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WAYS TO PRODUCE RENEWABLE ENERGY FROM CARBON DIOXIDE

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Abstract. *The interrelated problems of using renewable energy from carbon dioxide are considered. Particular attention was paid to the fact that on the one hand there is the possibility of obtaining renewable energy from carbon dioxide using new devices. At the same time, on the other hand, the Earth's atmosphere is cleared of such a gas and the greenhouse effect is also eliminated. To implement this approach, the current factors and their interaction, as well as examples of such installations with devices, are described. Their positive and negative aspects were emphasized.*

Keywords: renewable electricity, carbon dioxide, technology

ODNAWIALNA ENERGIA ELEKTRYCZNA Z DWUTLENKU WĘGLA

Streszczenie. *Opisano technologię i szereg problemów wykorzystania odnawialnej energii elektrycznej otrzymywanej z dwutlenku węgla. Zauważono, że z jednej strony możliwe jest pozyskiwanie odnawialnej energii elektrycznej z dwutlenku węgla za pomocą nowych urządzeń. Z drugiej strony – jednocześnie oczyszcza się atmosferę Ziemi z tego gazu i eliminuje efekt cieplarniany. Aby umożliwić wdrożenie prezentowanej technologii, opisano czynniki operacyjne i ich interakcje oraz podano przykłady takich instalacji z urządzeniami. Odnotowano pozytywne i negatywne strony prezentowanej technologii.*

Słowa kluczowe: odnawialna energia elektryczna, dwutlenek węgla, technologia

Introduction

Renewable energy is the production and use of energy from renewable sources, which include various energy flows in nature, such as water, wind, sun, thermal groundwater, biofuel, cold, etc. Their use was determined by the development of science and technology at individual stages. Modern development makes it possible to obtain renewable energy from carbon dioxide (CO₂). The use of renewable energy is becoming increasingly popular, especially in the context of energy-saving technologies and equipment. Renewable energy from CO₂, which is additional to the main source of energy, releases consumers from acute dependence on centralized energy networks. The consumption of other types of expensive energy is reduced. The issues of energy conservation and energy efficiency of renewable energy using CO₂ are also related to environmental safety issues, since it helps to reduce the amount of hazardous gas in the Earth's atmosphere.

In Ukraine, the Institute of Renewable Energy of the National Academy of Sciences of Ukraine, the Intersectoral Scientific and Technical Centre, the Bioenergy Association of Ukraine, as well as other research institutions and private organizations, deal with the problems of renewable energy depending on their financing. Irrational use of funds does not contribute to success. This paper presents a new way to capture greenhouse gases and convert them into electricity. In most modern methods, carbon capture is achieved by absorbing it with liquid or solid substances, which are heated or bled to release carbon dioxide. The concentrated gas can then be compressed and further used for combustion. All these things require improvement.

The total economically viable potential of renewable energy sources in Ukraine is approximately 454.4 billion kW·h. As of 2012, renewable energy sources had only 2% of energy consumption. Ukraine joined the European Energy Community and undertook unreasonable commitments to produce 11% of electricity from renewable sources by 2020 and the right to use the green tariff from 2009. In 2013, the share of renewable energy in the EU was 15%. However, by 2020, they suggest its increase to 20%. In Denmark, Sweden, Lithuania, and other countries this share is already equivalent to 42% and it is constantly growing. Carbon dioxide, which enters the atmosphere as a product of fuel combustion, should be beneficial. Such projects of more or less successful equipment and devices have been known for a long time. Nevertheless, they just indicate the beginning of serious developments. These are the first steps that should be maximized.

We can assume that it takes only 200 dollars to convert the tone of CO₂ into useful electricity [6, 17]. In this work, a well-known innovative method for producing cheap reducing energy and pure hydrogen from water, CO₂ dissolved in it, and two

catalysts is described. This use is double, since the Earth's atmosphere will be simultaneously cleaned for the same expenses, which is of great importance, as, according to statistics, every minute 32 thousand tons of CO₂ are released into the Earth's atmosphere. Practically carbon dioxide reserves are inexhaustible. Experts estimate the strategic volume of the capture, processing, and storage market at 22.5 billion euros per year. This combination of benefits is extremely important. According to the International Energy Agency, by 2019, the world plans to increase renewable energy by 40% in five years. At the same time, they warn of the complexity of the further development of this area due to a decrease in funding for renewal of energy, the use of green tariffs, etc.

By analysing this sequence of using energy sources, we can confidently predict that the next step will be the generation of electricity from space. However, science and technology are still preparing for this to happen.

