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Steel, Metallurgical Coal, and Coke: Markets and Innovations. A Review of Presentations at Eurocoke Summit 2017

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Abstract—This review analyzes the economy of the European Community, the market for steel, metallurgical coal, and coke, and price trends. Successful coke producers are identified, and information is provided regarding the repair of coke batteries, research topics, and the curtailment of CO_2 emissions in coke production.

Keywords: metallurgical coal, coke, steel, global markets, prices, environmental protection, coke-battery repair

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The Eurocoke Summit 2017, organized by Smithers Apex (Britain, United States), was held in Dusseldorf, Germany, on April 25–27, 2017, with the participation of 139 representatives from 70 companies based in Europe, Asia, Australia, and the Americas (in Austria, Belgium, Britain, Germany, Italy, Spain, Canada, Poland, Russia, the United States, Ukraine, the Czech Republic, Japan, and elsewhere).

Participating companies included coke producers, coal suppliers, consulting and engineering firms, and research organizations.

Topics at the five plenary sessions and 17 presentations included the following.

(1) The state of the global steel industry, coal mining, and coke production.

(2) Successful enterprises.

(3) The repair and maintenance of coke batteries.

(4) Curtailment of atmospheric emissions in coke and steel production.

(5) New research in Europe.

1. THE GLOBAL STEEL INDUSTRY, COAL MINING, AND COKE PRODUCTION

1.1. Eurofer

Eurofer (Belgium) reviewed the state of the European economy and steel market [1].

The beginning of 2017 was a time of both hope and unrest. On the one hand, there were positive trends in the economy, with indications of further growth; on the other, risks and indeterminacies were evident not only within the European Community but around the world.

The GDP of Europe grew. Unemployment in the European Community (EC) had fallen to 8% by February 2017 (the lowest level since January 2009). In March, inflation fell thanks to low oil prices. The value of the euro has benefited exporters. Fiscal policies are expanding. Overall, the prospects for 2017 and 2018 are regarded as favorable, but there are problems associated with Brexit, certain companies in the EC, population growth, protectionism and trade barriers, the lack of leadership in the EC, geopolitical conflicts, financial instability in China, and other factors.

According to Eurofer predictions, the sector of the EC that consumes steel will grow stronger in 2017 and 2018. In 2016, the demand for finished steel products rose by 3.2%. Steel imports rose by 9%. In the fourth quarter of 2016, it was building toward peak values in 2017. In the second quarter of 2016, the share of imports in steel consumption reached a record level: 24%. Local supplies of steel products increased by no more than 1.6% in 2016, and exports fell by 11%. Raw steel production fell from 166 million t in 2015 to 162 million t in 2016. The EC continued to experience pressure on its competitive markets, reflecting the influence of global overproduction and the lack of prospects for increases in European exports of steel products.

Eurofer noted the following.

(1) The EC economy is rising along with the global economy. However, it faces risks associated primarily with politics.

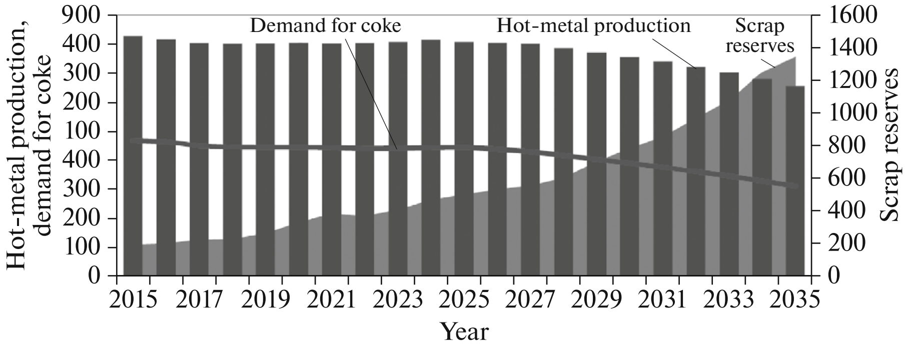


Fig. 1. Production of hot metal, demand for coke, and reserves of scrap in China, 10^6 t.

(2) There is a risk of weakening support for free markets on a global scale.

(3) Visible demand for steel products in the EC will grow very slightly in 2017 and 2018 (thanks to the construction sector). Steel producers have yet to benefit from the gradual recovery of the European market, which is impaired by heedless importers. Overall, activity in this sector is rising by 2%, but imports continue to grow, while European exports are falling.

1.2. CRU Group

The CRU Group (Britain) analyzed the influence of the consolidation of Chinese companies and the growth of Indian consumption on the demand for coke [2].

The presentation addressed the following aspects of China's situation:

—the influence of credit policies on the market for housing construction;

—the influence of steel consumption on the export market;

—the utilization of coke resources in China and CRU's view of the next five years;

—the long-term prospects: specifically, trends in China's coke production that will affect the demand for coke in steel production.

The growth of social financing facilitated the renewed growth of hot-metal production in the second half of 2016 to 870 million t (expressed as annual output).

However, the tightening of monetary policy by China's central bank slowed the decrease in house prices in the fourth quarter of the 2016, reduced construction rates, and correspondingly reduced demand for steel and coke. In 2016, the demand for steel was 270 million t in China's construction industry and 119 million t for manufacturing. For comparison, the total figures for Northeast Asia, Europe, and the United States were 136, 70, and 30 million t, respectively.

According to CRU forecasts, China's demand for coke will remain at levels of 450–470 million t/yr between 2014 and 2021, with a decline to about 450 million t/yr in 2021.

The export of Chinese coke is directly related to steel production. The excess is shipped by sea. Whereas the hot-metal production in China will shrink or the use of its production capacity will decline between 2017 and 2021, more coke will be exported and prices will fall. CRU supposes that, between 2016 and 2021, the degree of utilization of China's capacity for coke production will decrease from 74 to 70.5%.

China plans to reduce its excess steelmaking capacity and to continue its integration. CRU predicts that the Chinese market for commercial coke will experience problems associated with the utilization of available capacity and with the search for means of increasing production efficiency and controlling prices. As a result of recent price fluctuations for coke, new capacity will be created so as to ensure in-plant coke production, and commercial producers will more fully understand the market and experience less competition.

Assessing the period up to 2035, CRU expects that Chinese demand for steel will peak in 2027, thanks to its growing use in construction (around 45–51%) and continuing urbanization. By 2035, the expected demand for steel products will be more than 800 million t/yr.

The growing accumulation of scrap in China will affect levels of hot-metal production.

CRU's long-term predictions for Chinese production of hot metal and coke and for scrap accumulation are summarized in Fig. 1.

To increase the productivity and efficiency, small Chines blast furnaces (1000–2000 m^3) will be replaced by larger furnaces (3000–4000 m^3 or more). That increases the requirements on coke quality.

As regards India, CRU assumes that steel production will grow as a result of demand in the construction sector.

