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ESSAY

INNOVATION IN MINING

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Introduction

Global coal consumption and demand

Global coal reserves are significantly larger than those of any other natural resources. With 1 trillion tons, it is 3.2 and 2.5 times larger than gas and oil resources (Osborne et al., 2013). In 2010 coal consumption was at the level of 7.2 billion tons, showing rise of 28 percent over a decade – more than any other natural energy container. Most of the growth in the usage of this material was due to increased demand for it in developing countries, while in the EU there was a drop of 14 percent. (Fikkers, 2013).

The main consumers of coal are power generating and steel industry. And in coal they require different characteristics: metals production needs high grade coal with good reduction activity and high porosity, whereas coal for energy usage should have high energy content. In general, metallurgic coal usually is more than suitable to be used in power generation; however, less expensive low grade coal is more often utilized for this purpose.

Both coking and steam coal are widely used in all geographical regions, and the scale of their consumption is huge. Therefore, any changes in the patterns of coal usage will disturb national economies of all actors in energy and metals markets. However, increasing criticism of coal usage due to its harmful impact on environment has already started influencing global supply and demand for this resource. Hence, the future of coal industry fully depends now on whether there will emerge new technologies for decreasing pollution and improving efficiency of all processes in coal supply chain from extraction to end use.

It is anticipated that coking coal will sustain high demand in the future because there has not been found any alternative reducer that can fully satisfy large scale steel production. On the other hand, there are big concerns on the future of steam coal, as there are numerous substitute energy resources or novel technologies for power generation that can completely terminate coal utilization in energy sector.

Before discussing new technologies that can improve coal industry perspectives and their influences on advancement of adjacent spheres it is important to understand coal market and global supply and demand for this natural resource.

At present, coking coal is supplied to global market mostly from Australia, the United States, Canada, Russia, Indonesia, South Africa, and Colombia. Among the largest consumers are such countries as Japan, China, India, South Korea, Germany, Turkey, and Taiwan. It was projected by the US Department of Energy that Australia will continue to be the largest exporter of coking coal in the future. Southern Africa, the former Soviet Republics, and Canada will also sustain their share in this market. Other coal producers will likely remain flat in their production of this resource (Alderman, 2013).

The main consumers of coking coal in the future will be developing countries: by 2035 more than 60 percent of it will be utilized by India, China and other Asian nations; 30 percent will be exported to the Americas, primarily Brazil and Chile. The remaining incremental production of coking coal will be absorbed by European countries.

The top exporters of steam coal in 2010 were Indonesia, Australia, Russia, South Africa, Colombia, the United States, and Canada, and they supplied the same countries that imported coking coal. It is expected that Indonesia will decrease its share in export of non-coking coal in the foreseeable future, whereas Columbia and Southern African countries will strengthen their presence in global thermal coal trade. The increase of steam coal supply will mostly come from both Australia and South America and 84 percent of the increased volume will be sold to Asian nations.

Alderman argues that China will probably become the largest consumer of coal by 2035 (Alderman, 2013); however, this perspective is questioned by other researchers. With environmental issues that China is currently facing and increased concerns of energy security, the share of solid energy resources utilization in Chinese industry might decrease over the next years. Researches project that in 2019 China might experience the turning point in coal consumption, which will be followed by the decrease of coal import (Hao, Zhang, Liao, & Wei, 2015).

As shown above, the increase in coal demand will be dictated by growth of its consumption in Asia and the Americas, whereas developed European countries will most probably sustain their current levels of usage of both coking and steam coal. However, new efficient technologies and approaches are needed for the industry to continue growing.

Innovation generation in coal industry

The development of coal industry has effect on both global and local level. The scope of coal presence in global economy has been shown above; but changes in mining also affect the lives of ordinary people residing in coal producing regions as it is one of the industries that play vital role in maintaining and increasing the standard of living. Although, regions with high mining activity do not show outstanding quality of life indicators in many developed countries, in developing countries coal industry usually drives the advancement of the economy: it accumulates cash flows, creates jobs and facilitates the development of unrelated industries (Betz, Partridge, Farren, & Lobao, 2015; Hajkowicz, Heyenga, & Moffat, 2011; Lei, Li, & Pan, 2014). In order for the industry to continue growing and at the same time enhancing lives of communities in coal producing regions, it has to comply with emerging environmental regulations and find ways to increase productivity. And without innovations this cannot be achieved because traditional technologies are approaching the limit for improvements (Bartos, 2007).

Recently almost all new technologies in coal mining were dealing with the increase of extraction intensity and production capacity. However, today the industry faces numerous challenges: price volatility of natural energy containers, depletion of easily extractable high grade coal reserves, obsolete technologies on extraction sites and production factories, regional changes in demand for coal and concerns on the reasonability of coal usage from environmental activists and organizations like Intergovernmental Panel on Climate Change (IPCC). Therefore, the focus of research and development of technologies is drifting from just increasing production intensity and capacity towards the emerged challenges (Alderman, 2013; Hao et al., 2015; Osborne et al., 2013).

