

# Creation of Favourable Conditions for Introducing Hydrogen Fuel in Russia

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**Abstract.** The paper presents the key problems that hinder the introduction of new fuel for Russian automobile manufacturers. By analyzing the energy market, as well as trends and forecasts of crude oil and petroleum product prices, it proposes the necessary steps for the Government, along with oil producers and automakers, to gradually convert motor vehicles to hydrogen fuel and, therefore, to occupy a high-potential niche in the energy market. The recommended steps are assumed to be applicable not only to this specific case – introduction of hydrogen to the Russian market – but also to any other alternative fuel in a country with the similar or superior national economy.

## 1. Introduction

In the second half of the 20th century, people realized that they cause the irreparable harm to the environment. One of the most adverse factors turned to be the harmful substances emitted with exhaust gases of motor vehicles. It became clear that it was necessary to seek an alternative to hydrocarbon fuel.

Many scientists [1] paid their attention to hydrogen which, due to its properties, was recognized as a good substitute for traditional fuels. Having a number of advantages, hydrogen has been already introduced as a supplemental or even primary fuel for some car models. However, hydrogen is an explosive substance, and there is a risk of detonation and explosion when it is stored and transported under pressure. In order to avoid this, it is proposed to use the carbon-hydrogen bond at the molecular level which eliminates the possibility of spontaneous detonation.

The studies present the method of hydrogen accumulation by absorbing it with different carbon modifications [2]. This method provides the opportunity to develop the reusable fuel element with the capacity comparable to the standard fuel tank for hydrocarbon fuel.

Since the creation of the first hydrogen internal combustion engine, many engineering solutions have been proposed to introduce this new energy source. However, none of them have been implemented because of technological or legal barriers.

## 2. Key preconditions for transition to hydrogen fuel

The current economy largely depends on the energy market. Russia is one of leaders in export of hydrocarbon fuels, and its economic position is very sensitive to price fluctuations of energy products, especially oil. However, the comparison of current oil prices shows that even the most accurate forecasting models may fail [3]. This is why it is impossible to foresee the market trends to the full



extent. This is especially the case for long-term trends when oil prices are close to (or below) the critical level for the national economy.

In such circumstances it is necessary to look for new solutions [4] for the Government to significantly reduce the risks of unforeseen events in the global market. The most reasonable solution is to introduce a new alternative product to the global market – such a product that could meet the same demands or even exceed the characteristics of traditional hydrocarbon fuels.

The economic development of the country requires a strong growth of the industry; however, an increased output means increased emissions [5]. But not only the industry and agriculture significantly affect the environment; an increasing number of motor vehicles running on hydrocarbon fuels causes the powerful effects on all biological species of the planet. This is why reduction of emissions generated by exhaust gases of motor vehicles is an important challenge. Use of special filters does not solve this problem [6]. Therefore, the key focus is on the search for the most suitable alternative fuel for motor vehicles.

The most characteristic feature of the 21st century is the replacement of conventional hydrocarbon fuels since hydrocarbon reserves are being rapidly depleted. The current state of the global energy sector is estimated as follows (table 1):

**Table 1.** The Current State of the Global Economy.

Resource	Share in the global energy mix	Reserves (in raw condition), J
Oil	39%	$10^{22}$
Gas	23%	$10^{22}$
Coal	22%	$1.8 \cdot 10^{23}$
Nuclear energy	7%	$10^{30}$
Renewable sources	8%	-

The annual energy consumption has reached  $10^{20}$  J and is predicted to grow by 50% by 2020.

At the present time, transport vehicles consume more than a half of petroleum products [5]. Due to the rapid consumption of this fuel, as well as inevitable toxic emissions, the humanity has to find alternative energy sources. The long history shows that hydrogen is the most preferred source of energy.

The advantages of hydrogen include:

1. Being the main source of hydrogen, water is abundant in the Earth. Water reserves are able to meet the growing needs of the humanity for a very long period.
2. Various hydrogen-containing compounds, as well as the huge world's reserves of hydrogen sulfide can be also used as a source of fuel.
3. Hydrogen is a clean energy source, and its addition to a hydrocarbon fuel will reduce toxicity of exhausted gases by 65-75 percent.
4. The use of hydrogen will make it possible to overcome one of the major disadvantages of internal combustion engines – a significant loss of efficiency from 30 to 10 percent at partial loads.
5. It has a high content of energy per unit mass – 120.7 MJ / kg. This is superior to any fossil fuel [7].

The studies in Russia and abroad convincingly demonstrate the cost-effectiveness of hydrogen as a fuel. Figure 1 shows the engine efficiency as a function of the percentage of the air-hydrogen mixture.

It is easy to notice that the greatest efficiency is reached at 100% of the hydrogen content and the air volume of about 2.5 times of the hydrogen volume.