In India today, the intention is to increase the capacity for steel production to 300 million t/yr by 2025. Output is expected to be 280 million t/yr by 2035. Great increase in the demand for steel products is expected in construction (up to 59% of the total demand) and transportation (up to 27% of the total demand).

As in China, transition to blast furnaces of capacity 3000–4000 m^3 is expected, while the requirements on coke quality will increase (increase in *CSR* to 68.5% by 2039).

Efficient technologies will be needed to reach those targets. One trend is the use of rammed batch in coke production, a technology currently in use at 32% of Indian coke producers. This technology increases the loading density by 37% and the total productivity of the coke battery by 10–15%, while reducing operating costs. It also increases the *CSR* values of the coke when using 15–20% less hard coking coal in the batch. According to predictions, this technology will account for 85% of total coke production by 2035.

CRU notes two key trends in Indian coke production: coke production with the capture of chemical byproducts; and production without the capture of byproducts but with heat recuperation. Data for 2017 show that in China, coke production with the capture of chemical byproducts leads to net profits of $26 per ton.

The main benefits of coke production without the capture of byproducts are as follows: larger quantities of poorly coking coal may be used in the production of coke with average *CSR*; coking periods are longer; coking waste products may be burned to generate low-cost electric power; and there is great flexibility in the choice of coal and overall batch composition. (India has large reserves of poor-quality coal.)

The technology without byproduct capture is expected to be essential in order to obtain high-quality coke (with high *CSR*) in conditions of fierce price competition.

1.3. H & W Worldwide Consulting

H & W Worldwide Consulting (Australia) addressed the market for metallurgical coal in shipbuilding. This report discussed the situation in the coal market over the last few years, market problems from the point of buyers and suppliers, and forecasts for the next five years [3].

Lately, the market for metallurgical coal has been very unstable in China, which is one of the world's largest coal consumers. We have observed developments such as price jumps, wild fluctuations of Chinese imports, and the complete disappearance of local supplies. Measures have been taken to increase mine inspections, monitor the issuing of extraction permits, close old mines, and modernize small mines so as to ensure secure supplies and reduce waste and reserves. Steps have also been taken to increase prices (so as to reduce indebtedness) and reduce production costs (including an increase in miner's annual working days from 276 to 330). In 2015, there were signs that China's imports of coking coal might be stabilizing.

At the beginning and end of 2016, we noted particularly unfavorable aspects of the world market. Coal prices fell (with predictions of $65 per ton at the end of 2016). Coal was described as a thing of the past, and excess extraction was regarded as absolutely unnecessary. This was associated with mine closures and with a negative view of the market as a whole. In addition to the drop in coal prices, the situation was aggravated by a lack of coal reserves, disruptions of supplies (by winter rain in the United States and in Shanxi province in China and summer rain in Australia), and growth in hot-metal and steel demand.

At present, the market for metallurgical coal looks somewhat different. After falling from the end of 2016 to February 2017, coal prices have risen on account of the damage caused by Cyclone Debbie in Australia in March 2017. The global demand for steel is expected to rise to 1535 million t in 2017 and 1548 million t in 2018. In the first quarter of 2017, the Chinese GDP rose by 6.9%, which was more than expected. The United States economy grew up to the middle of 2017, and demand for American capital is rising, along with capital exports from Japan.

The United States is expanding in the global market for metallurgical coal. There is growing interest in the purchase and revival of mines in Australia, the United States, and Canada. Investment is growing. New owners are entering the field. Investments in coal mining are increasing in Russia, Mozambique, Indonesia, and elsewhere.

The predicted growth in global demand for steel also increases the demand for metallurgical coal delivered by sea. At the same time, China's exports of steel products fell to about 60 million t/yr in 2017 (from more than 100 million t in 2015 and 2016), which affected producers.

Buyers and sellers have different perspectives on the challenges that confront the market for metallurgical coal.

Buyers focus on factors such as the technical conditions (the age of the coke potteries, the quality of the batch and coke, the yield of coke, its piece size), the supply conditions (sources, reliability, availability of new coal ranks), the coke quality (rising ash content in coal, decreasing vitrinite content, the phosphorus content), economic factors (cost, the use of cheaper coal, and the expansion of pulverized-coal injection, again with a shift to cheaper coal), and environmental protection (emissions, regulations, use rights).

Suppliers focus on regulatory policies (increasing rigor and shorter timelines), environmental protection (emissions, permits and use rights), and economics (increase in mine depth, costs of mine restoration, logistical expenses, the requirements of professional associations, the availability of capital, etc.).

In the next five years, according to predictions, we may expect the development of new coal fields and the expansion of exploitation in existing fields (in Mozambique, Indonesia, and Russia). More of the coal produced will be characterized by moderate and low content of volatiles.

In China, the optimization of steel production capacity will increase in 2017–2018. Beehive ovens and small plants will be shut down. After 2020, the growth of steel production in China will slow. Capacity for the extraction of metallurgical coal will continue to undergo rationalization. Small mines will be closed. Decrease in the annual number of working days for miners to 276 (except for those producing coking coal) cannot be ruled out. Increase in mine depth and decline in coal quality will continue. It remains unclear how these processes will be affected by the growing coal extraction in Mongolia and whether China will be a stable coal importer.

Further development of India's steel industry is expected, with increase in its growth rate—perhaps to 10% per year. By 2020, steel output of 130 million t/yr is expected. The construction of new blast furnaces and the expansion of existing plants will continue. New players will appear in the market. Privatization in the industry remains an open question. By 2020, India will be the greatest importer of coking coal. In terms of metallurgical coal, rationalization of its production capacity will continue: old mines will close. New mines, ports, and other infrastructure will be built. The influence of Mozambique coal remains unclear as yet.

Overall, smoother development of the global market for metallurgical coal is expected, along with the favorable balance of supply and demand up to 2020. New coal ranks will be including in coking batch. Challenges will be more formidable than ever, but manageable.

In the next five years, the behavior of the coal market will depend primarily on the state of the global steel industry, which is the main coal consumer. Coal producers must recognize the same challenges that confront the steel industry: the need to produce high-quality steel with smaller capital and energy expenditures. Electrosteel production also poses a threat to coal producers.

1.4. Wood Mackenzie

Wood Mackenzie considered the impact of the United States steel industry on the prices of metallurgical coal [4].

The period from the beginning of 2011 to the middle of 2016 was marked by an overall decrease in expenditures on the production of metallurgical coal (approximately from \$125 to \$70 per ton). It is accompanied by a prolonged drop in world spot and contract prices for coal from \$330 per ton at the end of 2010, a high level due to the flooding in the Australian state of Queensland. At the same time, the United States reacted rapidly to this price rise by increasing its coal exports to Asia (Japan, China, India, and South Korea) by 15 million t/yr. Coal producers developed plans to increase their output by 18 million t/yr. However, by mid-2016, the price had fallen to \$75 per ton, with a new phase of fluctuation: by the end of the year, the spot prices almost quadrupled, and then fell by half (to \$140 per ton). A further increase in April 2017 was due to Cyclone Debbie, as a result of which the world market lost 13.1 million t of Australian metallurgical coal.