Based on a critical review and comparison with known solutions to the problem, the relevance of the article is to cover the primary issues of obtaining renewable energy from carbon dioxide, both in theory and, especially, in practice. Therefore, for a comprehensive increase in the organization of obtaining cheap renewable energy from carbon dioxide, the creation and implementation of scientific and practical developments of such processes, as well as efficient equipment and tools, is relevant.

1. Literature data analysis and problem statement

The use of carbon dioxide to generate electricity is a new modern efficient direction, about which there are not so many publications. Most publications [5, 11] describe a general approach to the topic. Since specifics are still very few, nobody is focusing on it. In subsequent works [1, 4], the authors also cite general factors that influence the production of renewable energy, describe the history, the beginning of work and the future, comparison with other methods of producing renewable energy (such as nuclear energy, wind energy, hydroelectricity, solar power, geothermal energy, etc.), which is confirmed by various digital data. Some materials are devoted to well-known installations and devices that implement this new direction. Hence, in the device for converting CO₂ into carbon fuel [3], hot and cold chambers are used on each side. In the centre, there is a row of 14 rings rotating at a speed of one revolution per minute. The outer edge of each ring contains iron oxide with a support compound of a zirconium matrix. A sunlight concentrator is installed inside one chamber to reach a temperature of 1500°C, which leads to the reaction of an oxygen molecule with iron oxide on one side of the ring. In the opposite chamber, the reacting side of the ring rotates,

gradually loses heat, and the amount of CO₂ decreases. This cooling allows iron oxide to remove oxygen molecules from CO₂ leaving carbon monoxide behind.

There is also a device for absorbing CO₂ with the production of electricity [7], which is based on the technology of converting water into an electrolyte by transmitting gases formed during the combustion of organic fuel through it. They installed membranes around the electrodes of this device, each of which transmits only one type of ion. As a result, ions accumulate on the electrodes. Thus, the battery separates the electric charges and generates an electric voltage. There is a device for generating electric current due to the flow of gas or air on piezoelectric elements in the form of wave-shaped plates located with a gap in the generator housing [12]. The air stream enters the generator housing through a bell-slot device, drives the materials of the piezoelectric elements (vibration, deformation), which produce electric current removed by current collectors.

According to the results of publications of periodical scientific publications, especially the Internet, which reflects the latest data, it can be considered that the "niche" of this problem for further developments is their diversity, which gives rise to structural complexity, a difference in their indicators, insufficient coefficient of conversion of air gas energy into electrical energy associated with the selection of part of the heat from the gases. It is also possible to note insufficient environmental friendliness, which is explained by the fact that flue gases contain 93% carbon dioxide and 7% sulphur dioxide, nitrogen oxides, carbon monoxide, soot, powder particles, and possible radioactive elements. Also, there is little initial performance associated with the instability and relatively long formation time of the plasma energy core. Therefore, the problem statement for future research can be considered both the development of the theoretical part of the processes of renewable energy from CO₂ and the selection of the best options for technological equipment, their unification, and the development of improvement methods.

2. The purpose and objectives of the research

The purpose of the article is to determine the prerequisites for the development of renewable energy sources (in particular from CO₂), to generalize the development trends in the field of alternative energy, to study methods for producing renewable energy from CO₂ (both modern and efficient). To achieve this goal it is necessary to meet the following objectives:

- to determine the features of processes as well as equipment and tools for energy recovery using CO₂;
- to establish all factors affecting the effectiveness of such processes and the relationship between them;
- to give examples of the most modern efficient devices and equipment for generating energy from CO₂.

3. The basics of getting energy from carbon dioxide

During energy generation [10], CO₂ is absorbed by liquid or solid substances, which are heated or bled to release carbon dioxide. Then they compress, transport, and use concentrated carbon dioxide. One of the disadvantages of the method is that for the capture of carbon dioxide it is necessary to use about 25% of the generated electricity. The electrochemical cell generates 13 ampere-hours per gram of porous carbon at a discharge potential of 1.4 V, which is comparable to the generation of current by a battery. In addition, the disadvantage is that the electrolyte is a liquid that connects the anode to the cathode, and which is very sensitive to water and has low productivity.