Recent innovation activity in coal mining mostly has been of incremental type. Before present, the industry has been relying on the effect of the economy of scale in terms of productivity improvement. The technology advancement was mostly directed to the increase of machinery size. For example, haul trucks over the period of 35 years from 1970 had increased in size by 1000 percent, at the same time lowering the cost of the haulage by 72 percent. However, the limit for such cost savings is already approaching (Bartos, 2007).

Traditionally, extraction industry has been utilizing an adaptor strategy in terms of new technology utilization. This means that large companies are often very skeptical about emerging innovations. They become interested in a new technology only after it has proven itself. This approach lowers risks and eliminates unnecessary R&D costs. Because of that, many coal companies become more reliant on equipment manufacturers and RTOs for providing new technologies, which in turn move from development of radical innovations towards incremental improvements of existing technology (Bartos, 2007; Thurner & Zaichenko, 2014).

Moreover, mining companies could be characterized as mature industry, which means that most of the advancements of core technologies have already been made, and the companies just do not see the need for big expenditures on innovation activity. That is why we have not seen a lot of radical innovations in the sector recently. Among all new technologies that have appeared in coal mining since 1990 only a small number can be seen as revolutionary, for example, long haul extraction, continuous mining and draglines (Bartos, 2007).

The mentioned aspects of innovation in coal mining industry resulted in the decrease of capital expenditure on in-house innovation activity of coal companies over the recent years. Moreover, the industry suffered from the decrease of federal subsidies in technology development in the beginning of the century (Hitzman, 2002), then – from economic crisis of 2008. And although R&D function in coal producing companies plays an important role, currently it does not receive substantial financing. On average, only 4 to 8 percent of the annual cash flow in mining companies are invested in in-house R&D. This numbers are relatively small in comparison with other sectors, for example Pfizer, a pharmaceutical company, allocates 51 percent of its revenues to R&D, and IT giant Microsoft invests in it 37 percent (Bartos, 2007; Thurner & Zaichenko, 2014).

The challenges that coal industry is currently facing and advancements in utilization of unconventional energy resources force coal companies to increase their innovation activity. With the strategy that the industry has chosen, it is expected that many of the new technologies will come from outside actors like universities, and Research and Technology Organizations (RTOs).

Both universities and RTOs play vital role in creation and distribution of novel technologies. However, RTOs are more successful in commercialization of new knowledge due to their unique set-up and strong industry links. Because many RTOs provide services to companies in the global market, such organizations are very effective in technology transfer in comparison with their peers. They also significantly contribute in decreasing the time for the diffusion of novel technologies. The cooperation of companies from various technology sectors with RTOs, therefore, allows them to from new technologies faster and at a lower cost (Thurner & Zaichenko, 2014).

In general, RTOs can provide companies more value than they could achieve relying only to in-house R&D because domestic technological change often has lower productivity impact in comparison with international technology transfer. However, large industry players will most certainly continue investing in developing technologies to keep their level of expertise.

The set-up of RTOs implies that more successful organizations will be those that provide services to more customers in different regions. This means that large international Research and Technology Organizations will attract most of the cash flow in the industry of technology creation. And that might threaten the technology security of many countries. Their local RTOs will most probably suffer from lack of financial resources due to the decreasing demand for their services, and with that, knowledge capital of such countries may start declining. This means that government will probably increase funding research and development activity in small RTOs and coal companies (Sun & Anwar, 2015).

Innovative technologies in coal mining

Coal mining is characterized by extremely large scale of operations, and it is expected that it will continue growing in the future. With the increase of mining intensity, the size of the equipment will proportionally increase; however, probably, at a slower pace than before. The size of the machines deployed in coal extraction has already become 10 times larger than they were just several decades ago: now typical trucks and excavators used in the industry can cost up to several million dollars. With machines of this scale, haul roads, slopes and other supporting facilities must be proportionally upgraded (Ramani, 2012). This indicates the size of capital expenditure that companies need to invest for the increase of coal production. Moreover, all of the processes of coal production starting from its extraction to its processing and transportation of the end product are closely interrelated.

Due to these features of the industry, coal companies are usually slow to adopt new technologies, and most of the recent innovations were more of incremental type rather than radical. However, some aspects of coal mining are currently undergoing rapid changes, among them are automation and waste utilization. It is expected that apart from mining operations, changes will also come from further coal beneficiation, transportation and processing because improvements in these areas can be rather fast and they will allow coal industry to comply with emerging environmental regulations.