Besides Debbie, another perturbing factor was the decision of Chinese owners to establish the annual number of working days for miners as 276, with a subsequent increase to 330, which was an absolute necessity for critical mines.

At that time, mines with high production costs were closed in the United States, 17000 miners were laid off, and the productivity at the remaining mines was increased. By the end of 2016, the output of metallurgical coal in the United States fell to 60 million t/yr (from 94 million t/yr in the second quarter of 2012). At the end of 2016, increase in the spot prices of coal to \$300 per ton was associated with increase in the country's mine workforce by 700 and increase in coal exports to ~3.8 million t/month.

With a price of \$150 per ton, the country's mines are able to export a total of ~38 million t/yr. With reliable equipment and workers, an additional 10 million t/yr could be produced at this price.

In 2017, coal exports from the United States increased by 11 million t, thanks to Asian demand. North American coal producers wanted to make as much profit as possible during the period of high coal demand, but expected that period to be short, with the recovery of Australian production to 5.0 million t/yr (including the 3.5 million t/yr predicted before Cyclone Debbie). Coal prices will inevitably f all as Australian production returns to its former levels.

1.5. BTU Baron

BTU Baron (United States) considered the prospects for happiness or grief in OTC trades for coking coal [5].[1]

With the thesis that transactions are not confined to the traditional market, BTU Baron noted that, in contrast to fuel coal, coking coal cannot be covered by a standard contract ensuring the protection of the buyer, if liquidity in the market is to be maintained. Coking coal accounts for 30% of global coal trades, by volume, but this is a small proportion of overall OTC trades.

According to the proceedings of the Metallurgical Coke 2012 conference, OTC trades in coking coal

[1] OTC (Over the Counter) trades are transactions made with various financial instruments, in which the parties are in direct contact, without an exchange as intermediary.

Table 1. Characteristics of coke production at Pohang steel plant

Characteristic	Coke battery				
	1	2	3	4	5
Introduction	1973	1976	1978	1981	07/1983
Number of units	2	2	2	2	2
Type of ovens	Otto	Otto	Otto	Otto	Otto
Number of ovens	86	88	146	150	150
Useful volume, m^3	29.5	29.5	38.8	38.8	38.8
Height, m	5.15	5.15	6.7	6.7	6.7
Width, m	0.43	0.43	0.43	0.43	0.43
Length, m	15.48	15.48	15.48	15.48	15.48
Moisture monitoringвлаги	+	+	+	+	+
Dry quenching of coke	+	–	–	–	–

(swaps) began in 2011. In 2016, there were 799 spot transactions, covering 57 million t of coking coal in the Asia–Pacific region. Prices corresponding to The Steel Index (TSI) and Platts values were used in 60–80% of the transactions.

Trades between a spot purchaser and a swap seller offer the possibility of conversion from fixed to floating prices within a specific interval or in the future and also provide other benefits. Swaps on the basis of index prices involve certain risks: the index prices may not correspond to the spot prices; or the product may not meet the requirements corresponding to the index price. In addition, there will be risks associated with unexpected circumstances, credit problems, and so on.

At present, OTC translations for metallurgical coal are in the early stages of development and will mature in 2019. The article assumes that spot trades in coking coal surpass trades in fuel coal, since coking coal is less common and the market is larger (the steel market is global, whereas the power market is regional), while prices undergo fluctuations.

Three main trends in trades for coking coal may be noted.

(1) Swaps through the Singapore exchange (SGX Swaps) based on TSI prices.

(2) Swaps through the futures exchange (CME swaps) according to Platts prices.

(3) Trades whose terms are set on the basis of global coal brands: Illawara, Goonyella, Moranbah, North, Oaky Greek, North Goonyella.

Monthly swap contracts for coking coal are financially based on the mean daily indices for the current month.

As of April 2017, most trades were SGX swaps.

Benefits of OTC trades in coking coal include the following:

—very rapid and transparent establishment of a price;

—the possibility of converting a supply contract based on index prices to a fixed-price contract and vice versa;

—the possibility of reference-point transactions, with the specification of upper and lower prices;

—the possibility of maximum benefits when commercial decisions are made independently of management decisions;

—the possibility of taking profit from the difference between operational and market prices;

—the possibility of selecting more precise prices;

—the possibility of involving credit and investment companies, which may ensure that the expected margin is obtained.

2. SUCCESSFUL ENTERPRISES

2.1. POSCO (South Korea)

POSCO reported on improvements in coke production with cost reduction [6].

The company has two steel plants: in Pohang, with raw-steel output of 14.7 million t/yr and a staff of 8200; and at Gwangyang, with raw-steel output of 20.7 million t/yr and a staff of 6700.

Tables 1 and 2 present the basic characteristics of coke production at POSCO.

All the coke machines at both plants are automatically controlled.

In Fig. 2, some operational characteristics in 2015 and 2016 are shown.

Despite the increasing utilization of the equipment and the higher content of semisoft coal in the batch, coke quality has been maintained on the basis of staff

Table 2. Characteristics of coke production at Gwangyang steel plant

Characteristic	Coke battery				
	123			4	5
Introduction	1987	1988	1990	1992	11/2011
Number of units	2	2	2	2	2
Type of ovens	Otto	Otto	Otto	Otto	Otto
Number of ovens	132	132	132	132	200
Useful volume, m^3	43.0	43.0	43.0	43.0	76.2
Height, m	6.7	6.7	6.7	6.7	7.6
Width, m	0.45	0.45	0.45	0.45	0.59
Length, m	16.4	16.4	16.4	16.4	18.0
Moisture monitoringвлаги	–	–	–	–	–
Dry quenching of coke	–	–	–	–	–

knowledge relating to batch preparation, improvement in heating, and optimization of dry quenching.

Table 3 presents data regarding coke production at POSCO in 2015 and 2016.

The content of volatiles in the batch has decreased at both plants.

Between 1976 and 2015, the blast-furnace capacity at POSCO has steadily increased. However, the old and inefficient coke batteries remain in use, coke quality has been declining, and production costs have increased.

Efforts at POSCO to improve coke quality and reduce costs have focused on the following.

(1) Debugging and regulation of heating (so as to establish optimal temperature in the heating channels) and visual monitoring of all the temperatures (so as to ensure effective heating conditions).

(2) Seasonal regulation of coke-battery heating, with allowance for change in the weather.

(3) Selective temperature regulation in individual furnace zones.

The heat supply is regulated by optimizing the time between reversals of heating and adjusting the pauses in the course of reversal. These measures increase the temperature of the combustion products and reduce the gas supply for heating.