There are three main schemes for CO₂ capture: removal of carbon dioxide after burning fossil fuels, until combustion and oxygen-fuel combustion. In a first gas capture scheme, CO₂ is separated from flue gases. A promising absorption method is used. The absorbent is an aqueous solution of monoethanolamine, as a result of which a mixture of bound CO₂ (which enters the

regenerator) is formed. It heats up regenerating the absorbent and releasing pure concentrated CO₂ (up to 99.9%). The efficiency of gas capture is up to 95%, while the disadvantages are significant energy costs for the restoration of absorbent and compression of CO₂ for transportation. In the second scheme, the primary fuel is processed in a reactor to produce a mixture of carbon monoxide, dioxide, and hydrogen, from which CO₂ and a mixture of H₂ and CO₂ are obtained, which are used as fuel for generating electricity. Oxygen-fuel combustion is based on the use of an oxidizer enriched with atmospheric oxygen with the release of nitrogen from it. After burning, they receive flue gases with a high concentration of CO₂ greatly facilitating the capture of gas.

By way of innovation, a new porous CO₂-absorbing material [2], which uses the structure of the new NOTT-202a material with cellular ordering, was invented. The material structure is used for selective adsorption of CO₂. While other gases (nitrogen, methane, and hydrogen) come back, CO₂ remains trapped in the material nanopores. There is also an innovative device [16] which uses modern Fischer-Tropsch technology. The installation combines CO₂ absorption with electricity production. This technology is based on the conversion of water or an ethanolamine solution to an electrolyte when burning fossil fuels, where CO₂ reacts with water to H₂CO₃ form carbonic acid. Around the electrodes are installed such membranes that pass only one type of ion, which leads to the accumulation of ions, separation of electric charges, and the formation of electric current.

However, the story gets better. The well-known plant, which is considered economically inefficient [14], produces aviation fuel with CO₂. With the help of catalysts, gas is purified from atmospheric air in a reactor; under pressure, it turns into a liquid that is used for industry. The most difficult and responsible is the capture of CO₂. For this, various devices, the disadvantage of which is the irrational use of funds and low productivity, are used.

The capture process consists in obtaining pure gaseous CO₂ from a mixture of gases. To do this, they use the following methods: absorption, membrane application, distillation, mineralization, heat treatment, thermochemical treatment, etc. For example, thermochemical treatment combines the absorption of CO₂ with the production of electricity.

The choice of CO₂ capture technology depends on many factors, such as sophistication, practical application, operating costs, etc. The most promising technology is post-combustion capture technology. As an example, one of these settings is shown in Fig. 1. The scheme uses a straightforward method in which smoke from the atmosphere enters a treatment tank, to which a liquid solvent, which reacts only with CO₂ without reacting with other components, is attached. Typical solvents are ammonia or its solutions in water.

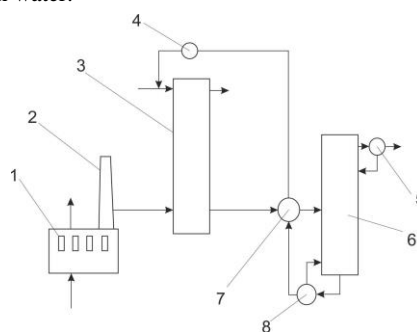


Fig. 1. Scheme of the installation for collecting CO₂ after fuel combustion:

- 1 – power station, 2 – exhaust gases with CO₂, 3 – gas scrubber column,
- 4, 5 – cooler, 6 – regeneration column, 7 – heat exchanger, 8 – heating element

In the tank, gaseous nitrogen remains at the top while liquid solvent remains at the bottom. Then the mixture of solvent and CO₂ is heated in the heat exchanger and the compound decomposes, after which CO₂ is released rising up the tank. Pure ammonia remains at the bottom of the tank and returns back to the treatment tank. Such capture technologies can produce up to 90% of CO₂. The disadvantages of this method include large volumes

of gas that are processed and require bulky equipment, additional energy, and significant costs.

One approach is carbon dioxide capture technology. To do this, oxygen-containing aluminium, which uses electrochemical reactions to both capture CO₂ and to generate electricity, has been developed. To do this, aluminium is used as the anode while mixed flows of CO₂ and oxygen as the active ingredients of the cathode. Electrochemical reactions between the anode and cathode bind CO₂ to carbon-rich compounds. In most devices, when carbon is captured, it is absorbed by liquid or solid substances, which are then heated or bled to release carbon dioxide. Concentrated gas can be compressed and transported for industrial use or stored. In addition, the process is able to turn CO₂ into more reaction molecules, such as oxalate, which contains two carbon atoms and represents new reaction processes that can be used to synthesize various products. Therefore, to increase the performance of electrochemical systems, it is necessary to use electrolytes that are less sensitive to water.

