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Priority Areas for Diversification of Enterprises of the Fuel and Energy Complex (FEC) Based on the Creation of Innovative Resource and Energy Saving Technologies for Processing Coal Mineral Stocks for the Production of Synthetic Gaseous and Liquid Fuels and Non-fuel Products.

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ABSTRACT

The article reviews the methodological, organizational, economic and technological principles of diversification of production at the enterprises of the fuel and energy complex. Research and development in the declared area are studied. The authors carried out retrospective historical analysis of the topics of methodological works of domestic and foreign scholars on the relevant problem of improving the efficiency and environmental safety of the use of traditional energy sources: coal, oil and gas and, most importantly, the creation of alternative competitive technologies for complex chemical processing of coal mineral stocks for the production of synthetic gaseous and liquid fuels and non-fuel products. Overview of research and development in the declared area is presented. The effectiveness of economic and technological model (ETM) for carrying out research is analyzed, which allows to systematize the information on the coal deposits under consideration, to choose and substantiate the areas of industrial processing of mineral stocks and diversification of enterprises, to calculate economic performance of newly established production facilities and optimize the production parameters and the product range. The study reveals priority areas of diversification of enterprises of the fuel and energy complex (FEC) based on the creation of innovative resource and energy saving technologies for processing coal mineral stocks for the production of synthetic gaseous and liquid fuels and non-fuel products.

Keywords: coal industry, synthetic fuel, organizational, economic and technological processes, processing, diversification, production, economic and technological model.

JEL Classifications: Q32, Q41, D24, L23, L71.

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INTRODUCTION

The reserves of traditional fossil fuels (oil, coal, gas) are finite. The ecological reserve of our planet is also finite. The increasing environmental pollution and atmosphere heat disorder gradually lead to global climate change.

In our view, across a variety of existing solutions to the above problems, the most effective are only three:

- First – austerity in spending the traditional energy resources;
- Second – use of alternative fuels and energy sources;
- Third – development and implementation of promising innovative technologies of processing of traditional stocks into alternative energy.

The first way is unacceptable, since the energy intensity of the economy is very high, and high rates of economic growth require growth of energy production. In addition, a proportion of costs and total costs of production of the fuel and energy complex due to losses during extraction, processing, transportation and sales is high.

The second way is possible with a focused and comprehensive support of development of alternative power economy by the state.

The third way is currently feasible. Application of new solutions for the development of generating sources makes it possible to save the traditional resources. Scientific and technical achievements of our country allow to implement and successfully compete with the West in areas such as processing of coal into generating gas and motor fuel.

The main criteria in determining the areas for diversification of coal mining, energy and industrial enterprises:

- Saving of financial resources to create new jobs, compared with continuation of only coal mining and generation of electric or thermal energy;
- Viability of enterprises in the market economy;
- Possibility of the return of investment resources;
- Diversification projects cost sharing by local and republican budgets, as well as commercial structures;
- Ensuring the social protection of residents of mining and energy settlements and towns.

Until the middle of last century, the global and Russian power economy relied on coal resources. Since the '50s due to the growth in consumption of oil and gas, there has been a steady decline in production and use of coals. Currently, the share of coals in the global energy mix is about 30% on average. The current level of oil and gas extraction, according to some estimates, will continue until the middle of the XXI century, and the demand for coal resources in the world will sharply increase after 2050.

Today coal should be considered as power technology stock and used on a large scale only in complex, dividing its potential chemical energy approximately equally between energy production (electricity and heat) and chemical products. By organizing power technology processing of solid fuels on the basis of a large power economy (heat and, possibly, nuclear), we will overcome the oil and gas crisis that is waiting for us in the XXI century. Negative trends in the resource base of oil and gas extraction – reduction in resources at the need to maintain high export deliveries – require a broad and rapid introduction of new coal technologies aimed at ecological and energy conservation and comprehensive utilization of all types of coal (Gnezdilov, Zhukov and Yakovlev 2007; Zhukov 2010; Zhukov, Zhukova, Mikhalkov and Umarov 2015; Vityuk 2004; Konovalenko 2013; Tezhik 2001).

The idea of the necessity and effectiveness of pre-treatment of the solid fuel prior to combustion has been formulated by Russian scientists back in the early XX century. Academician G.M. Krzyzhanowskiy – at the time a director of the Energy Institute of the Academy of Sciences of the USSR (ENIN) that he established – was one of the first to create the conditions for its implementation. The school of energy technologists established by G.M. Krzyzhanowskiy and headed by Corresponding Member of the AS USSR Z.F. Chukhanov substantiated and developed a process of high-speed pyrolysis of solid fuels (coal, peat, oil shale), which showed its high efficiency, first of all, on the basis of the implementation of large-scale consumers of solid fuel, such as power plants. Such processing of fuel allows in the most economical way to extract or obtain products valuable for the national economy from it: pyrolysis gas, 30-40% of which consists of unsaturated hydrocarbons, the main raw material of modern plasticate chemistry, now produced from natural gas and oil (through special processing) and pitch products, from which you can get different kinds of motor fuel and liquid fuel oil, the analogue of oil residue.

METHODOLOGY

In the XXI century, about 60% of extracted coal worldwide is used primarily as fuel. A quarter of the extracted raw material is used in the by-product coking industry, and the resulting coke in factories is used for the production of pig iron.