Other measures to reduce expenditures in coke production are seasonal regulation of the heating as a function of the ambient temperature; and individual regulation of the air supply over the length of the walls by changing the grating cross section. By reducing the

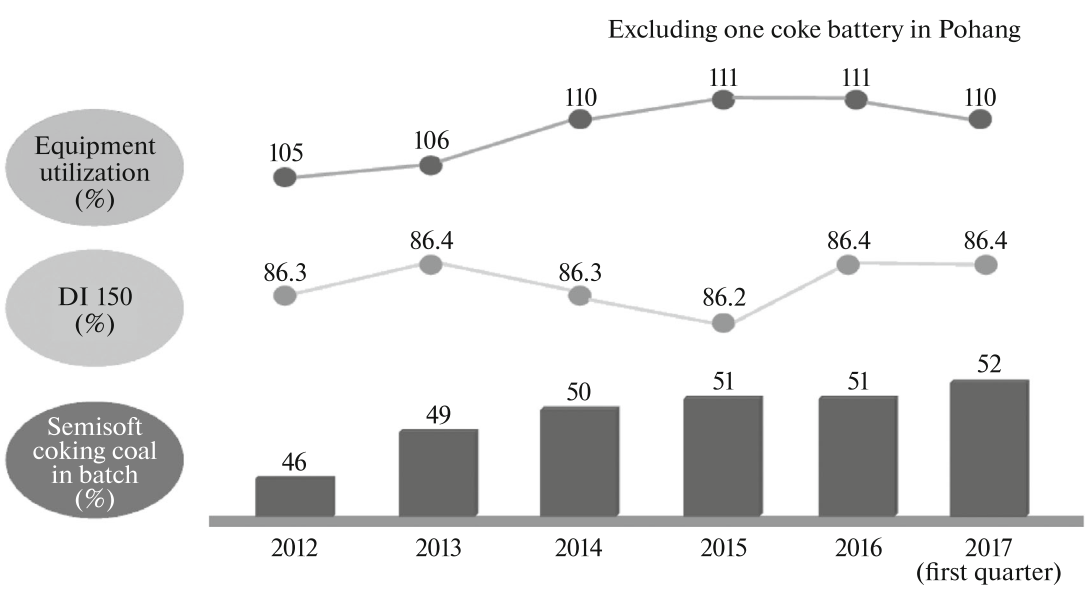


Fig. 2. Recent data for POSCO coke production

Table 3. Coke production at POSCO in 2015 and 2016

Characteristic	Pohang		Gwangyang	
	2015	2016	2015	2016
Coke output (excluding one coke battery in Pohang), 10^6 t/yr	4.3	4.1	6.8	6.6
Utilization (%)	117	123	107	103
Coal:				
Moisture content, %	9.7	9.7	5.9	5.8
Content of volatiles, %	26.7	26.3	26.2	25.8
Coke:				
Strength of DI 150 coke, %	86.5	86.5	86.6	86.6
MS, mm	56.2	56.1	55.7	56.8
Ash content, %	12.1	11.7	11.8	11.9
CSR, %	68.6	67.9	69.4	68.7

heating at the center of the walls and increasing the temperature at the head, the mean specified temperatures in the heating system may be lowered and the gas consumption in heating may be reduced.

In Fig. 3, the results of POSCO's efforts to reduce production costs are summarized.

2.2. ThyssenKrupp CSA (Brazil)

This paper discussed developments in production at the CSA plant [7].

The CSA coke plant (Companhia Siderurgica do Atlantico, Sepetiba, Rio de Janeiro state) went into production in 2010. It is intended to produce coke at a rate of 2.0 million t/yr, without byproduct capture.

The plant has three coke batteries (432 ovens) operating with a coking period of 63 h and 12 steam boilers (four per battery), with an output of 535 t/h. Serious problems developed after the plant went into operation.

Between February 2011 and February 2017, the plant became a successfully operating enterprise. With the goal of safe and economical operation and high performance, the operational staff was able to significantly boost plant performance, within the framework of strategic planning and with the aid of engineering improvements (more than 500 since startup), as is evident from the following figures:

	2014–2015	2015–2016	2016–2017
Planned downtime (h/yr)	1056	576	204
Total monthly output	3744	4455	4635

The reduction in planned downtime is 81%.

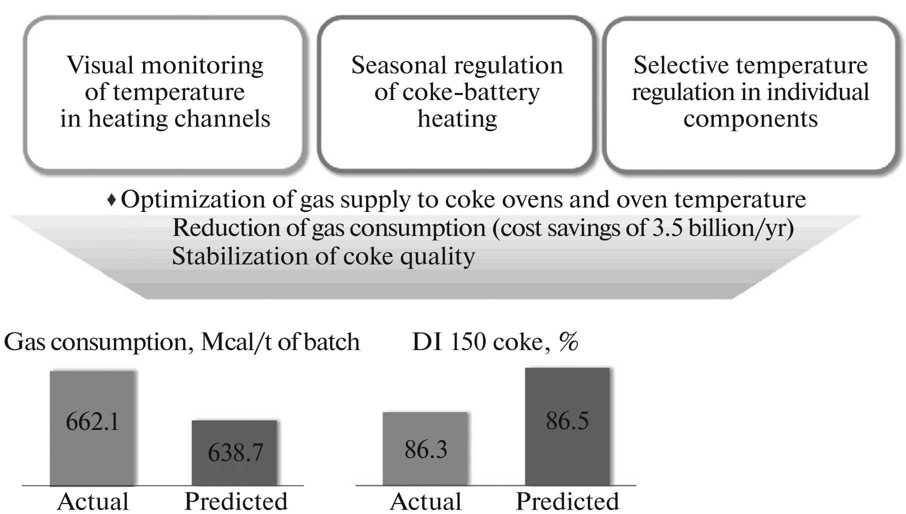


Fig. 3. Results of POSCO's efforts to reduce production costs.

In comparison with the 2012/2013 financial year, operating costs were lowered by 53%, while the cost of the batch fell by 8%, the moisture content in the coke by 59% (from 9.4% to 3.9%), and the coke losses by 51% (from 15 to 7.3%).

In the 2016/2017 financial year, the plant reached 92% of its intended capacity.

2.3. Schwelgern Coke Plant (Germany)

This paper described the development of a new product—ammonium bicarbonate (baking powder)—from coke-oven gas [8].

In the byproduct-capture shop at the Schwelgern Coke Plant, the raw coke-oven gas, which contains (g/m^3) 85 tar, 5.5 ammonia, 7.4 H_2S, 23 benzene, toluene, and xylene (BTX), and 6.5 naphthalene, is purified to the following levels (g/m^3): <0.01 tar, <0.02 ammonia, <0.5 H_2S, <6 BTX, and <0.1 naphthalene. Purified coke-oven gas is produced at a rate of 155000 m^3/h.

Since 1993, a group of specialists from the Technical University of Berlin, ThyssenKrupp, and the Schwelgern Coke Plant has been working to upgrade the equipment in the byproduct-capture shop. On the initiative of Technical University of Berlin, a new product has been produced from the vapor at the top of the desorption columns, which contains 35–52 vol % steam, 21–34 vol % NH_3, 15–34 vol % CO_2, 6–15 vol % H_2S, and 1–3 vol % HCN. The key points here are as follows.

