

LAPPEENRANTA UNIVERSITY OF TECHNOLOGY  
FACULTY OF TECHNOLOGY  
BIOENERGY TECHNOLOGY

**MASTER'S THESIS**

**ASSESSMENT OF COALS FROM RUSSIA AND COUNTRIES  
OF FORMER SOVIET UNION FOR UTILITY FLUIDIZED  
BED BOILERS**

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Lappeenranta, 2010

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## **ABSTRACT**

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### **Assessment of Coals from Russia and Countries of Former Soviet Union for Utility Fluidized Bed Boilers**

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With the occurrence of fossil fuels such as oil, gas and coal we found new sources of energy that have played a critical role in the progress of our modern society.

Coal is very ample compared to the other two fossil fuels. Global coal reserves at the end of 2005 were estimated at 847,5 billion tones.

Along with the major energy sources, coal is the most fast growing fuel on a global basis, it provides 26% of primary energy needs and remains essential to the economies of many developed and developing countries. Coal-fired power generation accounts for 41% of the world's total electricity production and in some countries, such as South Africa, Poland, China, Australia, Kazakhstan and India is on very high level.

Still, coal utilization represents challenges related to high emissions of air pollutants such as sulphur and nitrogen dioxides, particulate matter, mercury and carbon dioxide. In relation to these a number of technologies have been developed and are in marketable use, with further potential developments towards "Near Zero Emission" coal plants.

In present work, coals mined in Russia and countries of Former Soviet Union were reviewed. Distribution of coal reserves on the territory of Russia and the potential for power generation from coal-fired plants across Russia was shown. Physical and chemical properties of coals produced were listed and examined, as main factor influencing on design of the combustion facility and incineration process performance. The ash-related problems in coal-fired boilers were described. The analysis of coal ash of Russia and countries of Former Soviet Union were prepared. Feasible combustion technologies also were reviewed.

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## COAL DEFINITION

Coal is a sedimentary rock accumulated as peat, composed mainly of macerals and subordinately of minerals, and containing water and gases in submicroscopic pores. Macerals are organic substances derived from plant tissues, cell contents, and exudates that were variably subjected to decompose, included into sedimentary strata, and then changed physically and chemically by geological processes. Coal is not just a homogeneous mixture of carbon, hydrogen, oxygen, sulfur, and minor proportions of other elements; it is also a collection of microscopically discernible, physically distinct, and chemically diverse macerals and minerals.

Coals can be classified on the basis of variations in the proportions of the microscopically discernible components. Classification according to type is referred to such classification. Coals may also be classified according to degree of metamorphism (or degree of coalification); this is classification according to rank. These two classification methods are independent; thus, within certain limits, any type of coal can be found at any rank.

Classification according to type involves the comparative proportions of both the inorganic substances and the diverse organic substances. Rank classification is independent of inorganic content (Richard C. Neavel, 1981, 1-2). According to rank classification, coals can be divided on four main ranks, starting from less affected on degree of metamorphism to more affected:

- *Lignitic coals* are characterized by high moisture content (more than 35%) , ash content ranges from 14% to 42% , yield of volatile matter is between 16% and 38%, heat content on the moist, mineral-matter-free basis ranges between 14,7 MJ/kg and 19,3 MJ/kg
- *Subbituminous coals* contain 15%-30% inherent moisture by weight; heat content on the moist, mineral-matter-free basis ranges from 20 MJ/kg to 28 MJ/kg, carbon content varies from 35% to 45%, yield of volatile matter is more than 31% on a dry, mineral-matter-free basis

- *Bituminous coals* have volatile content on the dry, mineral-matter-free basis between 14% and 31%; heat content on the moist, mineral-matter-free basis ranges from 24,4 MJ/kg to 32,6 MJ/kg, fixed carbon on the dry, mineral-matter-free basis varies from 69% to 86%
- *Anthracites* are characterized relatively low moisture content that is only about 3%; volatile content on the dry, mineral-matter-free basis varies between 2% and 14%, fixed carbon on the dry, mineral-matter-free basis ranges from 86% to 98%

## 1 INTRODUCTION

After centuries of mineral exploration, the location, size and characteristics of most countries' coal resources are quite well known. Basic part of world total coal reserves is concentrated in the 5 following countries: USA- 240 million tonnes (Mt); Russia- 160 Mt; China- 120 Mt; Australia and India- 75 Mt and 52 Mt, correspondingly (WEC 2007). These resources consist of two groups of coals:

1. High quality coals: anthracite and bituminous coal (can be also called as hard coal)
2. Low quality coals: sub-bituminous coal and lignite (can be also called as brown coal and lignite)

Different ranks of coal have different uses. Lignites largely used for power generation; sub-bituminous coals used as lignites for power generation, also in cement manufacture and have industrial uses. Bituminous coals as “steam coal” can be used in heat power engineering (for heat and power production), also in cement manufacture and to cover industrial needs; as “coking coal” it is used in manufactory of iron and steel; anthracites can be utilized as smokeless fuel to meet domestic and industrial requirements (WCI, p.4).

Share of the USA in world reserves of the first group coals is 31%, of the second group is 24%; Russia accounts for 10% of the first group and 25% of the second group; China represents 12% and 13% for the first group and for the second group, correspondingly; the share of Australia and India is 8% and 19% of the first group and 9% and 1% of the second group, accordingly (BP 2006). At the current rate of production, global coal reserves are estimated to last for almost another 150 years. Over 5845 Mt of hard coal is currently produced around the world and 951 Mt of brown coal and lignite (WCI 2008). The largest coal producing countries are not confined to one region - the top five hard coal producers are China (2761Mt), the USA (1007Mt), India (490Mt), Australia (325Mt) and Russia (247Mt) (IEA 2009<sup>1</sup>). Much of global coal production is used in the country in which it was produced and only about 16% of hard coal

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<sup>1</sup> Source cites data calculated in year 2008.



production is used for the international coal market. Global coal production is expected to grow in following years with essential contribution of China, which share in world production is the highest nowadays and may increase in the future.

World coal consumption was estimated at 7192 million short tons (Mst) in year 2007. Since 2000, worldwide coal consumption has grown faster than any other fuel. In year 2007, the five largest coal consumers were China (2892Mst), USA (1252Mst), India (578Mst), Russia (261Mst) and Japan (206Mst) (EIA 2008).

Coal will continue to play an important role in the world's energy mix, with demand in definite regions set to grow rapidly. Development in both the "steam" and coking coal markets is expected to be durable in developing Asian countries, where demand for electricity and the need for steel in construction, demands for household appliances can raise as incomes increase.

It is important to use fuel as efficiently as possible; thus considerable improvements continue to be made in how efficiently coal is used so that more energy can be generated from each ton of coal mined.

The purpose of this work is to review the resources of coal in Russia and countries of Former Soviet Union. The review includes following matters:

- List the location of coal sources
- Coal sources mining potential
- Their potential to be used locally for power production
- Suitability of such coals to be fired in highly efficient circulating fluidized bed boilers (CFB) for power production with supercritical steam parameters

## 2 RUSSIA'S COAL RESERVES

Coal was the dominant fuel supporting Russia's industries, and many industrial centers were located near coal deposits for more than 150 years. Oil and natural gas overtook coal in the 1960s when bountiful reserves of those fuels became available and the coal mines of the European Soviet Union (located primarily in what is today Ukraine) were being exhausted.

Current coal reserves in Russia are located in 22 coal basins and 118 separate deposits across Russia, the biggest deposits concentrated in Siberia it accounts about 80% of total Russian coal reserves; the share of the Far East is around 11%, the rest part of coal reserves is located in the European part of Russia (IEA CCC, 2008). Distribution of coal reserves across Russia is illustrated on Map below. The major coal basins are the Kuznetsk and Kansk-Achinsk that are located in the Siberia. In 2007, the Kuznetsk basin produced 56% of all coal produced in Russia; Kansk-Achinsk basin produced 12%; 12% in East Siberian basins and 10% in coal basins of the Far East. Coal basins in these regions accounted for 90% of total Russian production.

Overall raw material base of Russia is estimated in 200 billion tonnes of coal that is included 106 billion tonnes of coals are category  $A_1+B+C_1$ <sup>2</sup>.

In perspective, the new more profitable deposits, such as Erukanovskiy in Kuznetsk basin, Elginskiy in Yakutia, Sadkinskiy in the East Donbass and deposits located in the east areas of Russia are expected to be operated.

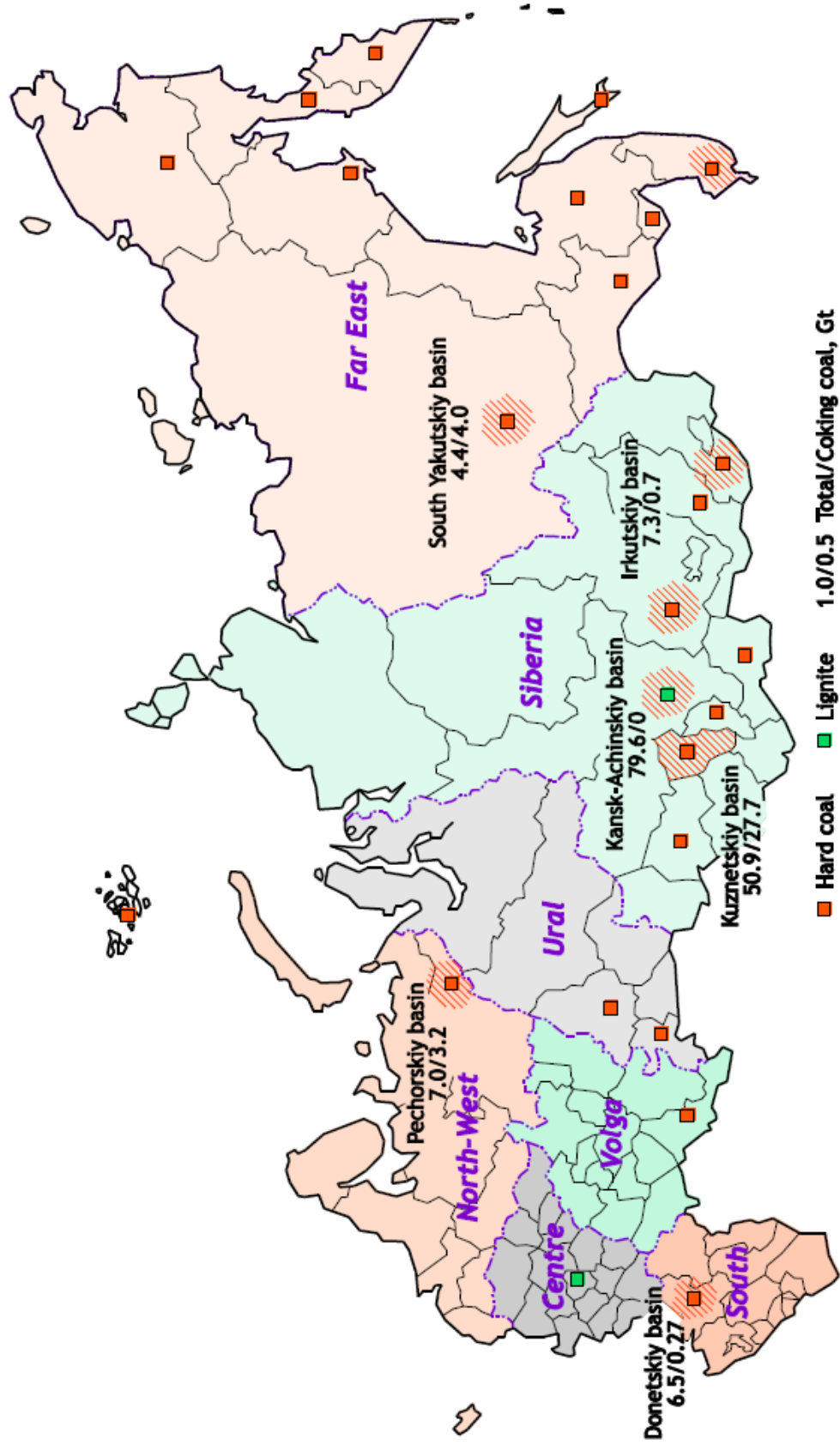
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<sup>2</sup> In Russia all coal deposits are evaluated on their recourses, quality of extracted fuel etc., and are divided on following categories:

A1- Deposits are ready for operation or have already being operated.

B- It is necessary the more detailed investigation of discovered raw material for following designing of industrial plants.

C1- It is necessary the more detailed geologic investigation; the amount of reserves is not determined; the quality of coal has not been investigated in details.



Map. Russian coal reserves (IEA CCC 2008)

### **3 RUSSIAN COAL INDUSTRY**

In the late 1990s after the end of the first phase of restructuring of Russian coal industry, the growth in the production of coal started. Period between years 1999 and 2008 was marked by high and rapid growth of Russian economy. Gross Domestic Product (GDP) increased by an average of 7% a year in real terms (in view of adjusted) and, given the gradual decrease in the population, per capita growth was faster still. In the same time, this “economic boom” has required increased investment and production of energy to stimulate the economy. The restructuring of the coal sector saw large-scale shutting of uneconomic mines, resulting in an increase in the sector’s competitiveness and labour productivity (IEA, 2002).

#### **3.1 Coal production**

The restructuring of Russia’s coal mining sector resulted in the closure of 188 loss making, uneconomic mines. This caused much social dislocation and the need to meet issues of relocation and retraining of coal miners. Most coal mines were privatized. Private owners made quite large capital investments into novel technologies, mining equipment, and development of mine facilities. This has led to increased production efficiency and worker safety. The output of coal face machinery increased on average 3-4 times over the period 1997-2007. Coal production has increased from a 1998 output of 221 Mt (including 141 Mt of hard coal) to 323 Mt (247 Mt of hard coal) in 2008 (IEA, 2009).

In accordance with the Ministry of Energy (year 2009), Russia’s coal production in January-March 2009 amounted to 69.5 Mt – a decline of 18.7% compared to the same period in 2008 due to the worldwide financial crisis.

The structure of Russia’s mining sector is changing with widespread employ of more efficient technologies. Nonetheless, output of coal mining industry is still reasonably low compared to international levels. Around 45% of all Russian coals are mined by underground method; average underground coal mine productivity accounts only 1 350 tonnes/man-year with some mines achieving less than 100 tonnes/man-year. Yet, there are some notable exceptions such as Kotinskaya mine

(Open Joint Stock Company “Siberian Coal Energy Company’s” (OAO SUEK)), achieving productivity of over 8,800 tonnes/man-year and approaching the best levels of productivity seen in other countries (Ros-Inform-Ugol, 2009).

### 3.2 Coal export

According to statistical data of Russian National Trade Point, export of hard coal increased on 62,3 million tonnes for the period from 2000 to 2009, in Russia, and it is expected continue to growth in following years (see Figure 1).

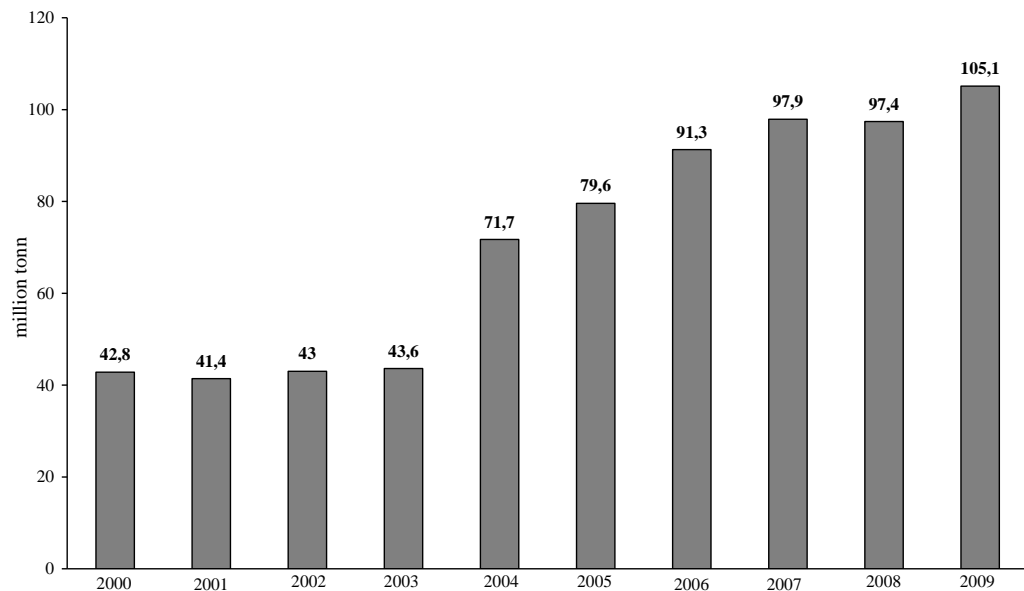


Figure 1. Export of hard coal 2000-2009 (“INTRADE”)

In year 2005, export of coal by Russian companies was 79,66 million tonnes; the biggest companies-exporters were Open Joint Stock Company “SUEK” (23%) and “Kuzbassrazrezugol”(23%). Much of coal exported from Russia is coal that can be used in the thermal industry (so-called “power coal”); it is exported mainly to European countries (e.g., Great Britain) and also to Asian countries (e.g., China). Such companies as “South Kuzbass” and “Yakutugol”, the share of which in export of year 2005 was 7% and 6%, accordingly, export coking coal ( for iron and steel manufactory) to Japan and Korea (Gorev D., 2006, p. 20). Structure of Russian coal export in year 2005 by companies is shown in Figure 2.

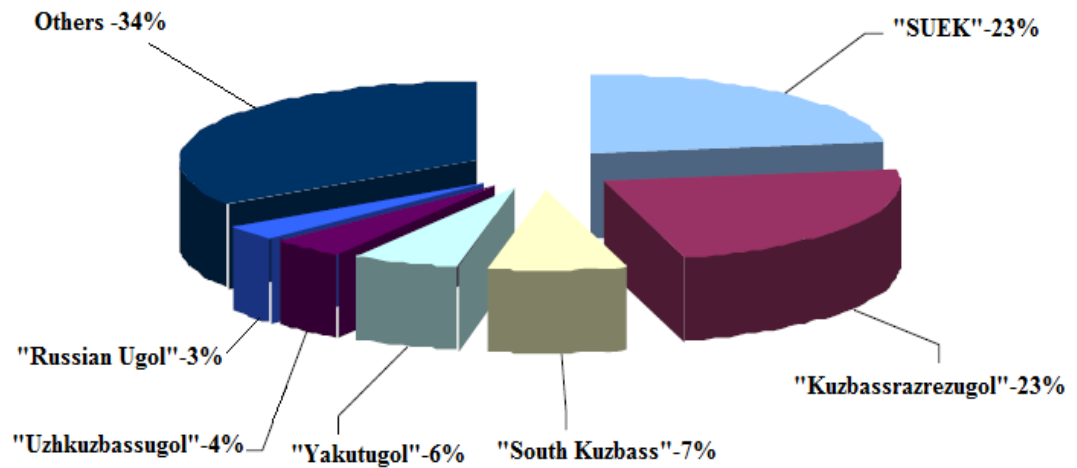


Figure 2. Structure of Russian exports by companies in year 2005 (Source: Companies' data).

The growth in the exports of Russian coal is caused by the stability of world price for coal, which is at a fairly high level for Russian companies-exporters in comparison with prices on internal market. This fact is beneficial for Russian companies due to possibility for them to sell coal for higher prices than inside the country and to get an advantage in production of coal compared to companies, which do not effectively attend the international market of coal.

Also, there is an active construction of new coal terminals at seaports. In 2005, construction of 15 coal terminals has been started, of which terminal in Ust-Luga is already built (design capacity of 8 million tonnes of coal per year); construction of large coal terminal in Murmansk city will be completed soon. The total design capacity of terminals is estimated at 30 million tonnes of coal per year and it is planned to bring them into operation by year 2011. Under condition of steady rise of coal production, export of coal by late 2010 may represent 41% of the volume of coal produced (for comparison, in 2005, exports share accounted for 27% of the amount of coal produced) (Gorev D., 2006, p. 20).

#### 4 RUSSIAN COAL–FIRED POWER SECTOR

In Russia, natural gas is dominant fuel type in the primary energy consumption while oil follows with 19% of the total primary energy consumption. Share of coal is 18%, while nuclear and hydro energy represents 5% and 6%, correspondingly, of the total primary energy consumption (see Figure 3).

Coal plays a leading role in the power generation mix in Russia. Regardless of increased utilization of natural gas in the power sector (roughly 62–65%), it is anticipated that the coal share in the fuel balance all over the country will be increased, in the foreseeable future (Martynova O.I.,2001, p. 126-130); CERTH/ISFTA, 2004).

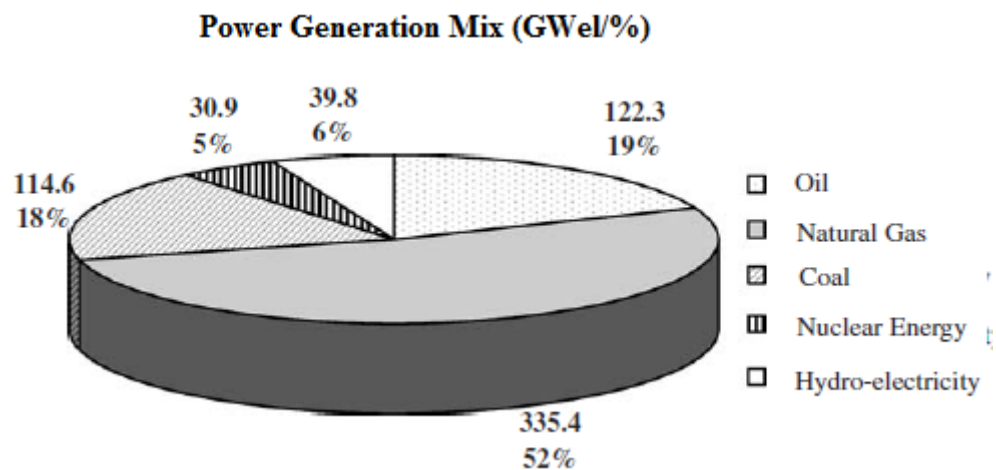


Figure 3. Russia's primary energy consumption distributed by fuel type (P. Grammelis et.al, 2005)

This is chiefly connected to the forecasts for the essential cost increase of natural gas purchase compared to coal. As for 2000, natural gas purchase cost was \$11 per thousand  $m^3$ , which when recalculated to the fuel equivalent turned out to be 1,5 times cheaper compared to coal. Also with its accessibility and valuable user properties, natural gas was considered at that time the most beneficial fuel source for the Russian utilities. Nevertheless, a new and rather positive tendency has been observed and cost of natural gas starts to increase rapidly. In 2006, the average natural gas purchase cost was 40 \$/thousand  $m^3$  and it is projected to increase in the late 2010 from 59 to 64 \$/thousand  $m^3$ . In the meantime, the coal

price will also raise, but at significantly lower levels. In 2006, basic centers of electricity generation were Western Siberia, Ural and European part of the country, where power plants are provided mainly by natural gas, although they were designed to use coal. In Central and East Siberia the resources are hydro and coal and in the North-West and the Far East the resources are nuclear power and coal, correspondingly, with the exception of some big power plants in the West Siberia, where natural gas is used. There are some modernizations focusing mainly on the reduction of emitted pollutants have been implemented in many Russian pulverized coal-fired boilers, as well as in gas- and oil-fired boilers. Better outcomes were obtained in gas- and oil-fired boilers when introducing at the same time three or four technological approaches, while more complicated problems are increased in the coal-fired boilers.

#### **4.1 Coal-fired power plant park**

There are 96 thermal power stations or 848 units of total capacity 50,5 GWe are installed in Russia. The 25 thermal power stations (180 units) of total capacity 29,3 GWe have thermoelectric units of capacity larger than 100 MWe (CERTH/ISFTA, 2004). Illustration of the distribution of these coal-fired units and the capacity in the regions where the power stations are situated is shown in Figure 4. The installed capacity per unit of around one-third of the Russian coal units ranges between 100 and 200 MWe. About half of the total installed capacity corresponds to units within the range of 200–300 MWe; thirty units have 300 MWe capacity.