Coal is used in the production of more than 400 goods of all kinds. Coal tar and tar water are used to obtain benzene, ammonia, phenols and other compounds used in the manufacture of paints, varnishes, linoleum and rubber (see Figure 1). (“A look into the future “ n.d.).

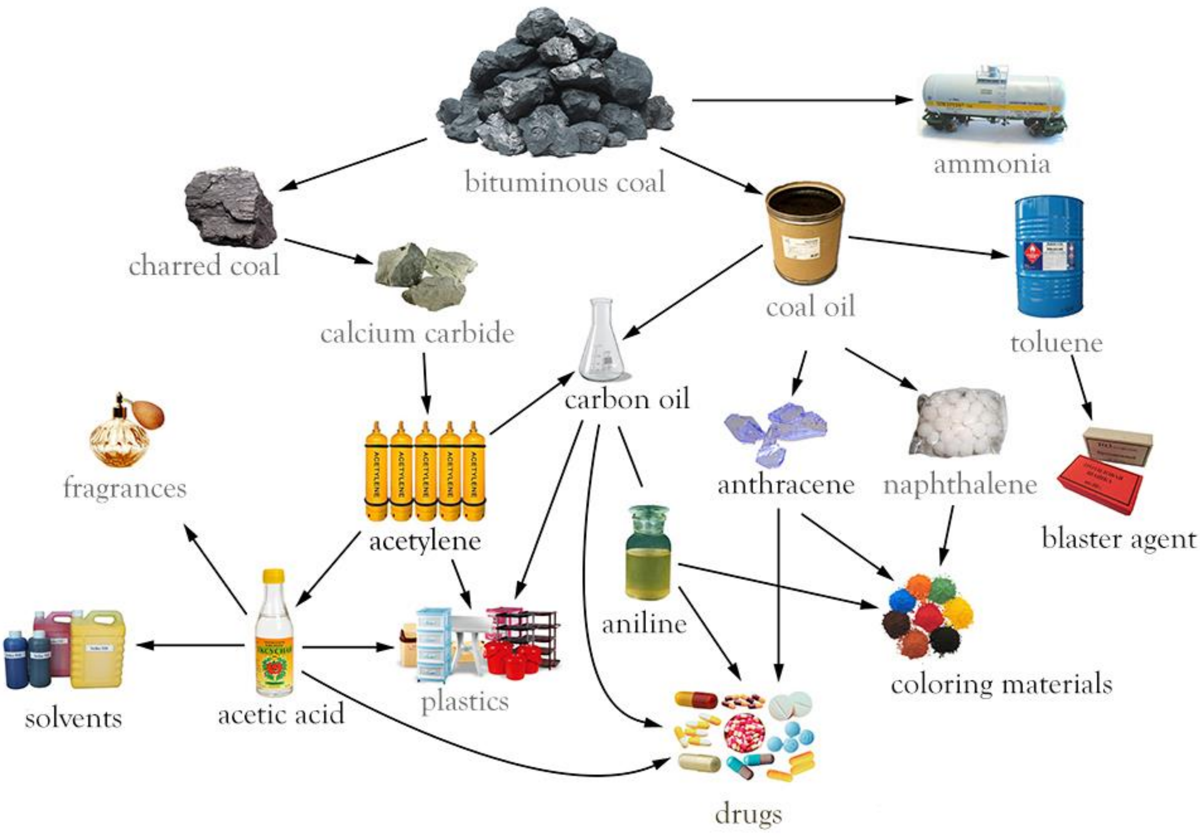

Figure 1: Products made from coal

In the process of coal gasification and production of gaseous and liquid fuels, three main areas are defined, related to the production of fuel gas and liquid energy products:

- Composition and calorific value of the gas produced;
- Construction of the gas generator used;
- Characteristics of the resulting substitute – low levels of CO and toxicity of gas that allows to extensively use the gas for household purposes.

In the process of industrial coal processing, the following combined technologies are most commonly used:

- Gasification + gas burning + production of heat energy and electricity;
- Semi-coking + gasification of solid residue (semi-coke);
- Semi-coking + production of adsorbents;
- Semi-coking + hydrogenation of liquid product (pitch);
- Gasification + synthesis of high molecular weight hydrocarbons from the produced synthesis gas ($CO+H_2$) (Fischer-Tropsch synthesis);
- Gasification + synthesis of methanol + gasoline production (Mobil process).

The composition and calorific value of the gas produced depends not only on the modes of gasification, but also on the construction of the gas generator used. Use of the fuel gas can solve environmental and technological problems in energy, metallurgy and other industries. A feature of substitute natural gas produced is low CO content and, therefore, relatively low toxicity, allowing wide use of the gas for household purposes. The synthesis gas is used for chemical processing into methanol, motor fuels or for hydrogen production. Processes of hydrogenation, pyrolysis and liquefaction with solvents are used to obtain liquid fuel directly from coal. To obtain the boiler fuel (substitute of the petroleum fuel oil) and motor fuels, additional processes of hydroprocessing of liquid coal products are required to reduce the content of sulfur and other undesirable impurities. The "coal oil" obtained during the catalytic hydrogenation of coal is most easily processed (Zhukov, Zhukova, Mikhalkov and Umarov 2015; Korneeva 2008; Ras and Sorokin 2001; Kozyukov, Krylova and Krylova 2006).