Particular attention should be paid to the device for generating electrical energy, which contains a gas reactor 1 with a pump source 2, a pipe 3 for supplying gas to the cavity of the reactor 1 and a nozzle 4 for removing plasma from the reaction zone (Fig. 2) [9].

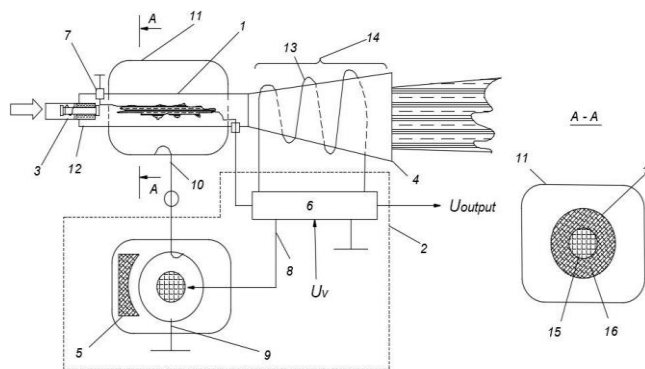


Fig. 2. Design of a device for generating energy from flue gases

The pumping source 2 of the reactor 1 contains an EMW generator, for example, a magnetron 5 and a high voltage arrester 6, the electrodes 7 of which are brought into the cavity of the reactor, and the modulating output 8 is connected to the cathode 9 of the magnetron 5. The EMW output of the magnetron 5 is connected by a waveguide 10 with a resonator 11 through the cavity of which a gas reactor 1 passes. The reactor vessel 1 has a cylindrical shape. It is made of a refractory dielectric material (for example, porcelain or ceramic). An inlet pipe 3 for supplying a gas reagent is installed on one end side of the reactor 1 while a nozzle 4 is installed on the other end side. The pipe 3 contains a check valve 12 while the nozzle 4 contains an inductive winding 13, forming a source of electrical energy 14 connected to the power input of the pump source 2 and external consumers of electricity. The high-voltage spark gap 6 is made in the form of an inductive or capacitive energy storage device with an adjustable pulse repetition rate (modulated by the magnetron 5) and beams of discharge pulses, which are supplied to the electrodes 7. The frequency f_{os} of high-frequency electromagnetic oscillations in each pulse of the magnetron 5 and the frequency f_{dp} of discharge pulses in the packet are selected corresponding to one or more resonant frequencies f_0 of absorption of electromagnetic waves by flue gas (CO₂ reagent and its impurities) introduced into the cavity of reactor 1. The volume of the inner chamber of the gas reactor 1 is selected from the condition of sufficiency of energy for injection sources for the resonant activation of flue gas and to exclude the rupture of chamber 1 during the explosion of the mass of the gas reagent enclosed in it.

The operation of the device is as follows. The energy storage device 6 is supplied with a supply voltage U_v . At the same time, flue gases fill the cavity of the gas reactor 1 through the valve 12, which is open in the normal state. When the high-voltage spark

gap 6 enters the operating mode, the latter (with a transit period T) produces high-voltage modulation pulses of negative polarity of duration τ to the cathode 9 of magnetron 5. Simultaneously with the same repetition period, beams of discharge pulses of duration τ and pump frequency f_p , which corresponds to or is a multiple of the resonant frequency f_0 of the absorption of the gas reagent, are emitted to the electrodes 7 of the gas reactor. Under the influence of a potential difference > 30 kV/cm between the electrodes 7 of the gas reactor 1, an electrical breakdown of the gas reagent and the formation of a streamer – path from the current carriers – ions and electrons with a charge density of the order of 10^{-7} cm⁻³ occurs. At the same time, magnetron 5, under the influence of high-voltage pump pulses, produces high-frequency EMW injection beams with a frequency of $f_p = f_0$ and with an energy density of at least 1 J/cm² and transmits them through waveguide 10 to resonator 11 for electromagnetic pumping of an ionized gas reagent in the chamber of gas reactor 1. At the same time, due to resonant absorption of EMW energy and impact ionization, molecular bonds and CO₂ molecules are broken into constituent elements that are released as a result of the reaction. The generated heat (which is unstable to steady ionization of CO₂ formation), as well as the resonant effect on the medium, which is ionized by EMW energy and sources of electric discharge injection, contribute to the development of the further process of ionization and destruction of oxygen atoms and ions with the formation of a deficit in their mass. An increase in the density of charge carriers to 10^{14} cm⁻³ in reactor 1 leads to the initiation of oxygen reactions, which is accompanied by explosive destruction of oxygen molecules, the release of a free electron of their bond and the quantum energy of the secondary ionizing radiation from the ultraviolet to soft X-ray range of electromagnetic waves leading to avalanche ionization of gas reagent in the reactor 1 and to the complete separation of electrons from positively charged nuclei of oxygen atoms as well as other components of the flue gas. The presence of a small percentage of nitrogen, which binds part of the oxygen in reactor 1, in flue gases slightly reduces the reaction rate due to the fact that nitrogen molecules (having a negative excess charge) surround parts of oxygen molecules, which have a positive excess charge, forming aggregates of oxygen shielded by nitrogen from the action of ionizing effects.