(1) It was decided not to break down the ammonia or to burn it.

(2) The goal was to create a new product: to synthesize ammonium bicarbonate from the vapor, which contains all the necessary ingredients.

(3) The CO_2 present is insufficient to bind the ammonia. Accordingly, additional CO_2 is supplied so as to permit the reaction

$$NH_3\ (gas) + CO_2\ (gas) + H_2O\ (gas) \leftrightarrow NH_4HCO_3\ (solid).$$

To evaluate this process, its parameters must be determined. For practical purposes, stable generation of ammonium bicarbonate from the toxic vapor must be possible in industrial conditions, without disrupting the operation of the byproduct-capture shop. In addition, the quality of the bicarbonate must meet market requirements. If these conditions may be satisfied, the next step is to verify the operating and capital costs.

After initial research at the Technical University of Berlin, a pilot plant operated at the coke plant from June 2009 to July 2016. The powder produced may be used as a fertilizer or as a raw material in the production of construction foam, soda, paint, and so on. The output of the pilot plant is 15 kg/h. An industrial plant could produce ammonium bicarbonate at a rate of ~2 t/h, with the consumption of vapor from the desorption column at a rate of 100000 m^3/h and the additional supply of CO_2 (1 t).

3. REPAIR AND MAINTENANCE OF COKE BATTERIES

3.1. ThyssenKrupp Industrial Solutions

ThyssenKrupp Industrial Solutions (Germany) addressed battery repair as a means of extending coke-plant life and avoiding expensive reconstruction [9].

At present, 49% of all coke batteries are more than 30 years old. Battery life largely depends on the satisfactory repair of the lining, stays, and other components. The goal is to ensure maximum productivity, high coke quality, appropriate extraction of coke-oven gas, and reduced emissions. It is important to optimize repair costs. Special teams are responsible for the lining, plant equipment, maintenance of spare-parts supplies, monitoring of the coke batteries, and so on. The appropriate documentation has been developed for repair purposes. An important role is played by relining of the heating walls, repair of the lining at the extreme heating channels and the top of the battery, and thermal regulation in the course of repair.

As coke batteries age, environmental emissions of CO, SO_x, H_2S, benzopyrene, NH_3, benzene, and dust increase, especially at the top of the battery. ThyssenKrupp has a series of patents on methods of charging coal in the coke oven so as to minimize emissions.

3.2. Fosbel

Fosbel (United States) described its proprietary products for the repair of refractory battery linings: MICOWALL™, MICOWALL™ 2.0, and MONOWALL™ [10].

The mean age of coke batteries by region is summarized in Fig. 4.

Fosbel offers the COMIT™ system for monitoring the state of the coke battery, with inspection of the battery lining and monitoring of the temperature in the heating walls, the forces at coke discharge, the swelling of the battery lining, the state of the stays, and gas leakage and emissions. Ceramic welding of the refractory lining has been improved, and the CERAWELD® repair system has been patented. New Nano-Tec™ powders permit ceramic welding with increased density and abrasive stability.

Fosbel offers an improved technology for modular repair of the refractory lining of the heating walls (MICOWALL™ 2) and the lining at the transverse flues (MICOCAST™).

Besides repairs, Fosbel is involved in improving the design of refractory linings, including the use of cast Dinas components.

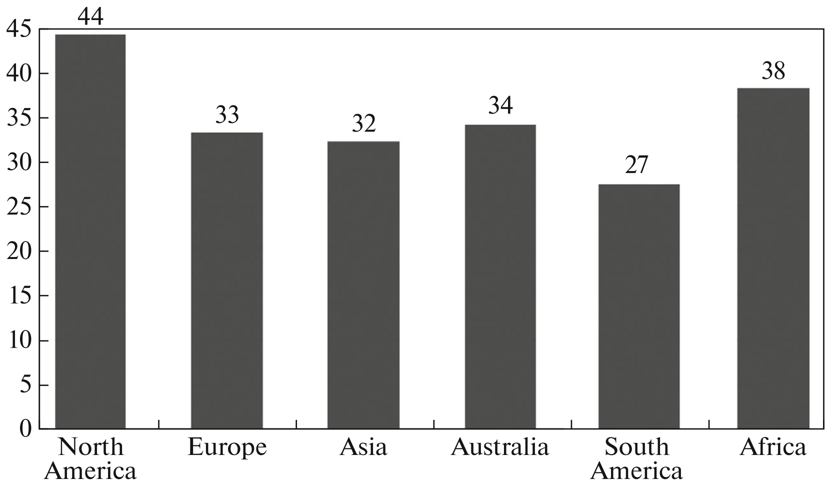


Fig. 4. Mean age (years) of coke batteries by region.

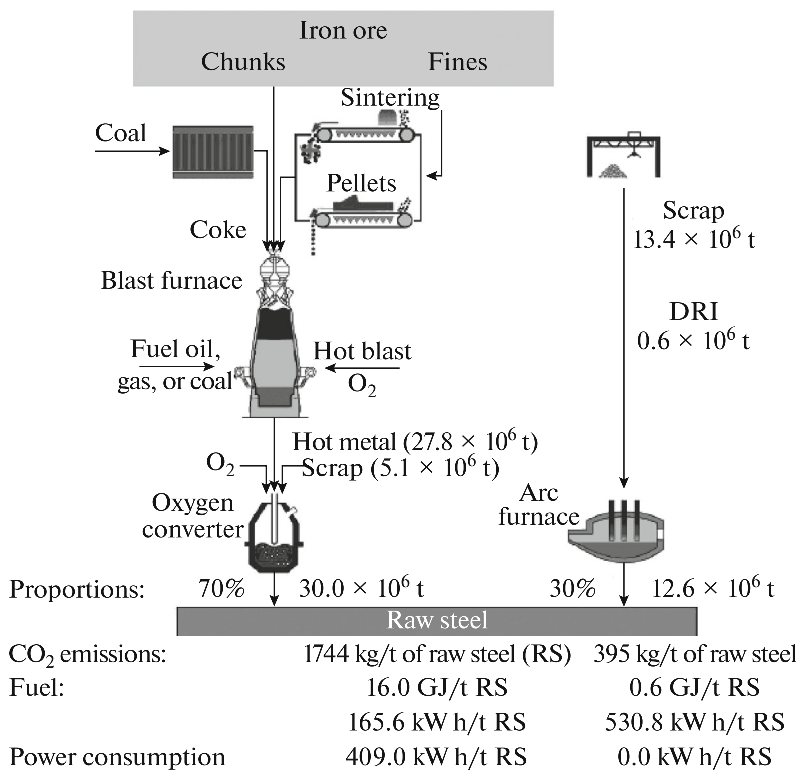


Fig. 5. Systems for steel production employed in Germany in 2015. The figure for the coke emissions in the blast-furnace system (1744 kg/t) includes the emissions from sintering and the coke shop.