With strengthening health and safety regulations, a lot of innovative approaches and technologies need to be developed to eliminate the risks of incidents. This problem is currently being solved with automation of typical processes. Current mining methods include drill and blast, continuous and longwall, that are being applied in underground sections and big open pits. The number and complexity of the machinery that is involved in such operations are very high. Typical equipment that is utilized in the extraction is bucket-wheels, continuous miners, conveyor systems, draglines, feeder-breakers, excavators, roof bolters, shovels, shuttle cars, and trucks. To operate all of them a lot of manpower is needed, and in such complex and stressful environment incidents happen quite often.

Current advances in the spheres of sensing, satellite communications and robotics are helping to increase the level of automation of mining operations. For example, remote, real-time monitoring, diagnostics and prognostics have already become the features of modern coal mines (Amadi-echendu, Lephauphau, & Maswanganyi, 2011).

The automation of mining processes can be driven by the application of the Industrial Internet of Things. This technology will enable the concept of digital mine, which relies on data collection from various sources and its further analysis with the means of cloud computation. While application of Internet of Things technology to mining processes is still under development, the implications of the emergence of digital mine model can be easily predicted. The interconnection of sensors collecting information on geological and hydrological aspects of mining processes, seismic activity, gas pressure and composition, and location of miners will allow to quickly react and adapt to changing environment of coal mine through the means of automation. Such technology will not only increase the transparency of current situation in mine, but will also improve safety of the processes and work conditions (Osborne et al., 2013; Yu-fang & Jin-xing, 2011).

A lot of technology improvements for increasing automation of processes are expected to emerge in surface mining. Many advancements in this method has already been introduced at iron mine in the Pilabara in Western Australia. And all of them can be transferred to coal industry. Rio Tinto, a company that owns this mine, in 2008 started developing the concept of the “mine of the future” that should utilize all the available technology for automation of mining processes. For example, in 2008 at a test site “A-Pit” the company started operating robotic trucks with artificial intelligence that learned the layout of the mine and used sensors to avoid obstacles. After the experiment, the company introduced to the real mine driverless trucks and haul trains that could carry ore to a seaport at the distances up to 450 km. All of the navigation of these transport was remotely controlled from Perth that was located 1300 km away from the mining site. The key technologies that were utilized in such processes were GPS, laser range finders, video equipment and artificial intelligence. (Lien, 2013).

The concept that Rio Tinto is developing assumes that in the future all of the mining operations will be controlled remotely without the need for direct human intervention. For this to happen a lot improvements still need to be made, among which is increasing the security of vast satellite networks from cyber-attacks. In general, such level of automation can also be achieved in underground mining; however, this requires much more new technology to be developed.

One of the most efficient underground mining technology is Longwall. It is based on the removal of coal in large blocks or panels with a mechanized shearer. While the technology itself brought a lot of improvement to the industry at the time it was introduced, it relied to great extent on manual work of operators. The operators at mines had to work in hazardous environment at close range to the production equipment. However, with current state of the sensing and computing technology, it is now possible to increase the level of automation of this highly effective technology (J. Ralston, Reid, Hargrave, & Hainsworth, 2014)..

At present, the automation of the Longwall coal extraction method is under development. Three principal problems need to be addressed in order for the technology to be efficient: face alignment, horizon and creep control. These problems could be solved with technology for measurement of absolute three-dimensional position of the shearer and sensing for coal seam geometry. For three-dimensional localization sensor that could provide precise measurements at harsh conditions the engineers found existing technology in the form of inertial measurement units that were originally developed for military and aerospace industries. However, coal seam geometry sensing technology had to be designed from scratch (J. Ralston et al., 2014).

The most common approach used by mine workers to identify coal seam boundaries relies on monitoring visual cues present in geology – thin horizontal ash layers in the seam that are usually called marker bands. For automation of the manual process of correcting shearer position a special sensor based on machine vision technology and algorithms for measuring vertical position of the shearer with respect to the coal seam were developed (J. C. Ralston & Strange, 2013; J. Ralston et al., 2014).

The developed technology for localization of shearer position are being further adapted for the use in other underground coal mining operations. One of the area of its application is enabling self-steering for continuous mining to maintain desired position and orientation under remote supervision. The case of the improvement of Longwall's automation is, therefore, a good example of how innovation in coal mining can be facilitated by advancements in other spheres, like military or aerospace, and at the same time drive innovation in non-related mining processes (J. Ralston et al., 2014).

Another area for innovation in mining is utilization of waste. One of the technologies that recently has been developed to tackle this problem in China is solid stowing. Introduction of fully mechanized integrated coal mining and solid stowing significantly improved safety and environmental friendliness of extraction processes through utilization of waste material like gangue, fly ash and construction garbage for stowing into the gob. At the same time this advancement could significantly increase mine's recovery and extend its service life (Junker & Witthaus, 2013).

