraine.

The main tasks of the mentioned program were [16,17]:

I. Hydrogen generation: development of new highly efficient technologies of hydrogen generation via water and water vapor electrolysis, catalytic and biological methods of hydrogen generation from biomass, hydrocarbons, waste water, hazardous organic waste, etc.; development and improvement of the processes to generate hydrogen with utilization of energy-accumulating substances, solar and wind energy; creating new efficient processes of photo-electro-chemical and photo-catalytic generation of hydrogen as well as hydrogen generation from non-conditional solid fuel and coalmine methane; research of production capacities to produce hydrogen at nuclear-technological installations.

II. Hydrogen storage: research of the fundamental patterns for hydrogen interaction with solid bodies and other active in relation to hydrogen materials; research electronic build-up, crystal-chemistry and chemical nature of the multicomponent hydride phases' surface; develop new metal-hydride materials for hydrogen storing with enhanced characteristics, like new carbon materials to include also intercalated and nanostructured materials, nanotubes, anions, compound hydrides, alanates etc.; develop new efficient materials for sorption and desorption of hydrogen, and new metal-hydride systems for comprehensive hydrogen processing, compression, cleaning, turning on, etc.

III. Hydrogen utilization: develop improved samples of low- and high-temperature fuel cells; develop new highly efficient materials on the basis of nanocrystal ZrO_2 and other oxide ion conductors for new generation of high-temperature hydrogen-oxygen fuel cells, as well as fuel cells on the basis of polymeric membranes with proton conductivity and long-term functioning resource, to be used at motor transport; test technology of using hydrogen as energy carrier for motor transport, develop hydrogen technologies to enhance efficiency of traditional energy systems, including the ones based on solid fuel combusting; develop physical-chemical principles of creating resistant to hydrogen structural materials, as well as modern methods and means for experimental evaluation of their strength and longevity while working in hydrogen environment; research hydrogen impact on welded joints characteristics and develop new welding technologies to minimize hydrogen impact on such joints.

The main results of implementing the Target comprehensive program for the National Academy of Science of Ukraine (NASU) scientific research "Fundamental problems of hydrogen energy (2006-2010)" are presented in Table 4 [17].

In 2010 Ukraine together with Germany launched a joint investment project "Hydrogen energy", which had become an important argument to continue the above mentioned developments. At the project first stage, which should have lasted for three years, it was planned to produce hydrogen in the amount of 1 billion nm^3 annually. Syngas and hydrogen should have been transported to Europe by way of admixing into Ukrainian gas transportation system. Hydrogen to be used primarily in motor transport. Development of the local hydrogen-energy technologies would primarily provide for this project implementation, and secondly, would help create Ukrainian internal market of highly technological hydrogen consumption [17].

To continue the started work in laying foundations for Ukrainian hydrogen power engineering the Presidium Resolution of the National Academy of Science of Ukraine (NASU) No.356, dated 29.12.2010 approved the Target comprehensive program (TCP) "Hydrogen in alternative energy and innovative technologies" for 2011–2015 [18].

Table 4. The main results of implementing the target comprehensive program for NASU scientific research "Fundamental problems of hydrogen energy (2006-2010)"