4. CURTAILMENT OF ATMOSPHERIC EMISSIONS

4.1. VDEh Metallurgical Institute

VDEh Institute (Germany) discussed means of reducing CO_2 emissions in steel production [11]. The main systems for steel production employed in Germany in 2015 were considered: blast furnace + oxygen converter; and scrap + arc furnace (Fig. 5).

Achievements in reducing CO_2 emissions in the EC include 14% reduction in the blast furnace + oxygen converter system. The absolute decrease in comparison with 1990 is 25% (from 298 to 223 million t). Between 1990 and 2010, the energy efficiency in the German steel industry was increased: 13% reduction in primary energy consumption (GJ/t of raw steel). In the same period, the CO_2 emissions (t/t of raw steel)

Reduction of iron ore by carbon monoxide and hydrogen

Carbon-based process	Hydrogen-based process
$3\,Fe_2O_3 + CO = 2\,Fe_3O_4 + CO_2$	$3\,Fe_2O_3 + H_2 = 2\,Fe_3O_4 + H_2O$
$2\,Fe_3O_4 + 2\,CO = 6\,FeO + 2\,CO_2$	$2\,Fe_3O_4 + 2\,H_2 = 6\,FeO + 2\,H_2O$
$6\,FeO + 6\,CO = 6\,Fe + 6\,CO_2$	$6\,FeO + 6\,H_2 = 6\,Fe + 6\,H_2O$
$C \rightarrow CO_2$	$H \rightarrow H_2O$

Fig. 6. Conversion of iron ore to metal.

have fallen by 12.4 million t/yr. (That is equivalent to the emissions from 4.9 million midsize cars in traveling 15000 km/yr, at a rate of 170 g CO_2/km). The consumption of reducing agents in hot-metal production was considerably reduced: from 1100 kg/t in 1950 to 498.6 kg/t (consisting of 329.5 kg/t of coke, 164.1 kg/t of coal, and 5 kg/t of other reducing agents).

In converting iron ore to metal, carbon monoxide and hydrogen may be used as the reducing agents (Fig. 6).

The potential for further decrease in CO_2 emissions in Germany may be summarized as follows.

(1) Blast furnaces cannot operate without coke. However, hydrogen may be used as a reducing agent in the blast furnace in limited quantities. At the same time, hydrogen is expensive.

(2) The consumption of reducing agents in the blast furnace may be decreased by using hot-briquetted iron (100 kg/t instead of 30 kg/t of coke).

(3) The proportion of scrap in the arc furnace may be increased, but the quantity of high-quality scrap available is limited.

(4) The blast furnace + oxygen converter system may be replaced by the DRI + arc furnace system based on natural gas, but that entails great energy and capital expenditures.

At present, besides proposals for reducing the CO_2 emissions based on the use of not only carbon but also hydrogen and natural gas as the reducing agents, European steel producers are interested in the following approaches:

—an oxygen blast furnace with the capture and storage of carbon dioxide (CCS);

—the ULCOS process;

—the HIsarna process with CCS (Tata Steel Europe and elsewhere);

—the use of the gases generated in steel production to obtained fuels and chemical raw materials: for example, the Carbon2Chem process (ThyssenKrupp) and the Steelanol process (ArcelorMittal);

—Carbon Direct Avoidance (CDA), in which direct reduced iron (DRI) is derived from the ore by means of the natural gas and hydrogen obtained by the hydrolysis of water (Salzgitter Flachstahl), the DRI is used in the arc furnace, and so on.

The conclusion offered in this presentation was that the steelmaking processes employed in the EC already operates in optimal conditions, and no dramatic decrease in emissions can be expected from existing technology. New technologies must be developed. The switch to hydrogen as the reducing agent calls for extensive research and investment. The classic blast furnace + oxygen converter system must be equipped with systems for CO_2 capture and storage/utilization. Research on new means of decreasing CO_2 emissions in the steel industry indicates that their practical introduction before 2050 is unlikely.

4.2. INCAR Institute

The INCAR Institute (Spain) addressed CO_2 capture technology based on the calcium cycle [12].

Between 2000 and 2012, INCAR worked to create CO_2 capture technology after fuel consumption by means of the calcium looping (CaL) cycle. Combustion in a circulating fluidized bed (CFBC) was the starting point.

A system for CO_2 capture from fuel-combustion products on the basis of the CaL cycle is shown In Fig. 7.

Note that the enclosure of calcium within the cycle (in the form of CaO) is practical as a means of gas separation if the heat released is utilized in the process.

The conceptual basis of the CaL process for thermoelectric plants is shown in Fig. 8. In Fig. 9, the components of the system are shown.

Benefits of this process are as follows.

(1) Low energy losses and low cost per 1 t of trapped CO_2.

(2) Low-cost sorbent.

(3) Release and purification of CaO by the methods used in the cement industry and elsewhere.

(4) No preliminary purification of the smokestack gas, since SO_2 is captured as part of the process.

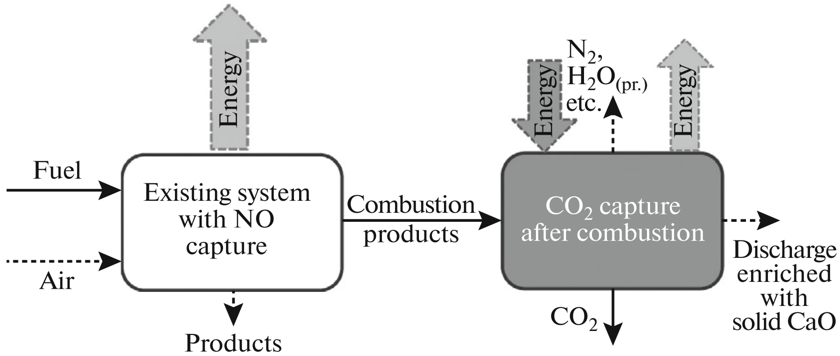


Fig. 7. CO_2 capture from fuel-combustion products on the basis of the CaL cycle.

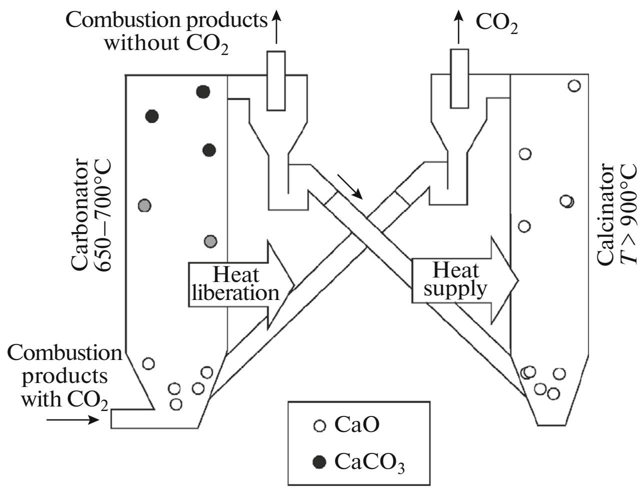


Fig. 8. Conceptual basis of the CaL process for thermoelectric plants.