Much of Russian coal-fired power plants are already at an advanced age. More than 50% of the installed capacity is older than 30 years, while about a quarter of the fleet's capacity is in the range of 20–30 years (see Figure 5).

Total efficiency of coal-fired power plants and its availability is on a low level in Russia. Total efficiency ranges between 27% and 33% for most of the thermoelectric units; the availability of the most units in the range of 30-70%.

The efficiency is mainly influenced from the main operating characteristics, such as the share of the heat load and steam parameters, as well as the service life and coal quality. Use of supercritical units increases efficiency up to 36,22% as in



Troitskaya TPP or even higher—in Berezovskaya TPP with small share of the heat load—the efficiency equals 39.1%.

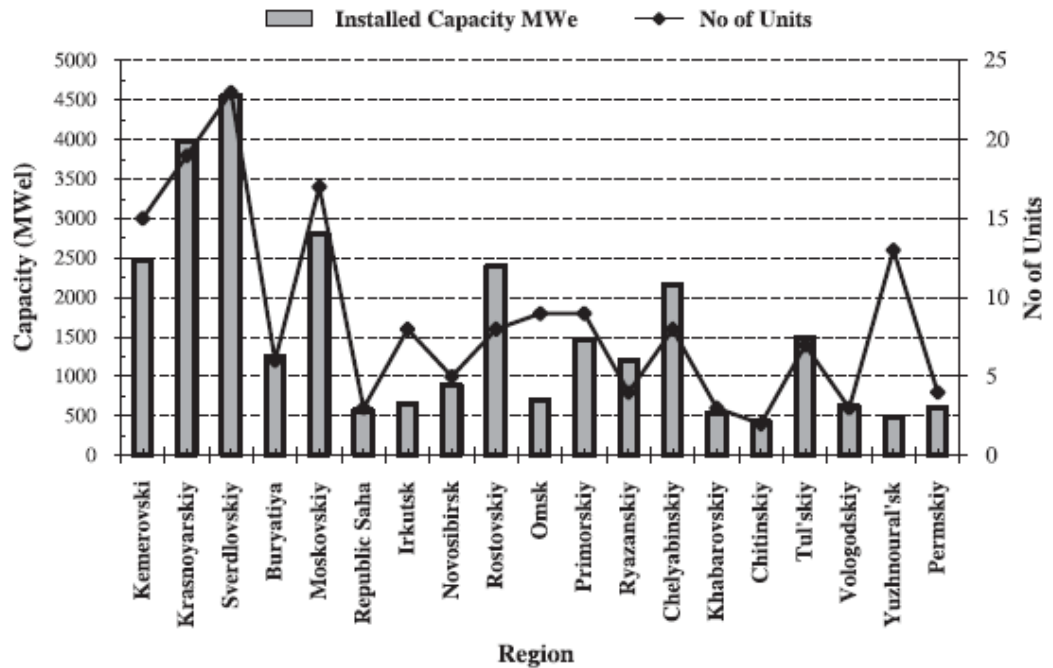


Figure 4. distribution of Russian coal-fired power plants (P.Grammelis et.al, 2005)

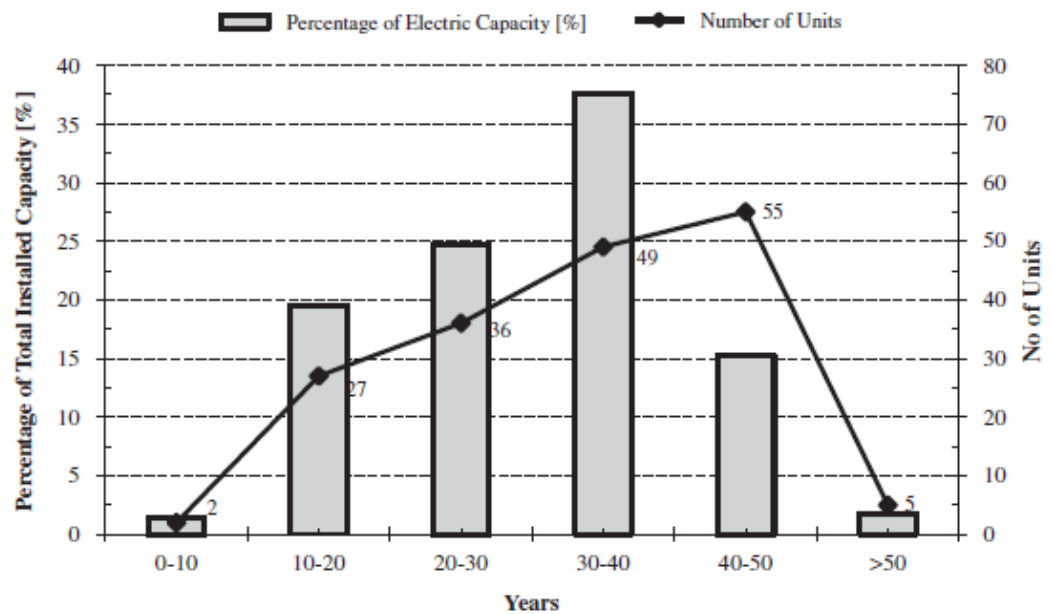


Figure 5. Units according to their age (P.Grammelis et.al, 2005)

The availability of the coal-fired TPP is generally defined by the contribution of natural gas in the power sector due to the lower gas cost on Gcal basis compared

to coal. Also, the heat loads demand and consequently the weather conditions influence the availability values, since large number of the existing cogeneration units are used to generate electricity in order to meet the heat supply needs.

In relation to environmental performance of power plants, the Russian legislation for the environmental protection has developed the State Standard 50831 for the new boilers and the law of the Russian Federation “On the Environmental Protection”, which requires the performance of the technical norms for the atmospheric pollutant emissions from the existing power plants.

Taking into consideration the high obsolescence level and low efficiency values, a high demand for new capacity is forecasted over the coming years. It is planned to bring into operation 44 coal-fired power units (average capacity of 300 MWe) by year 2015, of which 14 power units are expected to be installed in European part of Russia; in the Ural- 7 power units and in the sum for the Siberia and Far East- 25 coal-fired power units.

Also, the refurbishment of the power sector will increase the efficiency, extend the control capability and ensure efficient combustion of coals with varying characteristics. This will involve improved steam parameters, application of new structural materials and designs of heating surfaces. For the period of the refurbishment, the old boilers firing low-grade coals may be replaced by circulating fluidized bed boilers (CFB). It is anticipated that the reconstruction of the coal-fired sector will lead to considerable savings in the repairing and maintenance expenses. Also, the ecological problems of the old design boilers will be met by installing the up-to-date systems to capture  $\text{NO}_x$  and  $\text{SO}_x$  emissions.

It is expected that the substitution or retrofitting of some of the old power plants with Clean Coal Technologies will be among the favored technical options for the utilities (Grigori, 1999; Tumanovski, 2001).

## 5 RUSSIAN COAL CLASSIFICATION SYSTEM

In 1991 year, Russia and CIS<sup>3</sup> countries agreed a unified classification of coals according to state standard 25443-88<sup>4</sup>. Scope of this standard applies to unoxidized<sup>5</sup> brown coal, hard coal and anthracite. Coals are classified on the basis of the main characteristic attributes reflecting the genetic features and the basic technological characteristics.

In accordance with state standard 25443-88 fossil coals are divided into three main types: brown coal, hard coal and anthracite. Transitional type between hard coal and anthracite is semi-anthracite (Vdovichenko V. S. et al. 1991, p. 9).

Brown coals (grade B) are coals having higher heating value less than 5700 kcal / kg (24 MJ/kg) on the moist, ash-free basis and average reflectance index of vitrinite less than 0,60%. Brown coals by a content of moisture-holding thickness<sup>6</sup> are divided into three grades (Matveeva I. I. 1972a, p.10):

1. B1- moisture-holding thickness is more than 40%
2. B2- moisture-holding thickness is between 30% and 40%
3. B3- moisture-holding thickness is less than 30%

Brown coals compared with hard coals characterized by:

- High yield of volatile matter (more than 40 %) on dry, ash-free basis
- Not caked coke residue

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<sup>3</sup> Commonwealth of Independent States (CIS) was created in December 1991. At present the CIS unites: Azerbaijan, Armenia, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Uzbekistan and Ukraine. (Georgia withdrew from the CIS in 2008).

<sup>4</sup>“Brown coals,hard coals and anthracites. Classification according to genetic and technological parameters”. Date of entry into force January 1, 1991.Changed March 1, 2002. Published March 2002. Originally published as 25543-88. Last previous edition 25543-80 (SPH 2002a).

<sup>5</sup> Unoxidized coals are coals which did not change its properties in coal seam or while storing.

<sup>6</sup> Moisture-holding thickness is the moisture content in coal is fully saturated with water. Moisture-holding thickness is determined in terms established by the state standards (State standard 17070-87 “Coal. Terms and definitions.” 2003, p. 6).

- High hygroscopic and total humidity
- High carbon and oxygen content

Brown coals easily lose moisture and mechanical strength in the air and turn while in a coal fines. These coals also have an increased propensity to spontaneous combustion.

Hard coals are coals having higher heating value of 5700 kkal/kg (24 MJ/kg) or more on the moist, ash-free basis; the average reflectance index of vitrinite is between 0,40% and 2,39% and yield of volatile matter is more than 9%. The great bulk of these coals sinters and only a small part of these coals are noncaking coals.

Hard coals are divided into grade mainly on yield of volatile matter and thickness of the plastic layer<sup>7</sup>. The lower limit of a thickness of the plastic layer expressed in millimeters is put as an index at the grade of coal. For example: G<sub>10</sub> – the grade of coal is “gas,” minimum thickness of the plastic layer is 10 mm.

The state standard 25543-88 divides hard-coals on fourteen grades as shown in Table 1.

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<sup>7</sup> Thickness of the plastic layer is determined by carbonization of coal samples in the plastometer. Method of measurement based on the property of caking coals soften when heated without access of air in the temperature range 350 - 470°C; the ability of that coals to move into the plastic state , with further increase in heating temperature to form coke. The test uses a sample of coal crushed to a particle size of about 1,5 mm and weighing 100±1 g (Mitronov D.V., 2001a, p. 77-78)

Table 1. Grades of hard coal<sup>8</sup> (SPH 2002a, 6-10)

<i>Grade of coal</i>		<i>Designation of grade</i>		<i>Yield of volatile matter on dry, ash-free basis, %</i>	<i>Thickness of the plastic layer, mm</i>	<i>characteristic of the fixed residue</i>
Long flame coal		D		36 and greater	less than 6	pulverous or low-caking
Gas long-flame coal		DG		30 and greater	from 6 to 9	pulverous or low-caking
Gas coal	First Gas coal	G	1G	30 and greater	from 6 to 12	caking
	Second Gas coal		2G	38 and greater	from 13 to 16	
Gas lean fat coal	First Gas lean fat coal	GZhO	1GZhO	from 30 to 36	from 10 to 16	–
	Second Gas lean fat coal		2GZhO	36 and greater	from 10 to 16	
Gas Fat coal	First Gas fat coal	GZh	1GZh	30 and greater	17 and greater	caking

<sup>8</sup> In this table such genetic characteristics of coals as Roga index; anisotropy of reflectance of vitrinite; reflectance index of vitrinite; yield of low- temperature tar on dry, ash-free basis have been omitted.

<i>Grade of coal</i>		<i>Designation of grade</i>		<i>Yield of volatile matter on dry, ash-free basis, %</i>	<i>Thickness of the plastic layer, mm</i>	<i>characteristic of the fixed residue</i>
Gas Fat coal	Second Gas Fat coal	GZh	2GZh	36 and greater	from 17 to 25	caking
Fat coal	First Fat coal	Zh	1Zh	from 28 to 34	from 14 to 17	caking
	Second Fat coal		2Zh	Less than 38	from 18 to 26	
Coking fat coal		KZh		from 24 to 28	18 and greater	Caking
Coking coal	First Coking coal	K	1K	from 17 to 28	from 13 to 17	caking
	Second Coking coal		2K	from 17 to 28	13 and greater	
Coking lean coal		KO		from 20 to 28	from 10 to 12	–
Coking low-caking coal	First Coking low-caking coal	KS	1KS	less than 28	from 6 to 9	–
	Second Coking low-caking coal		2KS	less than 24	from 6 to 9	

<i>Grade of coal</i>		<i>Designation of grade</i>		<i>Yield of volatile matter on dry, ash-free basis, %</i>	<i>Thickness of the plastic layer, mm</i>	<i>characteristic of the fixed residue</i>
Lean caking coal	First Lean caking coal	OS	1OS	less than 24	from 9 to 12	—
	Second Lean caking coal		2OS	less than 20	from 6 to 9	
Lean caking coal		TS		Less than 20	Less than 6	caking
Low-caking coal	First Low-caking coal	SS	1SS	from 24 to 34	less than 6	pulverous or low-caking
	Second Low-caking coal		2SS	from 26 to 32	less than 6	
	Third Low-caking coal		3SS	from 16 to 24	less than 6	

<i>Grade of coal</i>		<i>Designation of grade</i>		<i>Yield of volatile matter on dry, ash-free basis, %</i>	<i>Thickness of the plastic layer, mm</i>	<i>characteristic of the fixed residue</i>
Lean coal	First Lean coal	T	1T	from 12 to 16	less than 6	pulverous or low caking
	Second Lean coal		2T	from 8 to 10	less than 6	



Numerical values of the yield of volatile matter and the thickness of the plastic layer of coals of the same grade vary for individual basins and deposits. They are specified in the classification of hard coals for individual basins and deposits in accordance with existing state standards (Kuznecov N. V. et al. 1973a, p. 9).

Anthracites are coals that include two grades: semi-anthracite (grade PA) (transition type between hard coal of grade “T” and anthracite) and anthracite (grade A) (Matveeva I. I. 1972b, p.11). The volatile content of these coals is less than 9% on the dry, ash-free basis. Semi-anthracites differ from anthracites by volumetric yield of volatile matter on dry, ash-free basis ( $V_{v,daf}^9$ ) and higher heating value in calorific bomb ( $HHV_{c,b}^{10}$ ) (Kuznecov N.V. et al. 1973b, p. 10):

- Semi-anthracites-  $V_{v,daf}$  ranges from 220 cm<sup>3</sup>/g to 330 cm<sup>3</sup>/kg;  $HHV_{c,b}$  is more than 8 350 kkal/kg (34.96 MJ/kg)
- Anthracites-  $V_{v,daf}$  is less than 220 cm<sup>3</sup>/g;  $HHV_{c,b}$  is equal to 8 100 kkal/kg (33.91 MJ/kg)

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*Note 1. Geologically oxidized brown and hard coals are out of the classification system described in this work. Oxidized hard coals having volatile content between 17 % and 40 % (on dry, ash-free basis) are characterized by a complete or partial loss of sintering ability, whereas unoxidized coals have this property. The content of hydrogen (in the case of strong oxidation of coal) as well as heat of combustion are reduced in all oxidized coals. With rare exceptions, these coals have low mechanical strength and increased propensity for oxidation and spontaneous combustion.*

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<sup>9</sup> The volumetric yield of volatile matter is determined by the combustion of coal sample mass of 1±0,1 gram in a tube furnace at 900-910°C for 15 minutes. The calculation of volumetric yield of volatile matter is followed for standard conditions (air temperature is 293K; atmospheric pressure is 760 mm Hg) (Mitronov D.V., 2001b, p. 52-53).

<sup>10</sup>  $HHV_{c,b}$  is the heat of combustion of fuel separated in result of combustion of the fuel sample in a bomb calorimeter under standard conditions (Interstate Council for Standardization, Metrology and certification March 2002, p. 5).

Brown coals, some grades of hard coals and anthracites are screened and subdivided into classes by size distribution according to state standard 19242-73<sup>11</sup> (see Table 2). Coals of all types can be utilized as run-of-mine coals, if their screening is inexpedient for economic or technical reasons.

Table 2. Classification of coals by particle size (SPH 2002b, p. 3-4)

<i>Class name</i>	<i>Symbol</i>	<i>Particle size, mm</i>
Plate	P	100-200
Large	K	50-100
Nut	O	25-50
Little	M	13-25
Kernel	S	6-13
Burgy	Sh	0-6
Ordinary	R	0-200 (300) <sup>12</sup>

Coals affected by screening in accordance with the size are denoted as in following examples:

- ASh = anthracite coal ("A") with "burgy" class ("Sh")
- GR = gas coal ("G") with "ordinary" class ("R")
- BK = brown coal ("B") with "large" class ("K")

Mixtures of coals varying in the size are denoted as in following examples:

- DOM = long-flame coal ("D") with class 13-50 mm ("O" = 25-50 mm , "M" = 13-25 mm – the minimum size of the least class is taken, i.e. 13 mm from class "M" and the maximum size of the largest class is taken, i.e. 50 mm from class "O")

<sup>11</sup> "Brown coals, hard coals and anthracite. Size classification". Date of entry into force January 1, 1975. Published July 2002. Originally published as 19242-73 (SPH, 2002b).

<sup>12</sup> 0-200 mm for underground mining; 0-300 mm for opencast mining.

- TOMSSh = lean coal ("T") with class 0-50 mm ("O" = 25-50 mm , "M" = 13-25 mm , S = 6-13 mm , Sh = 0-6mm)

## 6 REVIEW THE QUALITY OF RUSSIAN COALS

Review was prepared for coals mined in the Far East, Eastern Siberia and the Ural. The quality of coal of such basins as Kansk-Achinskiy, Kuznetskiy and Podmoscovniy was reviewed in separate subchapters. Data of proximate and ultimate analysis on different grades of coal were given. Values of carbon, hydrogen, nitrogen, oxygen and volatile content of coal were recalculated from the dry, ash-free basis on the dry basis of fuel (see Formula 1).

Formula 1. Multiplier for converting the results of the analysis of fuel from dry, ash-free basis on the dry basis.

$$(100-A_d)/100 \quad (1)$$

where

$A_d$  is ash fraction of fuel, mass-% of dry fuel

Lower heating value of fuel as received ( $LHV_{a.r.}$ ), lower heating value of dry fuel ( $LHV_d$ ) and higher heating value of dry fuel ( $HHV_d$ ) were determined according to following formulas:

Formula 2. Calculation of  $LHV_{a.r.}$

$$LHV_{a.r.} = LHV_{daf} \cdot (100 - W_r + A_d) / 100 - 25 \cdot W_r \quad (2)$$

where

$LHV_{daf}$  is lower heating value for dry, ash free part of fuel, KJ/kg

$W_r$  is the fuel moisture content, mass-% of the fuel as received

$A_d$  is ash fraction of fuel, mass-% of dry fuel

Formula 3. Calculation of  $LHV_d$

$$LHV_d = (25 \cdot W_r + LHV_{a.r.}) \cdot 100 / (100 - W_r) \quad (3)$$

where

$LHV_{a,r}$  is the lower heating value of fuel as received, KJ/kg

$W_r$  is the fuel moisture content, mass-% of the fuel as received

Formula 4. Calculation of  $HHV_d$

$$HHV_d = 225 \cdot H_d + LHV_d \quad (4)$$

where

$H_d$  is fraction of hydrogen, mass-% of dry fuel

$LHV_d$  is the lower heating value of dry fuel, KJ/kg

Particle size distribution of coals was presented according to the established state standard 19242-73. Also the chemical analysis of coal ash was presented according to data obtained in the analytical laboratory of All-Russian (former All-Union) Thermal Engineering Institute (VTI). Each component of chemical analysis of coal ash was recalculated on basis without sulphate (see Formula 5).

Formula 5. Recalculation of chemical ash composition

$$X_{w,s} = Y \cdot 100 / (100 - SO_3) \quad (5)$$

where

$X_{w,s}$  is the content of ash component on basis without sulphate,  
mass-% of ash

$Y$  is the content of ash component on basis with sulphate,  
mass-% of ash

$SO_3$  is the sulfur trioxide content in ash, mass-% of ash

Content of trace elements in the ash was submitted on the basis of quantitative spectral analysis performed in one laboratory at the same time for all deposits of the Far East. The review shows the values of trace elements in the ash for the

largest deposits of the Far East. Ranks of coal were determined in accordance with the standard classification of coals by rank (ASTM D388<sup>13</sup>).

The data of coal quality for individual basins and deposits were placed in the summary tables.

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*Note 2. Review the quality of coal mined in CIS countries and Georgia also was prepared. The ranks of coals were determined in accordance with standard ASTM D388. The data by coals quality see Appendix 1.*

*Note 3. Correspondence between Russian state standard 25543-88 and ASTM D388 is given in Appendix 2.*

Explanation the grades of coals reviewed is given in separate table according to Russian state standards 25543-88 and 19242-73 (see Table 3).

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<sup>13</sup> This classification is under the jurisdiction of ASTM committee D-5 on Coal and Coke and is the direct responsibility of subcommittee D05.18 on classification of Coals. Current edition approved October 30, 1992. Published March 1993. Originally published as D388-34 T. Last previous edition D388-92 ( Annual Book of ASTM standards. Vol. 05.05., 1993).

Table 3.Explanation of grades of coals (SPH. 2002).

<i>Location /basin name</i>	<i>Coal grade</i>	<i>Decoding</i>
<i>The Far East</i>	B3OM	Brown coal (humidity<30%) “B” with “nut”-“little” class (“O”-“M”)
	B2MS	Brown coal (humidity 30-40%) “B” with “little”-“kemel” class (“M”-“S”)
	B3SSh	Brown coal (humidity<30%) “B” with “kemel”-“burgy” class (“S”-“Sh”)
	DR	Long flame coal “D” with “ordinary” class (“R”)
	TR	Meager coal “T” with “ordinary” class (“R”)
	GR	Gas coal “G” with “ordinary” class (“R”)
	B2R	Brown coal (humidity 30-40%) “B” with “ordinary” class (“R”)
	B1R	Brown coal (humidity>40%) “B” with “ordinary” class (“R”)

<i>Location /basin name</i>	<i>Coal grade</i>	<i>Decoding</i>
<i>The Far East</i>	B2MSSh	Brown coal (humidity 30-40%) “B” with “little”- “kemel”- “burgy” class (“M”-“S”-“Sh”)
<i>The Eastern Siberia</i>	DR	Long flame coal “D” with “ordinary” class (“R”)
	ZhR	Fat coal “Zh” with “ordinary” class (“R”)
	B3R	Brown coal (humidity<30%) “B” with “ordinary” class (“R”)
<i>The Ural</i>	GMSSh	Gas coal “G” with “little”-“kemel”-“burgey” class (“M”-“S”-“Sh”)
	B1R	Brown coal (humidity>40%) “B” with “ordinary” class (“R”)
	ZhR	Fat coal “Zh” with “ordinary” class (“R”)
	GR	Gas coal “G” with “ordinary” class (“R”)



<i>Location /basin name</i>	<i>Coal grade</i>	<i>Decoding</i>
<i>The Ural</i>	B3R	Brown coal (humidity<30%) “B” with “ordinary” class (“R”)
<i>The Kansk-Achinsk basin</i>	B1	Brown coal (humidity>40%) “B”
	B2	Brown coal (humidity 30-40%) “B”
	B3	Brown coal (humidity<30%)”B”
<i>The Podmoscovniy</i>	B2MSSh	Brown coal (humidity 30-40%) “B” with “little”-“kemel”-“burgy” class (“M”-”S”-“Sh”)
	B2R	Brown coal (humidity 30-40%) “B” with “ordinary” class (“R”)
<i>The Kuznetsk</i>	DM	Long flame coal “D” with “little” class (“M”)
	OSR	Lean caking coal “OS” with “ordinary” class (“R”)

<i>Location /basin name</i>	<i>Coal grade</i>	<i>Decoding</i>
<i>Kuznetsk</i>	GR	Gas coal "G" with "ordinary" class ("R")
	TR	Lean coal "T" with "ordinary" class ("R")

## 6.1 The Far East

Coal is the main fuel and energy source used in the Far East. The balance resources of the region are estimated at 19451,1 million tons (coal deposits of category  $A_1+B+C_1$ <sup>14</sup>) and 7565,1 million tons of category  $C_2$  (Department of Energy of Russian Federation, December 25, 2007b). Review of coal quality of the Far East is shown in Table 4.

