ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

tpu.ru

Hydrogen Energy for Sustainability

Gubin Vladimir

22.04.2021

PUBLICATION ACTIVITY

more than **2500** articles indexed in Web of Science and Scopus

11 000+
undergraduate and graduate students

3 500+
university staff

170 000+
university graduates

28%
foreign students

RESEARCH POSITIONS IN RUSSIA

№1
among Russian universities

№1
among Russian universities

№1
Among Russian universities by volume of orders for research from foreign organizations

The only university-based research nuclear reactor in Russia

RESEARCH POSITIONS IN THE WORLD

26 в QS
«Petroleum engineering»

51-75 в ARWU
«Mechanical engineering»

ARWU
«Energy Science & Engineering»
(**3rd** place among Russian universities)

The only university in Russia in the Association of the Leading Engineering Universities of Europe

INSTITUTIONAL POSITIONS

401 QS

ТОП-10
Russian universities rankings

ТОП-3
by volume of R&D in the interests of industrial partners of the Russian Federation

World energy balance

21st Conference of the Parties to the United Nations Framework Convention on Climate Change:

United Nations Framework Convetion on Climate Change

All developed countries, including the Russian Federation, presented "Strategies for long-term development with low greenhouse gas emissions"

2015-2050 Changing the energy balance of Europe and the world

The Russian Federation is represented in the world energy balance - oil, gas, electricity

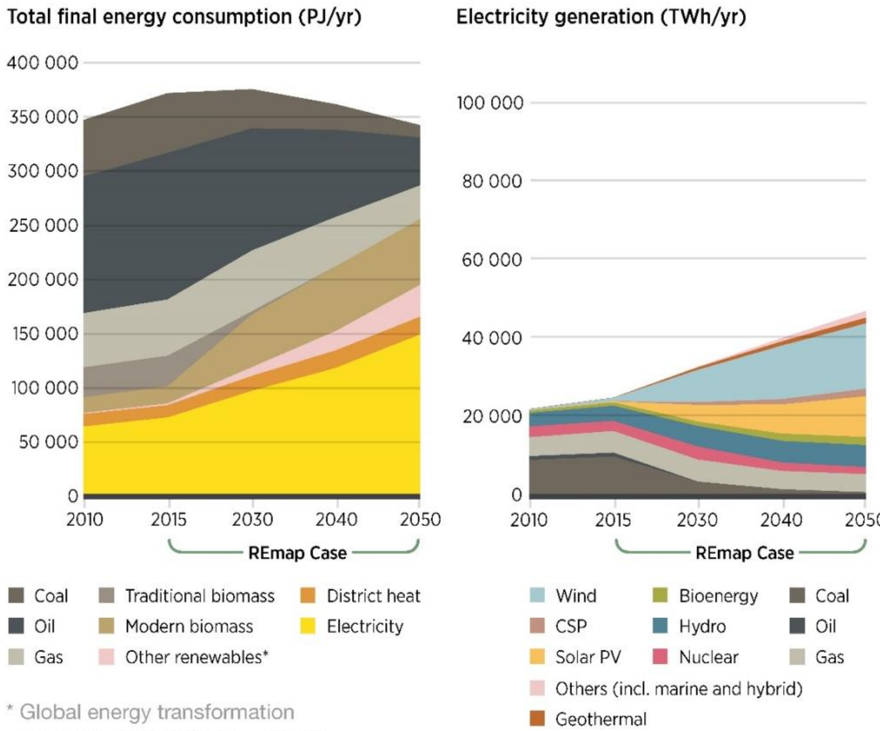
Oil is not a low carbon fuel. The share of oil is critically decreasing

Natural gas (CH4) and hydrogen are low-carbon fuels found in the energy strategies of all countries

Hydrogen strategies :
Japan, Australia, South Korea, Germany, Austria, Great Britain, USA, France

Road maps: Belgium, Brazil, China, Italy, Netherlands, Luxembourg, France, New Zealand, Saudi Arabia

World energy balance*



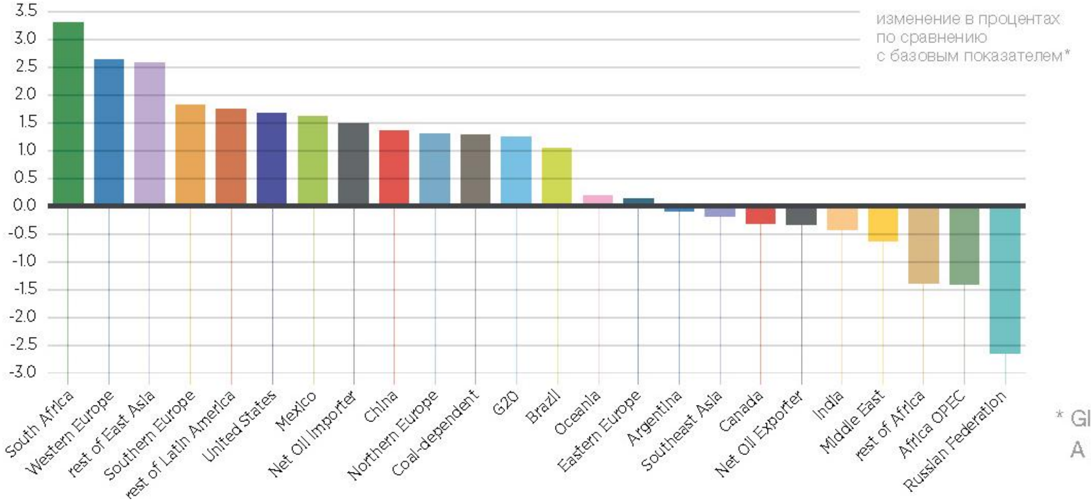
* Global energy transformation
A ROADMAP TO 2050 — IRENA

Investments in hydrogen energy

$ 20-25 billion

Low carbon country development

Impact of changes in the energy balance on the GDP of countries



* Global energy transformation
A ROADMAP TO 2050 — IRENA

Country goal

Integration of the Russian Federation into the world market of low-carbon energy resources

Most of the world's hydrogen is currently used in a country of production from its own resources.

