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On the sources of hydrogen for the global replacement of hydrocarbons

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Energy production is currently influenced by two global trends: the growing shortage of traditional fossil hydrocarbons and the threat of disruption of the global climate.1,2 The Paris Agreement3 proclaimed the leading role of renewable energy in solving climate problems. Recently, however, the focus has shifted to a wider use of hydrogen. Although there are well-founded concerns about the climatic impact of the additional emission of a large amount of water vapor into the atmosphere, we do not touch on this issue. But it is worth to assess the ways of hydrogen production to meet this goal, availability of necessary raw materials and energy, associated economic costs, and possible environmental impact.

There are no significant hydrogen resources on Earth, since the earth's gravity is insufficient to retain it in the atmosphere. Thus, hydrogen is not an energy source, but a secondary energy carrier that must be produced from other sources, spending additional energy. The transition to hydrogen as an energy carrier will require an increase in global energy consumption to compensate for the inevitable losses during energy transformation. If we take electrolysis with an efficiency of 60% as the basic technology, then, even without taking into account the efficiency of electricity production itself, we will need to almost double the world's energy production when replacing hydrocarbons with hydrogen.

Currently, the annual global production of hydrocarbons is 14 billion tons of oil equivalent,4 about 95% which are burned as energy and transport fuels. To affect the global CO2 emission, it is necessary to replace at least 10% of these hydrocarbons with hydrogen, that is, produce annually 1 billion tons of H2. For a complete replacement it will be necessary 10 billion tons of H2 obtained from non-carbon sources.

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In 2020, 87 million tons of hydrogen was produced worldwide, mainly for oil refining and the production of ammonia,5 which is 10 times lower than the minimum required and 100 times lower than actually needed. More than 3/4 of this H2 was produced from natural gas, which consumed 205 billion m3 of gas, and the rest from coal.

As the main method for obtaining “green hydrogen”, the electrolysis using renewable energy is considered,6 which theoretically requires 39 kWh of electricity to produce 1 kg of H2.7 Even with an overestimated efficiency of electrolysis of 80% and without taking into account other losses, it will actually take 50 kWh. Global energy production from all types of renewable sources amounted to 2,800 TWh in 2019, which allows receiving only 56 million tons of H2 annually, which is lower than its current production.

The cost of hydrogen produced using renewable energy is 3–5 times higher than that of traditional technologies,5,6 and a significant increase in the share of renewable energy in the global balance is impossible without disturbing natural ecosystems. The flux of solar radiation at noon at the equator is 1 kW/m2. Taking into account the change of day and night, its average value is three times lower, whereas in temperate latitudes it is still twice lower, 150 W/m2. With the actual efficiency of solar panels less than 24%, per 1 kW 30 m2 is required. Global production of energy in 2019 amounted to 160,000 TWh,4 which requires an installed capacity of 1.8 1010 kW. To generate this energy by solar panels, it will be necessary to equip with them 6 1011 m2. Taking into account auxiliary areas for equipment, roads, power lines, etc, an area of 1 million km2 will be required.

The entire terrestrial area is 150 million km2, and no more than half of it is suitable for economic activity. Therefore, the withdrawal of such a significant share of it from economic and natural ecosystems will cause irreparable damage to both. The Earth’s crust doesn’t contain the necessary amount of not only rare elements used in the production of solar panels, but also ordinary structural materials for their installation on such areas. And the manufacturing, updating, and subsequent disposal of panels and other equipment will be accompanied by the discharge of such amounts of toxic substances into the environment that the current environmental problems will seem trivial against this background.

Global hydropower production was 38 Exajoules (1 1013 kWh) in 2019,4 which allows to produce only 200 million tons of H2 annually, only three times more than its current production. Therefore, the hydropower, whose global potential has already been realized by more than 20%, is not able to solve this problem.

Global nuclear power produced 25 Exajoules (0.7 1013 kWh) in 2019,4 which allows to produce only 140 million tons of H2 annually, only twice as much as its current production. The possibilities of nuclear energy, even without taking into account the ambiguous attitude of the public towards it, are limited by the reserves of uranium in the earth’s crust. Of course,

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there are prospects for switching to breeder reactors and using thorium as a raw material, but these are not technologies of the near future.