Year	Program direction	Most vivid results	Practical value
1	2	3	4
2006 2010	Hydrogen generation	Scientific grounds for new technologies in hydrogen generation were developed basing on the utilization of electro-chemical, photo-electrochemical, plasma-chemical, microbiological methods, energy accumulating substances and catalyzers; potential of hydrogen generation using renewable energy sources was reviewed.	Scientific grounds for new technologies of hydrogen generation
		Scientific grounds for creating technology and installations to generate hydrogen from hydrocarbons, waste and with using renewable energy sources including also: - Theoretic model for the process of hydrogen generation with the help of hydro reacting complex substances at super-high pressure (up to 30 MPa); - Methodology of hydrogen generation from hydrocarbons in electro-chemical pseudo-rarefied layer; - Methodology of new alloys synthesis on the basis of Al, Mg with high reaction capacity to release hydrogen from water; - Photo-electrochemical system for hydrogen generation from water solutions, where hydrogen accumulation occurs on the cathode with metal hydride formation; - A number of new efficient photo-catalytic systems to receive hydrogen from electron-donor compounds solutions; - Electrolyzer design for water electrolytic splitting in hydrogenized liquid alloys of alkaline metals hydroxides	Scientific grounds of creating technologies and installations to generate hydrogen
		Theoretic and fundamental research has been performed to become a ground for: - Creating industrial technologies to reprocess carbon-hydrogen containing compounds; - Developing catalyzers to generate hydrogen and oxidize CO basing on the systems of Nano-disperse powders Cd, $Zn_{1-x}S$ &Ni (II), mezo-porous TiO_2 and a number of metals (Cu, Au, Ni, Ag); - Biochemical reprocessing of waste after waste water treatment and the method to prepare heterogeneous photo-catalyzers to transform those compounds into hydrogen; - Biotechnologies to generate hydrogen; also we studied the factors impacting the intensity of the process of hydrogen photo release by micro-algae cultures, as well as possibilities of hydrogen synthesis by anaerobic micro-organisms	Research to be a ground for creating hydrogen technologies
		The following has been studied: - Capability to intensify electrochemical hydrogen generation processes at the expense of electrode surface modification with multilayer carbon nanotubes faced with metal nanoparticles (Pb, Co, Ni); - Specific features of converting low-volatile high ash Donetsk anthracite, peat, wood and bioethanol solution; - Optimum conditions for the process of underground coal gasification at Lviv-Volyn basin to generate hydrogen	Possibility of hydrogen generation from hydrocarbons at the expense of electro-chemical processes
		The following has been created: - Experimental facilities and methods for the vapor gasification processes with the aim of hydrogen generation; - Efficient oxide catalyzer to treat gas mixes enriched with hydrogen from carbon monoxide admixtures; - Metal-oxide catalyzers Cu-ZnO on structured monolithic carriers Al_2O/cordierite, that ensure highly productive methanol reforming	Facilities and equipment for hydrogen generation
	Hydrogen storage	The ways to solve the issue of creating efficient hydrogen-accumulating materials have been investigated. The following research has been conducted: - Electro-chemical renewal issues: hydrogen oxidation on Nano-size carbon materials; it has been proved that	Research of the problems to create efficient hydrogen accumulating materials, including Nano tubes and

	nanotubes, modified with Pd nanoparticles, are the most efficient ones; - Mechanism of interaction between activated hydrogen and fullerenes; hydro-fullerenes with maximum hydrogen content were obtained by way of hydrating without catalyzer in gaseous environment; - Pattern of crack-like defects development in low-alloy steel under condition of its cyclic loading in hydrogen-containing environment; it has been ascertained that alloying of In 690 type metals with Yittrium oxide dispersive nanoparticles prevents its brittle fracture in gaseous hydrogen at temperatures near 20ºC	fullerenes
	The conducted research provided for: - Formulating principles of creating indestructible sintered composites by powder metallurgy method; - Demonstrating that in the materials with extreme structural condition kinetics of materials saturation with hydrogen and its desorption considerably improve; - New composites on the basis of Mg, Ti alloys with intermetallides of AB_2, AB_5 type were created having the characteristics that provide for their practical application	New composites that considerably improve the kinetics of materials saturation with hydrogen and its desorption
	New crystal porous materials of ion and coordination-polymer nature were obtained; possibility of getting and using new carbon-containing materials with porous structure on the basis of pyrophoric metals were demonstrated.	New crystal porous materials
	New carbon- and metal-containing materials were generated by the method of d-metals complexes carbonization, including also by Ni and Fe; hydrogen absorption indicators in them approach to the corresponding indicators fit for fullerenes and carbon nanotubes, but which are by an order of magnitude cheaper and much more accessible than other carbon forms	New carbon- and iron-containing materials with hydrogen adsorption indicators that are approximated to fullerenes and carbon nanotubes
	Potential of creating highly efficient photo-catalytic systems on the basis of mezo-porous titan dioxide, with Nickel ions adding, without using noble metals was identified; those systems are close to industrial sample Degussa P25 by their photo-catalytic activity in the reaction of molecular hydrogen evolution	Creation of highly-efficient photo-catalytic systems
	Theoretic and experimental research was carried out in the field of: - Getting materials for devices and equipment that could be efficiently utilized to store and transport hydrogen; - Testing the method of evaluating sensitivity to Nickel alloys and evaluating their welded joints hydrogen brittleness at the pressure of gaseous hydrogen up to to 25 MPa.	Materials for devices and equipment that could be efficiently used to store and transport hydrogen
	It has been identified that standard mechanical properties of pipeline steel are hardly changing in the course of long-term running. Absorbed hydrogen plays a decisive role in steel degradation through the development of damage-ability, which negatively impacts their mechanical and corrosion resistance properties	
Hydrogen utilization	Development and research of efficient materials for fuel cells (FC) on the basis of polymer proton-conducting membranes or zirconium ceramics. On the basis of sol-gel technology the methods of synthesizing innovative hybrid proton-conducting polymer-electrolyte membranes were developed and hybrid electric catalyzers to renew oxygen for hydrogen-oxygen FC were obtained. High capacity indicators of FC with newly created catalyzers on the basis of metal/carbon composite as a replacement for noble metals, were also obtained.	Hybrid electric catalyzers of oxygen renewal for hydrogen-oxygen fuel cells
	Battery made of five FC was tested with supplying propane-butane mixture as fuel. Research sample of FC tester high temperature unit was manufactured. Impact of additional alloying of basic system $ZrO_2 – Y_2O_3$ with Fe, Cr, Ce, etc. ions on other electro physical , physical-mechanical properties and on the fuel cell structure as well as on the ceramic sintering process was studied.	Testing the battery out of five FC
	Optimization of design solutions was carried out together with materials selection to manufacture different types fuel cells. Experimental hydrogen fuel cell that combines in itself electrolyzer, hybrid storage and fuel cell to obtain, store and	Hydrogen fuel cell to generate, store and utilize hydrogen with direct