Below in Figure 2, there is a schematic diagram of the conversion of natural gas into liquid fuels on the basis of Fischer-Tropsch synthesis:

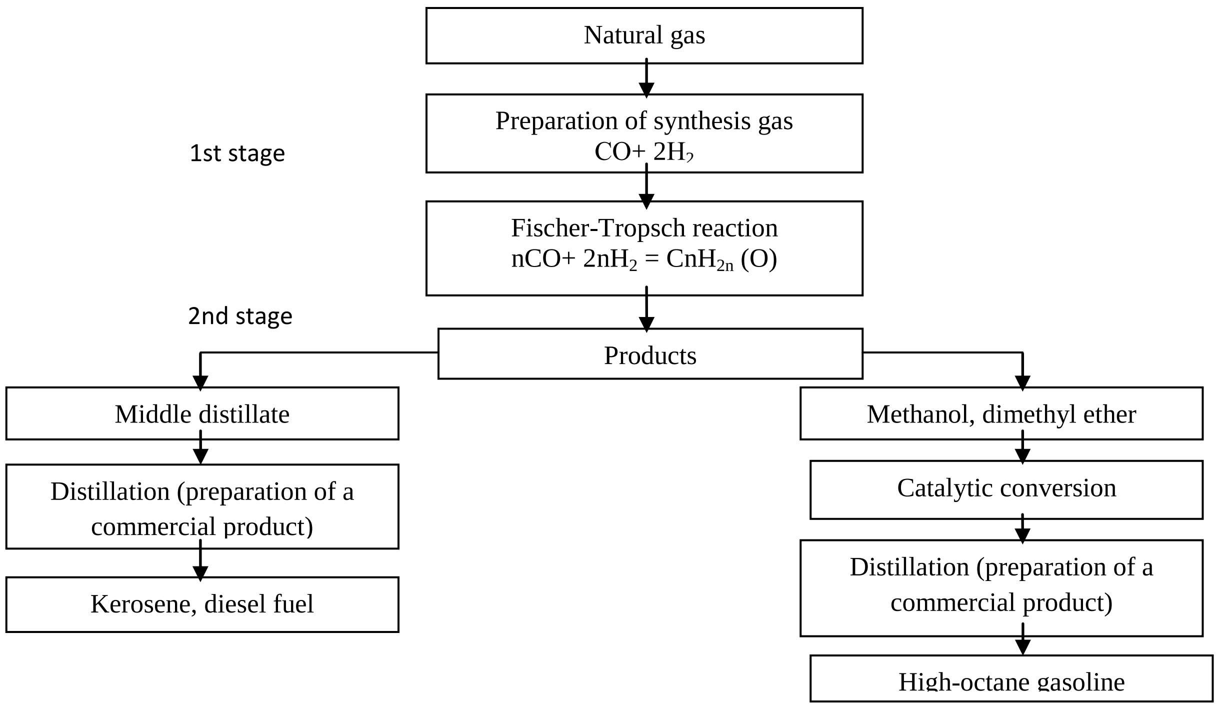

Figure 2: Schematic diagram of the conversion of natural gas.

The main purpose of brown coal processing is to obtain liquid fuels, lubricating oils and hydrocarbon gases, so they are aimed at downsizing (destruction) of the molecules of the feedstock and the relative increase in the hydrogen content. This is possible in the following ways:

- Redistribution of hydrogen and carbon existing in the original fuel in order to obtain the main products – hydrogen rich gas and solid product with a high carbon content. This is achieved through thermolysis processes of coking and semi-coking;

- Converting organic mass of solid fuel into the simplest molecules – CO, H_2, CH_4, CO_2, and H_2O, which is achieved by gasification with an oxidizing agent (O_2 or air) and steam at a temperature of 800... 1600 °C;
- Addition of hydrogen to the organic matter of coal in such a way that the ratio of "hydrogen: carbon" increases to a value characteristic for liquid fuels. This method is implemented in coal hydrogenation processes.

In the process of preparation of liquid fuels based on Fischer-Tropsch synthesis, various carbon compounds (natural gas, black and brown coal, heavy oil fractions, waste wood) are converted into synthesis gas (mixture of CO and H_2), and then it is converted into synthetic "crude oil" – synthoil. It is a hydrocarbon mixture, which in the subsequent process is separated into various kinds of practically clean fuel free from impurities of sulfur and nitrogen. Adding 10% of synthetic fuel in the conventional diesel fuel is sufficient to make combustion products of diesel fuel comply with environmental standards (see Figure 1).

Let's build a mathematical economic model, which allows to choose the best production option from the point of profits. Here we proceed from the assumption that the model is built for an enterprise of the coal and gas industries, which are involved in coal mining, gas production and production of natural and synthetic gaseous and liquid fuels, which is possible in the reconstruction and diversification of coal mining, gas producing and energy companies. Therefore, the developed economic and technological model (ETM) of the organization of production has a high degree of versatility. The ETM implementation should be performed through differentiated alternatives for coal mining, energy and gas producing companies (Gnezdilov, Zhukov and Yakovlev 2007; Zhukov, Zhukova, Mikhalkov and Umarov 2015; Zayats 2005; Konovalenko 2013; Korneeva 2008; "Americans opt for synthetics", n.d. ; Maloletnev and Shpirt 2008).