The 63 % of coal produced correspond to brown coal and 37 % are hard coal (most of hard coals are coking coals). Coal basins and deposits are located nonuniformly across the territory of the Far East.

### *Uglovskiy basin (Primorsk region)*

The area of Uglovskiy basin is about 3000 km<sup>2</sup>. Basin includes Tavrichanskiy, Artemivskiy, Glukhouskiy, Bonivurovskiy and Shkotovskiy deposits. The relief of Artemovskiy and Tavrichanskiy deposits is gentle rolling terrain. The relief of Shkotovskiy deposit is characterized by basalt plateau depth of 240 m.

Tavrichanskiy deposit is located in the western part of the basin and belongs to the western areas of Uglovskiy hollow. Coals of Tavrichanskiy deposit are strong, dense and black. According to structural features, coals are divided on homogeneous, fine-fibred and striated. Coals are characterized by high content of vitrinite (82-94%), low content of liptinite (6-13%) and inertinite (1-5%).

Artemovskiy deposit is located on the southeast of the Uglovskiy hollow. Coals are characterized as dense, brownish-black, semi-bright, semi-gloss (50-75%) and

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<sup>14</sup> In Russia all coal deposits are evaluated on their recourses, quality of extracted fuel etc., and are divided on following categories:

$A_1$ - Deposits are ready for operation or have already being operated.

B- It is necessary the more detailed investigation of discovered raw material for following designing of industrial plants.

$C_1$ -It is necessary the more detailed geologic investigation; the amount of reserves is not determined; the quality of fossil fuels has not been investigated in details.

$C_2$ - Reserves have been determined only on geophysical and geological forecasts; it is possible to carry out perspective planning of explorations.

matte (20-30%). Coals are mainly composed of vitrinite (93-99%), liptinite (up to 6%) and inertinite (roughly 2-3%).

Shkotovskiy deposit belongs to a fault trough which is located within the southern facies zone. Content of vitrinite is in range of 83% to 92%, liptinite- 2-10%, inertinite - 2-3% (Fandushkin G.A., 2000a).

#### *Partizanskiy basin (Primorsk region)*

The area of the Partizanskiy basin is 8000 km<sup>2</sup>, the length is more than 120 km and width is about 60-70 km. The reserves of the basin are about 0,5 billion tonnes, of which about 10% are coking coals.

There are two large retinues in the basin: Starosuchanskaya (depth of 260-800 m) and Severosuchanskaya (depth of 400-500 m). The Starosuchanskaya and Severosuchanskaya retinues include 26 and 22 bench coals, accordingly. Depth of bench coals is between 0,2 and 8,1 m. Conglomerates, sandstones and aleurolites are main components in formation the coalfields. The source materials of coals were stalks, shoots and leaves of ferns and conifers decomposed in strongly water-flooded anaerobic conditions. Coals of basin are hard, black and matte. The content of vitrinite is between 63% and 96%, inertinite no more than 5-10% and liptinite between 1% and 3% (Fandushkin G.A., 2000b).

#### *Deposit Svobodniy*

The deposit area is 700 km<sup>2</sup>; explored coal reserves are estimated at 1,7 billion tonnes.

Coal-bearing strata are related to Bizulinskaya retinue, which age falls into Oligocene-Miocene period. There is one seam of brown coal of thickness up to 19,2 m, it is split into layers of medium thickness about 4,8 and 10,4 m on the southeast of the retinue. Sediments contain mostly clay, sand and silt of total thickness up to 80 m. Seam of brown coal takes the greater part of the deposit, its reserves amount to 80% of total reserves of the deposit. Depth of the seam ranges between 21,7 and 99,2 m (on the average 61,8 m).

Hydrogeology of the deposit is complex due to relatively high water content in rockss and the presence of surface stream flows.

Coals mined are humic and relate to technological grade B1, are characterized by relatively high yield of tar on dry, ash-free basis (18%). Yield of semicoke of the analytical mass of fuel is 62,8%, yield of humic acids varies between 58,9% and 68,1%.

Deposit Svobodniy can be operated by opencast method. Resources of the deposit allow operating coal mines of total capacity up to 25 million tonnes of coal per year. Coals produced are suitable for energy purposes and for the chemical-engineering processing in the modern methods of integrated use.

#### *Deposit Erkovetskiy*

The deposit area is 250 km<sup>2</sup>; explored coal reserves of the Erkovetskiy field are 1,2 billion tonnes.

Coal measure rocks belong to sediments of paleogene age. Deposit position is horizontal and is characterized by a weak dip to the north and north-east from 5-30 to 180 m. The deposit consists of three sites (eastern, western and southern), each represented by three layers with a thickness of 2 to 8 m (average 5,2 m). Stratification depth on the eastern site ranges between 20 and 85 m, on the western site –38-110 m, and on the southern – 18-98 m. Coals mined are bright and semi bright, consist mainly of the micro components of orange, red and brown-red tones and are characterized by high degree of coalification.

Coal production at the field is carried out by opencast method.

#### *Deposit Rayxichinskiy*

The deposit area is about 400 km<sup>2</sup>; explored coal reserves are 500 million tonnes.

Deposit is confined to a suite of paleogene age. The suite contains two layers of brown coal – “top” and “bottom”. The average thickness of the “top” layer is 5-6 m (maximum 7,5 m). In most cases, “top” layer has a simple structure, sometimes, it contains 1-4 thin (to 0,20 m) interlayer of clay. “Bottom” seam lies below the

“top” seam at 4-9 meters and has a changeable thickness and the limited area of distribution.

Coals of both seams are humus and relate to the technical grade B2. For prolonged storage in air, coals crumble and are capable to spontaneous combustion.

The field is operated by opencast method (Ministry of Natural Resources of Russia).

Table 4. Physical and chemical analysis of the coals of the Far East (Vdovichenko V. S et.al, 1991g)

<i>Continent</i>			<i>Eurasia</i>		
<i>Location</i>			<i>Far East (Primorsk region)</i>		
<i>Basin Name</i>			<i>Uglovskiy</i>		
<i>Deposit Name</i>			<i>Artemovskiy</i>	<i>Shkotovskiy</i>	<i>Tavrighanskiy</i>
<i>Proximate Analysis</i>	Moisture, 105°C	wt%, a.r.	23	37	20
	Volatiles, 900°C	wt%, dry	30	35	28.8
	Ash content, 815°C	wt%, dry	40	30	40
	Fixed carbon	wt%, dry	30	35	31.2
<i>Ultimate analysis</i>	Carbon	wt%, dry	40.2	48.65	42.3
	Hydrogen	wt%, dry	3.36	3.85	3.48
	Nitrogen	wt%, dry	0.78	1.05	1.2
	Sulphur	wt%, dry	0.4	0.3	0.5

<i>Location</i>			<i>Far East (Primorsk region)</i>		
<i>Basin Name</i>			<i>Uglovskiy</i>		
<i>Deposit Name</i>			<i>Artemovskiy</i>	<i>Shkotovskiy</i>	<i>Tavrichanskiy</i>
<i>Ultimate analysis</i>	Oxygen (calculated)	wt%, dry	15.24	16.03	12.54
<i>Heating Value</i>	HHV	Mj/kg, dry	16.39	19.56	17.26
	LHV	Mj/kg, dry	15.64	18.70	16.48
	LHV as received	Mj/kg, a.r.	11.46	10.85	12.68
<i>Ashing temperature</i>		°C	800	800	800
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Na <sub>2</sub> O	wt%, ash	2	1.1	2.5
	K <sub>2</sub> O	wt%, ash	3.5	2.8	4
	CaO	wt%, ash	2	4.1	2
	MgO	wt%, ash	1.4	2.5	1.5
	Al <sub>2</sub> O <sub>3</sub>	wt%, ash	27.3	25.2	30
	Fe <sub>2</sub> O <sub>3</sub>	wt%, ash	4	3.4	6.5



<i>Location</i>			<i>Far East (Primorsk region)</i>		
<i>Basin Name</i>			<i>Uglovskiy</i>		
<i>Deposit Name</i>			<i>Artemovskiy</i>	<i>Shkotovskiy</i>	<i>Tavrichanskiy</i>
<i>Chemical ash composition. Analytical laboratory of VTI</i>	SiO <sub>2</sub>	wt%, ash	58.4	58.8	53
	P <sub>2</sub> O <sub>5</sub>	wt%, ash	0.7	0.8	–
	TiO <sub>2</sub>	wt%, ash	0.7	1.1	0.5
	MnO	wt%, ash	–	0.2	–
	Sum of oxides	wt%, ash	100	100	100
<i>Trace elements</i>	Co	mg/kg, dry	34	47	27
	Cr	mg/kg, dry	94	37	85
	Cu	mg/kg, dry	101	77	88
	Pb	mg/kg, dry	22	19	30
	Mn	mg/kg, dry	–	–	–
	Ni	mg/kg, dry	35	34	34
	Zn	mg/kg, dry	62	50	56
	Ti	mg/kg, dry	2913	1315	2200
	Sn	mg/kg, dry	3.6	3.4	3.7
	V	mg/kg, dry	120	68	108

<i>Location</i>			<i>Far East (Primorsk region)</i>		
<i>Basin Name</i>			<i>Uglovskiy</i>		
<i>Deposit Name</i>			<i>Artemovskiy</i>	<i>Shkotovskiy</i>	<i>Tavrichanskiy</i>
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	1320	1160	1200
	Sphere temperature	°C	1500	1430	1400
	Hemisphere temperature	°C	1500	1480	1450
<i>Calculated values</i>	Na <sub>total</sub>	mg/kg	5935.5	2448.4	7419.4
	K <sub>total</sub>	mg/kg	11617.0	6970.2	13276.6
	Na <sub>eg.,total</sub>	mg/kg	12786.5	6559.0	15249.1
	Ash generation	g/MJ	34.9	25.5	33.0
<i>Particle size distribution. State standard 19242-73</i>		mm	13-50	0-13	0-13
<i>Grade of coal. State standard 25543-88</i>			B3OM	B2MS	B3SSh

<i>Location</i>		<i>Far East (Primorsk region)</i>		
<i>Basin Name</i>		<i>Uglovskiy</i>		
<i>Deposit Name</i>		<i>Artemovskiy</i>	<i>Shkotovskiy</i>	<i>Tavrichanskiy</i>
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash	0.0	0.0	0.0
	A_ moist, SO <sub>3</sub> free	30.8	18.9	32.0
	VM, moist	23.1	22.1	23.0
	FC_ moist, SO <sub>3</sub> corrected	23.1	22.1	25.0
	S, moist	0.3	0.3	0.4
	HHV, moist	12.6	12.3	13.8
	FC, dry, Mm-free	52.9	51.9	55.1
	HHV, moist, Mm-fr	18.9	15.5	21.1
	<b>RANK</b>	<b>Lignite</b>	<b>Lignite</b>	<b>Sub-bituminous</b>

<i>Continent</i>			<i>Eurasia</i>		
<i>Location</i>			<i>Far East (Primorsk region)</i>		
<i>Basin Name</i>			<i>Partizanskiy</i>		
<i>Proximate Analysis</i>	Moisture, 105°C	wt%, a.r.	5.50	5.00	5.50
	Volatiles, 900°C	wt%, dry	23.04	8.40	20.46
	Ash content, 815°C	wt%, dry	36.00	30.00	34.00
	Fixed carbon	wt%, dry	40.96	61.60	45.54
<i>Ultimate analysis</i>	Carbon	wt%, dry	52.67	61.95	55.77
	Hydrogen	wt%, dry	3.39	2.80	3.37
	Nitrogen	wt%, dry	0.83	0.77	0.79
	Sulphur	wt%, dry	0.50	0.50	0.50
	Oxygen (calculated)	wt%, dry	6.66	3.99	5.68

<i>Location</i>			<i>Far East (Primorsk region)</i>		
<i>Basin Name</i>			<i>Partizanskiy</i>		
<i>Heating Value</i>	HHV	Mj/kg, dry	21.47	24.11	22.58
	LHV	Mj/kg, dry	20.71	23.48	21.83
	LHV as received	Mj/kg, a.r.	19.43	22.18	20.49
<i>Ashing temperature</i>		°C	800	800	800
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Na <sub>2</sub> O	wt%, ash	0.5	1.0	0.5
	K <sub>2</sub> O	wt%, ash	2.0	4.6	2.4
	CaO	wt%, ash	4.7	3.3	4.5
	MgO	wt%, ash	1.5	1.3	1.5
	Al <sub>2</sub> O <sub>3</sub>	wt%, ash	23.0	23.5	22.0
	Fe <sub>2</sub> O <sub>3</sub>	wt%, ash	4.0	5.8	6.5
	SiO <sub>2</sub>	wt%, ash	63.5	59.6	62.0
	P <sub>2</sub> O <sub>5</sub>	wt%, ash	–	–	–
	TiO <sub>2</sub>	wt%, ash	0.8	0,9	0.6
	MnO	wt%, ash	0.5	1,0	0.5

<i>Location</i>			<i>Far East (Primorsk region)</i>		
<i>Basin Name</i>			<i>Partizanskiy</i>		
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Sum of oxides	wt%, ash	100	100	100
<i>Trace elements</i>	Co	mg/kg, dry	27	–	–
	Cr	mg/kg, dry	65	–	–
	Cu	mg/kg, dry	91	–	–
	Pb	mg/kg, dry	17	–	–
	Mn	mg/kg, dry	30	–	–
	Ni	mg/kg, dry	45	–	–
	Zn	mg/kg, dry	2442	–	–
	Ti	mg/kg, dry	3.1	–	–
	Sn	mg/kg, dry	97	–	–
	V	mg/kg, dry	27	–	–
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	1320	1160	1200

<i>Location</i>			<i>Far East (Primorsk region)</i>		
<i>Basin Name</i>			<i>Partizanskiy</i>		
<i>Fusibility of ash (oxidizing atm)</i>	Sphere temperature	°C	1500	1430	1400
	Hemisphere temperature	°C	1500	1480	1450
<i>Calculated values</i>	Na <sub>total</sub>	mg/kg	5935.5	2448.4	7419.4
	K <sub>total</sub>	mg/kg	11617.0	6970.2	13276.6
	Na <sub>eg.,total</sub>	mg/kg	12786.5	6559.0	15249.1
	Ash generation	g/MJ	34.9	25.5	33.0
<i>Particle size distribution. State standard 19242-73</i>		mm	13-50	0-13	0-13
<i>Grade of coal. State standard 25543-88</i>			B3OM	B2MS	B3SSh
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash		0.0	0.0	0.0
	A <sub>moist</sub> , SO <sub>3</sub> free		30.8	18.9	32.0
	VM, moist		23.1	22.1	23.0

<i>Location</i>		<i>Far East (Primorsk region)</i>		
<i>Basin Name</i>		<i>Partizanskiy</i>		
<i>Classification of coal ASTM D 388</i>	FC_ moist, SO <sub>3</sub> corrected	23.1	22.1	25.0
	S, moist	0.3	0.3	0.4
	HHV, moist	12.6	12.3	13.8
	FC, dry, Mm-free	52.9	51.9	55.1
	HHV, moist, Mm-fr	18.9	15.5	21.1
	<b>RANK</b>	<b>Lignite</b>	<b>Lignite</b>	<b>Sub-bituminous</b>



<i>Continent</i>			<i>Eurasia</i>		
<i>Location</i>			<i>Far East (Amursk region)</i>		
<i>Deposit Name</i>			<i>Erkovetskiy</i>	<i>Raychixinskiy</i>	<i>Svobodniy</i>
<i>Proximate Analysis</i>	Moisture, 105°C	wt%, a.r.	38.00	37.00	52.50
	Volatiles, 900°C	wt%, a.r.	35.20	30.96	50.52
	Ash content, 815°C	wt%, a.r.	20.00	28.00	16.50
	Fixed carbon	wt%, a.r.	44.80	41.04	32.98
<i>Ultimate analysis</i>	Carbon	wt%, a.r.	56.48	50.40	55.95
	Hydrogen	wt%, a.r.	3.28	2.81	4.84
	Nitrogen	wt%, a.r.	0.88	0.72	0.67
	Sulphur	wt%, a.r.	0.40	0.50	0.20
	Oxygen (calculated)	wt%, a.r.	18.96	1.57	21.79
<i>Heating Value</i>	HHV	Mj/kg, dry	20.87	18.60	22.45

<i>Location</i>			<i>Far East (Amursk region)</i>		
<i>Deposit Name</i>			<i>Erkovetskiy</i>	<i>Raychixinskiy</i>	<i>Svobodniy</i>
<i>Heating Value</i>	LHV	Mj/kg, dry	20.13	17.96	21.36
	LHV as received	Mj/kg, a.r.	11.53	10.39	8.83
<i>Ashing temperature</i>		°C	800	800	800
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Na <sub>2</sub> O	wt%, ash	0.4	0.6	0.7
	K <sub>2</sub> O	wt%, ash	1.2	1.2	0.9
	CaO	wt%, ash	9.8	7.0	10.0
	MgO	wt%, ash	1.4	1.4	2.0
	Al <sub>2</sub> O <sub>3</sub>	wt%, ash	24.8	25.4	21.0
	Fe <sub>2</sub> O <sub>3</sub>	wt%, ash	12.0	7.7	11.6
	SiO <sub>2</sub>	wt%, ash	49.0	55.5	51.7
	P <sub>2</sub> O <sub>5</sub>	wt%, ash	0.1	0.2	1.1
	TiO <sub>2</sub>	wt%, ash	0.6	0.8	1
	MnO	wt%, ash	0.7	0.2	0.7
	Sum of oxides	wt%, ash	100	100	100

<i>Location</i>			<i>Far East (Amursk region)</i>		
<i>Deposit Name</i>			<i>Erkovetskiy</i>	<i>Raychixinskiy</i>	<i>Svobodniy</i>
<i>Trace elements</i>	Co	mg/kg, dry	–	–	20
	Cr	mg/kg, dry	–	–	36
	Cu	mg/kg, dry	–	–	82
	Pb	mg/kg, dry	–	–	8
	Ni	mg/kg, dry	–	–	17
	Zn	mg/kg, dry	–	–	65
	Ti	mg/kg, dry	–	–	1050
	Sn	mg/kg, dry	–	–	3.2
	V	mg/kg, dry	–	–	64
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	1140	1150	1140
	Sphere temperature	°C	1230	1240	1220
	Hemisphere temperature	°C	1310	1340	1260
<i>Calculated values</i>	Na <sub>total</sub>	mg/kg	593.5	1246.5	856.9

<i>Location</i>			<i>Far East (Amursk region)</i>		
<i>Deposit Name</i>			<i>Erkovetskiy</i>	<i>Raychixinskiy</i>	<i>Svobodniy</i>
<i>Calculated values</i>	K <sub>total</sub>	mg/kg	1991.5	2788.1	1232.2
	Na <sub>eg.,total</sub>	mg/kg	1768.0	2890.7	1583.6
	Ash generation	g/MJ	17.3	26.9	18.7
<i>Particle size distribution. State standard 19242-73</i>		mm	0-200/0-300	0-25	0-13
<i>Grade of coal. State standard 25543-88</i>			B2R	B2MSSh	B1R
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash		0.0	0.0	0.0
	A_ moist, SO <sub>3</sub> free		12.4	17.6	7.8
	VM, moist		21.8	19.5	24.0
	FC_ moist, SO <sub>3</sub> corrected		27.8	25.9	15.7
	S, moist		0.2	0.3	0.1
	HHV, moist		12.9	11.7	10.7
	FC, dry, Mm-free		57.2	59.0	40.2
	HHV, moist, Mm-fr		14.9	14.5	117

<i>Location</i>		<i>Far East (Amursk region)</i>		
<i>Deposit Name</i>		<i>Erkovetskiy</i>	<i>Raychixinskiy</i>	<i>Svobodniy</i>
<i>Classification of coal ASTM D 388</i>	<b>RANK</b>	<b>Lignite</b>	<b>Lignite</b>	<b>Lignite</b>

## 6.2 The Eastern Siberia

The balance resources of the region are estimated at 61113 million tons of category  $A_1+B+C_1$  and 28078 million tons of category  $C_2$ . Most deposits of the Eastern Siberia differ by the presence of powerful superficial flat seams, what allows produce a reservoir by opencast method. Brown coals make up the main part of the balance resources of category  $A + B + C_1$ .

Review of coal quality of the Eastern Siberia is shown in Table 5.

### *Irkutskiy basin*

The Irkutskiy basin is located in south part of Irkutskaya area. Area of the basin is equal to 42,7 thousand  $\text{km}^2$ , length is 500 km and average width is 80 km. Basin provides the fuel for railway transport, power stations, community services and industrial plants. There are 65 coal seams, which are unevenly distributed over the coal opencast (thickness of most layers is less than 1 m). Thick seams of thickness from 9 m to 18 m are available on Cheremkhovsky and Azeyskom fields. There is a vertical change in the quality of coals. While depth of coal seams is increasing, the humidity of coal and volatile content decrease, the carbon content increases and the coking thickness of coal improves. Operation of the basin is carried out mainly (87%) in the quarries, in south-eastern part of the basin - in the mines and partly in the adit (Department of Energy of the Russian Federation, 2007b.).

### *Minusinskiy basin*

Minusinskiy basin is located in Minusinskaya hollow on the territory of Hakasskaya autonomous republic and Krasnoyarskiy territory.

Coal-bearing strata thickness of 630-1800 m is characterized by a monotonous alternation of sandstones, argillites, siltstones and coal seams. Deposits include the symmetrically constructed brachy-synclines (charging boxes) on the north-east. Coal seams lie close to each other. Among the 80 coal seams, only about 40 have a thickness of over 0,7 m and only 6-10 coal seams are operated. Method of coal mining primarily is opencast (The geology of coal deposits and fells shale of USSR, 1964a, p. 235).