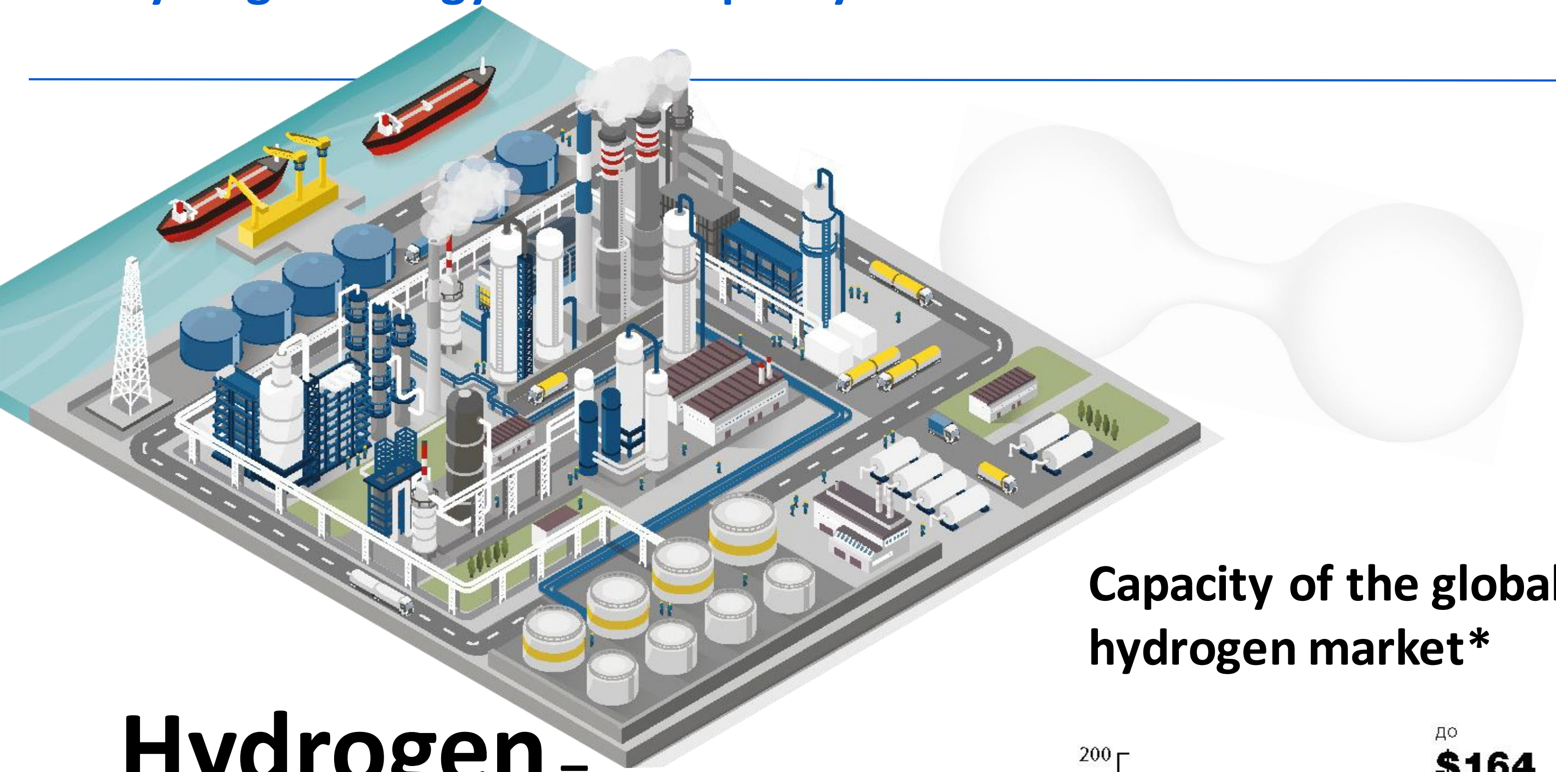
Government of the Russian Federation 2020

Long-term development strategy of the Russian Federation with low greenhouse gas emissions until 2050

4.9. Challenges and opportunities in the transition of the Russian Federation to low-carbon development

«At the same time, a radical change in the energy market creates new opportunities for Russian innovative companies to occupy new niches that are emerging in this market (hydrogen and nuclear energy, technologies and components for renewable energy sources and microenergy, export of green energy, Internet of energy and things)»

Hydrogen energy market capacity

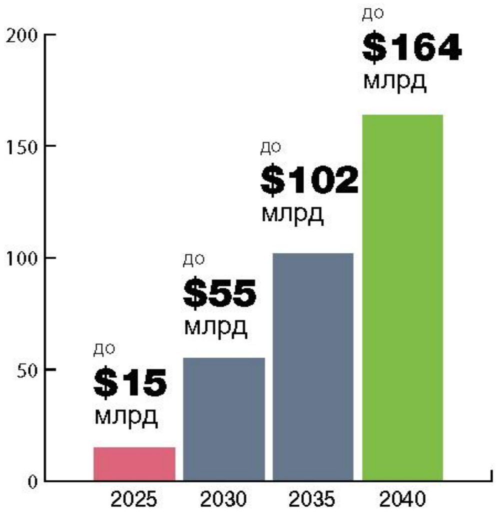


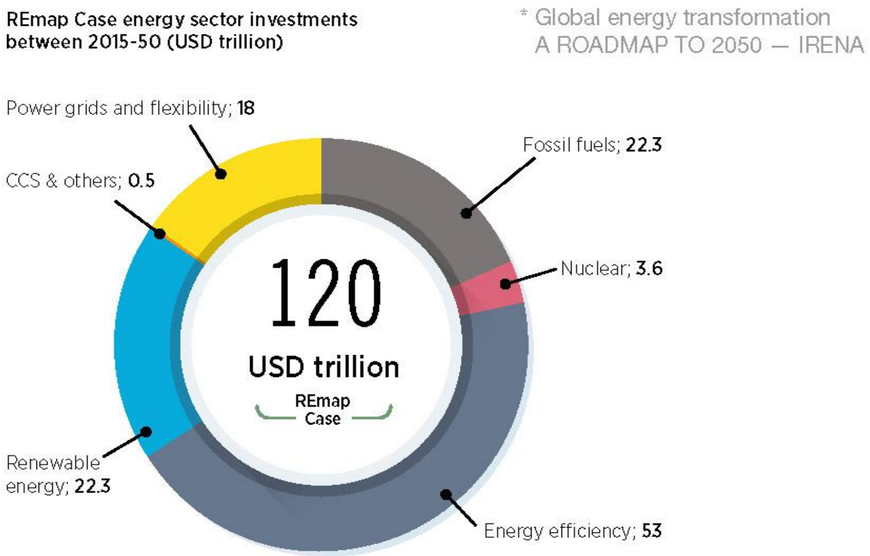
Hydrogen –

chemical energy carrier, can be obtained by various technologies

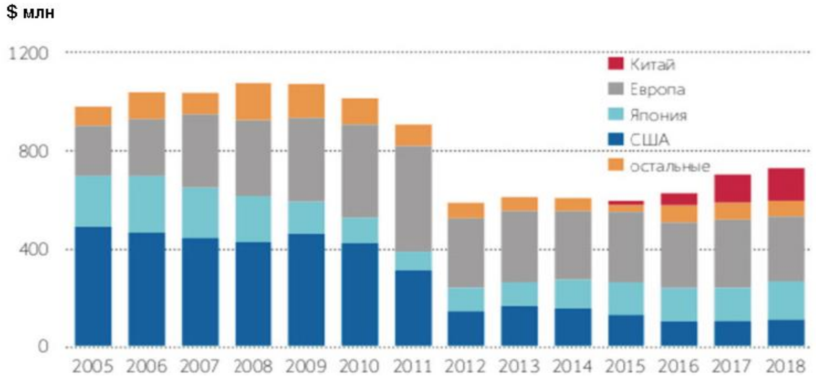
- Hydrogen is not a substitute for oil and gas
- Hydrogen has its niches: energy storage and transportation, distributed energy

Capacity of the global hydrogen market*





Which countries have invested the most in the development of hydrogen fuel?



World Challenges in Hydrogen Energy

Solving these challenges will allow hydrogen to occupy its niche in the global energy balance

Political:

- Ambition for climate change, the most important factor in the turn to hydrogen energy;
- Lack of clear and unshakable commitments of countries for sustainable development;
- The hydrogen in the mixture cannot be identified by its "low carbon" level;
- Variability of attitudes towards "types" of hydrogen in the strategies of states.