The disadvantages of this method include an insufficient coefficient of conversion of flue gas energy into electrical energy, low environmental friendliness, etc. These shortcomings were eliminated in the device [15] due to the introduction of a tank with CO₂, a reactor with a device for acting on a gas, ultraviolet radiation, pulsed activation of a gas reagent, and regulation of average outgoing power.

4. The results of a study of renewable energy processes from carbon dioxide

As of today, one of the promising areas is the generation of electricity from CO₂. However, work in this direction is at the beginning stage. Therefore, there is little material both on the recovery processes of electricity and on equipment (that is also imperfect and quite diverse), which in turn leads to the irrational use of working time and financing. Therefore, an important task for all complexes is the selection of the best theory of renewable energy and related technical equipment and tools as well as their partial unification at the outset.

The results were obtained on the most difficult generation of electricity from CO₂. Since there were few such studies due to lack of purpose (they were engaged in other methods of restoring electricity, for example, wind, solar, etc.), now we use well-known physical and chemical processes that still need to be adapted to this method. These are devices for capturing CO₂ from air or liquids. In the study of such CO₂ capture schemes, it was found that CO₂ removal is best done after fuel combustion and oxygen-fuel combustion. To implement this scheme, some rare original samples of technological equipment and tools are known that can be used right now to produce renewable energy from CO₂ by

installing them directly on the exhaust pipes. Despite the fact that they are slow, such devices capture up to 90% of CO₂ and are considered the best. When burning oxygen-enriched fuel, CO₂ capture occurs due to an increase in oxygen (rather than air), which in turn reduces the cost of energy recovery from CO₂. Less interesting are the schemes for CO₂ separation using solvents, membranes, mineralization, etc. However, in most cases, these are experimental samples that require structural refinement.

This work presents equipment for producing renewable energy from flue gases CO₂, which so far is also experimental and needs some changes. The above equipment is also quite complex, since it contains a gas generator, a pump source, an electromagnetic wave generator, etc. according to old technology for generating electricity (for example, they use a plasma to electric energy converter). That is, a well-known but rather complex and expensive design, which also requires additional refinement and reduction of technological costs for industrial use, is presented here.

Based on an analysis of studies of known and proprietary material, a universal installation for generating energy from CO₂ (for which a patent application was filed) was developed. The design consists of CO₂ traps that are placed above the environment with CO₂ (for example, pipes of power plants, boiler houses, thermal stations, plants, etc.). Captured CO₂ is converted to liquid fuel using new optimal catalysts. Thus, it is possible to solve the problem of global climate change through the purification of the Earth's atmosphere. The fuel cell consists of sodium alkali metal, a cathode, a separator, and anode catalyst. Known devices that are part of this installation are selected according to the criterion of modern design and high technical and economic indicators. Then a reservoir and devices for using liquid fuel are used. The novelty in such an installation is the interconnection of individual devices, the use of two sources of energy reserves (both a reservoir and a battery), the location of CO₂ traps and mechanical energy use devices. The technical and economic efficiency of the developed installation is justified by a new quality, which is obtained through the use of these devices.

5. Discussion of the results of a study on the production of renewable energy from carbon dioxide

The advantages of the study of obtaining renewable energy from CO₂ are in the comprehensive disclosure of the problem of CO₂ capture from air or water, the manufacture of carbon dioxide, its storage and transportation to the place of consumption. As a rule, well-known publications disclose certain elements of recovery technologies, known imperfect equipment and tools. Since such comprehensive studies are at the beginning stage, so far the technologies and equipment are at the initial level (that is, they are fragmented). At the same time, the whole complex requires significant improvement using the modern development of science and technology. So far, the basis of their functioning is the old physical and chemical principles that require additional changes and coordination. Their main disadvantages are low technical indicators and significant costs, which are stipulated by the lack of a coherent and effective theory as well as practice of recovering electricity from CO₂.