	utilize hydrogen with direct conversion of electric energy into energy carriers and vice versa, was tested	conversion of energy carriers to electric energy and vice versa
	Properties of oxygen-conducting materials on the basis of stabilized zirconium oxide with fluorite structure and Nano composite disperse-fiber non-organic material to be used as FC and its proton-conducting membranes were synthesized and researched. Fuel cells with initial work temperature of nearly 600^0C that have components in the form of films applied on porous metal-ceramic FC carrier were manufactured	Oxygen-conducting materials to be used as FC & its proton-conducting membranes electrolyte
	Equipment to check functioning of metal structures elements and welded joints when they are used in hydrogen environment	Equipment to check structures functionality in hydrogen environment
Developing hydrogen power supply system	The concept of creating a power supply system at the expense of hydrogen generation with utilization of renewable energy sources on the territory of research-testing facility of the Institute for the problems of materials engineering named after I.M.Frantsevich at National Academy of Science of Ukraine in “Burlivschina” district (town Pereyaslav-Khmelnitskiy). Interactive web-resource for common use in the domain nas.gov.ua was set up; program-focused arrays of survey and patent documentation was formed up; data-base of European organizations-potential partners in program development was established	Popularization of hydrogen energy practical capabilities

Composed according to [17]

The aim of the mentioned TCP include: ensuring further development of fundamental research in three main directions: hydrogen generation, storage and utilization with the purpose of creating new highly efficient processes, materials and technologies for hydrogen power engineering; providing for coordination of research performed by different NASU institutes as well as concentrating efforts on the most prospective developments obtained at the previous stage and capable to become in future the foundation for engineering decisions, which would ensure real implementation of hydrogen energy into power engineering, motor transport and other branches of the national economy; providing for improvement of Ukrainian energy balance including also increase of electric energy share in the general energy consumption pattern, development of progressive energy conservation and environmentally friendly technologies in motor transport, small and autonomous power engineering, house construction, etc [18].

The Program main tasks in the correspondence to its directions are the following [18]:

I. Hydrogen generation: develop scientific grounds for new technologies of hydrogen generation, with the priority to those basing on utilization of renewable energy sources, organic waste, non-conditional solid fuel; develop principally new photo-electro-chemical cells and high-temperature thermochemical reactor to generate hydrogen with using also concentrated solar light; develop new highly efficient catalyzers to generate hydrogen from non-conditional solid fuel and different organic waste; create new technologies for water electrolysis, move forward engineering solutions regarding new upgraded electrolyzers capable to work in a couple with windfarms; research the capabilities of implementing the closed cycle of hydrogen generation with attracting energy accumulating substances.