Technological uncertainty:

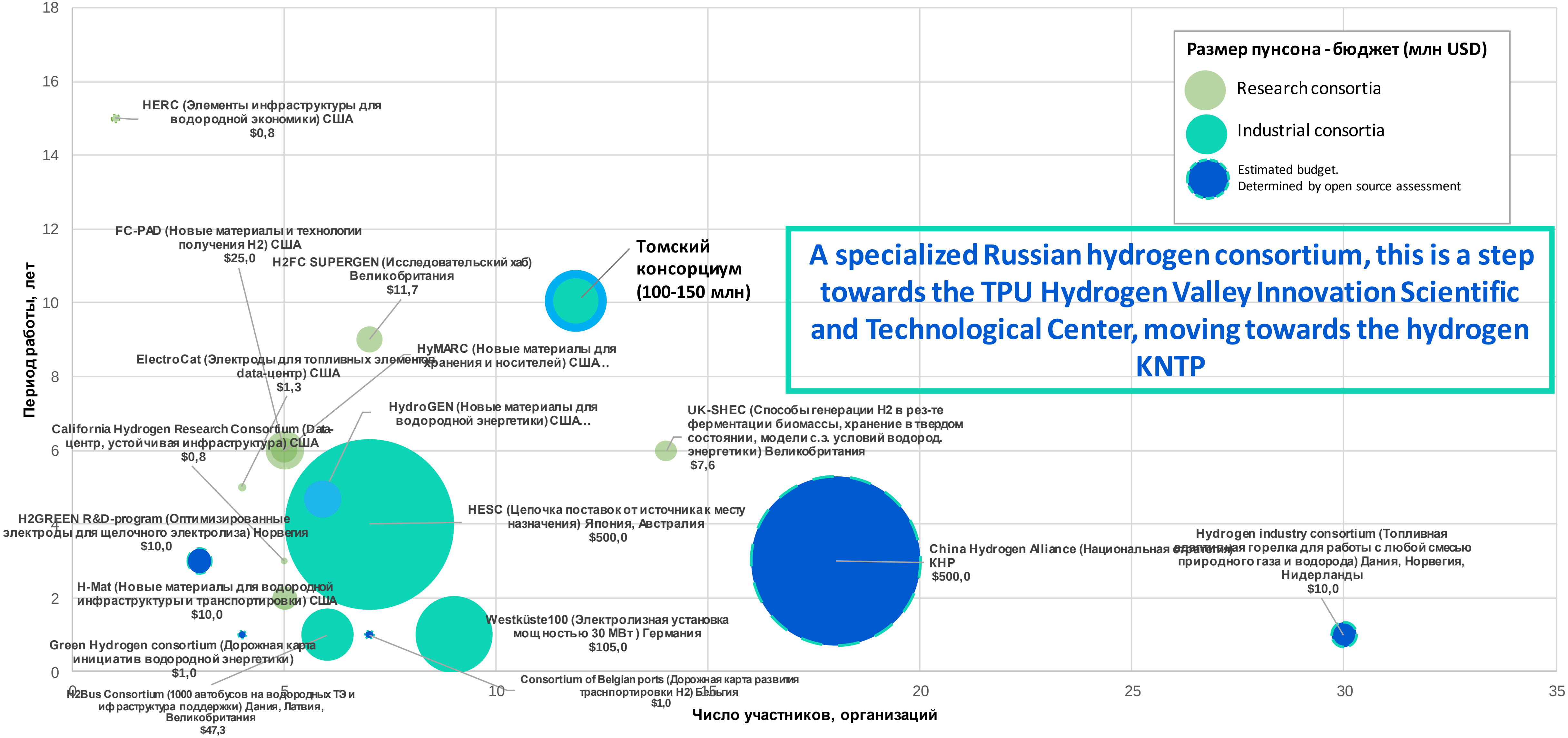
- Complex and customized value and value chains;
- Variability of technologies and infrastructure;Norms, rules and standards;
- Public acceptance.

The production of 69 million tons of H2 (current world consumption), with the current efficiency of electrolysers (60% to 81% depending on the type of equipment and the load factor), will require electricity in the amount of 3600 terawatt-hours, which is more than the total annual electricity production in the European Union.

The hydrogen value chain spans many different technologies and industries. As an alternative to traditional energy, most technologies for low-carbon hydrogen are uncompetitive at the moment without government support!

VALUE CHAINS

World hydrogen consortia



Technological hydrogen valley (Siberian H_2 valley)

Based:

10.11.2020, initiated by TPU

Consortium members:

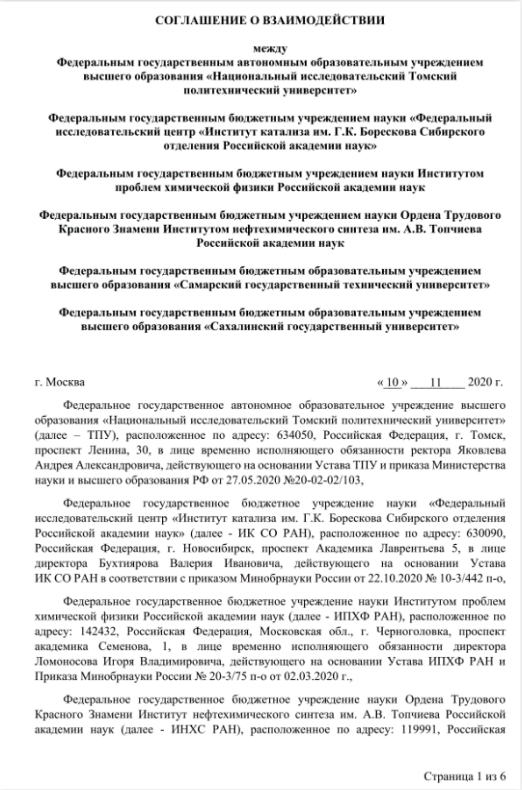
- Tomsk Polytechnic University
- Institute of Catalysis SB RAS
- Institute for Problems of Chemical Physics RAS
- Institute of Petrochemical Synthesis RAS
- Samara State Technical University
- Sakhalin State University

Supervisory Board:

Rosatom, Gazprom, Novatek, Sibur, Russian Railways, Severstal

Consortium directions:

- Hydrogen production technology;
- Methods and methods of hydrogen transportation;
- Rules and methods of hydrogen storage;
- The use of hydrogen.



СОГЛАШЕНИЕ О ВЗАИМОДЕЙСТВИИ

между
Федеральным государственным автономным образовательным учреждением высшего образования «Национальный исследовательский Томский политехнический университет»

Федеральным государственным бюджетным учреждением науки «Федеральный исследовательский центр «Институт катализа им. Г.К. Борескова Сибирского отделения Российской академии наук»

Федеральным государственным бюджетным учреждением науки Институтом проблем химической физики Российской академии наук

Федеральным государственным бюджетным учреждением науки Ордена Трудового Красного Знамени Институтом нефтехимического синтеза им. А.В. Топчиева Российской академии наук

Федеральным государственным бюджетным образовательным учреждением высшего образования «Самарский государственный технический университет»

Федеральным государственным бюджетным образовательным учреждением высшего образования «Сахалинский государственный университет»

г. Москва «10» 11 2020 г.