Table 5. Physical and chemical analysis of the coals of the Eastern Siberia (Vdovichenko V. S et.al, 1991h; Matveeva I. I., 1972c)

<i>Continent</i>			<i>Eurasia</i>		
<i>Location</i>			<i>Eastern Siberia</i>		
<i>Basin Name</i>			<i>Irkutskiy</i>		
<i>Deposit Name</i>			<i>Cheremxovski,Zabit uyskiy, Ishideyskiy</i>	<i>Elegestinskiy</i>	<i>Mugunskiy, Azeyskiy</i>
<i>Proximate Analysis</i>	Moisture, 105°C	wt%, a.r.	8	7	22
	Volatiles, 900°C	wt%, dry	38.25	35	37.26
	Ash content, 815°C	wt%, dry	25	9	19
	Fixed carbon	wt%, dry	36.75	56	43.74
<i>Ultimate analysis</i>	Carbon	wt%, dry	57	73.7	73.7
	Hydrogen	wt%, dry	4.275	5.8	5.8
	Nitrogen	wt%, dry	1.275	1.5	1.5
	Sulphur	wt%, dry	4.5	0.6	1.2
	Oxygen (calculated)	wt%, dry	7.65	17.5	17.5

<i>Location</i>			<i>Eastern Siberia</i>		
<i>Basin Name</i>			<i>Irkutskiy</i>		
<i>Deposit Name</i>			<i>Cheremxovskiy, Zabuyskiy, Ishideyskiy</i>	<i>Elegestinskiy</i>	<i>Mugunskiy, Azeyskiy</i>
<i>Heating Value</i>	HHV	Mj/kg, dry	23.85	33.35	24.47
	LHV	Mj/kg, dry	22.89	32.04	23.17
	LHV as received	Mj/kg, a.r.	20.86	29.62	17.52
<i>Ashing temperature</i>		°C	800	800	800
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Na <sub>2</sub> O	wt%, ash	0.2	1.7	0.2
	K <sub>2</sub> O	wt%, ash	1.2	0.4	0.9
	CaO	wt%, ash	4.3	5.1	6.7
	MgO	wt%, ash	2.8	0.5	1.6
	Al <sub>2</sub> O <sub>3</sub>	wt%, ash	22.8	35	34
	Fe <sub>2</sub> O <sub>3</sub>	wt%, ash	5.7	12.6	4.7



<i>Location</i>			<i>Eastern Siberia</i>		
<i>Basin Name</i>			<i>Irkutskiy</i>		
<i>Deposit Name</i>			<i>Cheremxovskiy,Zabituyskiy, Ishadeyskiy</i>	<i>Elegestinskiy</i>	<i>Mugunskiy, Azeyskiy</i>
<i>Chemical ash composition. Analytical laboratory of VTI</i>	SiO <sub>2</sub>	wt%, ash	62.4	44	51
	P <sub>2</sub> O <sub>5</sub>	wt%, ash	0.1	–	–
	TiO <sub>2</sub>	wt%, ash	0.5	0.7	0.9
	MnO	wt%, ash	trace	0.2	–
	Sum of oxydes	wt%, ash	100	100	100
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	1170	1125	1420
	Sphere temperature	°C	1320	1245	1460
	Hemisphere temperature	°C	1430	1260	1470
<i>Calculated values</i>	Na <sub>total</sub>	mg/kg	371.0	1135.2	281.9

<i>Location</i>			<i>Eastern Siberia</i>		
<i>Basin Name</i>			<i>Irkutskiy</i>		
<i>Deposit Name</i>			<i>Cheremxovskiy,Zabituyskiy, Ishadeyskiy</i>	<i>Elegestinskiy</i>	<i>Mugunskiy, Azeyskiy</i>
<i>Calculated values</i>	$K_{total}$	mg/kg	2489.4	298.7	1418.9
	$Na_{eg..total}$	mg/kg	1839.1	1311.3	1118.7
	Ash generation	g/MJ	18.5	5.7	15.0
<i>Particle size distribution. Interstate standard 19242-73</i>		mm	0-200/0-300	0-200/0-300	0-13
<i>Grade of coal. Interstate standard 25543-88</i>			DR	ZHR	B3R
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash		0.0	0.0	0.0
	A_ moist, SO <sub>3</sub> free		23.0	8.4	14.8
	VM, moist		35.2	32.6	29.1

<i>Location</i>		<i>Eastern Siberia</i>		
<i>Basin Name</i>		<i>Irkutskiy</i>		
<i>Deposit Name</i>		<i>Cheremxovskiy, Zabituyskiy, Ishideyskiy</i>	<i>Elegestinskiy</i>	<i>Mugunskiy, Azeyskiy</i>
<i>Classification of coal ASTM D 388</i>	FC_ moist, SO <sub>3</sub> corrected	33.8	52.1	34.1
	S, moist	4.1	0.6	0.9
	HHV, moist	21.9	31.0	19.1
	FC, dry, Mm-free	51.2	62.2	55.3
	HHV, moist, Mm-frr	29.8	34.2	22.8
	<b>RANK</b>	<b>Bituminous</b>	<b>Bituminous</b>	<b>Sub-bituminous</b>

<i>Location</i>			<i>Eastern Siberia</i>		
<i>Basin Name</i>			<i>Minusinskiy</i>		
<i>Deposit/coal seam name</i>			<i>Tulunskiy</i>	<i>Chernogorskiy</i>	<i>Izixskiy, Askizskiy, Beyskiy</i>
<i>Proximate analysis</i>	Moisture, 105°C	wt%, a.r.	26	12	9
	Volatiles, 900°C	wt%, dry	36	33.615	32.2805
	Ash content, 815°C	wt%, dry	25	17	19.5
	Fixed carbon	wt%, dry	39	49.385	48.2195
<i>Ultimate analysis</i>	Carbon	wt%, dry	54.75	66.4	63.9975
	Hydrogen	wt%, dry	3.825	4.316	4.991
	Nitrogen	wt%, dry	1.275	1.909	1.288

<i>Location</i>			<i>Eastern Siberia</i>		
<i>Basin Name</i>			<i>Minusinskiy</i>		
<i>Deposit/coal seam name</i>			<i>Tulunskiy</i>	<i>Chernogorskiy</i>	<i>Izixskiy, Askizskiy, Beyskiy</i>
<i>Ultimate analysis</i>	Sulphur	wt%, dry	0.5	0.4	0.6
	Oxygen (calculated)	wt%, dry	14.625	9.794	9.66
<i>Heating Value</i>	HHV	Mj/kg, dry	21.58	29.14	26.71
	LHV	Mj/kg, dry	20.72	28.17	25.58
	LHV as received	Mj/kg, a.r.	14.68	24.49	23.06
<i>Ashing temperature</i>		°C	800	800	800

<i>Location</i>			<i>Eastern Siberia</i>		
<i>Basin Name</i>			<i>Minusinskiy</i>		
<i>Deposit/coal seam name</i>			<i>Tulunskiy</i>	<i>Chernogorskiy</i>	<i>Izixskiy, Askizskiy, Beyskiy</i>
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Na <sub>2</sub> O	wt%, ash	0.2	1.1	2
	K <sub>2</sub> O	wt%, ash	0.6	0.9	0.6
	CaO	wt%, ash	7.9	4.6	4
	MgO	wt%, ash	2.1	2	1.8
	Al <sub>2</sub> O <sub>3</sub>	wt%, ash	28.6	33.7	38.2
	Fe <sub>2</sub> O <sub>3</sub>	wt%, ash	7.2	7.5	5.8
	SiO <sub>2</sub>	wt%, ash	52.5	48.5	48
	P <sub>2</sub> O <sub>5</sub>	wt%, ash	0.2	0.3	0.3

<i>Location</i>			<i>Eastern Siberia</i>		
<i>Basin Name</i>			<i>Minusinskiy</i>		
<i>Deposit/coal seam name</i>			<i>Tulunskiy</i>	<i>Chernogorskiy</i>	<i>Izixskiy, Askizskiy, Beyskiy</i>
<i>Chemical ash composition. Analytical laboratory of VTI</i>	TiO <sub>2</sub>	wt%, ash	0.4	1.7	1
	MnO	wt%, ash	0.3	1.1	2
	Sum of oxides	wt%, ash	100	100	100
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	1240	1200	1240
	Sphere temperature	°C	1340	1360	1320
	Hemisphere temperature	°C	1420	1400	1360
<i>Calculated values</i>	Na <sub>total</sub>	mg/kg	371.0	1387.4	2893.5
	K <sub>total</sub>	mg/kg	1244.7	1269.6	970.9

<i>Location</i>			<i>Eastern Siberia</i>		
<i>Basin Name</i>			<i>Minusinskiy</i>		
<i>Deposit/coal seam name</i>			<i>Tulunskiy</i>	<i>Chernogorskiy</i>	<i>Izixskiy, Askizskiy, Beyskiy</i>
<i>Calculated values</i>	Na <sub>eg..total</sub>	mg/kg	1105.0	2136.1	3466.1
	Ash generation	g/MJ	20.5	11.3	13.8
<i>Particle size distribution. State standard 19242-73</i>		mm	0-200/0-300	0-200/0-300	0-200/0-300
<i>Grade of coal. State standard 25543-88</i>			B3R	DR	DR
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash		0.0	0.0	0.0
	A <sub>_</sub> moist, SO <sub>3</sub> free		18.5	15.0	17.7
	VM, moist		26.6	29.6	30.0



<i>Location</i>		<i>Eastern Siberia</i>		
<i>Basin Name</i>		<i>Minusinskiy</i>		
<i>Deposit/coal seam name</i>		<i>Tulunskiy</i>	<i>Chernogorskiy</i>	<i>Izixskiy, Askizskiy, Beyskiy</i>
<i>Classification of coal ASTM D 388</i>	FC_ moist, SO <sub>3</sub> corrected	28.9	43.5	43.2
	S, moist	0.4	0.4	0.5
	HHV, moist	16.0	25.6	24.3
	FC, dry, Mm-free	53.5	60.6	60.3
	HHV, moist, Mm-frr	20.0	30.6	30.1
	<b>RANK</b>	<b>Sub-bituminous</b>	<b>Bituminous</b>	<b>Bituminous</b>

### 6.3 The Ural

The Ural is situated between East European and West Siberian plains. The Ural mountain range is a main part of the region, its length is more than 2000 km, width is from 40 to 150 km and height is up to 1895 m.

Review of coal quality of the Ural is shown in Table 6.

#### *Kizelovskiy basin*

Basin is located on the western slope of the middle Ural. The total area of the basin is 1500 km<sup>2</sup>; known reserves are estimated at 464 million tons. Coal-bearing strata contain two or three coal seams of thickness from 0,7 to 2,5 m. Depth of strata exceeds 1000 m. Coals of the basin belong to a group of humic dense, strong matte and semi-gloss durain. The peculiarity of coals is their ability to sinter at a high excretion of valuable chemical products. Coal mining is carried out mainly by underground method (Vdovichenko V.S. et.al. 1991b, p. 75).

#### *Chelyabinsk basin*

Chelyabinsk coal basin is located within the Chelyabinsk region on the eastern slope of the Ural, in the form of band of width 15 km and a length of 170 km. The total geological reserves of basin are estimated at 1634 million tons.

Coal-bearing strata refer to the early Jurassic, its thickness is 1600-3500 m and it contains up to 57 coal seams of varying thickness. There are coal seams of medium thickness (5-20 m) and super-thick seams (50-200 m). The latter occupy a central part of the deposits. The structure of coal seams basically is complex due to the presence lenticular formation of clay.

Soil of the coal seams contains sandstone and clay formations. Mining conditions of basin allow combining the extraction of coal by an opencast and underground method (Vdovichenko V.S. et.al. 1991c, p. 78).

#### *South Ural basin*

South Ural basin integrates the deposits of brown coals located on the territory of Bashkiria and Orenburg territory. The total geological reserves are 1765 million tons.

Main part of brown-coal deposits is a tabular or large, with lenticular fractions of variable thickness (from 2-3 to 110 m). Time of accumulation of coal seams is defined as the late Oligocene and late Miocene (Yahimovich V. L. et.al 1959, p. 300). Extremely low degree of lithification of soils composing the coal-bearing formations, as well as the quality of coal, indicate that metamorphism have not hardly influenced on the formation process of coals.

The peculiarity of the coals is the presence of bitumen, which makes them a valuable raw material for chemical industry. Coal mining is carried out by opencast method (Nemkova V. K. et.al 1970, p. 134).

Table 6. Physical and chemical analysis of the coals of The Ural (Vdovichenko V. S. et.al, 1991i)

<i>Continent</i>			<i>Eurasia</i>			
<i>Location</i>			<i>Ural</i>			
<i>Basin Name</i>			<i>Kizelovskiy</i>			
<i>Deposit/Mine Name</i>			<i>Name of V.I. Lenina, Severnaya, Kluchevskaya</i>	<i>Centralnaya, Shirokovskaya, Kospashskaya, Nagornaya, Krupskaya</i>	<i>Shumixinskaya</i>	
<i>Proximate Analysis</i>	Moisture, 105°C	wt%, a.r.	6.5	6.5	8	
	Volatiles, 900°C	wt%, dry	27.52	25.65	25.575	
	Ash content, 815°C	wt%, dry	36	43	45	
	Fixed carbon	wt%, dry	36.48	31.35	29.425	
<i>Ultimate analysis</i>	Carbon	wt%, dry	49.92	43.662	40.425	
	Hydrogen	wt%, dry	3.648	3.306	3.19	
	Nitrogen	wt%, dry	0.576	0.57	0.44	

<i>Location</i>			<i>Ural</i>		
<i>Basin Name</i>			<i>Kizelovskiy</i>		
<i>Deposit/Mine Name</i>			<i>Name of V.I. Lenina, Severnaya, Kluchevskaya</i>	<i>Centralnaya, Shirokovskaya, Kospashskaya, Nagornaya, Krupskaya</i>	<i>Shumixinskaya</i>
<i>Ultimate analysis</i>	Sulphur	wt%, dry	5.8	5.2	4.1
	Oxygen (calculated)	wt%, dry	4.672	4.674	4.675
<i>Heating Value</i>	HHV	Mj/kg, dry	21.38	19.22	18.28
	LHV	Mj/kg, dry	20.56	18.47	17.57
	LHV as received	Mj/kg, a.r.	19.06	17.11	15.96
<i>Ashing temperature</i>		°C	800	800	800
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Na <sub>2</sub> O	wt%, ash	0.2	0.2	0.2

<i>Location</i>			<i>Ural</i>		
<i>Basin Name</i>			<i>Kizelovskiy</i>		
<i>Deposit/Mine Name</i>			<i>Name of V.I. Lenina, Severnaya, Kluchevskaya</i>	<i>Centralnaya, Shirokovskaya, Kospashskaya, Nagornaya, Krupskaya</i>	<i>Shumixinskaya</i>
<i>Chemical ash composition. Analytical laboratory of VTI</i>	K <sub>2</sub> O	wt%, ash	1.8	1.8	2.1
	CaO	wt%, ash	1	0.6	0.4
	MgO	wt%, ash	1	0.9	1.1
	Al <sub>2</sub> O <sub>3</sub>	wt%, ash	28	28.4	29.4
	Fe <sub>2</sub> O <sub>3</sub>	wt%, ash	17	16	14.9
	SiO <sub>2</sub>	wt%, ash	49	50.4	50
	P <sub>2</sub> O <sub>5</sub>	wt%, ash	trace	0.1	0.1
	TiO <sub>2</sub>	wt%, ash	1.8	1.4	1.6

<i>Location</i>			<i>Ural</i>		
<i>Basin Name</i>			<i>Kizelovskiy</i>		
<i>Deposit/Mine Name</i>			<i>Name of V.I. Lenina, Severnaya, Kluchevskaya</i>	<i>Centralnaya, Shirokovskaya, Kospashskaya, Nagornaya, Krupskaya</i>	<i>Shumixinskaya</i>
<i>Chemical ash composition. Analytical laboratory of VTI</i>	MnO	wt%, ash	0.2	0.2	0.2
	Sum of oxides	wt%, ash	100	100	100
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	1280	1250	1350
	Sphere temperature	°C	1360	1330	1450
	Hemisphere temperature	°C	1410	1470	1480
<i>Calculated values</i>	Na <sub>total</sub>	mg/kg	534.2	638.1	667.7
	K <sub>total</sub>	mg/kg	5377.0	6422.6	7841.5

<i>Location</i>			<i>Ural</i>		
<i>Basin Name</i>			<i>Kizelovskiy</i>		
<i>Deposit/Mine Name</i>			<i>Name of V.I. Lenina, Severnaya, Kluchevskaya</i>	<i>Centralnaya, Shirokovskaya, Kospashskaya, Nagornaya, Krupskaya</i>	<i>Shumixinskaya</i>
<i>Calculated values</i>	$N_{\text{eg. total}}$	mg/kg	3705.3	4425.7	5292.2
	Ash generation	g/MJ	25.2	29.9	31.7
<i>Particle size distribution. Interstate standard 19242-73</i>		mm	0-200/0-300	0-200/0-300	0-13
<i>Grade of coal. Interstate standard 25543-88</i>			ZHR	GR	GMSSh
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash		0.0	0.0	0.0
	A <sub>1</sub> moist, SO <sub>3</sub> free		33.7	40.2	41.4



<i>Location</i>		<i>Ural</i>		
<i>Basin Name</i>		<i>Kizelovskiy</i>		
<i>Deposit/Mine Name</i>		<i>Named of V.I. Lenina, Severnay, Kluchevskaya</i>	<i>Centralnaya, Shirokovskaya, Kospashskaa, Nagornaya, Krupskaya</i>	<i>Shumixinskaya</i>
<i>Classification of coal ASTM D 388</i>	VM, moist	25.7	24.0	23.5
	FC_ moist, SO <sub>3</sub> corrected	34.1	29.3	27.1
	S, moist	5.4	4.9	3.8
	HHV, moist	20.0	18.0	16.8
	FC, dry, Mm-free	61.5	60.3	58.6
	HHV, moist, Mm-frr	32.5	32.9	31.3
	<b>RANK</b>	<b>Bituminous</b>	<b>Bituminous</b>	<b>Bituminous</b>

<i>Location</i>			<i>Ural</i>		
<i>Basin Name</i>			<i>Chelybinskiy</i>		<i>South-Ural</i>
<i>Deposit/Preparation plant Name</i>			<i>Kamishinkaya, Kopeyskaya, Kalachevskay, Emanjelinskay, Korkinskaya</i>	<i>Uglemoyka</i>	<i>Babaevskiy, Tulganskiy</i>
<i>Proximate Analysis</i>	Moisture, 105°C	wt%. a.r.	16	21	52
	Volatiles, 900°C	wt%. dry	25.8	29.92	45.85
	Ash content, 815°C	wt%. dry	40	32	30
	Fixed carbon	wt%. dry	34.2	38.08	24.15
<i>Ultimate analysis</i>	Carbon	wt%. dry	43.5	48.28	46.34
	Hydrogen	wt%. dry	3.12	3.468	4.41
	Nitrogen	wt%. dry	1.56	1.36	0.56
	Sulphur	wt%. dry	0.9	1.5	0.9
	Oxygen(calculatd)	wt%. dry	10.92	13.464	17.78

<i>Location</i>			<i>Ural</i>		
<i>Basin Name</i>			<i>Chelyabinskiy</i>		<i>South-Ural</i>
<i>Deposit/Preparation plant Name</i>			<i>Kamishinkaya, Kopeyskaya, K alachevskaya, Emanjelinskaya, Korkinskaya</i>	<i>Uglemoyka</i>	<i>Babaevskiy, Tulganskiy</i>
<i>Heating Value</i>	HHV	Mj/kg. dry	17.36	19.02	19.23
	LHV	Mj/kg. dry	16.66	18.24	18.24
	LHV as received	Mj/kg. a.r.	13.59	13.89	7.45
<i>Ashing temperature</i>		°C	800	800	800
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Na <sub>2</sub> O	wt%. ash	1	1.2	0.5
	K <sub>2</sub> O	wt%. ash	2.4	2	1.2
	CaO	wt%. ash	4	3.5	6.8
	MgO	wt%. ash	3.3	3	5.1
	Al <sub>2</sub> O <sub>3</sub>	wt%. ash	23.5	22	23.8
	Fe <sub>2</sub> O <sub>3</sub>	wt%. ash	8.6	12	5.2
	SiO <sub>2</sub>	wt%. ash	55	55	55.8

<i>Location</i>			<i>Ural</i>		
<i>Basin Name</i>			<i>Chelybinskiy</i>		<i>South-Ural</i>
<i>Deposit/Preparation plant Name</i>			<i>Kamishinkaya, Kopeyskaya, K alachevskay, Emanjelinskay, Korkinskaya</i>	<i>Uglemoyka</i>	<i>Babaevskiy, Tulganskiy</i>
<i>Chemical ash composition. Analytical laboratory of VTI</i>	P <sub>2</sub> O <sub>5</sub>	wt%. ash	0.7	0.3	0.2
	TiO <sub>2</sub>	wt%. ash	1.2	1	1.2
	MnO	wt%. ash	0.3	trace	0.2
	Sum of oxides	wt%. ash	100	100	100
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	1180	1170	1180
	Sphere temperature	°C	1290	1270	1330
	Hemisphere temperature	°C	1370	1340	1410
<i>Calculated values</i>	Na <sub>total</sub>	mg/kg	2967.7	2849.0	1112.9
	K <sub>total</sub>	mg/kg	7966.0	5310.6	2987.2

<i>Location</i>			<i>Ural</i>		
<i>Basin Name</i>			<i>Chelybinskiy</i>		<i>South-Ural</i>
<i>Deposit/Preparation plant Name</i>			<i>Kamishinkaya, Kopeyskaya, Kalachevskay, Emanjelinskay, Korkinskaya</i>	<i>Uglemoyka</i>	<i>Babaevskiy, Tulganskiy</i>
<i>Calculated values</i>	Na <sub>eg..total</sub>	mg/kg	7665.6	5980.9	2874.6
	Ash generation	g/MJ	32.7	27.1	26.2
<i>Particle size distribution. Interstate standard 19242-73</i>		mm	0-200/0-300	0-200/0-300	0-200/0-300
<i>Grade of coal. Interstate standard 25543-88</i>			B3-smalls <sup>15</sup>	B3R	B1R
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash		0.0	0.0	0.0
	A_ moist, SO <sub>3</sub> free		33.6	25.3	14.4
	VM, moist		21.7	23.6	22.0
	FC_ moist, SO <sub>3</sub> corrected		28.7	30.1	11.6
	S, moist		0.8	1.2	0.4

<sup>15</sup> Smalls are fractions of coal that have been extracted out coal of grade "ordinary" and have not been processed in coal preparation plant.

<i>Location</i>		<i>Ural</i>		
<i>Basin Name</i>		<i>Chelybinskiy</i>		<i>South-Ural</i>
<i>Deposit/Preparation plant Name</i>		<i>Kamishinkaya, Kopeyskaya, Kalachevskay, Emanjelinskay, Korkinskaya</i>	<i>Uglemoyka</i>	<i>Babaevskiy, Tulganskiy</i>
<i>Classification of coal ASTM D 388</i>	HHV, moist	14.6	15.0	9.2
	FC, dry, Mm-free	60.5	58.6	35.8
	HHV, moist, Mm-frr	23.0	20.8	10.9
	<b>RANK</b>	<b>Sub-bituminous</b>	<b>Sub-bituminous</b>	<b>Lignite</b>

## 6.4 The Kansk-Achinsk basin

The Kansk-Achinsk basin is one of the largest basins of Russia. The area of the basin is about 45 thousand km<sup>2</sup>. Its total geological reserves are estimated at 638 billion tons, the balance resources of category A<sub>1</sub>+B+C<sub>1</sub> amount to 142,9 billion tons.

Review of coal quality of the Kansk-Achinsk basin is shown in Table 7.

Coal-bearing strata are composed of Jurassic sediments of the continental type with an alternation of sandstones, conglomerates, gritstone, aleurolite, argillite and coal seams. The major part of the basin is shaped like a typical platform basin with horizontal bedding of the soil. In southeastern part of the basin the thickness of coal-bearing strata increases to 700-800 m. Coal-bearing strata are related to two cycles of sedimentation - latest Jurassic and middle Jurassic. There are 20 operating coal seams of total thickness of 120 m in the basin (The geology of coal deposits and fells shale of USSR 1964b, p. 347).

The most explored deposits of the basin are Irsha-Borodinskiy, Nazarovskiy, Berezovskiy, Barandatskiy, Itatskiy, Bogotolskiy and Abanskiy. The average thickness of bench coal:

- Nazarovskiy- 12,8 m
- Berezovskiy- 6-70 m
- Both the Barandatskiy and Itatskiy- 44-58 m
- Bogotolskiy- 33 m

Coals of the basin correspond to typical humus and brown in relation to composition of the source material and the degree of carbonification, accordingly. The coal mining mainly is carried out in quarries (Vdovichenko V.S. et.al. 1991d, 111, p. 128).