The studies performed are very important because they provide the double benefit: obtaining cheap renewable energy from inexhaustible reserves of CO₂ and cleaning the atmosphere from harmful gases. Provided that the well-known technological equipment and tools are improved to ensure its industrial use, it can be argued that it is natural to identify the influence of the main factors on these processes, in particular the relationship and technical and economic indicators. It is necessary to highlight their actions according to the impacts established. It is with the help of such a mechanism of influence of factors that it is possible to increase the efficiency of energy recovery from CO₂.

To study and obtain a rational technical solution for designing equipment and tools for obtaining renewable energy from CO₂, it

is first necessary to select the best prototypes among analogues and to skilfully improve them in the future using computerization and preferably virtual design [13] with an innovative approach. Thus, you can quickly get the desired design for use in industry and other sectors of the economy, including energy-saving technologies and equipment. This is a continuation of previous studies (however, this time it is about the highest industrial level) in specialized research centres, which must be organized taking care of their staffing and financial support. It is possible to do this in private firms with the help of highly qualified specialists who have no signs of overt or covert enrichment.

The continuation of relevant studies on the production of renewable energy from CO₂ in the near future would be very appropriate since it would make it possible to obtain cheap electricity and clean the atmosphere from harmful greenhouse gases. In addition, the presence of additional sources in electric networks helps to increase the reliability of power supply [8].

6. Summary

As a result of studies on the production of renewable energy from CO₂ using energy-saving technologies and equipment, the following things were proved:

- the greatest promise of obtaining renewable energy from CO₂, which is confirmed by the dual benefits, is to obtain cheap electricity from inexhaustible reserves of CO₂ sources, as well as to cleanse the Earth's atmosphere of harmful gas;
- the effectiveness of technological processes for obtaining renewable energy from CO₂ and components of energy-saving technologies is influenced by a number of external and internal interrelated factors, such as: the level of the general scientific and technical basis for such restoration, the basis for the development and production of renewable energy from CO₂, as well as the availability of technological equipment;
- despite the previous various well-known theories, technical equipment and tools retain their individual characteristics and remain separate; their existence in the general scientific and technical basis for obtaining cheap electricity from CO₂ is difficult and can be widely used both at the beginning of theoretical and practical developments;
- in most cases, the literature provides fragmentary multifaceted descriptions of both the theory as well as devices and equipment, which are distinguished by a variety of designs, technical characteristics, which hinder their professional design in specialized scientific and technical centres provided decent centralized funding;
- the various characteristics of such multifaceted equipment and tools are explained by individual (and not always qualified) approaches in the development, outdated organization of work, unstable supply, and lack of funding;
- the most efficient approach, which is responsible for the CO₂ capture cycle, uses post-combustion technology that can be applied to existing sources of air pollution from power plants, enterprises, metallurgical plants, and other organizations polluting the environment;
- in connection with the actual start of CO₂ capture technology development, most of the technological equipment and tools are distinguished by structural imperfection and low performance;
- a typical structure of technological equipment for generating electricity from CO₂ is devices for capturing CO₂ from a medium saturated with it (air, water), storage and transportation for use, as well as processing it into fuel;
- to increase the development efficiency, it is necessary to single out both typical best examples of the technology for producing carbon fuel and technological equipment and tools with their subsequent unification, which can only be better provided with innovative solutions of narrow specialists in the field of energy supply of renewable energy from CO₂;
- significant development improvements are provided by the use of computerization, that is, when you can quickly make the

necessary changes (especially with a modular concept and virtual development) without any loss;

- first, obtaining rational layouts of technological equipment and equipment for renewable energy from CO₂ involves the development of a recovery technology, the selection of the best samples, as well as the search for innovative solutions and design;
- the research is of great importance for operations to further develop energy-supplying technologies and equipment by reducing the traditional fuel base in transport and the economy in general;
- the negative side of this problem is the complete lack of preparedness and possible misunderstanding of the importance of implementation in resource-saving technologies and equipment, since now completely different tasks dominate (in most cases, they are political) and the general situation is also unfavourable. Subject to a change in the situation in the near future for the better, we can assume that such work will be in demand and used.

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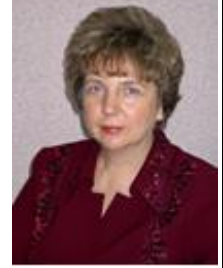
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