Let's introduce the following symbols (all figures are calculated for the same period):

n_i – physical quantity of the i-th type of coal mined by coal mining enterprises;
m_i – physical quantity of the j-th type of coal processed;
n_{ij} – physical quantity of the i-th type of coal and consumed in the production of one unit of the j-th type of the product processed;
c_i – selling price of the unit of physical quantity of the i-th type of coal;
s_i – cost of the unit of physical quantity of coal mined by coal mining enterprises;
u_i – selling price of the unit of physical quantity of the j-th type of the product processed;
v_i – cost of the unit of physical quantity of the j-th type of the coal product processed;
k – number of types of coal mined by the enterprises;
l – number of new products produced by the restructured and diversifiable enterprise.

Profits of an enterprise of coal (gas) industry is composed of two main components:

- obtained through the sale of part of the coal (gas) produced by enterprises and equal to:

$$\sum_{i=1}^{k}\left[\left(n_i - \sum_{j=1}^{l} n_{ij} m_j\right) c_i - n_i s_i\right] \qquad (1.1)$$

- obtained through the sale of new products made by the enterprise and equal to

$$\sum_{j=1}^{l}(u_i - v_i)m_i \qquad (1.2)$$

Summarizing the expressions (1.1) and (1.2), we obtain the amount of profit of the enterprise of the coal (gas) industry from major and diversifiable activities (coal mining and chemical processing of coal mineral resources or natural gas). Consequently, the optimality criterion is as follows:

$$\sum_{i=1}^{k}\left[\left(n_i-\sum_{j=1}^{l}n_{ij}m_j\right)c_i-n_is_i\right]+\sum_{j=1}^{l}(u_i-v_i)m_i= \qquad (1.3)$$

$$\sum_{i=1}^{k}n_ic_i+\sum_{j=1}^{l}u_im_i-\left(\sum_{i=1}^{k}n_is_i+\sum_{j=1}^{l}\left(v_i+\sum_{i=1}^{k}n_{ij}c_i\right)m_j\right)\longrightarrow \max$$

The last expression is the objective function of the optimization task. To formulate the task as a whole, limits should be set on the variables. In the ratio (1.3), n_{ij} and c_i are respectively selected on the basis of technology and external business environment.

Optimization of the production costs in this case is carried out on the basis of the following criteria:

$$\Pi = \sum_l^m \sum_l^n \left(C_{ji}-S_{ji}\right)V_{ji} \to max, \quad (1.4)$$

where Π – the total value of profit of the coal and energy enterprises from product sales; ***m*** **–** number of coal grades; ***n*** **–** number of ways of processing and use; $\boldsymbol{V_{ji}}$ **-** physical quantity of the ***J***-th coal grade processed and used in the ***I***-th way; $\boldsymbol{S_{ji}}$ – cost of the ***J***-th coal grade, processed and used in the ***I***-th way; C_{ji}- price of the ***J***-th coal grade and ***I***-th type of fuel.

At that, the following limits are set:

$\mathbf{C_{ji} \le C_{ji} \le C_{ji}}$, limits are set on the basis of market research;
$\mathbf{0 \le V_{ji} \le}$ **minimum** $\mathbf{(v_{ji}^{techn.}; v_{ji}^{cons.})}$, where $\mathbf{v_{ji}^{techn.}}$ **–** the maximum possible volume of production; $\mathbf{v_{ji}^{cons.}}$ **–** the maximum possible volume of sales.

The analysis of studies and economic and technological process modeling allows to consider in more detail the configuration and system parameters of restructuring and diversification of coal-mining and energy enterprises, coordinate and define modes of subsystems of management and organization of production and predict the technological and economic performance of the restructured and newly established industrial complexes.

RESULTS

The data presented in Table 1 show that the coal industry in Europe has been steadily declining. This is due to very strict environmental legislation of EU member states, as well as the gradual depletion of coal deposits at shallow depths.

Analysis of the dynamics of coal production by countries is presented in Table 1.

Table 1: Dynamics of coal mining by main countries and in the whole world since 1985, mln tons o.e.

Countries	1985	1990	1995	2000	2001	2006	2007	2008	2009	2010	2011	2012	2013	2014	Growth, %
China	436.1	539.9	680.4	707.1	749.2	1327.8	1438.7	1491.4	1538.0	1664.9	1852.6	1872.5	1893.7	1844.6	322.9
USA	487.0	565.9	555.1	570.1	590.3	595.1	587.7	596.7	540.8	551.2	556.1	517.8	500.9	507.8	4.3
Indonesia	1.2	6.6	25.7	47.4	56.9	119.2	133.4	147.8	157.6	169.2	217.3	237.3	276.2	281.7	22800
Australia	88.3	109.3	130.1	166.9	180.4	211.6	217.9	224.9	232.6	240.5	233.4	250.4	268.2	280.8	218.1
India	71.4	91.9	117.7	132.2	133.6	170.2	181.0	195.6	210.8	217.5	215.7	229.1	228.8	243.5	240.9
Russia	179.3	178.3	178.3	120.0	116.9	123.6	145.5	148.4	153.8	151.4	158.8	169.5	168.8	170.9	-4.7
South	99.8	100.	116.	126.	126.	138.	138.	141.	139.	144.	143.	146.	145.	147.	48

Africa		1	9	6	3	3	4	0	7	1	2	6	3	7	
Colombia	5.8	14.0	16.7	24.9	28.5	42.6	45.4	47.8	47.3	48.3	55.8	57.9	55.6	57.6	899.8
Kazakhstan	68	67.7	42.6	38.5	40.7	49.1	50.0	56.8	51.5	54.0	56.2	58.6	58.2	55.3	-18.7
Poland	118	94.5	91.1	71.3	71.1	67.0	62.3	60.5	56.4	55.5	56.6	58.8	57.6	55.0	-53.4
World	2104.4	2264.5	2264.5	2252.4	2310.1	2410.4	3174.7	3311.2	3412.7	3604.3	3869.4	3912.4	3961.4	3933.5	86.9
Share of 10 countries	73.9	78.1	84.2	86.7	87.2	90.3	90.7	91.1	91.3	91.5	91.6	92.0	92.2	92.7	

Source: 11

Coal production in the world is reducing. Production growth was seen in Colombia, which recently surpassed Kazakhstan, Poland and Germany; India and Australia.
Analysis of the dynamics of coal consumption by countries is presented in Table 2.