Table 7. Physical and chemical analysis of the coals of The Kansk-Achinsk basin (Matveeva I. I., 1972d)

<i>Continent</i>			<i>Eurasia</i>		
<i>Location</i>			<i>South of Central Siberia</i>		
<i>Basin Name</i>			<i>Kansk-Achinsk</i>		
<i>Deposit Name</i>			<i>Abanskiy, Barandakiy, Urupskiy</i>	<i>Bogotolskoe, Itatskoe</i>	<i>Irsha-Borodinski, Nazarovski</i>
<i>Proximate Analysis</i>	Moisture, 105°C	wt%, a.r.	37	44.00	39.00
	Volatiles, 900°C	wt%, dry	44.64	42.24	42.24
	Ash content, 815°C	wt%, dry	7	12.00	12.00
	Fixed carbon	wt%, dry	48.36	45.76	45.76
<i>Ultimate analysis</i>	Carbon	wt%, dry	66.495	61.16	61.60
	Hydrogen	wt%, dry	4.557	4.31	4.22
	Nitrogen	wt%, dry	0.651	0.62	0.70
	Sulphur	wt%, dry	0.3	0.90	0.70
	Oxygen (calculated)	wt%, dry	21.018	21.03	20.77



<i>Location</i>			<i>South of Central Siberia</i>		
<i>Basin Name</i>			<i>Kansk-Achinsk</i>		
<i>Deposit Name</i>			<i>Abanskiy, Barandakiy, Urupskiy</i>	<i>Bogotolskoe, Itatskoe</i>	<i>Irsha-Borodinski, Nazarovski</i>
<i>Heating Value</i>	HHV	Mj/kg, dry	26.03	24.00	23.90
	LHV	Mj/kg, dry	25.00	23.03	22.95
	LHV as received	Mj/kg, a.r.	14.82	11.80	13.02
<i>Ashing temperature</i>		°C	800	800	800
<i>Chemical ash composition. Analytical laboratory of ATI</i>	Na <sub>2</sub> O	wt%, ash	0.7	1.0	0.5
	K <sub>2</sub> O	wt%, ash	0.6	1.0	0.5
	CaO	wt%, ash	42.7	28.0	32.0
	MgO	wt%, ash	9	5.0	5.0
	Al <sub>2</sub> O <sub>3</sub>	wt%, ash	11	13.0	13.0
	Fe <sub>2</sub> O <sub>3</sub>	wt%, ash	9	15.0	18.0

<i>Location</i>			<i>South of Central Siberia</i>		
<i>Basin Name</i>			<i>Kansk-Achinsk</i>		
<i>Deposit Name</i>			<i>Abanskiy, Barandakiy, Urupskiy</i>	<i>Bogotolskoe, Itatskoe</i>	<i>Irsha-Borodinski, Nazarovski</i>
<i>Chemical ash composition. Analytical laboratory of ATI</i>	SiO <sub>2</sub>	wt%, ash	27	37.0	31.0
	P <sub>2</sub> O <sub>5</sub>	wt%, ash	–	–	–
	TiO <sub>2</sub>	wt%, ash	–	–	–
	MnO	wt%, ash	–	–	–
	Sum of oxydes	wt%, ash	100	100	100
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	1300	1150	1200
	Sphere temperature	°C	1320	1170	1220
	Hemisphere temperature	°C	1340	1190	1240

<i>Location</i>			<i>South of Central Siberia</i>		
<i>Basin Name</i>			<i>Kansk-Achinsk</i>		
<i>Deposit Name</i>			<i>Abanskiy, Barandakiy, Urupskiy</i>	<i>Bogotolskoe, Itatskoe</i>	<i>Irsha-Borodinski, Nazarovski</i>
<i>Calculated values</i>	Na <sub>total</sub>	mg/kg	363.5	890.3	445.2
	K <sub>total</sub>	mg/kg	348.5	995.7	497.9
	Na <sub>eg..total</sub>	mg/kg	569.1	1477.6	738.8
	Ash generation	g/MJ	4.7	10.2	9.2
<i>Particle size distribution. State standard 19242-73</i>		mm	–	–	–
<i>Grade of coal. State standard 25543-88</i>			B2	B1	B2
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash		0.0	0.0	0.0
	A_ moist, SO <sub>3</sub> free		4.4	6.7	7.3
	VM, moist		28.1	23.7	25.8
	FC_ moist, SO <sub>3</sub> corrected		30.5	25.6	27.9

<i>Location</i>		<i>South of Central Siberia</i>		
<i>Basin Name</i>		<i>Kansko-Achinsk</i>		
<i>Deposit Name</i>		<i>Abanskiy,Barandakiy, Urupskiy</i>	<i>Bogotolskoe,Itatskoe</i>	<i>Irsha-Borodinski, Nazarovski</i>
<i>Classification of coal ASTM D 388</i>	S, moist	0.2	0.5	0.4
	HHV, moist	16.4	13.4	14.6
	FC, dry, Mm-free	52.4	52.7	52.7
	HHV, moist, Mm-frr	17.2	14.5	15.8
	<b>RANK</b>	<b>Lignite</b>	<b>Lignite</b>	<b>Lignite</b>

## 6.5 The Podmoskovniy basin

Podmoskovniy brown-coal basin is one of the oldest coal basins of the country. Basin is located within the central industrial region that includes the Ryazan, Tula, Moscow, Kaluga, Smolensk and Novgorod regions (Vinogradov B.G et.al. 1957, p. 250). The total area of the basin is about 120 thousand km<sup>2</sup>; explored reserves<sup>16</sup> of coal amount to about 4 billion tonnes.

Review of coal quality of the Podmoskovniy basin is shown in Table 8.

Geographical position of the basin is favorable for coal mining in spite of rather low quality of coal and complex geological conditions (Vdovichenko V.S. et.al. 1991e, p. 56). Basin belongs to the southwest bench face of Moscow syncline located on the East European platform. Coal-bearing strata of thickness up to 50 m refer to the horizon of the lower Carbon and contain up to 14 seams and bands of coal; an average thickness of the operating seams ranges from 1,5 to 2 m and sometimes to 12 m. Mining is carried out mainly through the mines (The geology of coal deposits and fells shale of USSR, 1962; Yablokov V.S., 1967).

Mined coals are related to humus coals and less often to sapropelites. Mineral impurities in coals are composed of kaolin clay, silica sand and iron pyrite. High-ash coals are distributed in southwestern part of the basin. The distribution of high-ash coal is connected with local changes in mode of occurrence of coal seams, deep-seated washouts and karstic undershooting (Vdovichenko V.S. et.al. 1991f, p. 57-58).

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<sup>16</sup> Proportion of reserves valued and studied in detail as suitable for extraction with the existing technical possibilities. However, the economic feasibility of utilisation of these coals in the current conjuncture is not obvious.

Tbale 8. Physical and chemical analysis of the coals of The Podmoskovniy basin (Vdovichenko V. S. et.al, 1991j)

<b><i>Continent</i></b>			<b><i>Eurasia</i></b>	
<b><i>Location</i></b>			<b><i>Central industrial region</i></b>	
<b><i>Company</i></b>			<b><i>Open Joint Stock Company "Tulaugol"</i></b>	
<b><i>Basin Name</i></b>			<b><i>Podmoskovniy</i></b>	
<b><i>Mine Name</i></b>			<b><i>Seredeyska, Pokrovskay, Kozelskaya</i></b>	<b><i>Zapadnaya, Shekinskaya, Mostovaya, Lipkovskaya 9/16, Borodinskaya 13, Smirnovskaya</i></b>
<b><i>Proximate Analysis</i></b>	Moisture, 105°C	wt%, a.r.	31.90	30.70
	Volatiles, 900°C	wt%, dry	28.33	29.02
	Ash content, 815°C	wt%, dry	43.00	44.20
	Fixed carbon	wt%, dry	28.67	26.78
<b><i>Ultimate analysis</i></b>	Carbon	wt%, dry	37.45	35.66
	Hydrogen	wt%, dry	3.02	3.01
	Nitrogen	wt%, dry	0.40	0.67
	Sulphur	wt%, dry	4.00	4.00

<i>Location</i>			<i>Central industrial region</i>	
<i>Company</i>			<i>Open Joint Stock Company "Tulaugol"</i>	
<i>Basin Name</i>			<i>Podmoskovniy</i>	
<i>Mine Name</i>			<i>Seredeyska, Pokrovskay, Kozelskaya</i>	<i>Zapadnaya, Shekinskaya, Mostovaya, Lipkovskaya 9/16, Borodinskaya 13, Smirnovskaya</i>
<i>Ultimate analysis</i>	Oxygen (calculated)	wt%, dry	13.05	12.50
<i>Heating Value</i>	HHV	Mj/kg, dry	15.60	14.58
	LHV	Mj/kg, dry	14.92	13.90
	LHV as received	Mj/kg, a.r.	9.36	8.87
<i>Ashing temperature</i>		°C	800	800
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Na <sub>2</sub> O	wt%, ash	0.1	0.2
	K <sub>2</sub> O	wt%, ash	0.9	0.8
	CaO	wt%, ash	3.6	1.7
	MgO	wt%, ash	0.9	1.3

<i>Location</i>			<i>Central industrial region</i>	
<i>Company</i>			<i>Open Joint Stock Company "Tulaugol"</i>	
<i>Basin Name</i>			<i>Podmoskovniy</i>	
<i>Mine Name</i>			<i>Seredeyaska, Pokrovskay, Kozelskaya</i>	<i>Zapadnaya, Shekinskaya, Mostovaya, Lipkovskaya 9/16, Borodinskaya 13, Smirnovskaya</i>
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Al <sub>2</sub> O <sub>3</sub>	wt%, ash	36.2	35.5
	Fe <sub>2</sub> O <sub>3</sub>	wt%, ash	7.8	11.2
	SiO <sub>2</sub>	wt%, ash	49.4	48.2
	P <sub>2</sub> O <sub>5</sub>	wt%, ash		
	TiO <sub>2</sub>	wt%, ash	1.1	1.1
	MnO	wt%, ash	–	–
	Sum of oxydes	wt%, ash	100	100
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	1170	1090
	Sphere temperature	°C	1560	>1500



<i>Location</i>		<i>Central industrial region</i>		
<i>Company</i>		<i>Open Joint Stock Company "Tulaugol"</i>		
<i>Basin Name</i>		<i>Podmoskovniy</i>		
<i>Mine Name</i>		<i>Seredeyaska, Pokrovskay, Kozelskaya</i>	<i>Zapadnaya, Shekinskaya, Mostovaya, Lipkovskaya 9/16, Borodinskaya 13, Smirnovskaya</i>	
<i>Fusibility of ash (oxidizing atm)</i>	Hemisphere temperature	°C	1580	–
<i>Calculated values</i>	Na <sub>total</sub>	mg/kg	319.0	655.9
	K <sub>total</sub>	mg/kg	3211.3	2934.1
	Na <sub>eg.,total</sub>	mg/kg	2212.9	2386.3
	Ash generation	g/MJ	45.9	49.9
<i>Particle size distribution. Interstate standard 19242-73</i>		mm	0-200/0-300	0-200/0-300
<i>Grade of coal. Interstate standard 25543-88</i>			B2R	B2R

<i>Location</i>		<i>Central industrial region</i>	
<i>Company</i>		<i>Open Joint Stock Company "Tulaugol"</i>	
<i>Basin Name</i>		<i>Podmoskovniy</i>	
<i>Mine Name</i>		<i>Seredeynska, Pokrovskay, Kozelskaya</i>	<i>Zapadnaya, Shekinskaya, Mostovaya, Lipkovskaya 9/16, Borodinskaya 13, Smirnovskaya</i>
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash	0.0	0.0
	A_ moist, SO <sub>3</sub> free	29.3	30.6
	VM, moist	19.3	20.1
	FC_ moist, SO <sub>3</sub> corrected	19.5	18.6
	S, moist	2.7	2.8
	HHV, moist	10.6	10.1
	FC, dry, Mm-free	54.7	52.3
	HHV, moist, Mm-fr	15.7	15.2
	<b>RANK</b>	<b>Lignite</b>	<b>Lignite</b>

<i>Location</i>			<i>Central industrial region</i>
<i>Basin Name</i>			<i>Podmoskovniy</i>
<i>Company</i>			<i>Open Joint Stock Company "Novomoskovskugo"</i>
<i>Mine Name</i>			<i>Shirinskaya, Sokolnichenskaya</i>
<i>Proximate Analysis</i>	Moisture, 105°C	wt%, a.r.	33.00
	Volatiles, 900°C	wt%, dry	31.58
	Ash content, 815°C	wt%, dry	34.00
	Fixed carbon	wt%, dry	34.42
<i>Ultimate analysis</i>	Carbon	wt%, dry	43.36
	Hydrogen	wt%, dry	3.10
	Nitrogen	wt%, dry	0.86
	Sulphur	wt%, dry	5.50
	Oxygen (calculated)	wt%, dry	13.73
<i>Heating Value</i>	HHV	Mj/kg, dry	17.69

<i>Location</i>			<i>Central industrial region</i>
<i>Basin Name</i>			<i>Podmoskovniy</i>
<i>Company</i>			<i>Open Joint Stock Company "Novomoskovskugo"</i>
<i>Mine Name</i>			<i>Shirinskaya, Sokolnichenskaya</i>
<i>Heating Value</i>	LHV	Mj/kg, dry	17.00
	LHV as received	Mj/kg, a.r.	10.56
<i>Ashing temperature</i>		°C	800
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Na <sub>2</sub> O	wt%, ash	0.2
	K <sub>2</sub> O	wt%, ash	0.4
	CaO	wt%, ash	3.3
	MgO	wt%, ash	0.9
	Al <sub>2</sub> O <sub>3</sub>	wt%, ash	32.7
	Fe <sub>2</sub> O <sub>3</sub>	wt%, ash	17.2
	SiO <sub>2</sub>	wt%, ash	44.4
	P <sub>2</sub> O <sub>5</sub>	wt%, ash	–

<i>Location</i>			<i>Central industrial region</i>
<i>Basin Name</i>			<i>Podmoskovniy</i>
<i>Company</i>			<i>Open Joint Stock Company "Novomoskovskugo"</i>
<i>Mine Name</i>			<i>Shirinskaya, Sokolnichenskaya</i>
<i>Chemical ash composition. Analytical laboratory of VTI</i>	TiO <sub>2</sub>	wt%, ash	0.9
	MnO	wt%, ash	–
	Sum of oxides	wt%, ash	100
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	–
	Sphere temperature	°C	–
	Hemisphere temperature	°C	–
<i>Calculated values</i>	Na <sub>total</sub>	mg/kg	504.5
	K <sub>total</sub>	mg/kg	1128.5
	Na <sub>eg..total</sub>	mg/kg	1170.0
	Ash generation	g/MJ	32.2

<i>Location</i>		<i>Central industrial region</i>
<i>Basin Name</i>		<i>Podmoskovniy</i>
<i>Company</i>		<i>Open Joint Stock Company "Novomoskovskugo"</i>
<i>Mine Name</i>		<i>Shirinskaya, Sokolnichenskaya</i>
<i>Particle size distribution Interstate standard 19242-73</i>	mm	0-25
<i>Grade of coal Interstate standard 25543-88</i>		B2MSSh
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash	0.0
	A_ moist, SO <sub>3</sub> free	22.8
	VM, moist	21.2
	FC_ moist, SO <sub>3</sub> corrected	23.1
	S, moist	3.7
	HHV, moist	11.9
	FC, dry, Mm-free	55.8
	HHV, moist, Mm-frr	15.9
	<b>RANK</b>	<b>Lignite</b>

## 6.6 The Kuznetsk basin

Kuznetsk basin is the second largest coal basin in Russia after Kansk-Achinsk basin. Its total geological reserves are estimated at 693 billion tonnes (Kemerovo territory, 2009). Area of the basin is about 26 thousand km<sup>2</sup>. The main part of the basin is located within the Kemerovo region and the small part is in the Novosibirsk region and Altay territory.

Review of coal quality of the Kuznetsk basin is shown in Table 8.

Kuznetsk basin belongs to the Kuznetsk hollow. The total area of the Kuznetsk hollow is about 70 thousand km<sup>2</sup>. Basin represents a large deflection formed in the late Cambrian period. Coal-bearing strata contain about 260 coal seams of total maximum thickness of 370 m.

In most cases, the thickness of the coal seams is 1,3-3,5 m; also there are seams of thickness 9-15 m and more than 30 m. In accordance with the petrographic composition, coals are divided into humus, hard coals and a transitional grade between brown coal and hard coal. Vitrinite content ranges from 30-60% and 60-90% in humus coals and hard coals, respectively. The degree of metamorphism of coals decreases from lower to upper stratum horizons. Coal mined in the basin can be used in the coke industry and as an energy fuel. Coal mining is conducted in quarries (30 %) and in mines (70 %) (The geology of coal deposits and fells shale of USSR, 1969, p. 178).

Table 9. Physical and chemical analysis of the coals of the Kuznetsk basin (Matveeva I. I., 1972e).

<i>Continent</i>			<i>Eurasia</i>	
<i>Location</i>			<i>South of West Siberia</i>	
<i>Company</i>			<i>energy company “Kuzbassugol”</i>	
<i>Basin Name</i>			<i>Kuznetsk</i>	
<i>Mine Name</i>			<i>Gramoteinskaya, named Yaroslavskogo, Zhurink a №3</i>	<i>mine №5/7; №9/15</i>
<i>Proximate Analysis</i>	Moisture, 105°C	wt%, a.r.	11.50	5.00
	Volatiles, 900°C	wt%, ash	37.17	11.48
	Ash content, 815°C	wt%, ash	11.50	15.00
	Fixed carbon	wt%, ash	51.33	73.53
<i>Ultimate analysis</i>	Carbon	wt%, ash	69.47	77.18
	Hydrogen	wt%, ash	4.96	3.66
	Nitrogen	wt%, ash	2.30	1.53
	Sulphur	wt%, ash	0.30	0.60
	Oxygen (calculated)	wt%, ash	11.42	2.04
<i>Heating Value</i>	HHV	Mj/kg, dry	28.65	30.65



<i>Location</i>			<i>South of West Siberia</i>	
<i>Company</i>			<i>energy company "Kuzbassugol"</i>	
<i>Basin Name</i>			<i>Kuznetsk</i>	
<i>Mine Name</i>			<i>Gramoteinskaya, named Yaroslavskogo, Zhurink a №3</i>	<i>mine №5/7; №9/15</i>
<i>Heating Value</i>	LHV	Mj/kg, dry	27.53	29.83
	LHV as received	Mj/kg, a.r.	24.08	28.21
<i>Ashing temperature</i>		°C	800	800
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Na <sub>2</sub> O	wt%, ash	5.0	4.6
	K <sub>2</sub> O			
	CaO	wt%, ash	5.5	3.8
	MgO	wt%, ash	2.5	1.9
	Al <sub>2</sub> O <sub>3</sub>	wt%, ash	20.5	18.3
	Fe <sub>2</sub> O <sub>3</sub>	wt%, ash	6.5	4.7
	SiO <sub>2</sub>	wt%, ash	59.0	66
	P <sub>2</sub> O <sub>5</sub>	wt%, ash	–	–
	TiO <sub>2</sub>	wt%, ash	1	0.7

<i>Location</i>			<i>South of West Siberia</i>	
<i>Company</i>			<i>energy company “Kuzbassugol”</i>	
<i>Basin Name</i>			<i>Kuznetsk</i>	
<i>Mine Name</i>			<i>Gramoteinskaya, named Yaroslavskogo, Zhurink a №3</i>	<i>mine №5/7; №9/15</i>
<i>Chemical ash composition. Analytical laboratory of VTI</i>	MnO	wt%, ash	–	–
	Sum of oxydes	wt%, ash	100	100
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	1110	1130
	Sphere temperature	°C	1170	1300
	Hemisphere temperature	°C	1285	1395
<i>Calculated values</i>	(Na+K) <sup>17</sup> <sub>total</sub>	mg/kg	4266-4771	5119-5726

<sup>17</sup> These values were calculated in an average range of value of potassium and sodium.

<i>Location</i>			<i>South of West Siberia</i>	
<i>Company</i>			<i>energy company "Kuzbassugol"</i>	
<i>Basin Name</i>			<i>Kuznetsk</i>	
<i>Mine Name</i>			<i>Gramoteinskaya, named Yaroslavskogo, Zhurina №3</i>	<i>mine №5/7; №9/15</i>
<i>Calculated values</i>	Ash generation	g/MJ	4.8	5.3
<i>Particle size distribution. State standard 19242-73</i>		mm	13-25	0-200/0-300
<i>Grade of coal. State standard 25543-88</i>			DM	OSR
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash		0.0	0.0
	A_ moist, SO <sub>3</sub> free		10.2	14.3
	VM, moist		32.9	10.9
	FC_ moist, SO <sub>3</sub> corrected		45.4	69.8
	S, moist		0.3	0.6
	HHV, moist		25.4	29.1
	HHV, moist, Mm-frr		28.5	34.5

<i>Location</i>		<i>South of West Siberia</i>	
<i>Company</i>		<i>energy company “Kuzbassugol”</i>	
<i>Basin Name</i>		<i>Kuznetsk</i>	
<i>Mine Name</i>		<i>Gramoteinskaya, named Yaroslavskogo, Zhurina №3</i>	<i>mine №5/7; №9/15</i>
<i>Classification of coal ASTM D 388</i>	<b>RANK</b>	<b>Bituminous</b>	<b>Anthracite</b>

<i>Location</i>			<i>South of West Siberia</i>
<i>Basin Name</i>			<i>Kuznetsk</i>
<i>Company</i>			<i>Energy company "Kuzbassugol"</i>
<i>Mine Name</i>			<i>Ziryaevskaya</i>
<i>Proximate Analysis</i>	Moisture. 105°C	wt%, a.r.	7.50
	Volatiles. 900°C	wt%, dry	38.64
	Ash content, 815°C	wt%, dry	8.00
<i>Proximate Analysis</i>	Fixed carbon	wt%, dry	53.36
<i>Ultimate analysis</i>	Carbon	wt%, dry	76.82
	Hydrogen	wt%, dry	5.24
	Nitrogen	wt%, dry	2.48
	Sulphur	wt%, dry	0.40
	Oxygen (calculated)	wt%, dry	6.99
<i>Heating Value</i>	HHV	Mj/kg, dry	31.69
	LHV	Mj/kg, dry	30.51
	LHV as received	Mj/kg, a.r.	28.03

<i>Location</i>		<i>South of West Siberia</i>	
<i>Basin Name</i>		<i>Kuznetsk</i>	
<i>Company</i>		<i>Energy company "Kuzbassugol"</i>	
<i>Mine Name</i>		<i>Ziryaevskaya</i>	
<i>Ashing temperature</i>		°C	800
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Na <sub>2</sub> O	Mj/kg, dry	3.8
	K <sub>2</sub> O		
<i>Chemical ash composition. Analytical laboratory of VTI</i>	CaO	Mj/kg, dry	4.7
	MgO	Mj/kg, dry	1.7
	Al <sub>2</sub> O <sub>3</sub>	Mj/kg, dry	25.8
	Fe <sub>2</sub> O <sub>3</sub>	Mj/kg, dry	8.7
	SiO <sub>2</sub>	Mj/kg, dry	54.2
	P <sub>2</sub> O <sub>5</sub>	Mj/kg, dry	–
	TiO <sub>2</sub>	Mj/kg, dry	1.1
	MnO	Mj/kg, dry	–
	Sum of oxides	Mj/kg, dry	100
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	1190

<i>Location</i>			<i>South of West Siberia</i>
<i>Basin Name</i>			<i>Kuznetsk</i>
<i>Company</i>			<i>Energy company "Kuzbassugol"</i>
<i>Mine Name</i>			<i>Ziryaevskaya</i>
<i>Fusibility of ash (oxidizing atm)</i>	Sphere temperature	°C	1460
	Hemisphere temperature	°C	>1500
<i>Calculated values</i>	(Na+K) <sub>total</sub>	mg/kg	2255-2523
	Ash generation	g/MJ	2.9
<i>Particle size distribution. Interstate standard 19242-73</i>		mm	0-200/0-300
<i>Grade of coal. Interstate standard 25543-88</i>			GR
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash		0.0
	A_ moist, SO <sub>3</sub> free		7.4
	VM, moist		35.7
	FC_ moist, SO <sub>3</sub> corrected		49.4
	S, moist		0.4
	HHV, moist		29.3

<i>Location</i>		<i>South of West Siberia</i>
<i>Basin Name</i>		<i>Kuznetsk</i>
<i>Company</i>		<i>Energy company "Kuzbassugol"</i>
<i>Mine Name</i>		<i>Ziryaevskaya</i>
<i>Classification of coal ASTM D 388</i>	FC, dry, Mm-free	58.5
	HHV, moist, Mm-fr	31.9
	<b>RANK</b>	<b>Bituminous</b>



<i>Location</i>			<i>South of West Siberia</i>		
<i>Basin Name</i>			<i>Kuznetsk</i>		
<i>Deposit Name</i>			<i>Krasnoborodskiy</i>	<i>Krasnogorskiy</i>	<i>Listvyanskiy</i>
<i>Proximate Analysis</i>	Moisture, 105°C	wt%, a.r.	7.50	8.00	8.00
	Volatiles, 900°C	wt%, dry	9.45	5.04	8.40
	Ash content, 815°C	wt%, dry	10.00	22.50	20.00
	Fixed carbon	wt%, dry	80.55	72.46	71.60
<i>Ultimate analysis</i>	Carbon	wt%, dry	81.45	72.08	71.52
	Hydrogen	wt%, dry	3.51	1.94	3.04
	Nitrogen	wt%, dry	1.89	1.71	1.92
	Sulphur	wt%, dry	0.60	0.30	0.60
	Oxygen (calculated)	wt%, dry	2.61	1.47	2.96
<i>Heating Value</i>	HHV	Mj/kg, dry	31.72	26.39	27.38
	LHV	Mj/kg, dry	30.93	25.95	26.70