Федеральное государственное автономное образовательное учреждение высшего образования «Национальный исследовательский Томский политехнический университет» (далее – ТПУ), расположенное по адресу: 634050, Российская Федерация, г. Томск, проспект Ленина, 30, в лице временно исполняющего обязанности ректора Яковлева Андрея Александровича, действующего на основании Устава ТПУ и приказа Министерства науки и высшего образования РФ от 27.05.2020 №20-02-02/103,

Федеральное государственное бюджетное учреждение науки «Федеральный исследовательский центр «Институт катализа им. Г.К. Борескова Сибирского отделения Российской академии наук» (далее - ИК СО РАН), расположенное по адресу: 630090, Российская Федерация, г. Новосибирск, проспект Академика Лаврентьева 5, в лице директора Бухтиярова Валерия Ивановича, действующего на основании Устава ИК СО РАН в соответствии с приказом Минобрнауки России от 22.10.2020 № 10-3/442 п-о,

Федеральное государственное бюджетное учреждение науки Институтом проблем химической физики Российской академии наук (далее - ИПХФ РАН), расположенное по адресу: 142432, Российская Федерация, Московская обл., г. Черноголовка, проспект академика Семенова, 1, в лице временно исполняющего обязанности директора Ломоносова Игоря Владимировича, действующего на основании Устава ИПХФ РАН и Приказа Минобрнауки России № 20-3/75 п-о от 02.03.2020 г.,

Федеральное государственное бюджетное учреждение науки Ордена Трудового Красного Знамени Институт нефтехимического синтеза им. А.В. Топчиева Российской академии наук (далее - ИНХС РАН), расположенное по адресу: 119991, Российская

Страница 1 из 6

The first joint scientific event was the conference (December 2020).

TPU and Economics partnership: strategy formation and risk sharing

TRL1 → TRL2 → TRL3 → TRL4 → TRL5 → TRL6 → TRL7 → TRL8 → TRL9

UNIVERSITY

- TRL 1-4 through internal competitions of development programs
- Synchronizing R&D, testing hypotheses, building flexible scientific teams
- Organization of consortia of executors
- Transfer of international knowledge and technology, in the context of sanctions
- Creation and management of RIA

COMPANY

- Accompanies search projects up to TRL3-4, generates an order
- Does not bear financial risks for exploratory research, if there is government fundingInvests in proven technology
- Gains access to international knowledge and technology
- Becomes a technology benchmark in a specialized field
- Participates in or initiates consortia
- Improving operational efficiency by integrating universities and academic institutions into their strategic and operational directions

*Technology readiness levels (TRL) – уровень готовности технологий
*Manufacturing Readiness Level (MRL) – уровень готовности производства
*Commercial Readiness Level (CRL) – уровень рыночной готовности

Universities and research centers have transformed the agenda for work in the * TRL logic. But projects in the logic of economics require work at three levels of readiness, including MRL and CRL

The transition between TRL levels (* MRL, * CRL) is arranged as a "Stage-Gate"
- leaving the chain or continuing work is considered in the economic framework

ISTC Tomsk Polytechnic University (TPU) – the first Hydrogen Valley in the Russian Federation

Hydrogen Valley Specialization

- **R&D in all segments of the value chain**
- **Process systems for hydrogen production**
- **Value chain technology systems**

MAIN OBJECTIVE OF THE PROJECT: creation of Russia's first large-scale center for the concentration of innovative activities in the emerging market for hydrogen energy technologies

PROJECT OBJECTIVES:

1. **INFRASTRUCTURE:** Creation of infrastructural conditions for the localization of suppliers of R&D solutions and science-intensive products in different segments of the technological value chain

2. **COOPERATION:** Implementation of effective mechanisms of cooperation between universities, scientific organizations and business, shaping the hydrogen energy markets of the future, organization of a system for attracting technological projects and teams from all over the country

3. **URBAN ENVIRONMENT:** Ensuring the development of a comfortable urban environment as a prerequisite for the effective work of high-tech business employees

"Hydrogen" valleys are an established format for the development of new energy systems. Developed countries are actively investing in the creation of R&D centers and increasing the concentration of competencies in hydrogen technologies

A distinctive feature of such centers is their focus both on the technology of hydrogen production and on the technology of its application (fuel cells). Universities are at the core of such centers.

Zentrum für Brennstoffzellen Technik (ZBT) (Центр водорода и топливных элементов), Дуйсбург, Германия

- ZBT is one of the leading research institutes in Europe for fuel cells and hydrogen technologies
- ZBT GmbH is a non-profit limited liability company, the sole shareholder of which has been the University of Duisburg-Essen since 2005
- 7 directions of the Center:
  - ✓ Fuel and fuel processes
  - ✓ Hydrogen infrastructure
  - ✓ Electrolysis and fuel cells
  - ✓ Electrochemical components
  - ✓ Fuel cells and stacks
  - ✓ Fuel cell systems
  - ✓ New materials and technologies
- Leading companies operating in the valley: **Shell, Bosch**

Yamanashi Fuel Cell Valley(Valley for the production of hydrogen cells), Japan

- Research and development:
  - ✓ R&D analysis / evaluation of PEFC (Polymer Electrolyte Fuel Cell)
  - ✓ New materials for PEFC (low PGM catalyst, membranes, etc.)Демонстрационный проект «Power to Gas» (с электролизом PEM 1,5 МВт)
- Development of new industries:
  - ✓ Small fuel cell power supply system, metal separator integrated with GDL, CCM production process, etc.
- FCV (fuel cell vehicle), HRS (hydrogen refueling)
- Leading companies operating in the valley: **Panasonic, Toray Industries, Kobe Steel, Nissan Arc**

Hydrogen Valley (Hydrogen Valley), Northern Netherlands

- Created with a grant from the European Union
- The main initiator and organizer is the university consortium "New Energy Coalition"
- The main stake is green hydrogen based on renewable energy
- The idea is to reproduce in a single cluster of the entire technological chain - from hydrogen production to filling stations.
- Leading companies operating in the valley: **GasTerra (natural gas supply), Gasunie (gas transmission company), Alliander (grid company).**

Hydrogen Valley Partnerships and Networks

- Not only hydrogen valleys are being created, but also their partner networks
- European Hydrogen Valley Partnership established in the EU
- Such networks make it possible to speed up the exchange of experience and to create unified technological chains.