Table 2 – Dynamics of coal consumption by main countries and in the whole world since 1985, mln tons o.e.

Countries	1985	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Growth,%
China	406.9	524.7	681.2	699.9	1318.2	1445.5	1573.1	1598.5	1679.0	1740.8	1896.0	1922.5	1961.2	1962.4	382.3
USA	440.4	483.1	506.2	569.0	574.5	565.7	573.3	564.2	496.2	525.0	495.4	437.9	454.6	453.4	2.9
India	72.5	95.5	125.0	144.2	184.4	195.4	210.3	230.4	250.3	260.2	270.1	124.4	324.3	360.2	396.5
Japan	73.7	76.0	86.2	98.9	121.3	119.2	125.3	128.7	108.8	123.7	117.7	88.3	128.6	126.5	71.6
South Africa	62.4	67.3	71.3	74.6	80.1	81.5	83.6	93.3	93.8	92.8	90.4	98.4	88.7	89.4	43.3
Russia	198.1	182.3	119.4	105.8	94.6	97.0	93.9	100.7	92.2	90.5	94.0	98.4	90.5	85.2	-57.0
South Korea	22.0	24.4	28.1	43.0	54.8	54.8	59.7	66.1	68.6	75.9	83.6	81.0	81.9	84.8	285.1
Germany	149.3	131.5	90.6	85.3	81.3	84.6	86.7	80.1	71.7	77.1	78.3	80.5	81.7	77.4	-48.2
Indonesia	0.9	3.4	5.4	13.2	24.4	28.9	36.2	31.5	33.2	39.5	46.9	53.0	57.6	60.8	6655.8
Poland	99.9	80.2	71.1	57.6	55.7	58	57.9	56	51.9	56.4	56.1	54.3	55.8	52.9	-47.1
Peace	2076.9	2233.3	2257.7	2252.4	2310.1	2410.4	3174.7	3311.2	3412.7	3604.3	3869.4	3798.8	3961.4	3881.8	86.9
Share of 10 countries	73.9	74.7	79.1	79.8	82.9	83.3	83.9	84.3	85.3	85.3	85.5	85.4	86.0	86.4	

Source: 11

Table 2 shows the dynamics of coal consumption by 10 countries and in the whole world as results. The greatest growth in consumption, as well as production, is seen in Indonesia. The growth of the coal consumption in China and India is almost the same, the only difference is in the starting position, and India keeps up the pace. At the same time, consumption fell in Russia, Germany and Poland, mainly due to the transition to the more environmentally friendly natural gas. Also, the growth is observed in South Korea.

According to projections made by the International Energy Agency, there are three ways of development of the coal industry in the next few decades:

- Coal consumption will continue to grow and will increase by 70% by 2035.
- Demand for coal will fall sharply by 2020 due to the stringent environmental requirements of the majority of developed countries.
- Peak consumption of coal will be seen in 2020, and further the demand for this resource will be gradually declining.
- Table 3 shows the forecast of world consumption of coal for the period through to 2020, mln tons

Table 3: Forecast of world consumption of coal for the period through to 2020, mln tons

Regions of the world	2015	2020
Total	6209.8	6865.7
North America	1175.7	1239.2
Western Europe	436.4	409.1
Industrialized countries of Asia	268.5	272.2
Countries of the former USSR	623.3	564.3
Developing countries	3696.8	4380.9

Source: 42

According to the data presented in Table 3, China and India will remain the leading consumers of coal in Asia and in the world.

Russia has considerable energy resources, which leads to the development of the country's powerful fuel and energy complex, which is not only the basis for the development of the economy, but also an instrument of foreign policy.

Production and export of coal is an important component of the Russian economy.

The Government of the Russian Federation adopted the document on January 24, 2012 No.14-r "On the long-term program of development of coal industry in Russia for the period through to 2030." It considers two main options of volume indicators of the Russian coal industry. ("On a long-term program of development of coal industry in Russia for the period through to 2030" 2012).

The first option is the extraction of coal in the amount of not more than 410 mln tons and is due to lower prospective gas/coal price ratio (less than 2) and the availability of infrastructure constraints. However, it assumes the implementation of risk management measures determined by a project of the Energy Strategy of Russia for the period through to 2035. ("On a long-term program of development of coal industry in Russia for the period through to 2030" 2012).

The second scenario, an optimistic one (technological upgrading), assumes extraction of coal in the amount of 480 mln tons. The fulfillment of these indicators will be achieved through favorable tax environment established by the Federal law (dated 30.09.2013 No. 267-FZ) for high-tech projects carried out in the Far East and Eastern Siberia, as well as high rates of modernization of production, transition of the internal gas market to the conditions equal to the export sales yield, higher rates of industrial development of coal processing technologies, including deep processing. Changes in tariff and tax legislation are assumed. Increase in the price of coal on the international market within the period under review is projected. ("On a long-term program of development of coal industry in Russia for the period through to 2030" 2012).