<i>Location</i>			<i>South of West Siberia</i>		
<i>Basin Name</i>			<i>Kuznetsk</i>		
<i>Deposit Name</i>			<i>Krasnoborodskiy</i>	<i>Krasnogorskiy</i>	<i>Listvyanskiy</i>
<i>Heating Value</i>	LHV as received	Mj/kg, a.r.	28.43	23.68	24.36
<i>Ashing temperature</i>		°C	800	800	800
<i>Chemical ash composition.</i> <i>Analytical laboratory of VTI</i>	Na <sub>2</sub> O	wt%, ash	0.4	0.3	0.3
	K <sub>2</sub> O	wt%, ash	1.7	2.4	2.0
	CaO	wt%, ash	1.5	0.9	2.1
	MgO	wt%, ash	0.6	1.4	1.8
	Al <sub>2</sub> O <sub>3</sub>	wt%, ash	31.5	25.4	27.4
	Fe <sub>2</sub> O <sub>3</sub>	wt%, ash	15.2	9.5	7.2
	SiO <sub>2</sub>	wt%, ash	47.0	59.0	58.0
	P <sub>2</sub> O <sub>5</sub>	wt%, ash	0.8	trace	0.2
	TiO <sub>2</sub>	wt%, ash	1.3	0.8	1

<i>Location</i>			<i>South of West Siberia</i>		
<i>Basin Name</i>			<i>Kuznetsk</i>		
<i>Deposit Name</i>			<i>Krasnoborodskiy</i>	<i>Krasnogorskiy</i>	<i>Listvyanskiy</i>
<i>Chemical ash composition.</i> <i>Analytical laboratory of VTI</i>	MnO	wt%, ash	trace	0.3	trace
	Sum of oxides	wt%, ash	100	100	100
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	1160	1240	1260
	Sphere temperature	°C	1450	1390	1450
	Hemisphere temperature	°C	>1500	1400	1490
<i>Calculated values</i>	Na <sub>total</sub>	mg/kg	296.8	500.8	445.2
	K <sub>total</sub>	mg/kg	1410.6	4480.9	3319.1
	Na <sub>eg.,total</sub>	mg/kg	1128.7	3143.4	2402.6
	Ash generation	g/MJ	3.5	9.5	8.2
<i>Particle size distribution. State standard 19242-73</i>		mm	0-200/0-300	0-200/0-300	0-200/0-300

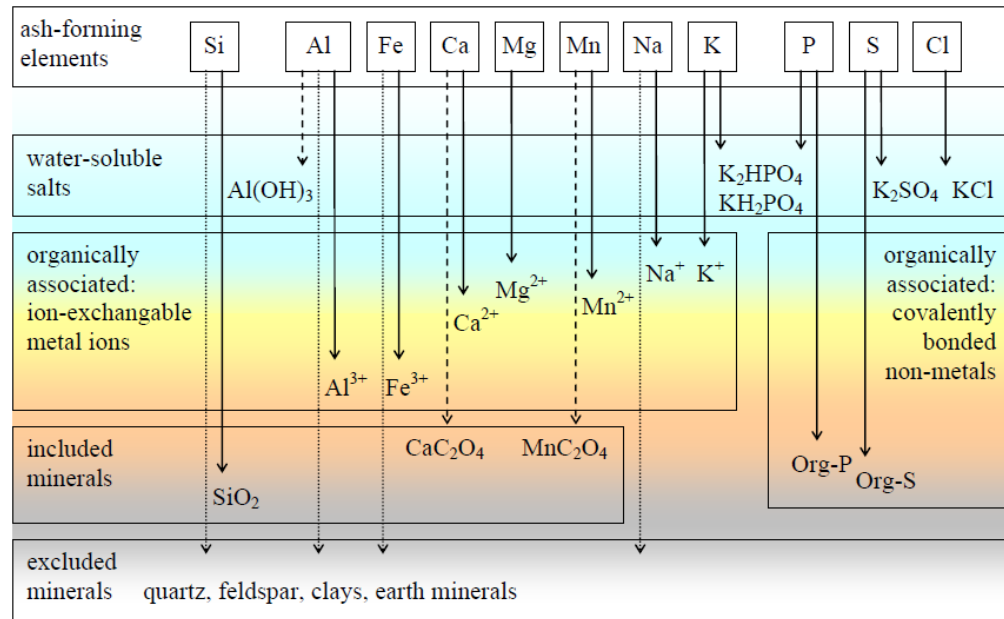
<i>Location</i>		<i>South of West Siberia</i>		
<i>Basin Name</i>		<i>Kuznetsk</i>		
<i>Deposit Name</i>		<i>Krasnoborodskiy</i>	<i>Krasnogorskiy</i>	<i>Listvyanskiy</i>
<i>Grade of coal. State standard 25543-88</i>		TR	TR	TR
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash	0.0	0.0	0.0
	A_ moist, SO <sub>3</sub> free	9.3	20.7	18.4
	VM, moist	8.7	4.6	7.7
	FC_ moist, SO <sub>3</sub> corrected	74.5	66.7	65.9
	S, moist	0.6	0.3	0.6
	HHV, moist	29.3	24.3	25.2
	FC, dry, Mm-free	90.5	95.9	91.6
	HHV, moist, Mm-fir	32.7	31.3	31.5
	<b>RANK</b>	<b>Anthracite</b>	<b>Anthracite</b>	<b>Anthracite</b>

## 7 ASH-RELATED PROBLEMS IN COAL-FIRED BOILERS

Performance of incineration systems depends on ash composition which in turn depends on inorganic composition of the fuel and operating settings of the facility. Ash is a major concern that results in decreased efficiency, unscheduled outages, gear failures and leads to high cleaning expenses. In coal utilization, the most problems occurred are related to complex associations of inorganic compounds. The association and plenty of main, minor and trace elements in coal is dependent on coal rank and depositional conditions. Understanding the tendencies of ash in formation of deposits is important in the boiler construction process which must adapt the inorganic composition of the coal feedstock (R.P. Gupta et.al, 1999, p.1).

The main ash-forming elements (see Picture 6) in solid fuels are silicon (Si), aluminum (Al), iron (Fe), calcium (Ca), magnesium (Mg), manganese (Mn), sodium (Na), potassium (K), phosphorous (P), sulphur (S), and chlorine (Cl). The ash-forming matter is constituted by different chemical forms of these elements and consists of water-soluble salts (in the fuel moisture), organically associated ash-forming elements (in the combustibles), and included or excluded minerals (included in the combustibles or not) (Zevenhoven M, 2001, p.88; Reid WT, 1984, p. 159-69).

Different ranks of coal have changeable content of species. In general, high-rank coals (anthracites and bituminous coals) include most of the ash-forming compounds as minerals, while for low-rank coals (lignite and sub-bituminous coals) the organically bound inorganics are more inherent. Typical minerals in coals are silicates (e.g. clays (kaolinite, Illite, montmorillonite), quartz), carbonates (e.g. calcite ( $\text{CaCO}_3$ ), siderite ( $\text{FeCO}_3$ )), sulfides (e.g. pyrite ( $\text{FeS}_2$ )) and oxides that can be determined as basic oxides ( $\text{Fe}_2\text{O}_3$ ,  $\text{MgO}$ ,  $\text{CaO}$ ,  $\text{K}_2\text{O}$ ,  $\text{Na}_2\text{O}$ ) and acidic oxides ( $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{TiO}_2$ ).



Picture 6. Ash-forming elements in solid fuels (Warkelin, 2008).

The ash-related problems in a boiler can be considered as follows:

- Decreased heat transfer
- Resistance to gas flow
- Physical harm to pressure parts
- Corrosion of pressure parts
- Erosion of pressure parts

Slagging is generally referred to ash deposition on boiler walls in the radiant section of a furnace. Deposition of ash on convection tube sections downstream of the furnace radiant zone is normally regarded to as fouling. Both slagging and fouling can cause first four problems listed above; erosion of pressure parts is the result of impingement of abrasive ash on pressure parts. Frequently coal ash deposit effects are inter-related. For instance, slagging will limit water wall heat absorption changing the distribution of temperature in the boiler which in turn influences the behavior and thickness of ash deposition in downstream convective sections. Ash deposits accumulated on convection tubes can diminish the cross sectional flow area increasing fan necessities and also creating higher local gas

velocities which accelerates fly ash erosion. Deposit reactions can produce liquid phase components (water soluble salts) which can cause tube corrosion.

One of the most widespread problems caused by ash deposition is reduced heat transfer in the radiant zone of a furnace. The combination of radiative properties of the deposit (emissivity/absorptivity) and thermal resistance (conductivity) of a deposit results in decreased heat transfer and reduction in surface absorptivity. Thermal resistance (thermal conductivity and deposit overall thickness) is typically more important because of its effect on absorbing surface temperature. Radiative properties of the deposit can be significantly dependent of the physical state of the deposit; particularly molten deposits show higher emissivities/absorptivities than sintered or powdery deposits (G. J. Goetz et.al, 1978). Thin, molten deposits are less difficult from a heat transfer aspect than thick, sintered deposits. Molten deposits are usually harder to remove and cause frozen deposits to collect in the lower reaches of the furnace; physical exclusion then becomes a trouble for the wall blowers.

Heavy fouling on tubes in the convective section of a boiler leads to the impedance to gas flow. Such problems are most likely to occur with coals having high sodium contents. Strong, bonded deposits can arise which are resistant to removal by the retract soot blowers.

Physical damage to pressure parts can occur if large deposits have accumulated in the upper furnace and proceed to become dislodged or blown off and drop onto the slopes of the lower furnace. Such deposits are usually characterized by the irrelatively high bonding strengths and their heavily sintered structure.

Fireside corrosion can affect on both water wall and superheater tube surfaces. Water wall corrosion is frequently caused by normal sulfates and pyrosulfates, also reducing conditions can cause depletion of protective oxide coatings on tube surfaces. On higher temperature metal surfaces, (superheaters, reheaters) alkali-iron-trisulfates ( $\text{Na}_3\text{Fe}(\text{SO}_4)_3$ /  $\text{K}_3\text{Fe}(\text{SO}_4)_3$ ) are often lead to corrosion due to there high reactive propensity to melt at the temperature in the surfaces. Chlorine can also be a contributing factor in superheater metal corrosion. Although exact

mechanisms can be argued there have been examples of both liquid phase and gas phase corrosion when chlorides have been present (R. W. Borio, 1969).

Erosion of convective pass tubes is not a function of deposits; it is caused by the abrasive components in fly ash. Fly ash size and shape, ash particle content and concentration, and local gas velocities take important part in erosion occurrence. Quartz particles above a certain particle size are very powerful in the erosion process and that furnace temperature history plays an essential role in determining erosive characteristics of the particles (F. Raask, 1981; W.P. Bouver et.al, 1984).

### **7.1 Analysis of coal ashes of Russia.**

The coals examined in this study are mined in various parts of Russia, in varying geological conditions of coal beds and different effects of metamorphism on their physical and chemical composition. Inorganic part (or ash) of these coals contain different proportions of certain elements which presence, as described earlier, can lead to various problems in an utilization of the coals in utility boilers. For coals of various grades produced in the different basins and deposits across Russia, the diagrams were prepared that show the dependence of the content of the various components in the ash from the ash content in coal, as well as the dependence of the lower heating value of fuel as received from the ash content in coal.

As shown in Diagram 1, which illustrates the dependence of the total alkali content in coal ash on the percentage of the ash content in dry fuel; coals mined in the Far East are characterized by relatively high total alkali content in the ash at the same high percentage of ash content. For Uglovsky basin total content of potassium and sodium in the ash varies from 9,4 g/kg to 20,6 g/kg, ash content is 30-40%. In Partizanskiy basin  $(Na+K)_{total}$  content varies from 7,3 g/kg to 13,6 g/kg, while the ash content of dry fuel in the range of 30-36%. Amursk region - one of the considered regions of the Far East, where the total alkali content drops to 2-4 g/kg and the ash content is also at a low level (in comparison with other basins of the Far East) within the 16,5-20%.

Coals mined in the Ural are characterized by relatively high ash content in dry fuel, but the middle/low total alkali content in the ash. The highest parameter of



(Na+K)<sub>total</sub> content as well as the ash content among the Ural's coals was marked in the Chelyabinsk basin, where the total alkali content is in the range of 8,1-10,9 g/kg, while the ash content of 36-40%. Kizelovskiy basin is the second highest total content of alkalis in the ash and in the first place on the ash content in dry fuel (for some ranks of coal); (Na+K)<sub>total</sub> content ranges of 6 g/kg to 8,5 g/kg and ash content is within the 36-45%. The last coal basin of the Ural is the South-Ural basin, which is characterized by relatively low total alkali content (compared with its neighbors) - 4,1 g/kg and the ash content up to 30%.

Coal mined in such large basins as Kuznetsk and Kansk-Achinsk generally characterized by middle/low alkali content and low-ash residue. In the Kansk-Achinsk basin (Na+K)<sub>total</sub> content is low and does not exceed 1 g/kg (in the range of 0,7-0,9 g/kg), ash content is also low at 7-12%. In the Kuznetsk basin total alkali content in the range of 1,7-10,8 g/kg, while the percentage of ash content in these coals in only a few considered deposits exceeds 20% (the ash content varies from 8% to 22,5% ).

Coals of the Eastern Siberia are characterized by low total content of alkalis in ash and low/medium content of ash in dry fuel. In the Irkutsk basin the content of (Na+K)<sub>total</sub> varies between 1,4 g/kg and 2,8 g/kg, whereas the ash content in the range of 9-25%. Coals mined in Minusinskiy basin do not very differ of Irkutsk's coals; their (Na+K)<sub>total</sub> content changes in the range of 1,6g/kg to 2,6 g/kg and ash content in dry fuel varies from 17% to 25%.

For brown coals of Podmoskovniy basin is characteristic the low content of alkali in ash (1,6-3,5 g/kg) and high content of ash in dry fuel (34-43%).

Generally, in accordance with Diagram 1 it is possible to assume the high heterogeneity of the alkalis distribution in the ash. Some of coals have high alkali content and ash content (e.g. Uglovskiy, Partizanskiy basins) what says about high propensity of that coals to cause such problems as fouling, slagging and corrosion in boilers, to a great extent than that coals having low alkali content in ash and low ash content in dry fuel. It is more complicated to assume the negative effect of such coals which have high alkali content in ash and low ash content in dry fuel. This tells, that for these coals the content of alkalis in ash is higher, than

amount of other ash-forming species, therefore these alkalis can have similar negative influence on boiler performance as those coal ashes which have high alkali content in ash and high ash content in dry fuel.

Diagram 2 shows dependence of ash generation versus ratio of some of basic to acidic oxides in ash. In the subsequent description, the ash generation will be denoted as  $A_g$  and the ratio of some of basic to acidic oxides in ash as  $B_s/A$ .

It should be noted that  $B_s/A$  of coals from all considered parts of Russia (with the exemption of Kansk Achinsk basin) is in the range of 0,2%. The  $B_s/A$  for Kansk-Achinsk basin exceeds this value and achieves 1,39%, whereas  $A_g$  varies between 4,7 g/MJ and 10,2 g/MJ.

Far Eastern coals in a case of Uglovskiy basin have  $B_s/A$  in the range of 0,1% to 0,12% and  $A_g$  of 27,6 to 34,9 g/MJ; the  $B_s/A$  for Patrizanskiy basin varies around 0,1% and  $A_g$  is between 13,5 g/MJ and 18,5 g/MJ. Amursk region coals (Erkovetskiy, Svobodniy, Rayxichinskiy deposits) have  $B_s/A$  in the range of 0,12% to 0,18%,  $A_g$  varies between 17,3 g/MJ and 26,9 g/MJ.

The values of  $B_s/A$  and  $A_g$  for both Minusinskiy and Irkutskiy basin that are located in the Eastern Siberia vary in the range from 0,097% to 0,13%, and from 3 g/MJ to 17 g/MJ, respectively.

The coals of Ural's basins – Chelyabinskiy and Kizelovskiy are characterized by high and medium contents of  $A_g$  (23-29,4 g/MJ for Chelyabinskiy basins; 18,9-25,1 g/MJ for Kizelovskiy basin),  $B_s/A$  for Chelyabinskiy basins varies in the range of 0,126% to 0,136%; for Kizelovskiy basin  $B_s/A$  ranges between 0,044% and 0,171%.

Kuznetsk basin distinguished from the other basins by quite low content of  $A_g$  (2,9-9,5 g/MJ), the  $B_s/A$  does not exceed overall value and ranges between 0,054% and 0,164%.

Coals mined in Podmoskovniy basin are characterized by relatively high  $A_g$  content (32,2-49 g/MJ), the  $B_s/A$  is in the range of 0,48% to 0,64%.

High value of ratio of basic to acidic oxides in ash can lead to high deposition of ash on the different surfaces in the boiler. Among coals observed, the ratio of basic to acidic oxides exceeds 1% only in coals mined in Kansk-Achinsk basin, also ash content of these coals is quite small (4,7-10,2 g/MJ); this allows assume that these coals are more inclined to form deposits on the boiler surfaces.

Diagram 3 illustrates a dependence of the lower heating value of fuel as received (LHV<sub>a.r.</sub>) from the ash content of dry fuel. As can be seen (in most cases), the higher ash content of dry fuel the lower LHV<sub>a.r.</sub>

The ash content of dry fuel for coals mined in the Uglovskiy and Partizanskiy basins (Far East) varies in the similar range of 30% to 40%, whereas LHV<sub>a.r.</sub> for Partizanskiy basin is higher (19,4-20,1 MJ/kg) than for Uglovskiy basin (10,8-12,6 MJ/kg). Coals produced in Amursk region (Svobodniy, Rayxichinskiy, Erkovetskiy deposits) have LHV<sub>a.r.</sub> between 8,8 MJ/kg and 11,5 MJ/kg, ash content ranges from 16,5% to 28%.

The ash content of dry fuel for coals from Irkutskiy basin (Eastern Siberia) varies from low value (9%) to medium value (25%), resulting in decrease of LHV<sub>a.r.</sub> from 29,6 MJ/kg to 17,5 MJ/kg. The similar sequence is for coals mined in Minusinskiy basin (Eastern Siberia), ash content increases from 17% to 25% and LHV<sub>a.r.</sub> decreases from 24,5 MJ/kg to 14,6 MJ/kg.

Basically, coals from the Ural show the similar rectilinear dependence of LHV<sub>a.r.</sub> from the ash content of dry fuel. In Chelybinskiy basin coal ash content varies between 32% and 40%, when LHV<sub>a.r.</sub> ranges from 13,9 MJ/kg to 13,6 MJ/kg. Coals from Kizelovskiy basin represent ash content in the range of 36% to 45%, and LHV<sub>a.r.</sub> of 19 MJ/kg to 16 MJ/kg. In the same time, South-Ural basin shows lower ash content (32%) than other two basins, and also lower value of LHV<sub>a.r.</sub> - 7,45 MJ/kg.

In the case of Kansk-Achinsk basin, ash content varies between 7% and 12% and LHV<sub>a.r.</sub> of 14,8 MJ/kg to 11,8 MJ/kg. It should be noted that for the same ash content (12%), the value of LHV<sub>a.r.</sub> is unequal and varies between 13,02 MJ/kg and 11,08 MJ/kg.

The dependence of ash content from LHV<sub>a,r</sub> for coals mined in Kuznetsk and Podmoskovniy basin also is non-uniform, in some cases, higher values of the LHV<sub>a,r</sub> correspond to large values of the ash content (as was marked earlier, usually the higher values of the LHV<sub>a,r</sub> correspond to low values of the ash content). Ash content ranges of 8% to 22,5% and of 34% to 44,2% for coals from Kuznetsk and Podmoskovniy basin, correspondingly; LHV<sub>a,r</sub> varies from 28 MJ/kg to 23 MJ/kg and from 10,5 MJ/kg to 9,3 MJ/kg for Kuznetsk and Podmoskovniy basin, respectively.

## 7.2 Analysis of coal ashes of CIS countries and Georgia

According to data tables on physicochemical properties of coals mined in CIS countries and Georgia (see Appendix 1), it is possible to review the dependence of alkali total content and the ratio of some of basic to acidic oxides in ash from ash content in fuel, and to determine the dependence of LHV<sub>a,r</sub> from ash content.

Dependence of alkali total content from ash content of dry fuel is shown in Diagram 4. For Ukrainian coals (Donetsk, Lvovsk-Volinskiy basins) the total content of potassium and sodium in ash varies in the wide range of 4 g/kg to 20 g/kg, while ash content of dry fuel is on medium/high level and ranges between 20% and 35%. Kazakhstan and Georgian coals are characterized by relatively high ash content of 28% to 40%, the content of (Na+K)<sub>total</sub> is in the range from 1,8 g/kg to 27 g/kg. The highest ash content (40%) and alkali total content (27 g/kg) is marked in Tkibulskiy basin (Georgia). Uzbekistan represented by one coal deposit (Angrenskiy) shows ash content of 22% and content of (Na+K)<sub>total</sub> of 11 g/kg.

Diagram 5 illustrates the dependence of ratio of some of basic to acidic oxides in ash ( $B_s/A$ ) from ash generation ( $A_g$ ). In general, the value of  $B_s/A$  in coals either from CIS countries and Georgia does not exceed of 0,2%, only coals from deposit Argenskiy (Uzbekistan) and Donetsk basin (Ukraine) are over of this value; the  $B_s/A$  is 0,5% and 0,6%, for Uzbekistan coals and Ukrainian coals, respectively. The  $A_g$  content for coals mined in Ukraine is within from 11 g/MJ to 16,6 g/MJ; in Georgia it ranges between 17,6 g/MJ and 27,2 g/MJ; Kazakhstan coals have 19,2-22,9 g/MJ.

Concerning dependence of LHV<sub>a,r</sub> from ash content of dry fuel (see Diagram 6), it can be marked that in some cases there is a non-linear dependence of LHV<sub>a,r</sub> from ash in fuel. Both Ukrainian and Kazakhstan coals show an increase of LHV<sub>a,r</sub> with increasing of ash content in dry fuel. Donetsk coals (Ukraine) have ash content in the range of 20% to 26% , when LHV<sub>a,r</sub> ranges from 17,5 MJ/kg to 23,7 MJ/kg; coals mined in Lvovsk-Volinskiy (Ukraine) basin represent ash content within of 30-35% and LHV<sub>a,r</sub> of 19,4-21,1 MJ/kg. The ash content in Kazakhstan coals varies between 28% to 39,5%, the value of LHV<sub>a,r</sub> is within from 12,2 MJ/kg to 17,3 MJ/kg. An opposite situation is for coals mined in Georgia; here LHV<sub>a,r</sub> decrease with increasing of ash content of dry fuel. The ash content varies in the range of 30% to 40% and LHV<sub>a,r</sub> decreases from 17 MJ/kg to 14,7 MJ/kg. In Uzbekistan coals have ash content of 22% and LHV<sub>a,r</sub> of 13,4 MJ/kg.