According to the above analysis, fossil hydrocarbons remain the main industrially significant source of hydrogen in the foreseeable future. The most effective modern technology is the separation of H2 from syngas obtained by steam reforming of methane (SRM) (80% of current H2 production) and coal (20% of H2 production). Renewable sources account for less than 1% at several times higher cost. Therefore, in addition to the issues of storage, transportation, and distribution of large volumes of hydrogen, which are still very far from practically acceptable solutions, the fundamental problem of hydrogen energy is to reduce the cost of hydrocarbons conversion into hydrogen.

Taking into account the subsequent steam conversion of the resulting CO, four hydrogen molecules can be obtained from one methane molecule at SRM. Their heat content (4 × 10,800 kJ/m3) is approximately equivalent to that of methane molecule (35,840 kJ/m3). However, taking into account the large additional energy consumption for heating raw materials and producing a large volume of steam, the real consumption of methane in this complex energy-intensive technology is about twice as high.

Since the production of hydrogen by steam reforming is accompanied by the formation of 10 kg of CO2/kg of H2, such hydrogen is considered "gray" according to "ecological" gradation. That is, it is environmentally unattractive and does not solve the task of reducing CO2 emission. To make the resulting hydrogen "environmentally" cleaner and more suitable for solving environmental and climate problems, it is necessary to sequester both the CO2 contained in flue gases formed during the heating of the reagents and steam production, and the CO2 formed during the steam conversion of CO, that is, to supplement the SRM process with Carbon Capture and Storage (CCS). The hydrogen produced in such a combined process can already be qualified as "blue". However, this requires additional energy and, accordingly, an additional consumption of natural gas. That is, along with considerable capital costs and complex processing, the production of "blue" hydrogen by combining SRM+CCS technologies will require almost tripling the total consumption of natural gas and, accordingly, the rate of depletion of its resources. The addition of CCS technology increases the capital costs of SRM by almost 90% and operating costs by 30%. The cost of hydrogen increases almost 1.5 times, up to 1.8 euro/kg.8

In principle, "blue" hydrogen can be obtained by the pyrolysis of natural gas to hydrogen and solid carbon.9 Such processes are now used on a limited scale for the production of carbon black. The thermodynamics of the process requires an additional consumption of about 20% of the resulting hydrogen. However, taking into account the

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inevitable technological losses, the actual amount of additional gas required for hydrogen production will be 50%. Thus, the pyrolysis of 1 m3 CH4 requires 1.5 m3 CH4 with a total heat of combustion of about 54,000 kJ. In this case, 2 m3 of hydrogen will be obtained with a total heat of combustion of 21,600 kJ. The overall energy efficiency of this process will be only 40%. To obtain the same amount of energy when switching from natural gas to hydrogen produced by methane pyrolysis, it will be necessary to increase global methane consumption by about 2.5 times, from the current 4 trillion m3/year to 10 trillion m3/year. To reach such a level, the world economy will need decades and huge investments, and gas resources will be depleted 2.5 times faster. In addition, 7 billion tons of fine coal will be formed annually, the world demand of which is only about 40 million tons. For the resulting hydrogen be considered "blue", this carbon cannot be used as fuel, and there will be an additional problem of its sequestration.

This analysis shows that before the development of nuclear fusion energy, fossil hydrocarbons remain the only real resource for the development of hydrogen energy. Therefore, the creation of efficient technologies for converting large volumes of natural gas into hydrogen will be crucial.

References

1. V. S. Arutyunov and G. V. Lisichkin, *Russ. Chem. Rev.*, 2017, 86, 777.

2. V. S. Arutyunov, *Her. Russ. Acad. Sci.*, 2021, 91, 102.

3. The Paris Agreement.

4. BP Statistical Review of World Energy, 2020.

5. Hydrogen production.

6. D. Gardner, 2009, Hydrogen production from renewables.

7. D. Vitchev, *Academia Letters*, 2021, A brief analysis of the physical requirements for converting coal-fired power plants to hydrogen.

8. N. Mitrova, Y. Melnikov, D. Chugunov, The hydrogen economy - a path towards low carbon development, 2019, Skolkovo Energy Centre, Moscow School of Management, Skolkovo.

9. A. M. Amin, E. Croiset, W. Epling, *Int. J. Hydrogen En.*, 2011, 36, 2904.

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