II. Hydrogen storage: research the pattern in hydrogen interaction with light hydride forming metals, intermetalllides and composites on their basis, including also the ones under conditions of high-energy mechanical synthesis in hydrogen environment; research the impact of atomic structure, electron build-up and surface condition on the hydrogen-sorption properties of materials-hydrogen accumulators and especially the materials with considerably heterogeneous, disordered and Nano-structures; create materials with hydrogen content for more than 4 mas.%, capable to absorb and release hydrogen in the conditions necessary for its utilization in motor transport.

III. Hydrogen utilization: Implement targeted fundamental research, develop new highly efficient functional and structural material for high-temperature oxide-ceramic fuel cells and low-temperature fuel cells on the basis of polymer membranes; develop mono-block ceramic fuel cells on the basis of ZrO2 and improved electrode materials, new proton-conducting polymer membranes with the enhanced thermal stability; create and research experimental samples of the mentioned oxygen-hydrogen fuel cells, study their performance characteristics. Propose technologies of utilizing materials' hydrogen processing with the aim of modifying their structure, improving their mechanic and other performance properties; develop scientific grounds for destructive hydratation-recombination of intermetallic compounds and alloys containing hydride forming metal; develop principles to evaluate structural materials working capacity when running them in water environment. Perform fundamental research and propose methods to minimize hydrogen harmful influence on welded joints.

In the result of the program implementation it is planned to: develop scientific grounds for new technologies of hydrogen generation based on utilization of renewable energy sources, organic waste, non-conditional solid fuel; research patterns of hydrogen interaction with light hydride-forming metals, intermetallides and composites on their basis, as well as impact of the atomic structure, electron build-up and surface condition on the hydrogen-sorption properties; create materials with hydrogen content of more than 4 mas. %, capable to absorb and release hydrogen in the conditions necessary for its utilization in motor transport; develop new highly efficient functional and structural materials for high-temperature oxide-ceramic fuel cells and low-temperature fuel cells on the basis of polymer membranes; develop mono-block ceramic fuel cells on the basis of ZrO2 and improved electrode materials, new proton-conducting polymer membranes with the enhanced thermal stability; create and research experimental samples of the mentioned oxygen-hydrogen fuel cells; propose technologies of utilizing materials' hydrogen processing with the aim of modifying their structure, improving their mechanic and other performance properties;

develop scientific grounds for destructive hydratation-recombination of intermetallic compounds and alloys containing hydride forming metal, as well as principles to evaluate structural materials working capacity when running them in water environment; perform fundamental research and propose methods to minimize hydrogen harmful influence on welded joints [18].

The main results of implementing the Target comprehensive program (TCP) "Hydrogen in alternative energy and innovative technologies" for 2011–2013" are presented in Table 5 [19-21].

Table 5. Main results of implementing the target comprehensive program (TCP) "Hydrogen in alternative energy and innovative technologies" for 2011–2013"