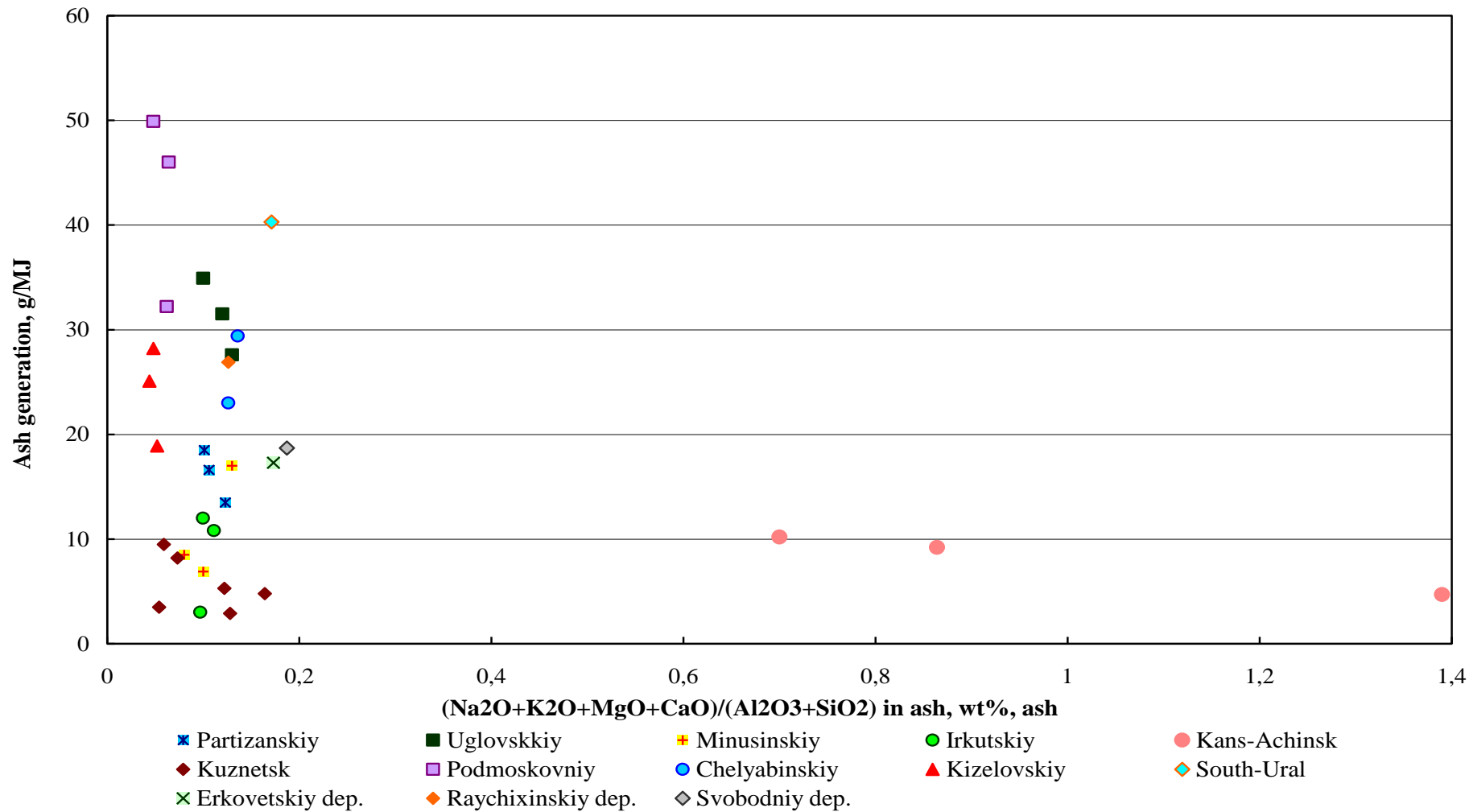


Diagram 2. Ash generation of dry fuel vs. (Na<sub>2</sub>O+K<sub>2</sub>O+MgO+CaO)/(Al<sub>2</sub>O<sub>3</sub>+SiO<sub>2</sub>) in ash

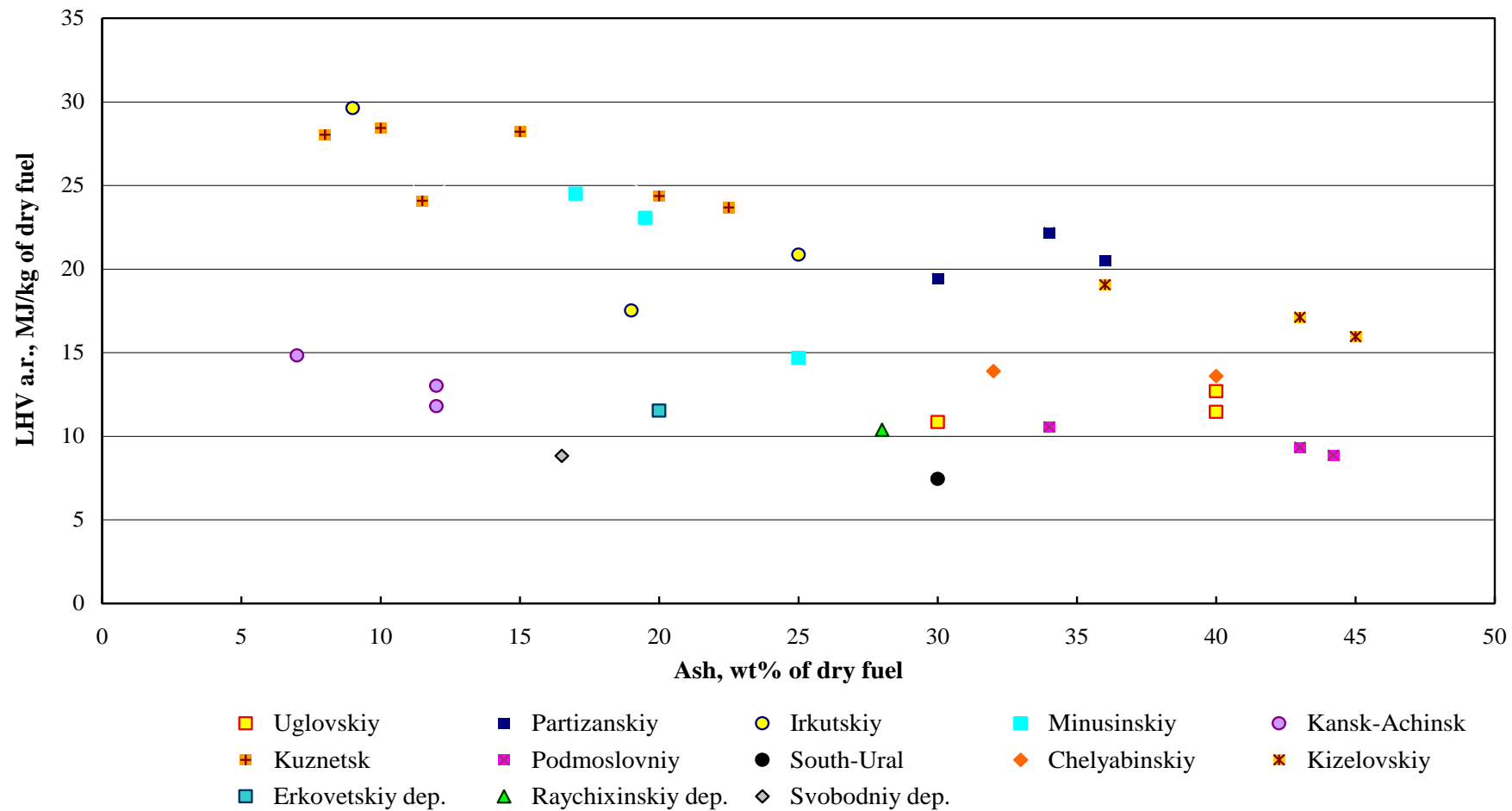
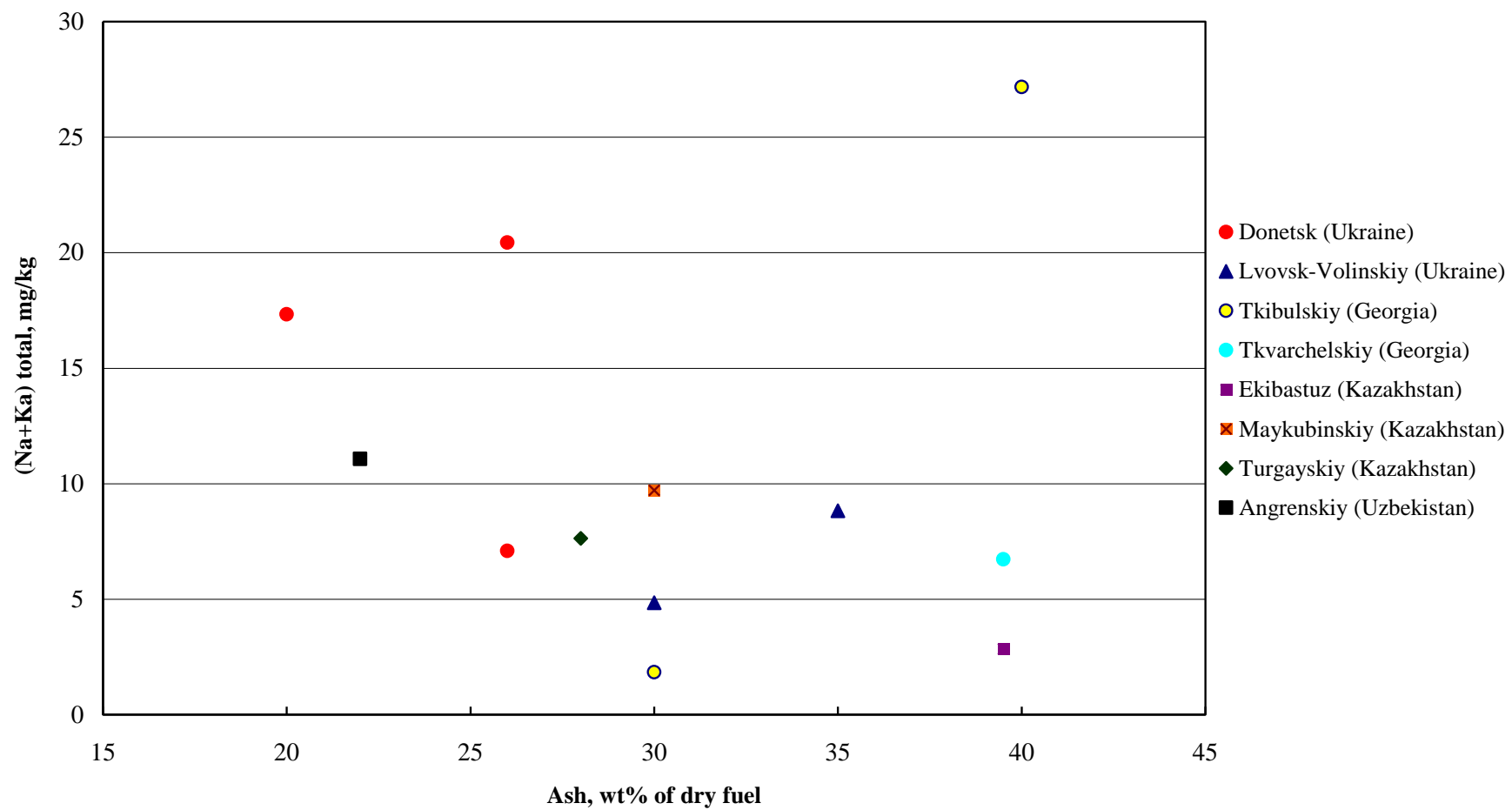


Diagram 3. LHV of fuel as received vs. ash content of dry fuel.



Diagram 4. (Na+K)<sub>total</sub> content vs. ash content of dry fuel.

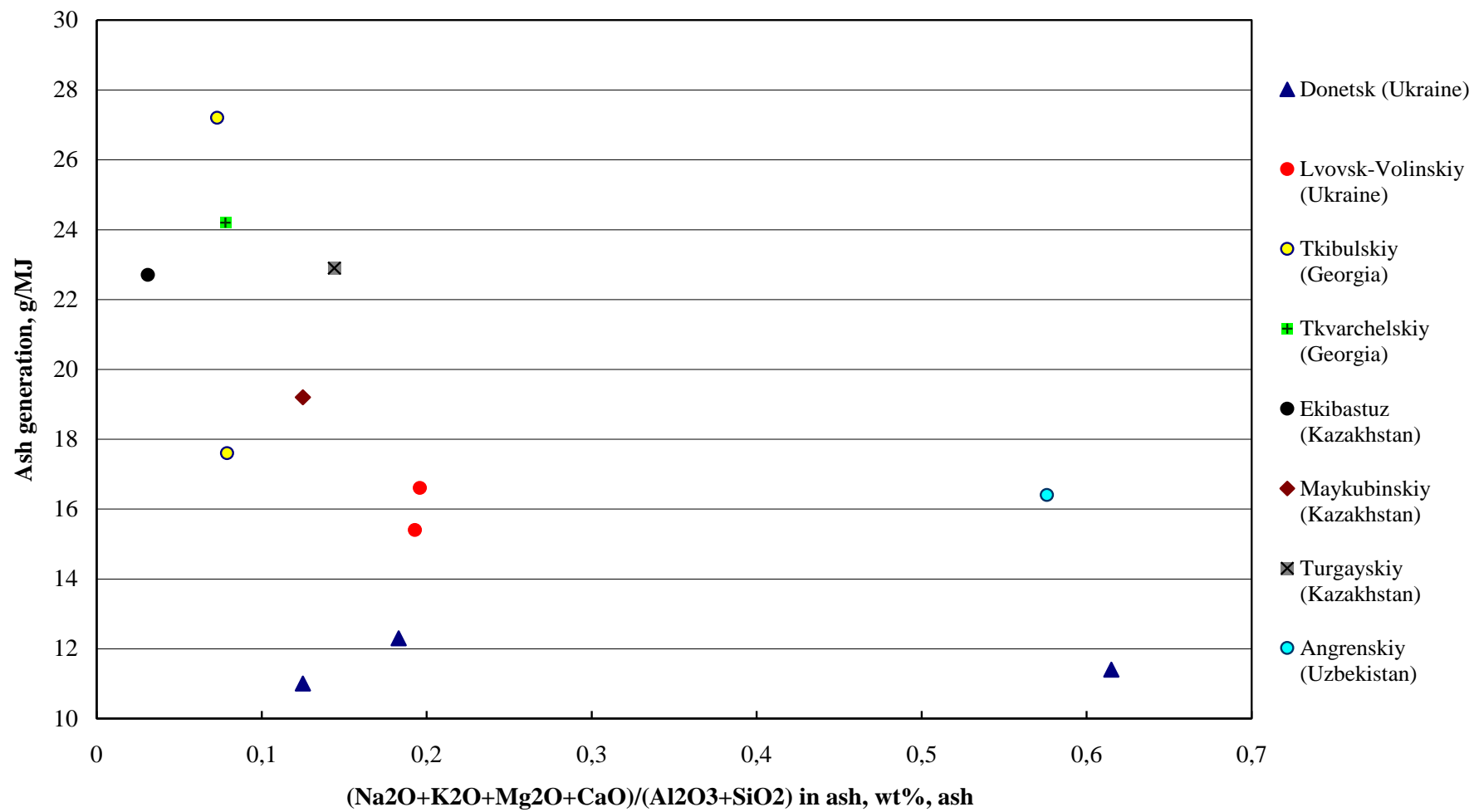


Diagram 5. Ash generation of dry fuel vs. (Na<sub>2</sub>O+K<sub>2</sub>O+MgO+CaO)/(Al<sub>2</sub>O<sub>3</sub>+SiO<sub>2</sub>) in ash

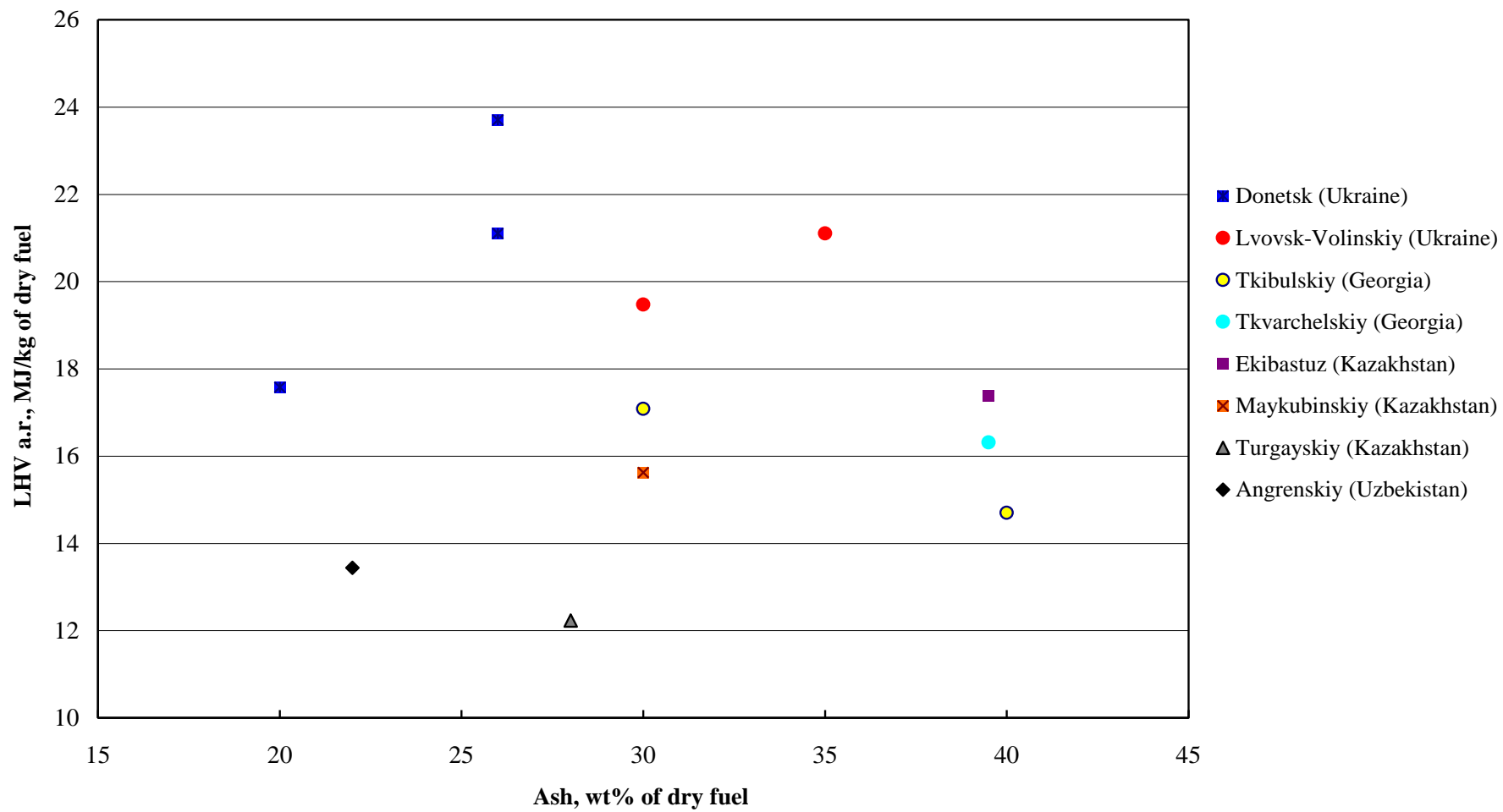


Diagram 6. LHV of fuel as received vs. ash content of dry fuel.

## 8 COMBUSTION TECHNOLOGIES

Russia is a country where the bulk of total coal reserves are represented by low-quality coals (23% of world). These coals are characterized by low heat content (especially in case of lignites), relatively high moisture and ash content and in some cases high sulphur content. The process of selecting combustion system and auxiliary equipment is strongly influenced by the fuel type. Boiler size and construction, facility for preparing and combusting the fuel, the amount of heating surface and its placement, and the methods that must be applied before, during, and after the fuel is combusted to reduce pollutant emissions are all fuel-dependent (J. G. Singer, 1991, p. 35).

Presently, the most widespread combustion technology used in coal-fired power plants is pulverized coal combustion (PCC) technology that is capable to utilize both high and low-rank coals. Power plants used PC-fired units account for about 97% of the world's coal-fired capacity. PCC power plants operated under subcritical steam parameters (steam pressure of about 180 bar, temperature 540°C) with size of combustor unit up to 1000 MW, are commercially obtainable and use worldwide. Larger subcritical plants using higher quality coal have average net efficiency of around 35%-39%. In the PCC plants that incinerate low quality coal, the overall efficiency can be less than 30%. Also supercritical steam-cycle plants (steam pressures of around 240 bar to 260 bar, temperatures of 570°C) using PCC boilers for fuel combustion are exist. The net thermal efficiency of that plants ranges between 42% and 45%.

For poor quality coals with high ash, moisture and sulphur content boilers with fluidized bed combustion (FBC) operating at atmospheric pressure could be more efficient than PCC (IEA, 2008, p. 255). As was mentioned earlier, coals mined in Russia mainly are low quality; hence considerations in present work are focused on the fluidized bed units which can be more preferable option for utilization of such coals.

P. Basu et.al, 1999a, p. 302 : *“A fluidized boiler is a type of steam generator in which fuels burn in a special hydrodynamic condition called the fluidized state and transfer the heat to boiler surface via some noncombustible solid particles”*

There are two major types of fluidized bed boilers: bubbling fluidized bed (BFB) boilers and circulating fluidized beds (CFB) boilers, both operated under atmospheric conditions. Latter have by far the biggest market share which is partly due to that large FBC boilers for power generation are large CFB boilers (installed capacity more than 100 MW ) while BFB boilers are mostly used in smaller CHP boilers in district heating systems or in industrial applications (F. Johnsson, 2007, p.4). The installed capacity for much CFBC power plants is in the range of 250 MW to 300 MW. Very large CFBC units can be also operated under supercritical steam parameters with increased power plants efficiency. For instance, in Lagisza, Poland, a 460 MW supercritical CFBC boiler with thermal efficiency of 43% has been installed and brought in to operation in 2009. Designs for even larger 600 MW supercritical CFBC units have also been developed.

One of the main superiority of the fluidized bed technology compared with conventional combustion systems is its ability to burn a variety of fuels in the same unit. Coal is often burned in FBC boilers, but it is also possible to burn biomass and other solid fuels; co-firing of coal with biomass either in large and smaller FBC boilers also is feasible. Fuel flexibility is becoming increasingly significant since there is an enhanced need to burn a broad spectrum of fuels around the world.

Reduced emissions of NO<sub>x</sub> and sulfur dioxides are also an important advantage of fluidized bed boilers utilization. For capture of sulfur dioxide, limestone is fed into the fluidized bed. The limestone is converted to free lime which reacts with the SO<sub>2</sub> to form calcium sulfate. Fluidized bed consists of unburned fuel, limestone, free lime, calcium sulfate and ash. Due to the well-mixed conditions of the bed and the fairly long residence time of the fuel particles (in the case of CFB unit) efficient incineration can be carried out at temperatures as low as 800–900°C. Combustion at such temperature range is the optimum for in-situ capture of SO<sub>2</sub> by the free lime.

Significantly low level of NO<sub>x</sub> emissions is achieved in FBC boilers due to the relatively low combustion temperatures of the fluidized combustion process. In conventional boilers, most of the nitrogen oxides are formed through to oxidation of the nitrogen in the combustion air. This reaction is important above 1480°C,

while for FBC units operated at the temperature range of 800-900°C this reaction is negligible (P. Basu et.al, 1999b, p. 306). In FBC boilers NO<sub>x</sub> emissions are typically varies between 36 and 145 ppm (at 3% O<sub>2</sub>) without additional equipment for NO<sub>x</sub> control. In contrast, in PC boilers with an advanced low-NO<sub>x</sub> burners and over-fire air the NO<sub>x</sub> emissions are in the range of 145 to 290 ppm (at 3% O<sub>2</sub>). The use of relatively inexpensive selective non-catalytic reduction (SNCR) systems with CFB can reduce emissions of NO<sub>x</sub> up to 50–90%, depending on ammonia slip and detached plume considerations. The same flue gas NO<sub>x</sub> level can be achieved in PC boilers, but this would probably require the installation of more expensive selective catalytic reduction (SCR) system than that one which is used in FBC (J. M. Beer, 2006, p. 5).

In addition, fluidized bed boilers have a number of operating advantages compared to conventional PC technology.

***Reduced ash deposition.*** FBC boilers are characterized by a reduced ash deposition on the boiler surfaces. The potassium and sodium in ash which can lead to slagging and fouling in boiler cannot evaporate at the low operating temperatures of a fluidized bed furnace. As result the possibility of their condensing in a cooler part of the boiler to cause fouling is much fewer. Consequently, it is possible to fire even high-slagging or high-fouling fuels in FBC boilers without a major fouling problem.