(5) Applicability at existing power plants.

After extensive research, a 1.7-MW pilot plant was constructed at the 50-MW La Pereda power plant, which has operated for more than 2000 h with 90% efficiency of CO_2 capture and >99% efficiency of SO_2 capture.

INCAR is also investigating a Ca–Cu cycle for CO_2 capture (Fig. 10).

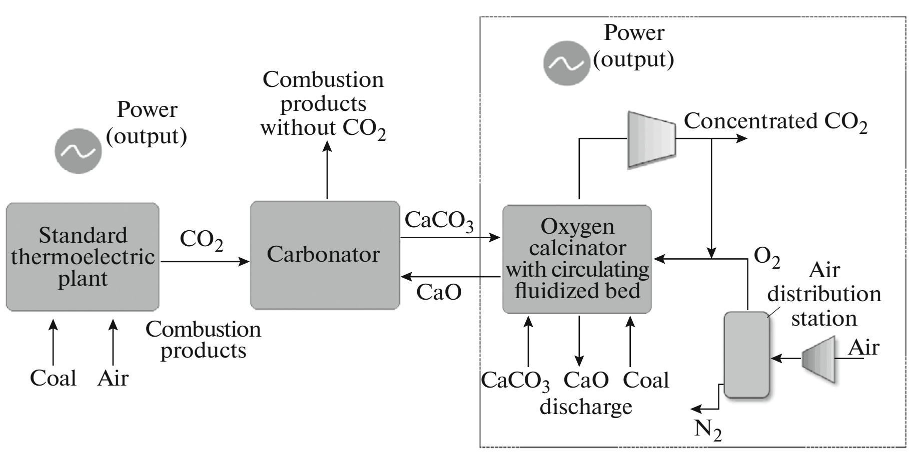
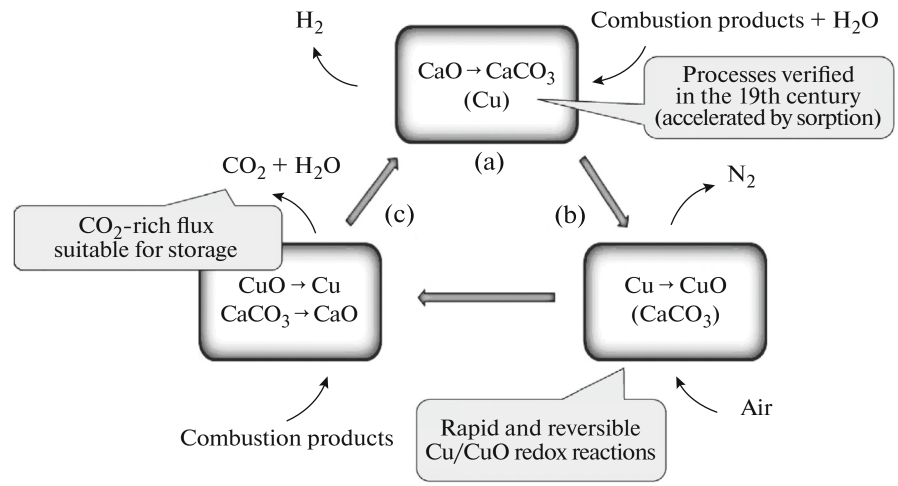


Fig. 9. Components in the CaL process for thermoelectric plants.



The reduction of the oxygen carrier (CuO) by combustion products provides heat to $CaCO_3$ calcination. Endo-exothermic reactions take place in the same matrix, which ensures the intensification of the process.

Fig. 10. Ca–Cu cycle.

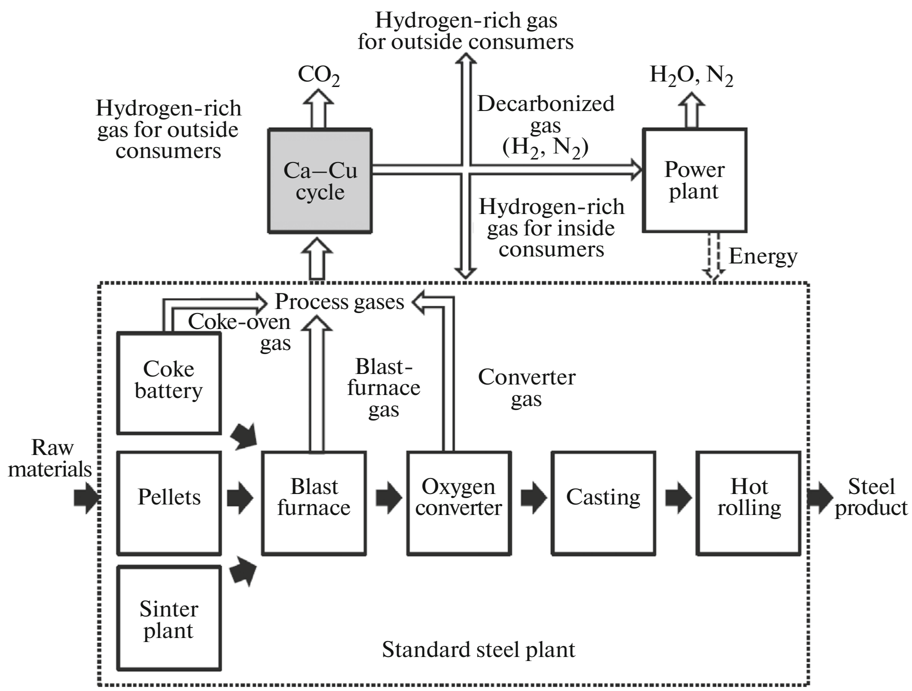


Fig. 11. Integration of Ca–Cu cycle into steel plant.

This process permits the production of hydrogen (on the basis of Ca–Cu cycles for accelerated sorption of the product or shift of the water–gas equilibrium) and integration of the CaL cycles into the steel plant (Fig. 11).

4.3. ECN

ECN (Holland) reported on work in STEPWISE, the European program for gradual reduction in CO_2 emissions from steel plants [13].

This approach is based on the SEWGS (sorptionally enhanced water–gas shift) method. The starting point is the processing of producer gas with enriched blast-furnace gas (after CO_2 removal and the conversion of CO to H_2)and the monetization of hydrogen in producer-gas fluxes containing CO_2/CO.

A high degree of CO_2 capture is obtained with exceptionally low steam consumption (H_2O/CO_2 < 1.0). Operation in acidic medium with the capture of H_2S

and CO_2 is possible. SEWGS technology is intended for wide use with pressurized absorption systems (PSA). The process may be intensified as a result of the combination of several stages, with high efficiency in the short and medium term. For CO_2 capture in the blast furnace, for example, the costs per 1 t of CO_2 are at least 25% less than in any other available technology.