EUROPEAN HYDROGEN VALLEYS PARTNERSHIP

данные GTI's Hydrogen Technology Center

Potential participants of the ISTC "Hydrogen Valley"

Key partners

РОСАТОМ

Yellow hydrogen
Nuclear-hydrogen complexes

ГАЗПРОМ

Gray hydrogen
Blue hydrogen

Technologies for adiabatic conversion of natural gas to hydrogen
Decomposition of natural gas into hydrogen and carbon without CO2
Methane-hydrogen gas turbine
Hydrogen production from natural gas in non-equilibrium low-temperature plasma with zero CO2 emissions

СИБУР

The use of hydrogen in chemical production

Potential partners

ГНЦ РФ - ФЭИ

JSC "SSC RF - IPPE" (SC "Rosatom»)
Liquid Metal Electrochemical Hydrogen Generator
Solid oxide fuel cells and power devices based on them

АО «СКТБЭ»

JSC "Special Design and Technological Bureau for Electrochemistry with a pilot plant" (JSC "USC")
EHRV systems, afterburner furnaces, hydrogen / oxygen generators, thermosorption hydrogen compressors, hydrogen accumulators, technical hydrogen, safety and environmental control devices and devices, gas supply system for aerological stations

Potential JVs with residents of the Skolkovo innovation center (Topaz, BM power, AT energy)
Production of hydrogen fuel cells

топаз BMPower ATEnergy

УЭХК Уральский электрохимический комбинат

FSUE Ural Electrochemical Plant
Electrochemical generators based on alkaline and proton-exchange fuel cells

ТВЭЛ

Storage of hydrogen in gaseous form

АО «СХК»

Production of anhydrous hydrogen fluoride (for use in the production of lithium-ion batteries)

УРАЛХИММАШ

OJSC "Uralkhimmash“
Production of electrolysis plants for hydrogen production

Organizations to be involved in 2020 and the first quarter of 2021

Северсталь

Green Steel (zero carbon footprint steel production)

РОСКОСМОС Ростехнологии
РЖД НОВАТЭК

ЖД-транспорт на водороде

Производство водорода в промышленных масштабах

ОАО Концерн Созвездие

Concern Sozvezdie JSC
Autonomous power supply systems based on electrochemical power sources with fuel processors

Энергия

JSC Rocket and Space Corporation Energia named after SP Korolev
Power devices based on fuel cells for vehicles and household needs

КАМАЗ

Hydrogen freight transport

РусГидро

Green hydrogen

Томский политехнический университет

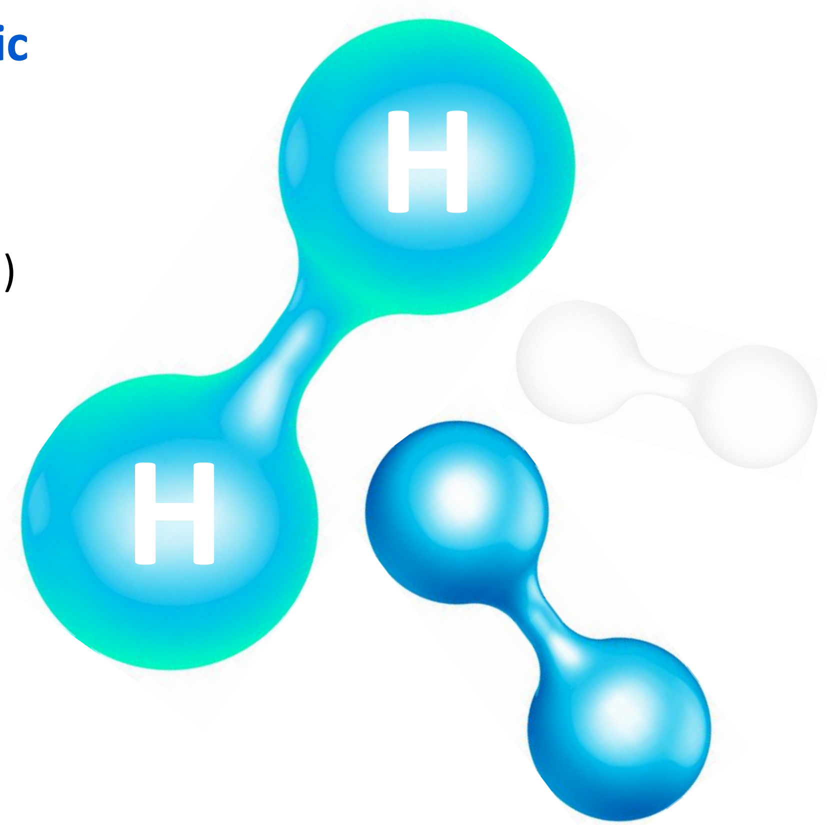
Companies "near" TPU, ready to take a new technological step in the INTC

TPU competencies in the field of hydrogen energy

TPU has accumulated experience in hydrogen technologies. The first R&D successes of the university made it possible to attract the attention of such companies as PJSC Gazprom, PJSC SIBUR Holding. High potential for cooperation in the hydrogen field - with the State Atomic Energy Corporation Rosatom (including TVEL JSC)

The list of TPU competences on hydrogen topics confirmed by the scientific organizations of the Russian Academy of Sciences and companies:

- Hydrogen production using sunlight
- Production of hydrogen from natural gas without CO2 emissions (hydrogen + carbon)
- Gasification with capture of released CO2
- Processing biomass and waste (including plastic) into hydrogen
- Technology for creating thin-film electrolytes for SOFC fuel cells
- Hydrogen fuel cells based on polymer membranes
- Materials modification technologies to increase resistance to prolonged exposure to hydrogen
- Hydrogen storage in exhausted gas collectors
- Electrophysical Shale Conversion



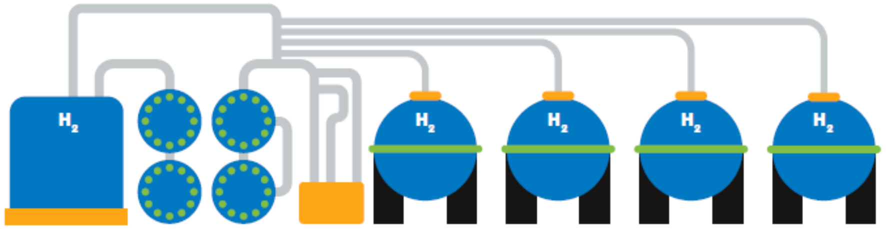
TPU progress in the areas of hydrogen energy

OBTAINING

- Methane-hydrogen fuel, TRL 4;
- Low carbon hydrogen from natural gas TRL 3;
- Electrophysical conversion of shale TRL 3.

DIVERSIFICATION

- Gasification of low-grade coals with the utilization of the released CO2 and the production of H2, TRL 4;
- Processing of biomass and waste (including plastic) into hydrogen, TRL 2;
- Water electrolysis, TRL 2;
- Hydrogen production using sunlight - photonics and plasmonics, TRL 1



STORAGE

- Solid state materials for storage in vehicles, TRL 2;
- Hydrogen Fuel Cell Systems, TRL 2;
- Safety of hydrogen and fuel cells;
- Storage in underground storage (porous reservoirs), TRL 1;
- Hydrogen material compatibility (material reliability, material cost, fuel cell durability), TRL 2.

TRANSPORT

- Joint transport in gas networks;
- Hydrogen material compatibility (material reliability, material cost), TRL 2;
- Transport network security;
- Determining the financial, technical and regulatory aspects of the entire supply chain.

USING

- Technology for creating thin-film electrolytes for SOFC fuel cells and hydrogen fuel cells based on polymer membranes, TRL 4.

DEVELOPMENT OF CO-CATALYST FOR WATER ELECTROLYSIS*

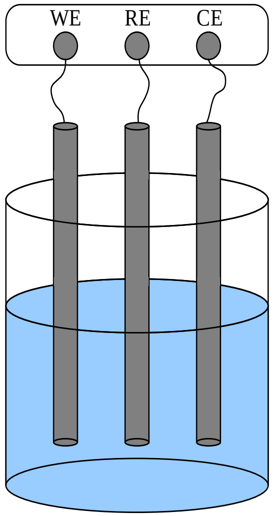
- Development of a co-catalyst for water electrolysis to reduce the cost of commercial platinum catalysts. Obtaining cubic tungsten carbite WC1-x. Doping with 1% Pt significantly improves the electrocatalytic activity, while the addition of 10% Pt achieves characteristics almost similar to commercial platinum samples.