***Decreased erosion.*** Due to low temperature of the furnace the ash produced in FBC boilers is quite soft. This provides a reduced erosion of tubes in convective section of the boiler.

***Easier fuel preparation.*** For better fuel utilization in combustion facility the special fuel preparation systems (e.g, crusher, pulverizer) are usually required in conventional boilers. In fluidized bed boilers the typical size of coal fed to a furnace is less than 6000 micrometers (µm), whereas PC-fired boilers require less than 75 µm. As result, a PCC unit has to have both a crusher and pulverizer. The pulverizers are very expensive and require a relatively high level of maintenance; the major part of the boiler outage comes from the failure of its pulverizer. FBC

boilers does not need a pulverizer, consequently its fuel preparation is considerably more maintenance free and simple than that of a PCC units.

The above listed advantages are universal either for BFB and CFB boilers, however it should be noted that the CFB units have some additional advantages.

***Decreased limestone consumption for sulphur removal.*** The CFB boilers for reduction of SO<sub>2</sub> emissions by 90% require 1,5 to 2,5 times the stoichiometric amount of limestone in comparison with to 2,5 to 3,5 for BFB boilers. This is due to finer particle sizes and longer gas particle residence time that is used in CFB boilers. The residence time of gas in CFB boilers is about 3-6 s, while it is 1-2 s for BFB; particle size of limestone in circulating fluidized bed is 150 μm, in BFB it is 1000 μm.

***Improved combustion.*** The primary air, which is flows through the grid or around it, in CFB boilers, is a bit less than the stoichiometric amount. The rest of the combustion air (20% excess) is added further up in the furnace. Such combustion method further reduces the NO<sub>x</sub> emission from the CFB boiler.

***Good turndown and load potential.*** In CFB boilers a control for the heat absorption in the furnace is carried out by varying the suspension density in the upper part of furnace. This provides faster response to a varying load. In PC boilers during combustion of high-ash coal it is difficult to maintain a high load without the assistance of costly fuel oil. In CFB units the suspension density can be decreased to nearly inessential amount dropping the furnace heat absorption to the level of freeboard of BFB units. Therefore, the CFB boilers can be operated in very low load conditions without the help of auxiliary fuels (P. Basu, 1999c, p. 308-09)

The significant numbers of FBC units for utilization of wide range fuel have been developed and are under operation nowadays. The tendency of use the FBC boilers in variety of applications keeps growing in many countries. However, in case of Russia the application of such technology develops significantly slow. The first considerations about the implementation of fluidized bed boilers in Russia appeared not so long ago. In year 2007, the designing of two units of capacity of 220 MW each, using CFB boilers, for reconstruction of TPP “Cherepetskaya”

(Moscow region) was started. Russian Joint Stock Company “SibCOTES” with cooperation of Finnish company “POYRY” have been employed to develop the project. It is planned to finish construction of the new units by the end of year 2010 (E4 GROUP).



## CONCLUSION

At the present time, resulting in the reduction of gas reserves an attention to coal as a type of power-generating fuel is growing rapidly. Due to such situation, Russia as the second country in coal reserves and, consequently, is unlimited of imports has great potential for increasing utilization of coal locally.

However, as was noted in this work the Russian coal-fired power plants have a number of problems such as obsolescence of equipment due to its advanced age, low availability and total efficiency. It is anticipated, that possible options to solve such shortcomings of Russian coal-fired power plants can be their replacement or partial reconstruction.

In accordance with the review the quality of coals made in this work, coals mined in Russia can be both high and low quality. However, most of the reserves consist of low-quality coal with high ash and moisture content and low heating value. Among the considered regions of Russia, it can be noted that reserves of low quality coal are mainly concentrated in the coalfields of the Far East; in the Podmoskovniy basin the bulk of coals produced is lignite, and also large Kansk-Achinsk basin reserves coals of low rank. The quality of coal mined in the Ural and Eastern Siberia ranging from lignite to bituminous. The Kuznetsk basin is the only one among the considered basins with coals of high quality, mainly anthracites.

Review the quality of coals mined in the countries of Former Soviet Union demonstrated the presence of coals of both low and average quality. Only Ukrainian coals mostly are bituminous, while Georgia, Kazakhstan, Uzbekistan and Tajikistan mine coals in the range of lignite to bituminous coals.

Analysis of coal ash has shown that in general the coals mined in Russia and countries of former Soviet Union are characterized by medium to high propensity to the formation of ash deposits in various parts of a boiler.

Due to relatively low quality of reviewed coals, the fluidized bed boilers, which main features are fuel flexibility and low air emissions, are more preferable option compared to conventional pulverized boilers.

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## APPENDICES

APENDIX 1

Table 1. Physical and chemical analysis of the coals of the Ukraine (Vdovichenko V. S et.al, 1991b).

<i>Continent</i>			<i>Eurasia</i>		
<i>Location</i>			<i>Voroshilivgradskaya, Donetsk territory</i>		
<i>Basin name</i>			<i>Donetsk</i>		
<i>Basin resources (in billion tonnes)</i>			<i>About 45</i>		
<i>Deposit name</i>			<i>Novomoskovskiy, Severo-Aleksondrovskiy 1-2, Uspenskiy 1-4</i>	<i>Novosvetlovskiy, Chapaevskiy, Svetlanovskiy rudnik</i>	<i>East Uglegorskiy</i>
<i>Proximate Analysis</i>	Moisture, 105°C	wt%, a.r.	22.50	11.00	5.00
	Volatiles, 900°C	wt%, ash	33.60	29.60	5.55
	Ash content, 815°C	wt%, ash	20.00	26.00	26.00
	Fixed carbon	wt%, ash	46.40	44.40	68.45
<i>Ultimate analysis</i>	Carbon	wt%, ash	60.00	60.00	66.00
	Hydrogen	wt%, ash	4.26	4.16	2.84
	Nitrogen	wt%, ash	1.16	1.24	1.16
	Sulphur	wt%, ash	1.16	2.13	1.89
	Oxygen (calculated)	wt%, ash	0.65	1.24	0.63

<i>Location</i>			<i>Voroshilivgradskaya, Donetsk territory</i>		
<i>Basin name</i>			<i>Donetsk</i>		
<i>Basin resources (in billion tonnes)</i>			<i>About 45</i>		
<i>Deposit name</i>			<i>Novomoskovskiy, Severo-Aleksondrovskiy 1-2, Uspenskiy 1-4</i>	<i>Novosvetlovskiy, Chapaevskiy, Svetlanovskiy rudnik</i>	<i>East Uglegorskiy</i>
<i>Heating Value</i>	HHV	Mj/kg, dry	12.77	6.18	1.47
	LHV	Mj/kg, dry	24.37	24.95	25.72
	LHV as received	Mj/kg, a.r.	23.41	24.02	25.08
<i>Ashing temperature</i>		°C	800	800	800
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Na <sub>2</sub> O	wt%, ash	10.0	1.1	5.0
	K <sub>2</sub> O	wt%, ash	1.5	2.3	
	CaO	wt%, ash	15.0	8.0	3.0
	MgO	wt%, ash	3.0	1.2	1.0
	Al <sub>2</sub> O <sub>3</sub>	wt%, ash	20.0	23.0	23.0
	Fe <sub>2</sub> O <sub>3</sub>	wt%, ash	22.0	17.5	18.0
	SiO <sub>2</sub>	wt%, ash	28.0	46.0	49.0
	P <sub>2</sub> O <sub>5</sub>	wt%, ash	–	–	–
	TiO <sub>2</sub>	wt%, ash	0.5	0.9	1
MnO	wt%, ash	–	–	–	

<i>Location</i>			<i>Voroshilivgradskaya, Donetsk territory</i>		
<i>Basin name</i>			<i>Donetsk</i>		
<i>Basin resources (in billion tonnes)</i>			<i>About 45</i>		
<i>Deposit name</i>			<i>Novomoskovskiy, Severo-Aleksondrovskiy 1-2, Uspenskiy 1-4</i>	<i>Novosvetlovskiy, Chapaevskiy, Svetlanovskiy rudnik</i>	<i>East Uglegorskiy</i>
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Sum of oxides	wt%, ash	100	100	100
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	1180	1180	1060
	Sphere temperature	°C	1240	1240	1250
	Hemisphere temperature	°C	1300	1300	1300
<i>Calculated values</i>	Na <sub>total</sub>	mg/kg	14838.7	2121.9	9645-10787
	K <sub>total</sub>	mg/kg	2489.4	4962.1	
	Na <sub>eg.,total</sub>	mg/kg	16306.8	5048.3	–
	Ash generation	g/MJ	11.4	12.3	11.0
<i>Particle size distribution. State standard 19242-73</i>		mm	–	–	–
<i>Grade of coal. State standard 25543-88</i>			D;G	G	T ; A

<i>Location</i>		<i>Voroshilivgradskaya, Donetsk territory</i>		
<i>Basin name</i>		<i>Donetsk</i>		
<i>Basin resources (in billion tonnes)</i>		<i>About 45</i>		
<i>Deposit name</i>		<i>Novomoskovskiy, Severo-Aleksondrovskiy 1-2, Uspenskiy 1-4</i>	<i>Novosvetlovskiy, Chapaevskiy, Svetlanovskiy rudnik</i>	<i>East Uglegorskiy</i>
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash	0.0	0.0	0.0
	A <sub>+</sub> moist, SO <sub>3</sub> free	15.5	23.1	24.7
	VM, moist	26.0	26.3	5.3
	FC <sub>+</sub> moist, SO <sub>3</sub> corrected	36.0	39.5	65.0
	S, moist	0.5	1.1	0.6
	HHV, moist	18.9	22.2	24.4
	FC, dry, Mm-free	59.3	62.1	95.5
	HHV, moist, Mm-fr	22.7	29.8	33.4
	<b>RANK</b>	<b>Sub-bituminous</b>	<b>Bituminous</b>	<b>Anthracite</b>

Table 2. Physical and chemical analysis of the coals of the Georgia (Vdovichenko V. S et.al, 1991d).

<i>Continent</i>			<i>Eurasia</i>		
<i>Location</i>			<i>Western Georgia</i>		
<i>Deposit name</i>			<i>Tkibulskiy</i>		<i>Tkvarchelskiy</i>
<i>Deposit resources (in million tonnes)</i>			<i>300</i>		<i>380</i>
<i>Proximate Analysis</i>	Moisture, 105°C	wt%, a.r.	13.00	15.00	11.50
	Volatiles, 900°C	wt%, dry	27.60	30.80	21.78
	Ash content, 815°C	wt%, dry	40.00	30.00	39.50
	Fixed carbon	wt%, dry	32.40	39.20	38.72
<i>Ultimate analysis</i>	Carbon	wt%, dry	42.87	52.82	48.02
	Hydrogen	wt%, dry	3.56	4.12	3.62
	Nitrogen	wt%, dry	0.57	1.06	1.02
	Sulphur	wt%, dry	1.49	2.00	1.02
	Oxygen (calculated)	wt%, dry	0.80	10.00	0.45
<i>Heating Value</i>	HHV	Mj/kg, dry	10.69	21.46	6.33
	LHV	Mj/kg, dry	18.07	20.54	19.57
	LHV as received	Mj/kg, a.r.	17.27	17.08	18.75
<i>Ashing temperature</i>		°C	800	800	800
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Na <sub>2</sub> O	wt%, ash	3.7	0.6	1.4
	K <sub>2</sub> O	wt%, ash		0.2	0.8
	CaO	wt%, ash	2.1	5.0	4.1
	MgO	wt%, ash	0.6	0.8	0.5
	Al <sub>2</sub> O <sub>3</sub>	wt%, ash	34.3	31.5	31.0
	Fe <sub>2</sub> O <sub>3</sub>	wt%, ash	4.8	8.0	5.0



<i>Continent</i>			<i>Eurasia</i>		
<i>Location</i>			<i>Western Georgia</i>		
<i>Deposit name</i>			<i>Tkibulskiy</i>		<i>Tkvarchelskiy</i>
<i>Deposit resources (in million tonnes)</i>			<i>300</i>		<i>380</i>
<i>Chemical ash composition. Analytical laboratory of VTI</i>	SiO <sub>2</sub>	wt%, ash	53.4	52.5	56.0
	P <sub>2</sub> O <sub>5</sub>	wt%, ash	–	–	–
	TiO <sub>2</sub>	wt%, ash	1.1	1.4	1.2
	MnO	wt%, ash	–	–	–
	Sum of oxides	wt%, ash	100	100	100
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	1460	1450	1450
	Sphere temperature	°C	1470	1470	>1500
	Hemisphere temperature	°C	1480	1480	>1500
<i>Calculated values</i>	Na <sub>total</sub>	mg/kg	14890.1-12281	1335.5	4102.9
	K <sub>total</sub>	mg/kg		497.9	2622.1
	Na <sub>eg.,total</sub>	mg/kg	–	1629.1	5649.3
	Ash generation	g/MJ	27.2	17.6	24.2
<i>Particle size distribution. State standard 19242-73</i>		mm	0-25	0-200/0-300	–
<i>Grade of coal. State standard 25543-88</i>			DMSSh	GR	Zh
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash		0.0	0.0	0.0
	A <sub>–</sub> moist, SO <sub>3</sub> free		34.8	25.5	35.0
	VM, moist		24.0	26.2	19.3
	FC <sub>–</sub> moist, SO <sub>3</sub> corrected		28.2	33.3	34.3
	S, moist		0.7	1.7	0.4
	HHV, moist		15.7	18.2	17.3

<i>Continent</i>		<i>Eurasia</i>		
<i>Location</i>		<i>Western Georgia</i>		
<i>Deposit name</i>		<i>Tkibulskiy</i>		<i>Tkvarchelskiy</i>
<i>Deposit resources (in million tonnes)</i>		<i>300</i>		<i>380</i>
<i>Classification of coal ASTM D 388</i>	FC, dry, Mm-free	57.3	58.5	67.7
	HHV, moist, Mm-fr	25.3	25.4	27.9
	<b>RANK</b>	<b>Sub-bituminous</b>	<b>Sub-bituminous</b>	<b>Bituminous</b>

Table 3. Physical and chemical analysis of the coals of the Kazakhstan(Vdovichenko V. S et.al, 1991e).

<i>Continent</i>			<i>Eurasia</i>		
<i>Location</i>			<i>Pavlodar/Kustanai regions</i>		
<i>Basin Name</i>			<i>Ekibastuz</i>	<i>Maykubinskiy</i>	<i>Turgayskiy</i>
<i>Basin resources (in billion tonnes)</i>			<i>10</i>	<i>5</i>	<i>6.7</i>
<i>Deposit Name</i>			–	<i>Shobtikolskiy</i>	<i>Kushmuruvskiy. Priozerniy. Orlovskiy</i>
<i>Proximate Analysis</i>	Moisture, 105°C	wt%, a.r.	6.50	18.00	37.00
	Volatiles, 900°C	wt%, dry	15.13	28.70	34.92
	Ash content, 815°C	wt%, dry	39.50	30.00	28.00
	Fixed carbon	wt%, dry	45.38	41.30	37.08
<i>Ultimate analysis</i>	Carbon	wt%, dry	47.91	50.73	53.97
	Hydrogen	wt%, dry	3.21	3.66	3.97
	Nitrogen	wt%, dry	0.86	0.73	0.95
	Sulphur	wt%, dry	0.43	0.61	2.38
	Oxygen (calculated)	wt%, dry	0.32	14.27	15.71
<i>Heating Value</i>	HHV	Mj/kg, dry	7.81	20.42	21.77
	LHV	Mj/kg, dry	19.48	19.60	20.88
	LHV as received	Mj/kg, a.r.	18.76	15.62	12.23
<i>Ashing temperature</i>		°C	800	800	800

<i>Location</i>			<i>Pavlodar/Kustanai regions</i>		
<i>Basin Name</i>			<i>Ekibastuz</i>	<i>Maykubinskiy</i>	<i>Turgayskiy</i>
<i>Basin resources (in billion tonnes)</i>			<b>10</b>	<b>5</b>	<b>6.7</b>
<i>Deposit Name</i>			–	<i>Shobtikolskiy</i>	<i>Kushmuruvskiy, Priozerniy, Orlovskiy</i>
<i>Chemical ash composition. Analytical laboratory of VTI</i>	N <sub>2</sub> O	wt%, ash	0.3	1.9	3.0
	K <sub>2</sub> O	wt%, ash	0.6	2.2	0.6
	CaO	wt%, ash	1.1	4.0	5.9
	MgO	wt%, ash	0.8	2.3	2.2
	Al <sub>2</sub> O <sub>3</sub>	wt%, ash	28.3	25.3	23.6
	Fe <sub>2</sub> O <sub>3</sub>	wt%, ash	5.1	5.4	5.3
	SiO <sub>2</sub>	wt%, ash	62.7	57.9	57.8
	P <sub>2</sub> O <sub>5</sub>	wt%, ash	–	–	–
	TiO <sub>2</sub>	wt%, ash	1.1	1	1.6
	MnO	wt%, ash	–	–	–
Sum of oxides	wt%, ash	100	100	100	
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	1270	1200	1180
	Sphere temperature	°C	>1500	1400	1280
	Hemisphere temperature	°C	>1500	1490	1360
<i>Calculated values</i>	Na <sub>total</sub>	mg/kg	879.2	4229.0	6232.3
	K <sub>total</sub>	mg/kg	1966.6	5476.6	1394.0
	Na <sub>eg..total</sub>	mg/kg	2039.0	7458.8	7054.4

<i>Location</i>			<i>Pavlodar/Kustanai regions</i>		
<i>Basin Name</i>			<i>Ekibastuz</i>	<i>Maykubinskiy</i>	<i>Turgayskiy</i>
<i>Basin resources (in billion tonnes)</i>			<i>10</i>	<i>5</i>	<i>6.7</i>
<i>Deposit Name</i>			–	<i>Shobtikolskiy</i>	<i>Kushmuruvskiy, Priozerniy, Orlovskiy</i>
<i>Calculated values</i>	Ash generation	g/MJ	22.7	19.2	22.9
<i>Particle size distribution. State standard 19242-73</i>		mm	0-200/0-300	0-200/0-300	0-200/0-300
<i>Grade of coal. State standard 25543-88</i>			SSR	B2R	B3R
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash		0.0	0.0	0.0
	A_ moist, SO <sub>3</sub> free		36.9	24.6	17.6
	VM, moist		14.1	23.5	22.0
	FC_ moist, SO <sub>3</sub> corrected		42.4	33.9	23.4
	S, moist		0.3	0.5	1.5
	HHV, moist		18.2	16.7	13.7
	FC, dry, Mm-free		79.3	61.3	53.6
	HHV, moist, Mm-fir		30.4	22.9	17.0
<b>RANK</b>			<b>Bituminous</b>	<b>Sub-bituminous</b>	<b>Lignite</b>

Table 4. Physical and chemical analysis of coals of the Uzbekistan(Vdovichenko V. S et.al, 1991j).

<i>Continent</i>		<i>Eurasia</i>	
<i>Location</i>		<i>Tashkent region</i>	
<i>Deposit name</i>		<i>Angrenskiy</i>	
<i>Deposit resources (in billion tonnes)</i>		<i>1.9</i>	
<i>Proximate Analysis</i>	Moisture, 105°C	wt%, a.r.	34.50
	Volatiles, 900°C	wt%, dry	26.13
	Ash content, 815°C	wt%, dry	22.00
	Fixed carbon	wt%, dry	51.87
<i>Ultimate analysis</i>	Carbon	wt%, dry	59.69
	Hydrogen	wt%, dry	2.90
	Nitrogen	wt%, dry	0.31
	Sulphur	wt%, dry	1.98
	Oxygen (calculated)	wt%, dry	13.13
<i>Heating Value</i>	HHV	Mj/kg, dry	22.49
	LHV	Mj/kg, dry	21.84
	LHV as received	Mj/kg, a.r.	13.44
<i>Ashing temperature</i>		°C	800
<i>Chemical ash composition. Analytical laboratory of VTI</i>	Na <sub>2</sub> O	wt%, ash	3.2
	K <sub>2</sub> O	wt%, ash	
	CaO	wt%, ash	24.3
	MgO	wt%, ash	3.6
	Al <sub>2</sub> O <sub>3</sub>	wt%, ash	21.5
	Fe <sub>2</sub> O <sub>3</sub>	wt%, ash	14.9
	SiO <sub>2</sub>	wt%, ash	32.5

<i>Location</i>		<i>Tashkent region</i>	
<i>Deposit name</i>		<i>Angrenskiy</i>	
<i>Deposit resources (in billion tonnes)</i>		<i>1.9</i>	
<i>Chemical ash composition. Analytical laboratory of VTI</i>	P <sub>2</sub> O <sub>5</sub>	wt%, ash	–
	TiO <sub>2</sub>	wt%, ash	–
	MnO	wt%, ash	–
	Sum of oxides	wt%, ash	100
<i>Fusibility of ash (oxidizing atm)</i>	Deformation temperature	°C	1450
	Sphere temperature	°C	1470
	Hemisphere temperature	°C	1480
<i>Calculated values</i>	(Na+ K) <sub>total</sub>	mg/kg	5223-5843
	Ash generation	g/MJ	16.4
<i>Particle size distribution. State standard 19242-73</i>		mm	0-50
<i>Grade of coal. State standard 25543-88</i>		B2OMSSh	
<i>Classification of coal ASTM D 388</i>	SO <sub>3</sub> in ash		0.0
	A <sub>moist</sub> , SO <sub>3</sub> free		14.4
	VM, moist		17.1
	FC <sub>moist</sub> , SO <sub>3</sub> corrected		34.0
	S, moist		1.3
	HHV, moist		14.7
	FC, dry, Mm-free		68.6
	HHV, moist, Mm-frr		17.5
	<b>RANK</b>		<b>Lignite</b>

APPENDIX 2



Table 1. Correspondence between ASTM D388 and State standard 25543-88.

ASTM D388		State standard 25543-88	
<i>Limiting values</i>	<i>Rank of coal</i>	<i>Rank of coal</i>	<i>Limiting values</i>
$14.7 \text{ MJ/kg} \leq$ Gross calorific value on the moist, mineral-matter-free basis $< 19.3 \text{ MJ/kg}$	<b>Lignite</b>	<b>Brown coal</b>	Higher heating value on the moist, ash-free basis $< 24 \text{ MJ/kg}$
$19.3 \text{ MJ/kg} \leq$ Gross calorific value, on the moist mineral-matter-free basis $< 26.7 \text{ MJ/kg}$	<b>Sub-bituminous</b>		
$24.4 \text{ MJ/kg} \leq$ Gross calorific value, on the moist mineral-matter-free basis $< 32.6 \text{ MJ/kg}$ ; $14\% <$ Volatile content on the dry, mineral-matter-free basis $\leq 31\%$ $69\% \leq$ Fixed carbon on the dry, mineral-matter-free basis $< 86\%$	<b>Bituminous</b>	<b>Hard coal</b>	Higher heating value, on the moist, ash-free basis $\geq 24 \text{ MJ/kg}$ ; Volatile content on the dry, ash-free basis $> 9\%$

ASTM D388		State standard 25543-88	
<i>Limiting values</i>	<i>Rank of coal</i>	<i>Rank of coal</i>	<i>Limiting values</i>
<p>2% &lt; Volatile content on the dry, mineral-matter-free basis <math>\leq 14\%</math></p> <p>86% <math>\leq</math> Fixed carbon on the dry, mineral-matter-free basis &lt; 98%</p>	<b>Anthracite</b>	<b>Hard coal (partially)</b>	–
		<b>Semi-anthracite</b>	<p>Volatile content on the dry, ash-free basis &lt; 9%;</p> <p>Volumetric yield of volatile matter is between 220 cm<sup>3</sup>/kg to 330 cm<sup>3</sup>/kg;</p> <p>Higher heating value (in calorimetric bomb) &gt; 34.96 MJ/kg</p>
		<b>Anthracite</b>	<p>Volatile content on the dry, ash-free basis &lt; 9%</p> <p>Volumetric yield of volatile matter &lt; 220 cm<sup>3</sup>/kg;</p> <p>Higher heating value (in calorimetric bomb) <math>\approx 34</math> MJ/kg</p>