Both the global forecast and the forecast for the Russian Federation see increase in the consumption of coal. Increased consumption of fossil coal will be accompanied by the growth of the environmental pressure on the environment, since burning and processing of coal produce more waste products in comparison with oil and gas. Damage to the environment from coal-fired power can be reduced by switching to more environmentally friendly fuels of the coal origin. These include treated or "clean coal" and synthetic gaseous and liquid fuels obtained by the chemical processing of coal. When using these synthetic fuels, emissions are significantly lower than when using ROM coal.

In our opinion, the promising areas of processing low-ash brown coal are the following:

- When using hydrogenation processes: gasoline – 10%; diesel fuel – 25%; gas from the organic synthesis – 15%; fuel oil and solid residue – 50%;
- Coal briquetting: fuel briquettes – 70%; water for technological needs –30%;
- Gasification of fuel briquettes: combustible gas from raw coal – 57%; ashes – 13%;
- Hot briquetting: treated solid fuel (hot briquettes) – 57% of the raw coal; ballast losses – 13% of raw coal.

DISCUSSION

According to Russian experts in the field of coal processing who confirm the relevance and demand of our research on the world market, a "lifeline" for the coal industry is the use of technology for deep processing of coal, which allows to vastly increase business profitability (“A look into the future “ n.d.). Compared to oil and gas, coal is inexpensive raw material, so most coal mining companies operate with low margins. Tough environmental standards in some cases may become not an obstacle, but rather a stimulus for the development of coal mining. The Kyoto Protocol establishes quotas on emissions of methane, the gas that is present in mines. Methane utilization has become a lucrative business for many businesses that reduce emissions in mines and then sell their quotas to other companies. Profits from such projects totals to tens of millions of dollars.

Another promising technology is coal gasification, which is rapidly developing in China. It is planned that by 2020 the country will produce 50 billion tons of synthesis gas, which is equivalent to 25 billion tons of natural gas, taking into account the differences in calorific value. Moreover, according to official figures, the cost of production of one million units of heat of the synthesis gas is almost twice cheaper than the cost of one million units of heat of fossil fuels imported into the country. Ukraine is also reliant on the synthesis gas – it was included by the Ukrainian Ministry of Finance in the list of 8 alternative sources of imported gas substitution in 2014. (“A look into the future”, 2014).

Coal can even replace oil: there are several factories that produce motor fuel from coal in South Africa at the moment. Such technology has been used for a long time. South Africa began to develop the production of synthetic fuels in the ‘80s of the 20th century, when western sanctions prevented the importation of petroleum products.

There are also opinions and comments on the issue from foreign authors in other countries:

1. Technology of production of liquid fuel by blowing superheated steam through the coal in the presence of catalysts (**Fischer-Tropsch process** and similar processes) was invented back in the 20s of the last century in Germany and was actively used by the Third Reich and its ally Japan, which experienced heavy oil shortage, for production of synthetic gasoline, diesel fuel, lubricating oil and paraffin. After World War II, with the fall in oil prices, these enterprises have been shut down, and the only major plant producing synthetic diesel fuel has operated only in South Africa for a long time. A small plant for the synthesis of liquid hydrocarbons assembled from the German captured equipment also worked in the USSR (Novocherkassk) until the early 90s. Princeton group approached the problem systematically and came to the conclusion that the Americans need to build 130 plants for the production of synthetic fuels using coal, natural gas and biomass as raw materials in order to meet the needs of the US economy in motor fuels and lubricants (“Americans opt for synthetics, n.d.; “Coal: review by energy type”, n.d.).

2. Alternative sources of hydrocarbon fuels. Current state of technologies for producing liquid fuel from coal. Domestic and foreign practice has accumulated considerable experience in processing of solid fossil fuels (SFF) – coal, oil shale, peat – into synthetic liquid fuels (SLF) and chemical products using processes of gasification, direct hydrogenation, coking, thermal dissolution, pyrolysis hydropyrolysis, etc. (Kozyukov, Krylova and Krylova 2006; Gorlov 2007; Kagan, Krechetova and Shpil'rain 2004).

3. Review of publications on the industrial processing of coal into liquid fuels abroad shows that the current SFF industrial processing to produce motor fuels and chemical products is carried out to a limited extent. In Germany (Zeitz), approximately 0.5 mln tons of semi-coking coal tar is processed into components of motor fuels, lubricating oils and paraffin through direct hydrogenation. In Estonia, the liquid products are obtained from gasification tar or pyrolysis of the Baltic shale, while in Russia they are obtained from the semi-coking coal tar of Cheremhovsky deposit. In South Africa, there are 3 Sasol plants with total capacity of about 33 million tons of coal per year or 4.5 million tons per year of motor fuels since 1983. The technology is based on a Lurgi method of coal pressure gasification followed by synthesis of hydrocarbons using Fischer-Tropsch method (Krylova and Kozyukov 2007). In China, the 1st line of a large plant for coal gasification followed by the Fischer-Tropsch synthesis of motor fuels will apparently launch in late 2008 (Kechang, Wenying and Wie 2007, August). Scientific fundamentals of chemistry and technology of obtaining liquid products from coal using hydrogen pressure were developed in the early XX century by V.N. Ipatiev, N.D. Zelinsky, F. Bergius, F.F.