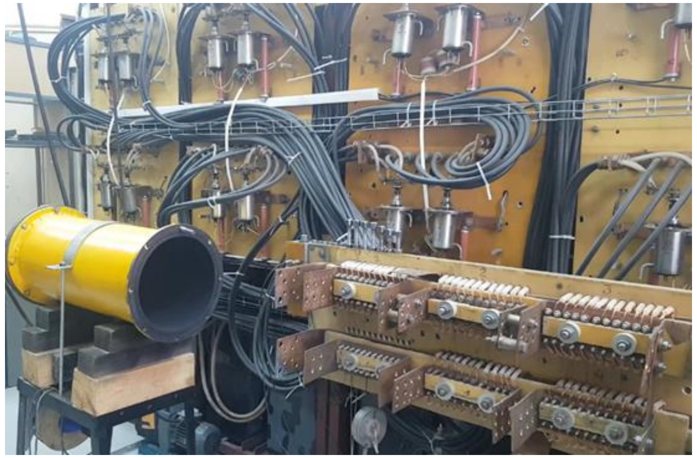
Hydrogen production (in H2SO4 solution):

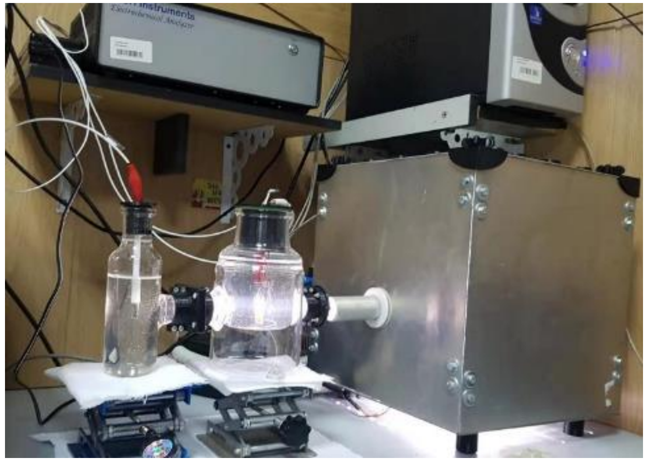
A(+): $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$

C(-): $4H^+ + 4e^- \rightarrow H_2$

WE - working electrode
RE - reference electrode
CE - counter electrode
Three-electrode cell method





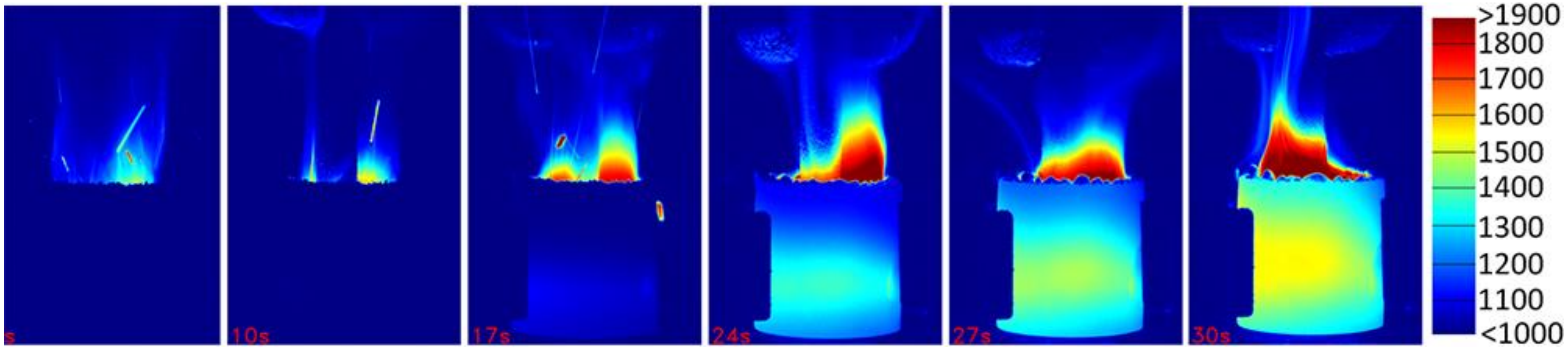


experimental setup based on the three-electrode cell method

SYNTHESIS OF CATALYSTS FOR HYDROGEN PRODUCTION

- Simplification of the synthesis of catalysts based on molybdenum carbide for hydrogen production by electrolysis (to replace platinum catalysts)
- Obtained molybdenum carbide, catalytic activity confirmed experimentally

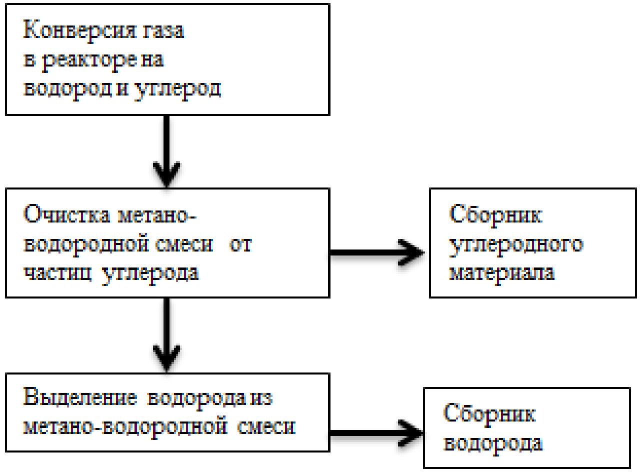
Laboratory reactor



Thermogram of the process of electric arc synthesis of molybdenum carbide

PLASMA-CHEMICAL CONVERSION OF METHANE INITIATED BY NON-EQUILIBRIUM LOW-TEMPERATURE PLASMA

- Development of technology for low-tonnage hydrogen production without CO2 emissions. Convert natural gas to hydrogen and fine carbon particles using microwave plasma.
- To develop a digital twin of the hydrogen production process, to solve the problem of finding the optimal parameters of the installation from the given input and output requirements for gases.



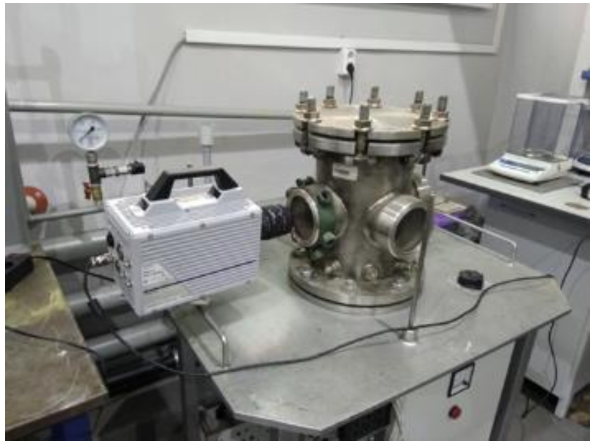
PLASMA-CHEMICAL CONVERSION OF METHANE INITIATED BY A PULSE ELECTRON BEAM

- Implementation of non-oxidative, carbon dioxide, steam, oxidative and mixed conversion of methane initiated by a pulsed electron beam.
- Obtaining experimental data on the composition of the reaction products, their energy yields and optimal conditions for the flow to determine the optimal parameters in the practical application of the method.