Year	Program direction	Most vivid results	Practical value
1	2	3	4
2011	Hydrogen generation	Design of the facility to generate hydrogen from water in industrial scale was developed together with new energy accumulating substances on the basis of Stibium, Bismuth and Stannum;	Facility to generate hydrogen from water in industrial scale
		Processes to generate hydrogen with utilizing waste including also during electro-chemical treatment of waste water as well as by way of thermo-chemical water-vapor treatment of metallurgical production waste.	Processes to generate hydrogen with utilizing waste
		Processes of Ukrainian hard and brown coals carbonization were researched to get syngas with high hydrogen content as well as by way of ethane and propane vapor-oxygen reforming	Processes of hard and brown coal carbonization to get syngas with high hydrogen content
		Research was carried out to produce hydrogen at the expense of wind energy. Wind power plant of 800 W capacity was commissioned on the territory of Pereyaslav-Khmelnitsk Research-measuring facility of the Institute for the problems of materials	Research in hydrogen production at the expense of wind energy
	Hydrogen storage	New compounds were researched that are prospective to create on their basis materials that are capable to accumulate hydrogen; the materials include: micro-porous coordination polymers, alloys on the basis of magnesium and composites, carbon nanomaterials.	Research of new alloys and materials capable to accumulate hydrogen
	Hydrogen use	Capacities to improve electrode and electrolyte materials for fuel cells were researched together with development of new methods for researching hydrogen permeation through steel and determining hydrogen concentration in structural steel	Improvement of electrode and electrolyte materials for fuel cells
2012	Hydrogen generation	Researching the processes of hydrogen generation, including also when recycling waste, electro-chemical treatment of waste water, carbonization of Ukrainian hard and brown coal, ethane and propane vapor-oxygen reforming, as well as with participation of micro-algae	Researching the processes of hydrogen generation
		The concept of catalytic extraction of hydrogen from liquid bio stock – ethanol was developed	Hydrogen extraction from liquid bio stock - ethanol
		The processes of electro-chemical evolution of hydrogen from acid and alkaline water solutions on cathodes, modified by carbon multi-wall nanotubes were studied.	Hydrogen evolution from acid and alkaline water solutions
		Adjustment operations for windfarm together with electrolizer to get hydrogen were conducted	Windfarm with electrolizer to get hydrogen
		Optimization of plasma technologies for hydrogen generation on the example of biomass vapor-plasma gasification was started	Optimization of plasma technologies for hydrogen generation

	Hydrogen storage	New energy accumulating substances were developed on the basis of zinc, modified with lead and stanum	New energy accumulating substances
		Prospective alloys to create materials with enhanced hydrogen-sorption properties on the basis of Ti-Fe-Mn system were proposed	Alloys for materials with enhanced hydrogen-sorption properties
		New alloys on the basis of magnesium and carbon nanotubes were researched; they are also prospective for storing considerable amounts of hydrogen	Carbon nanotubes to store hydrogen
		Within the framework of research in hydrogen utilization, electrode electrolyte materials for fuel cells on the basis of polymer proton-conducting membranes and Nano composite ceramic monoblocks were improved	Electrode electrolyte materials for fuel cells
		The method to obtain organic-non-organic nanostructured proton conducting membranes for the temperatures higher than 100ºC was developed together with the new electrochemical technology for high pressure hydrogen production	Electrochemical technology of hydrogen production
	Hydrogen use	Scheme to transform the surplus of electric energy into hydrogen and oxygen was proposed	Surplus electric energy transformation into hydrogen and oxygen
		The capacity for using hydro-reacting alloys on the basis of aluminum to process productive formations of oil wells was experimentally proved.	Application of hydro-reacting alloys to process oil wells
		Positive impact from employing zirconium powder hydride to increase alloys density after hydrogen desorption was proved	Using powder zirconium hydride for hydrogen desorption
2013	Hydrogen generation	Development of processes to generate hydrogen with using waste, including also when waste water undergo electrochemical treatment by way of thermochemical vapor-water treatment of metallurgical production waste with utilizing concentrated solar energy as well as research of hydrogen generation by micro-algae and research of microbe technologies for hydrogen generation.	Processes of hydrogen generation with using waste
		The concept of catalytic generation of hydrogen from liquid bio stock – ethanol was proposed	Catalytic hydrogen generation from ethanol
		Optimization of plasma technologies to generate hydrogen on the example of vapor-plasma biomass gasification	Biomass vapor-plasma gasification to generate hydrogen
		Research and adjustment of hydrogen production facility at the expense of wind energy	Hydrogen production facility at the expense of wind energy
	Hydrogen storage	Research of new alloys on magnesium basis to be prospective materials to store considerable amounts of hydrogen	Alloys on magnesium basis to store hydrogen
		It has been demonstrated that the composites, synthesized by the method of reactive milling in the hydrogen environment, have the best hydrogen-sorption properties	Composites with the best hydrogen-sorption properties
		Prospective alloys to create materials with enhanced hydrogen-sorption properties on the basis of Ti-Fe-Mn system as well as micro-porous coordination polymers were proposed	Prospective alloys to create materials with enhanced hydrogen-sorption properties
		Photo electrochemical properties of nanostructured semi-conducting films CdSe to be used in photoelectro-chemical system to release and accumulate “solar” hydrogen were studied	Nanostructured semi-con-ducting films to release and accumulate “solar” hydrogen
		Carbon nanomaterials (nanotubes) to be used as hydrogen	Carbon nanotubes as