The SEWGS process is based on the reaction

$$CO + H_2O \leftrightarrow CO_2 + H_2,$$

which is shifted to the right, with simultaneous CO_2 capture. For this reaction, $\Delta H = -41$ kJ/mol. The CO is converted in two stages (12% → 35% → 0.5%), with change in temperature from 350–400 to 180–250°C, at 20–30 bar.

This process is in use at a pilot plant. It is intensified by combining the water–gas shift reaction with sorbent, so that hydrogen at high temperature is produced at the same time as CO_2 capture. At this stage, the scaling of the process from 10–16 g to a 100-kg pilot plant with a complete cycle has been solved. A demonstration system will be created before 2019. The reliability of ALKASORB sorbent has been confirmed.

5. RECENT RESEARCH IN EUROPE

Presentations in this section were made by Centre de Pyrolyse de Marienau (France), DMT (Germany), INCAR (Spain), the Institute for Chemical Processing of Coal (Poland), and ThyssenKrupp Schwelgern Coke Plant.

5.1. Centre de Pyrolyse de Marienau

At present, Centre de Pyrolyse de Marienau is cooperating with ArcelorMittal and Dillingen coke plant [14]. Its recent work has addressed topics such as the following:

—the oxidation of coal;

—thermal optimization of coke batteries;

—the packing density of batch and the coking pressure of coal in industrial coke ovens;

—simulation of the heating wall.

Centre de Pyrolyse de Marienau has accumulated much experience in the last 70 years. Its current projects include:

—optimization of the composition of coal batch and coke quality;

—improvement in coking;

—attainment of coke-battery lives of 50 years or more;

—reduction in production costs.

5.2. DMT (Deutsche Montan Technologie)

Created in 1990 on the basis of the Bergbau Forschung research center, DMT has been a part of TÜV NORD since 2007 [15]. The company provides engineering services internationally for producers of coal, coke, and steel, in relation to raw materials, environmental impact, and technological processes—especially in byproduct-capture shops.

5.3. INCAR

Organized in 1947 in Oviedo, INCAR has strong links to Spanish and other coke and steel producers and chemical companies [16]. The staff includes 154 scientists.

At present, two main directions of research are underway: carbon and inorganic materials for the construction and power industries and for environmental protection; and coal conversion and clean technologies. INCAR assists coke producers in terms of batch composition and additives; coal preparation (heating, briquetting); coking processes; metallurgical coke; coke-oven gas; and also tar, oil, and pitch.

5.4. Institute of Chemical Processing of Coal (IChPW)

Created in 1955 in Zabrze, which is close to Katowice, IChPW has a staff of 180 [17]. Research interests include coking technology; batch preparation; environmental protection (emissions reduction); and byproduct capture and processing. The Institute also provides economic analysis and auditing; and consultation and expert analysis.

At present, IChPW is assisting the Polish coke industry in the area of effective management and operation: prediction of coke quality; development of modern coke-preparation systems for ramming; integration and production of coke-battery monitoring systems (BATMON systems); the development of new refractories for coke-battery repair; environmental protection (EMI BAT system); and the introduction of individual pressure regulation in the coke furnace (ZAR_eO).

IChPW is equipped with the latest research equipment (KARBOtes) and laboratory systems.

CONCLUSIONS

The prospects for the EC economy in 2017 and 2018 are regarded as favorable, but with risks and uncertainties. The European economy will develop in harmony with the global economy. Metal consumption in the EC will continue to grow, but slowly. As before, the market for steel products will depend on the competition with imports, which exceed exports. Production of raw steel in the EC shrank from 166 million t in 2015 to 162 million t in 2016.

Along with other positive trends, forecasts of the growth in global steel demand (to 1548 million t in 2018) offer hope that demand for metallurgical coal will also expand. In recent years, this market has been unstable, on account of new consumers in China, unfavorable trends in the global coal production, and difficult weather conditions in some regions.

The market for metallurgical coal is improving today. A favorable balance of supply and demand is expected, along with the development of new coal fields and the expansion of exploitation in existing fields (in Mozambique, Indonesia, and Russia). Coal of new ranks is being included in coking batch, and exports of coal from North America to the Asia–Pacific region are increasing.

As before, the largest coke producer—China—will continue to affect the global and European market for coke and its prices. Chinese demand for coke in the period from 2014 to 2021 is expected to be 450–470 million t/yr, with a decline to about 450 million t/yr in 2021. Chinese coke exports will directly depend on Chinese levels of steel and coke production. Excess capacity is being reduced, while production is being integrated and optimized. By 2035, increase in steel demand to 800 million t/yr is expected in China, with a rise in India to 280 million t/yr.

In India, as in China, the trend is to use blast furnaces of capacity 3000–4000 m^3, with greater demands on coke quality and improved production technology.

Globally, the technology for coke production is being improved. Improvements in coke-plant operation are under development and new products are being sought.

Researchers are paying close attention the maintenance of coke-battery linings. Timely repair of the refractory lining is critical to extending battery life and reducing reconstruction costs.

In the EC, measures for reducing carbon-dioxide emissions from steel plants are a high priority. New methods are being developed and tested.

Large research centers in Europe are strengthening their links with coke producers and offering assistance in terms of coking batch, coking processes, coke quality, economic analysis, auditing, and more.

REFERENCES

1. Vermeij, J., Outlook for EU economy and steel market, *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.
2. May, W., With consolidation in China and growth in India how will coke consumption react? *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.
3. Bristow, N., Challenges and evolution of the seaborne metallurgical coal market, *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.
4. Truman, J., How will the USA respond to the current metcoal pricing landscape? *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.
5. Doyle, S., OTC coking coal trading: a reason to cheer or jeer? *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.
6. Jeong, H., Posco way of coke making operation and technology development through reduced production costs, *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.
7. Soares, E., CSA coke plant performance evolution, *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.
8. Liszio, P., Ammonium bicarbonate or "baking powder" by coke oven gas—a new by-product-process of innovative COG-utilization, *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.
9. Ballon, M., Battery repair techniques to keep ageing coke plants running and avoid expensive rebuilds, *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.
10. Randolph, R., New technology developments for coke oven maintenance, *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.
11. Lungen, H.B., Closing keynote: paths to reduce CO_2 emissions in the steel industry, *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.
12. Abanades, C., Emerging CO_2 capture technologies by Calcium Looping and their applicability to the Iron & Steel Industry, *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.
13. Cobden, P., STEPWISE: cost-effective CO_2 capture for the iron and steel industry, *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.
14. Gaillet, J.-P., Recent progress in cokemaking science at Centre de Pyrolyse de Marienau, *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.
15. Gajic, D., DMT Cokemaking Service and the last 10 years of research and development, *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.
16. Diez, M., Exploring the relationship between INCAR research and cokemaking, *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.
17. Sobolewski, A., IChPW R&D activities for cokemaking, *Proc. Eurocoke Summit 2017, April 25–27, 2017*, Düsseldorf, 2017.

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