While mining operations play a big role in coal production, a lot of the advancements that will change the face of the industry will come from innovations at coal processing factories, power plants and in transportation of coal. Research topics on coal technology that currently have great interest in scientific community mostly concern sustainable development of coal in both economic and environmental terms. Among them are development of technology for the usage of low quality coals in industrial processes, fly ash capturing and utilization and reduction of CO_2 emissions (Gupta, 2005).

Because of the depletion of the sources of high grade coal, scientific community has started the search for alternatives for it. One of the most possible substitute is low grade coal that is currently used mainly as energy resource. For example, the reserves of lignite or sub-bituminous coal with high mineral content, are very big, and they have not found a lot of advanced applications in the industry yet. At present, most of the produced lignite is burned at extraction sites to produce electricity. However, this material may become an alternative for coking and specialty coal if it undergoes some treatment.

High content of mineral matter in low quality coal increases the costs of its transportation and beneficiation and makes it useless for a lot of industrial processes. However, thermal pretreatment at semi-coking temperatures of 450-600 °C may significantly improve such coal. At these temperatures, physicochemical processes of coal carbonization and pore structure improvement occur, which widen the range of application of low quality coal. Also, semi-coking of raw materials increases surface tension between organic and mineral parts, and makes feasible further beneficiation of coal with high mineral content. Such technology enables low quality coal which does not have big demand in industry to find its application, and partially solve the problem of depleting resources of high grade coal (Syroejko et al., 2015).

Dry beneficiation is also a very perspective technology. It has different approaches; however, the technology itself is very straightforward. The benefits of using dry beneficiation instead of more traditional ways are huge. It completely eliminates the usage of water from the process, which dramatically decreases the costs of water treatment on sites, allows cheaper transportation due to less moisture in coal, and diminishes the risks of coal freezing at low temperatures (Xia, Xie, & Peng, 2015; Yuemin et al., 2011).

A lot of changes in coal industry can occur with inclusion of the gasification and liquification technologies to the processes at coal factories. Such methods produce of gaseous and liquid fuels from coal that are much more convenient for further transportation to end users. Moreover, with already developed technologies they can be transformed in valuable chemicals that can be used in in different industries.

Another area that can decrease environmental influence of coal usage is treatment of ash from coal firing at power plants. Ash has very complex composition and it is one of the recoverable resources that is produced in the form of waste during coal processing and utilization. This waste product find use in soil amelioration and construction industry; however, it could be more useful in catalysts and zeolites synthesis, water filtering and metals recovery. For the purpose of ash recycling the technology for its transformation to the needed material should be incorporated in power plant processes (Yao et al., 2015).

The polygeneration plants are also a good alternative to traditional approach of coal processing. Such pilot projects are at different stages of development in such countries as Australia, China, Japan, Europe, Canada and the USA. Polygeneration means that such factories produce electricity and various other products. Such approach allows to dramatically decrease the costs of production and the amount of emissions due to efficient utilization of coal and synergy that may occur in producing multiple products. Apart from electricity such plants can export hydrogen, SNG, ammonia, methanol, dimethyl ether and other liquids from the syngas (Osborne et al., 2013).

To summarize, the innovations in coal mining faces the barrier of slow pace of development of the industry. However, when the companies operate at the environment of strengthening regulations, they allow big changes to occur that have big influence on economy. The row of incremental innovations that helped increase production efficiency and intensity is probably going to be interrupted in the future by radical innovations that will be aimed at satisfying environmental, safety and health policies.

Among developing the technologies most of the changes in the industry will come from those directed at increasing the level of automation and efficiency. Such innovations will be based on sensing technologies, satellite communications and robotics. At the same time, advancements in coal mining may drive the improvements in the technologies of adjacent spheres. Also, a lot of changes will come from other coal-related operations due to the need for equipment renewal, emissions decrease and increase of flexibility of processes. And in the future coal industry will probably look completely different than now.

Conclusion

Global economy has been highly dependent on coal resources for energy generation, production of metals and other purposes. In the future, the demand for coal will most probably remain high; however, many regional changes in its consumption are inevitable.

Coal industry is now facing a lot of obstacles which it needs to overcome. The solution to many of current problems will come from introducing new technology. Although, the industry has not seen a lot of radical innovations recently, it is expected that they will occur in the near future. And in their development a big role will play RTOs which will allow faster diffusion of technologies and, therefore, will allow big changes to occur in coal companies at a more rapid pace.

The technologies that will allow coal mining to continue growing will be in the field of automation of operations and decreasing their harmful impact on environment. And with the development of mining technology in terms of safety and environmental friendliness, the industry will most probably change its current bad perception and will be seen as vital for the prosperity of people.

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