	accumulators as well as impact of catalyst carrier thermal processing on the process of their generation were researched	hydrogen accumulators
	Works to understand micromecha-nisms of polycrystalline bodies destruction with accounting of different structural components and hydrogen embrittlement action in structural steel were performed	Study of hydrogen embrittlement action in structural steel
Hydrogen use	Electrode and electrolyte materials for fuel cells on the basis of polymer proton conducting membranes as well as on the basis of Nano composite ceramic monoblocks were upgraded	Upgrade of electrode and electrolyte materials for fuel cells
	Technology to produce fuel cell with electrolyte on ZrO_2 basis was developed. It has been ascertained that high oxygen conductivity of synthesized ZrO_2, stabilized by complex admixtures on the basis of scandium oxide, provides for recommending it to be used as solid electrolyte in fuel cells working at temperatures 600–700ºC	Technology of fuel cell production with electrolyte on ZrO_2 basis
	Weighty results as regards interconnection between hydrogen concentration in metal and applied stress under different conditions of hydrogen doping were obtained	Intercon-nection between hydrogen concentration in metal and applied stress
	Directions of hydrogen technological application, including the energy sphere, were proposed: - Application of hydrogen technologies to transform electric energy surplus with the help of electrolysis into hydrogen and oxygen; - Recommendations in practical application of power generating facilities that use hydrogen as energy carrier were developed	Directions of hydrogen technologic use in power engineering
	New electro-chemical technology to produce high pressure hydrogen was developed and tested	Electro-chemical technology to produce high pressure hydrogen

Composed according to [19-21]

4. CONCLUSION

Due to energy and environmental problems aggravation, the prospect of gradual exhaustion of fossil hydrocarbons, the issues of a wider attraction of renewable energy sources, search for new efficient and environmentally friendly energy carriers are becoming more and more acute. Ukraine, which of today is struggling for its energy independence, performs intensive research in creating alternative energy as a basis to develop the next economy – highly efficient, environment friendly, independent from the whims of other countries possessing hydrocarbon resources.

The main branches of applying NBIC-technologies in energy sector, including energy generation (transformation, production), accumulation, transfer and storage, are as follows: production of synthetic hydrocarbon fuel; solar energy conversion; ethanol production; oil products reprocessing; fuel cells; batteries and energy accumulators; energy transfer and distribution; hydrogen generation; light electric diodes (LED).

Hydrogen could become the most prospective energy carrier, which is capable to satisfy industrial and private consumers' energy requirements worldwide and in Ukraine. As of today only inconsiderable part of the produced hydrogen reaches high technology branches, as, for example, small energy, motor transport, instrumentation, etc. This could be attributed to insufficient development of innovative technologies to generate hydrogen especially with the help of alternative and renewable energy sources, technologies and materials to produce cheap and reliably working fuel cells as the most attractive end-element of hydrogen-energy cycle.

Hydrogen generation innovative NBIC-technologies development, creation of the corresponding materials and highly efficient processes could lead to a considerable decrease of the costs of hydrogen itself and of supplementary systems, especially concerning

fuel cells, which would provide for wide commercialization of the mentioned technologies, which are components of hydrogen power engineering. Principles of hydrogen power engineering could only be implemented at the expense of innovative revolutionary solutions in the spheres of hydrogen generation, storage and utilization. The majority of the developed countries as well as Ukraine continue intensive fundamental and applied research in the mentioned branches. Moreover, the further development and wider application of hydrogen technology agree with the general trend of developed countries energy complex improving, which could be specified by increased utilization of solar, wind, geothermal energy and other local resources as well as maximum possible decentralization of energy supply.

For Ukraine, which satisfies its energy demands by 50% with locally produced energy carriers, utilization of alternative energy sources with application of NBIC-technologies, including hydrogen, is extremely important and could satisfy nearly 20% of the general national demand with no environmental risks whatsoever. Exactly this development trend would provide for hydrogen energy, which is universal, environmentally friendly, adjusted to any primary energy sources, to play a leading role when creating the next economy.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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