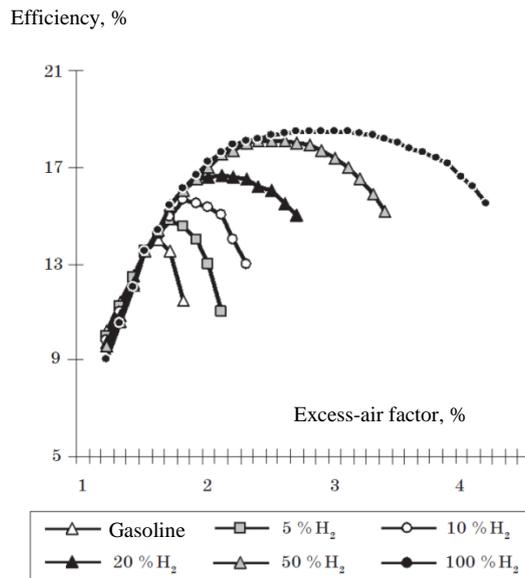
According to this graph, even a minimal addition of hydrogen to gasoline considerably increases the efficiency. The gasoline-hydrogen mixture with 5-10% of hydrogen is proposed to be used for the gradual transition to pure hydrogen. In this case, a volume of harmful emissions will be considerably reduced.

The following conclusions can be made from figure 2.

1. In case of a lean mixture, the CO concentration in exhaust gases decreased to zero and did not depend on a fuel.

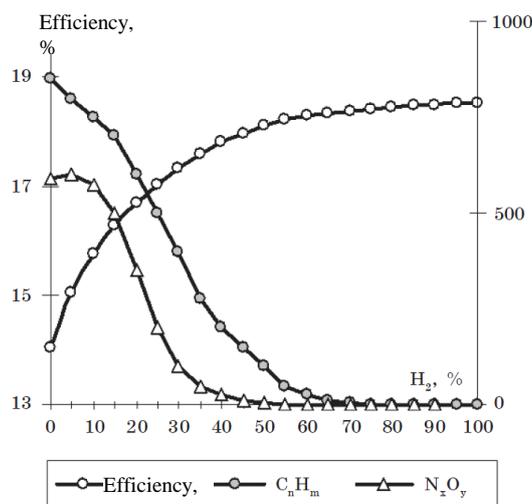
2. An increase in the relative concentration of hydrogen in the gasoline-hydrogen mixture significantly reduces emissions of  $C_nH_m$  hydrocarbons;

A type of fuel does not affect the generation of nitrogen oxides  $N_xO_y$ ; however it is determined by combustion temperature of the fuel-air mixture. The use of hydrogen and gasoline-hydrogen mixtures reduces the highest temperature of the cycle inside the internal combustion engine. Hence, it will significantly decrease  $N_xO_y$  concentration and, therefore, volume of emissions [8].



**Figure 1.** Control performance of the engine as a function of the mixture ratio.

Table 2 shows the performance of harmful emissions during combustion of certain fuels. It is easy to notice that the gasoline has the worst emission rates. The combustion products of hydrogen do not include carbon dioxide and hydrocarbons that affect the environment. Volume of harmful emissions is significantly reduced in the gasoline-hydrogen mixture as well.



**Figure 2.** Effects of hydrogen additions on economic and ecological performance of internal combustion engines.

Nevertheless, with all advantages of hydrogen taken into account, it can be expected that widespread use of hydrogen fuels will be unprofitable to companies engaged in development of oil fields, oil refining and export. Increased use of hydrogen will certainly reduce the consumption of traditional fuels and, therefore, profits of oil producers. In the specific conditions of the Russian society, large companies will likely to prevent any attempt to introduce hydrogen as an alternative to hydrocarbon fuels.

The cost of hydrogen fuel is determined by the relevant infrastructure costs. At the present time, the average cost of industrial hydrogen (99.99% purity) is 61.06 roubles per liter. The average cost of A1-92 petroleum is 34 roubles per liter. However, it should be taken into account that petroleum has the environmental impact in the form of exhausted gases, while hydrogen fuel does not have such an effect. Although the retail price of hydrogen is significantly higher than that of petroleum, prices of hydrogen fuel are expected to be naturally falling due to the continuous development of technologies and methods of production.

**Table 2.** Harmful emissions from combustion of different fuels.

Fuel	Emission of harmful substances, g/km		
	CO	CH	NO <sub>x</sub>
Gasoline	42	8.5	9.1
Liquefied petroleum gas	19	4.8	8.7
Compressed natural gas	8.5	4.5	8.5
Gasoline-hydrogen mixture	3	2.8	4.55
Methanol	28	4.6	4.4
Gasoline-methanol mixture	32	5.4	7.6
Syngas-methanol mixture (H <sub>2</sub> +CO)	5	2.5	3.5
Syngas (H <sub>2</sub> +CO)	0	0.4	2.3
Hydrogen	0	0	2.5
EURO 1	2.72	0.93	-

It will be economically profitable and environmentally sustainable to use hydrogen as a fuel (both separately and in combination with petroleum). The multi-year experience of different countries shows that the benefit from the introduction of hydrogen internal combustion engines will be considerable. Nevertheless, this conversion has not been implemented yet for a number of reasons. They include:

1. The lack of clear technical regulatory, administrative and legal framework that would be used to formulate requirements for automakers and fuel corporations. This problem is proposed to be solved by creating the expert committee at the Government of the Russian Federation for coordinating this issue with business stakeholders and research institutes relying on the existing experience in this field.