Лабораторный стенд на базе ТЭУ-500

PRODUCTION OF HYDROGEN BY THE METHOD OF GASIFICATION WITH UTILIZATION OF THE GENERATED CARBON DIOXIDE GAS*

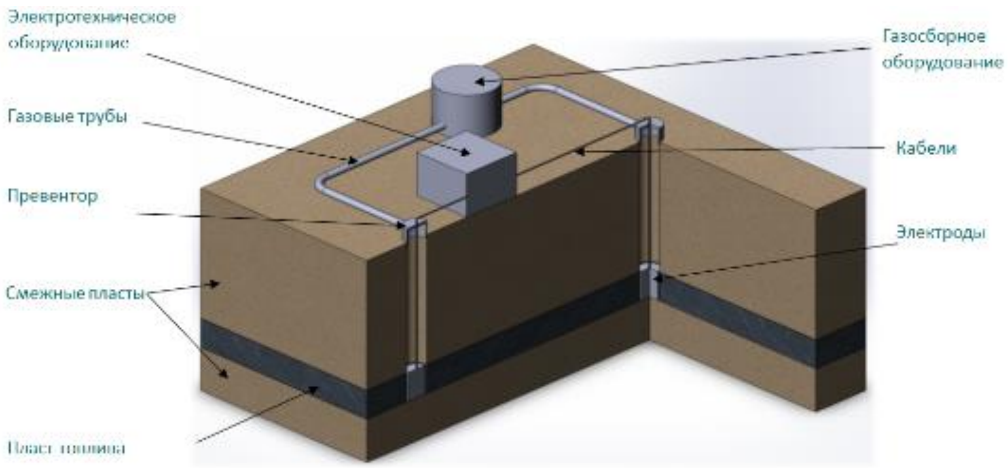
- Optimization of the main parameters of the gasification process, high-quality and low-calorie coal; industrial organic and solid household waste; biomass and products of its processing based on numerical and field experiments; assessment of changes in the process of gasification of power-generating coals with the addition of alkaline and alkaline-earth compounds.



ELECTROPHYSICAL SHALE CONVERSION

- Development of technology for hydrogen production by underground electrophysical conversion of low-grade fossil solid fuels

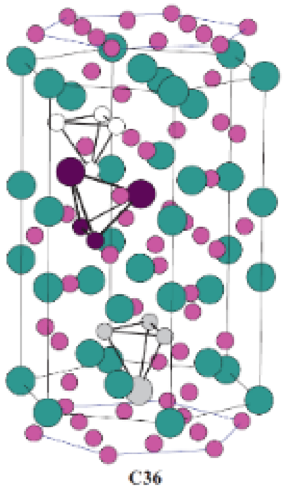
Field tests of the method were carried out at the Bogatyr open-pit mine (Kazakhstan, Ekibastuz). Based on the results of pilot demonstration tests, the amount of gas that meets the lower threshold of profitability of the application of electrophysical conversion was obtained.

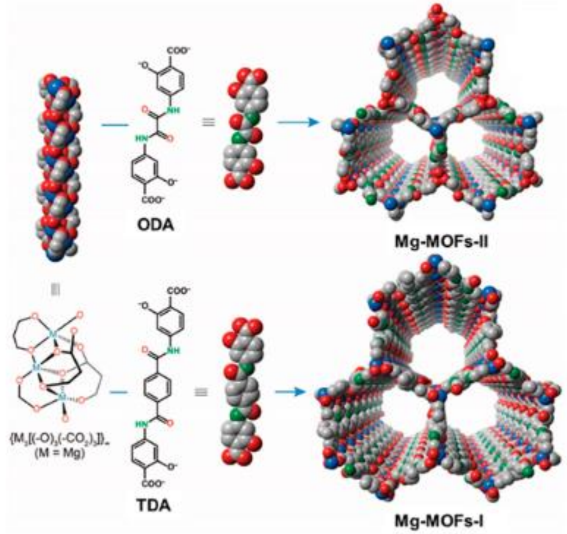


Purification and storage of hydrogen

Development of hydrogen storage materials with high sorption capacity and resistance to multiple hydrogenation / dehydrogenation cycles

- Synthesis of compounds and their composites based on
  - hydride-forming metals,
  - carbon nanomaterials,
  - metal-organic structures.
- Development of recommendations for the selection of hydrogen storage materials with a high sorption capacity and resistant to multiple hydrogenation / dehydrogenation cycles.





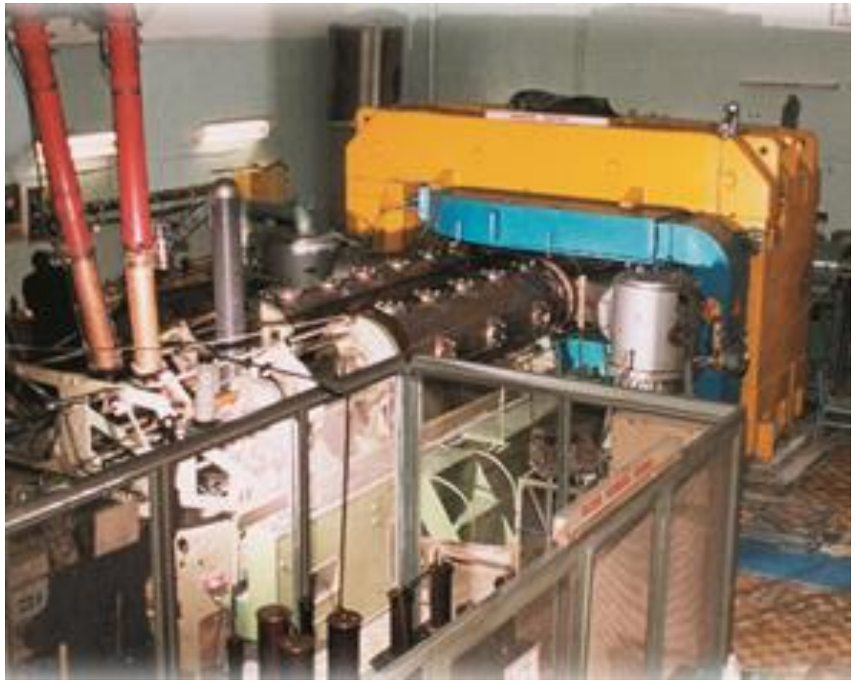
Development of hardware and software systems for the certification of characteristics of hydrogen storage materials

TECHNOLOGY FOR CREATING THIN FILM ELECTROLYTES FOR SOFC FUEL CELLS*

- Technologies for the formation of nanoporous functional layers of solid oxide fuel cells have been developed, which make it possible to increase the catalytic efficiency of electrodes, reduce the resistance to charge transfer in fuel cells at the electrode / electrolyte interface, increasing the specific power of individual cells.

HYDROGEN FUEL CELLS BASED ON POLYMER MEMBRANES

- A radiation-chemical technology for the production of polymer proton-exchange membranes has been developed, which consists in irradiating the polymer with a high-energy alpha-beam (Cyclotron R-7M NLRVT) extracted into the air, followed by chemical treatment.