Fischer and then further developed by Soviet scientists M.S. Nemtsov, I.B. Rapoport (1955), A.V. Lozovoy (Dyakova and Lozovoy 1940), V.I. Karzhev (Karzhev and Orochko 1951; Karzhev and Shavolina 1956), I.V. Kalechits (1984), A.A. Krichko (Kozyukov, Krylova and Krylova 2006; Krichko 1980) and others. In the US (Krichko and Maloletnev 1997), Exxon, Gulf Oil Corp., Pittsburgh and Midway Coal Mining and others have mastered the technology of 20 MPa pressure coal hydrogenation with recirculating paste-forming hydrogen donor in the presence of suspended aluminium-cobalt-molybdenum catalyst – Solvent Refining Coal (SRC) process, as well as the modification of the H-Oil (Hydrocarbon Oil) process implemented by Hydrocarbon Research, a non-catalytic process Exxon Donor Solvent (EDS), and others. It has been reported about the beginning of construction of the plant processing 1,500 tons of coal/day in Ohio (Kuhlmann & Jung 1993). China conducts extensive work in the field of producing liquid fuels using coal hydrogenation and will probably have industrial production of motor fuels from coal by 2010. Shenhua Group, one of the largest coal companies in China, has acquired 80% stake in the Research Center for Coal Liquefaction, of the total value of USD 12 million. USA. The center is intended to develop technologies for processing coal into diesel fuel, gasoline and other petroleum products. The Chinese government supports the creation of a technology that can quickly increase the supply of oil products to the domestic market should oil imports fall or its prices grow. At present, China is the second largest importer of oil after the United States. China conducted joint work with Japan (Wenhua and Wenxin 1999), to build an industrial plant with a capacity of 5,000 tons of coal per year, where Yilan brown coal deposits from Province Helongiiang will be used for hydrogenation. Kazakhstan is building Priozersky experimental coal chemistry complex for processing 65 thous tons of Karazhirinsky coal to liquid fuels and other fuel products per year. The largest coal company in Poland Kopalnia Wenglowy (KW) has started the drafting of a plant for the production of liquid fuels and chemicals from coal. The cost of construction of the plant is estimated at USD 645 million. The plant is to be commissioned in 2012; 1 liter of gasoline from coal is projected to cost half the current price. The plant will process 5 million tons of coal annually (Maloletnev and Shpirt 2008).

4. Conversion of coal to liquid hydrocarbons in Poland. Conversion of coal-to-liquids (CTL) is a well-known technology that enables to produce liquid fuels from coal. Although only one example of the application of this technology on a commercial scale (company Sasol in South Africa) is known, the growth in oil prices in 2007 and security concerns have contributed to a renewed interest in the liquefying technology in coal rich countries ("Technical and Economic Assessment of Small-Scale Fischer-Tropsch Liquids Facilities" 2007; "Technologies for Producing Transportation Fuels, Chemicals, Synthetic Natural Gas and Electricity from the Gasification of Kentucky Coal" 2007). The main problems in relation to CTL technology are:

- High investment costs;
- Uncertainty about oil prices in the long term;
- Environmental issues, especially those related to CO2 emissions.

These uncertainties have led some governments to support and develop plans to stimulate the development of the industry of synthetic fuel production. These incentives can range from loan guarantees through tax credits to the removal of restrictions on imports or a guaranteed volume of production. Provided that the currently developing legal framework for CTL is accepted in the US and that China completes its comprehensive program to build CTL plants, the unprecedented growth of the CTL industry may begin. Despite serious concerns about the environment in connection with the high level of carbon dioxide emissions, there are technological solutions (carbon capture and sequestration) (Wicks 2005, February; World Coal Institute 2006; World Coal Institute 2005).

Poland is heavily dependent on oil and gas imports. In this regard, the use of large domestic reserves of coal for the production of liquid fuels or synthetic natural gas (SNG) is justified in terms of energy security. However, the enterprise should be economically viable and ensure a reasonable rate of return on large investments (about 5 bln dollars) and compensation of market uncertainty. Thus, it is necessary to undertake a detailed study to assess the feasibility of development of CTL industry in Poland. At the same time, careful monitoring of international developments and adequate funding of the study is a prerequisite. In order to balance the issues of profitability and safety reasons, the involvement of state coal, oil and gas companies in Poland and state support for the creation of this industry may be required (Bartis 2007; Ministerstwo Gospodarki 2007, June; Kochanek 2007; Świądrowski, Rejman-Burzyńska and Jędrysik 2007; Bagajewicz, M., Sujo, Martinez and Savelski 2007; Bezdek and Wendling 2006, May).

5. Fuel of microbes that feed on coal. The processing of coal into natural gas would reduce emissions. Luca Technologies has spent 76 mln dollars to represent the large-scale use of microorganisms that absorb carbon to convert coal into methane. The process takes place underground in coal seams. Methane is a key component of natural gas, which can then be used to generate electricity. If the process is economically proven, it will help to reduce carbon dioxide emissions since the process of combustion of natural gas requires half the carbon dioxide, just like burning of coal does. This will also reduce or eliminate the expected demand for natural gas imports in the future, said Garry Stigel who manages the gasification process at the National Energy Technology Laboratory in Philadelphia. Only one hundredth percent of US coal processed into methane using microbes will meet the needs of the country in the amount of current annual consumption of natural gas, said Andrew Scott, Professor of Economic Geology at the University of Texas at Austin. Scott is the founder of the Altuda Power Corporation founded in San Antonio, Texas, which develops such a process (Bullis 2009, January, 8).