2. There is no infrastructure for automakers to change the technology and to produce more environmentally friendly cars. The development of the necessary legal framework will provide the possibility to design new and upgrade existing filling stations, as well as to plan logistics solutions.

3. The unsatisfactory economic situation in the Russian automotive industry which suffers significant financial losses from the crisis. The solution of this problem is to provide the governmental support and to attract investments, including foreign ones, for developing new, environmentally friendly models.

This support to automakers must be combined with the strict policy of lean manufacturing in order to identify weak points in production processes and to eliminate or minimize them. It is proposed to use the experience of Toyota in elimination of losses affecting the value of a product. The manufacturing process of Toyota Production System and other companies that have adopted its approach is considered to be consistent with the lean manufacturing concept.

In addition, a large marketing campaign is proposed to restore reputation of Russian automobile manufacturers.

The lean manufacturing policy and the marketing campaign will contribute to production of cars at a lower price and better quality and, therefore, attraction of domestic consumers and investors.

4. Reluctance of domestic consumers to purchase domestic cars. This problem can be solved by improving quality of products. This issue has been detailed in the previous clause.

5. Resistance of oil companies to the increasing demand for hydrogen fuel. It should be reasonably expected that major oil producers will not endure decreasing the demand for their products. They will slow down reduction of the dependence on hydrocarbons by all available means, as this is the case in other countries.

Nevertheless, the gradual replacement of petroleum products as the primary fuel is inevitable. Russian and international corporations will gain significant advantages if they begin to develop the hydrogen fuel market by its own efforts.

### **3. Measures for Transition to the Alternative Fuel**

A number of steps representing the most important operations are suggested for more effective introduction of hydrogen as a new fuel. Implementation of all these steps will ensure the most effective and trouble-free transition not only to hydrogen energy but also to any other alternative fuel.

1. To develop, in cooperation with automakers, the plan for converting motor vehicles to the gasoline–hydrogen mixture. Due to this, automakers will reduce losses from sales of oil products and compensate them by sales of hydrogen.

2. To convert a part of their facilities to production and sales of hydrogen fuel.

3. To create the reliable infrastructure for consumers to assure them that they purchase environmentally friendly cars.

4. Automakers should participate in training of service staff and monitor training of young specialists. To maintain the necessary stock of spare parts.

5. Before putting hydrogen fuel into widespread use, it is necessary to implement a pilot project in one of regions and to demonstrate effectiveness of the new development program to consumers.

6. To significantly expand the production of alternative consumer goods based on petroleum products.

Even today, major oil producers can convert a part of their production facilities and resources to non-fuel products from hydrocarbons. Nowadays, oil is used to produce many everyday products. Almost all polymers serving as raw materials for production of plastics and rubbers, as well as household chemicals such as detergents, coloring materials, solvents, and varnishes are made of oil. We should not forget about the light industry, including synthetic fabrics, fertilizers, and pesticides.

Moreover, oil products are used to produce a wide range of lubricants, including hydraulic and electrical insulating oils, cutting fluids, and petroleum jelly. There are many other products from hydrocarbons, such as coloring agents for artificial limbs, perfume products, strings, paraffin wax for candles and lipsticks, toothpastes, and chewing gums.

Certainly, amount of oil products used for non-fuel production is significantly less than the amount consumed by motor vehicles. Nevertheless, the scientific and technical progress does not stand still: there are increasingly more new substances and materials which may become key oil-based products for the next several decades. This is why R&D costs must be one of the most important elements in cost planning of any oil producer. This will allow them to eventually create new categories of high-demand products.

Thus, these recommended steps will provide the opportunity to gain a share in the hydrogen fuel market and to prepare the industry and the business for the gradual transition to the new source energy. It can be asserted that conversion of production facilities to hydrogen fuel will significantly reduce the harmful environmental impact and the dependence of the Russian economy on world market prices of energy resources.

On the basis of the foregoing, it can be concluded that there is a need for transition to the new fuel, which, thanks to its physical and chemical properties, is capable to eliminate harmful effects on the environment and to significantly improve the technical, economic and operational performance of existing and future internal combustion engines.

The study shows that even a small amount of hydrogen mixed with the gasoline significantly reduces the effect of exhaust gases on the environment, as well as increases engine efficiency and, therefore, reduces fuel consumption.

The trend towards more eco-friendly motor vehicles will lead to the introduction of new energy sources in the coming years. The largest automotive companies are well aware of the current realities and invest significant financial and intellectual resources to find solutions associated with the development of eco-friendly cars. A share of hybrids and models using electricity or hydrogen will only increase, making it necessary to search for new technological solutions.

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