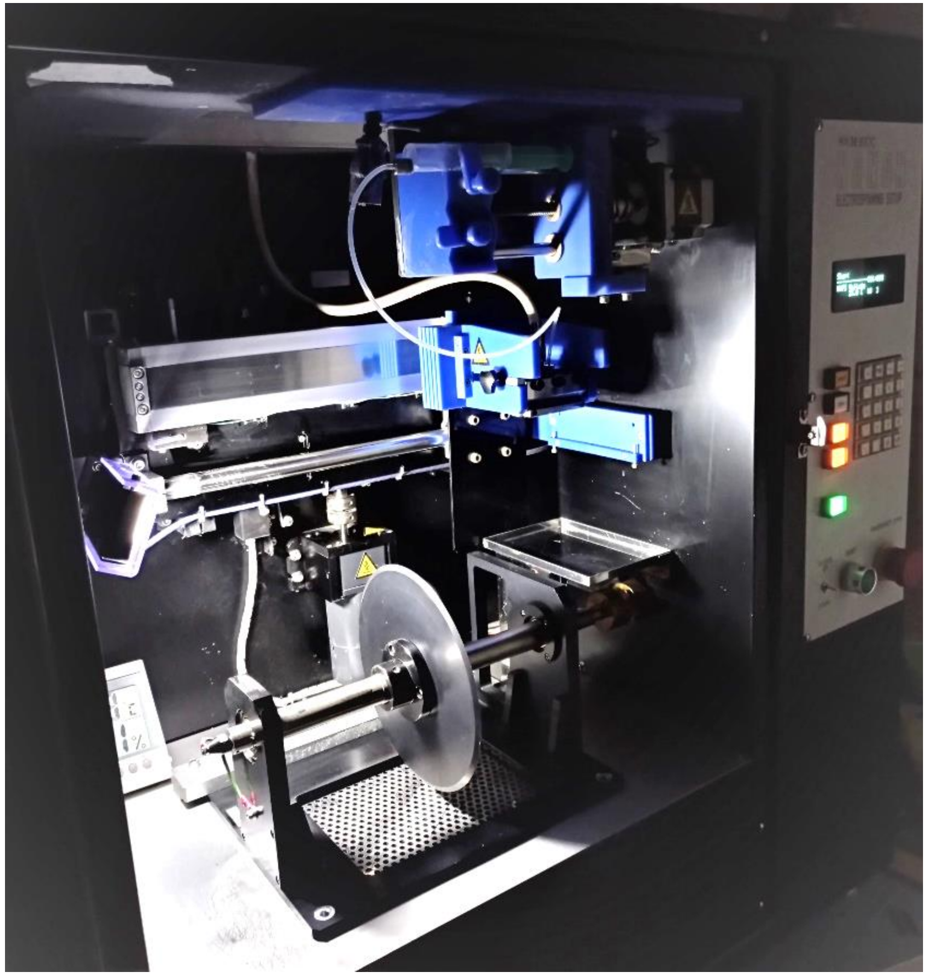


COMPOSITE POLYMER MATERIALS FOR FUEL CELLS BASED ON FLUOROPOLYMERS

- Development of an import-substituting scalable technology for the formation of proton-conducting polymer membranes combining high mechanical, electrophysical and chemical properties for use in fuel cells.

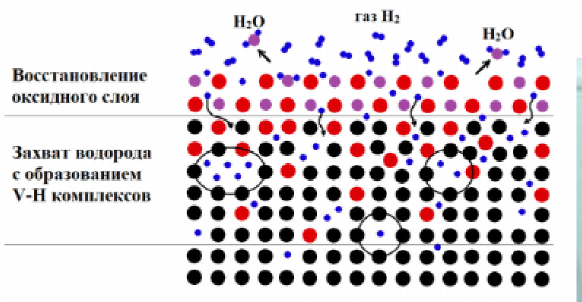
RESULTS:

- The technology of producing composite membranes with the content of proton-conducting polymers of the
- Nafion type up to 70% has been developed. Methods for controlling the structure and morphology of composites have been worked out.
- The technological parameters of the production are optimized.

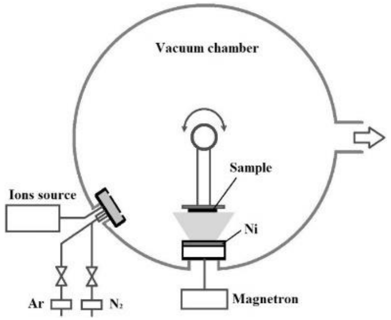


Installation for the formation of composites for fuel cells

TECHNOLOGIES FOR PRODUCTION AND MODIFICATION OF MATERIALS RESISTANT TO LONG EXPOSURE TO HYDROGEN

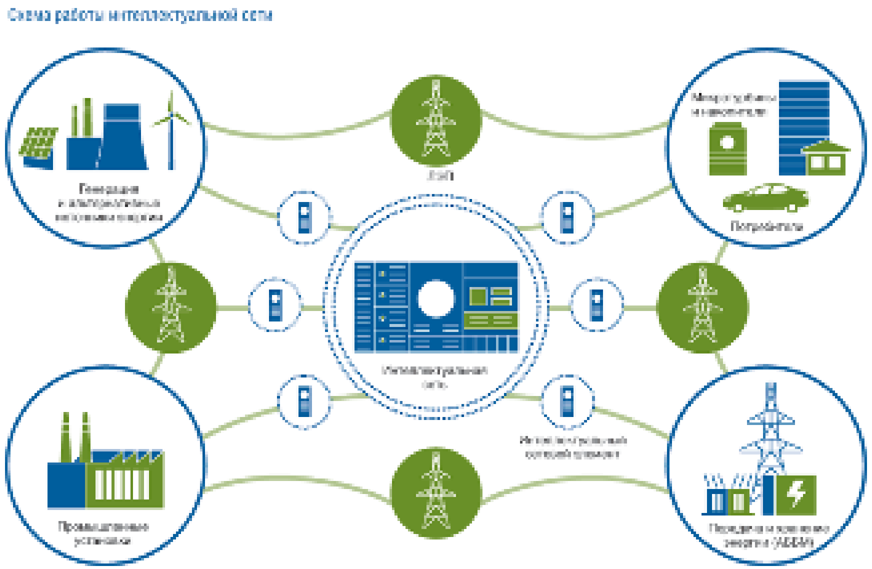


- Theoretical and experimental study of the modification of structural materials by methods of ion-plasma treatment in order to increase the hydrogen resistance of elements of systems for the production and use of hydrogen.
- Development of recommendations for increasing the hydrogen resistance of structural materials using ion-plasma treatment methods for complex installations for the production of synthesis gas and solid oxide fuel cells.



USE OF HYDROGEN WITH THE USE OF INTELLIGENT POWER SYSTEMS*

- Development and creation of hybrid models of elements of modern power systems with hydrogen as an energy storage device using an all-mode real-time modeling complex of electric power systems; creation of a self-diagnosis system for the power complex.
- Integration of renewable energy sources, hybrid systems of autonomous power supply with the production and use of hydrogen, including for remote hard-to-reach areas.



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Thanks for attention!

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