6. Demonstration of equipment for carbon dioxide recycling. Sandia scientists have successfully tested the machine that is able to produce fuel from carbon dioxide. The scientists from Sandia National Laboratories have successfully demonstrated a prototype of the machine that uses solar energy to convert water and carbon dioxide into the molecular building blocks that are part of transport fuel. The "Sunlight into Petrol" system may ultimately prove the existence of a practical method to process carbon dioxide at energy and industrial facilities into gasoline, diesel and jet fuel, suggesting that this process may ultimately be twice as efficient as natural photosynthesis (Hamilton 2009, November, 23).

7. Elimination of coal problem in China. China establishes the order at its coal plants due to strong air pollution in big cities and small towns. Before 2013, China was engaged in large-scale purification of coal companies, now the phase 2 comes: converting coal into a synthetic gas, or syngas. In the future, the reduction of air pollution will allow the country to take skillful steps in this direction, such as implementation of the process of capturing carbon dioxide, as well as to significantly reduce the domestic use of coal and its use on a larger scale. The big question now is what will happen to carbon dioxide, says William Latta.

"Coal-to-gas" – the significance of the issue is evident when you visit a coal industry company in the province of Shangqiu in northern China near the border with Mongolia, as I did in 2014 in the process of gathering material for my book "Coal Wars". There, below the ridge, since the Great War, hundreds of small, dirty coalmines still supply huge companies operating on coal, which emit millions of tons of carbon dioxide into the atmosphere each year. Very little is done in accordance with the main program of the government – to close coalmines in the east, on the coast. In fact, there is a tendency on the expansion of the coal industry in the west and north of the country in the next decade according to the latest five-year plan (Martin 2015, May, 27).

Germans have obtained synthetic diesel fuel from carbon dioxide and water. The first factory that will produce the new fuel is currently being built in Dresden, and the construction of full-scale industrial complex is planned. The well-known German company has invented a carbon-neutral diesel fuel, which can be obtained only from water, carbon dioxide and renewable energy sources. The crystal-clear "e-diesel" has already passed the run-in a car owned by the German Minister of Education Johanna Wanke. The basic product, which the developers call "blue raw", is the result of a three-stage process. The first stage accumulates clean energy from renewable sources, such as wind, solar and hydroelectricity. Then this energy is used to decompose water into oxygen and pure hydrogen, which is mixed with carbon monoxide (CO) derived from carbon dioxide collected from the atmosphere. The two substances react under pressure and at high temperature, resulting in long chains of hydrocarbon compounds, which the "raw blue" consists of. After purification, the resulting e-diesel may be blended with conventional diesel fuel or used in pure form. Analyses of biochemical companies have shown that this synthetic fuel is not only more environmentally friendly, but also has better combustion characteristics compared to fossil fuels. According to their reports, the overall energy efficiency of e-diesel engine today is 70 percent. Of course, the initial plant, which produces only 160 liters of fuel per day, will not have any appreciable impact on the market. However, it is currently planned to build a large complex, and according to their calculations, the scale of production will allow to sell the e-diesel at a price of between 1 and 1.5 euros per liter, depending on the price of renewable energy. At the current price of conventional diesel over 1.5 euros per liter in Germany, it will make the new synthetics incredibly competitive. (Germans made synthetic diesel fuel from carbon dioxide and water n.d.).

Thus, the analysis of the relationship between the growth of coal consumption and innovative technologies remains relevant in the current economic situation.

CONCLUSION

1. The methodological, economic and technological principles of competitive production based on the creation of environmentally friendly resource and energy saving technologies for complex chemical processing of coal mineral stocks reviewed in the article are a necessary step towards the development of new coal processing steps under the circumstances of development of the coal industry.
2. We believe that the specific fields with various qualitative characteristics of coals require the development of physical, technical, economic and technological models to select optimal option of processing brown or black coals to produce synthetic gaseous and liquid fuels or non-fuel products.
3. One way to solve the problem of increasing the efficiency of energy companies is to choose the optimal structure (range) of the products and apply new solutions in the development of generating sources that allow to save traditional resources through innovative technologies of processing coal mineral stocks.
4. Studies of innovative technologies for processing coal mineral stocks indicate that the most promising are:

    - creation and application of modular and fixed installations producing synthesis gas and synthetic liquid fuel (SLF);
    - technology of semi-coke and fuel gas production from low-ash brown coal using semi-coke to produce calcium carbide and steel;
    - combined-cycle plants with the production of power gas from brown coal;
    - energy complexes based on the combined power cycle and coal gasification.

5. The world practice shows that overcoming the technological backwardness of the coal industry will promote the application of new solutions in the development of synthetic generation sources, which allows to save traditional resources (coal, oil and gas). Scientific and technical achievements of the Russian Federation allow to introduce and successfully compete with Western countries in such areas as processing of coal in power gas and motor fuel. The previously patented method of processing of carbon-carbonate mineral stocks comprehensively solves the problem of environmental management by creating resource- and energy-saving technologies, but we are going to write more on this area of research and development in our future articles.

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