Development of Mining Machinery and Future Outlook for Electrification

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OVERVIEW: Accompanying the rapid industrialization of emerging economies, particularly the heavily populated nations of China and India, the 21st century has seen ongoing growth in demand for mined resources such as coal and iron ore. It is generally recognized that increasing demand for resources will remain as long as this growth in emerging economies continues. Against this background, Hitachi Construction Machinery Co., Ltd. has developed and released a series of mining machines, including working jointly with Hitachi, Ltd. on the development of dump trucks with AC drives based on the latest technology. Hitachi Construction Machinery is also committed to the planned development and release of environmentally conscious trolley-assisted dump trucks, autonomous dump trucks, and electric excavators.

INTRODUCTION

HITACHI Construction Machinery Co., Ltd. first entered the mining market in earnest in 1979 with the release in the North America of the ultra-large UH801 hydraulic excavator (operating mass: 157 t) designed for the mining industry. Since then, as the mining industry has grown in scale, Hitachi Construction Machinery has established a comprehensive range of ultra-large hydraulic excavators that extends all the way up to the EX8000-6 (operating mass: 811 t). The company has retained a large share of the market for ultra-large hydraulic excavators of 200 t or more, the category that forms the mainstay of the mining market.

In the market for dump trucks, meanwhile, Hitachi Construction Machinery was a late arrival, first entering the market in earnest in 2008 with the release of the EH3500ACII, which featured a Hitachi alternating current (AC) drive and freight mass in the 190-t class. With a pressing need to differentiate its technology from that of its competitors in order to establish itself in the truck market, Hitachi Construction Machinery is developing advanced vehicle control systems incorporating the latest insulated-gate bipolar transistor (IGBT) inverter technology, with plans to release a series of new models onto the market from 2012.

With the growth in international resource demand having now resulted in a chronic shortage of machine operators, and with a strong emphasis being placed on safety measures to prevent accidents due to inexperience, a growing need is emerging for autonomous (driverless) dump trucks. Various companies are seeking to develop these vehicles, including Hitachi Construction Machinery working in collaboration with Hitachi, Ltd. Regarding environmental protection, Hitachi Construction Machinery has also commercialized trolley-assisted dump trucks and released a series of electric excavators that help reduce carbon dioxide (CO_2) emissions.

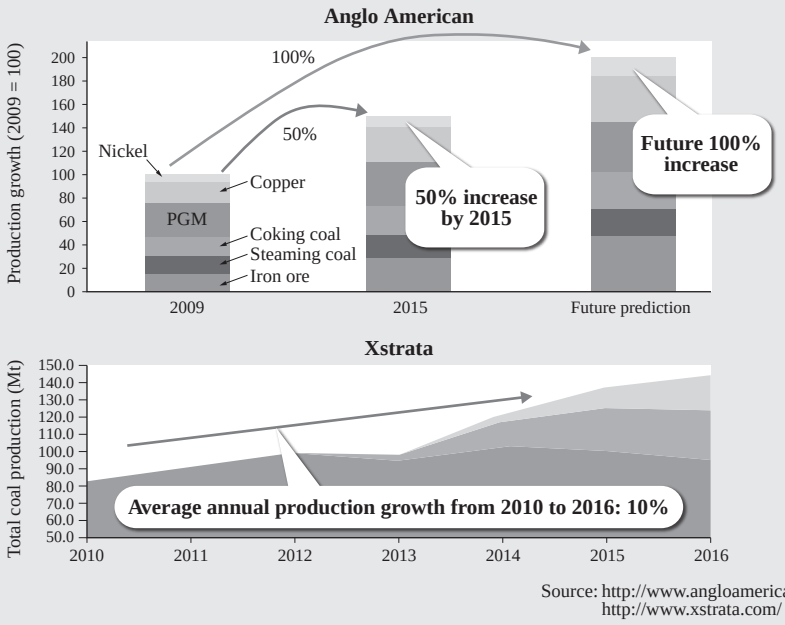
This article recounts the history of mining machinery made by Hitachi Construction Machinery, and describes both recent developments and future mining machinery.

TRENDS IN MINING MARKET

North America is a major resource consumer, and use of opencast mining spread from the North American continent to the rest of the world from the 1960s onwards, replacing the underground mining (tunneling) that had predominated in the past. The total market for opencast mining equipment was approximately 1 trillion yen in the 2011 fiscal year. It is also predicted that global resource production will double over the next decade (see Fig. 1).

History of Opencast Mining

Many opencast mines have been developed since the advent of large digging machines required for efficient opencast mining, such as draglines and mechanical excavators. Nowadays, production from opencast mining represents about 45% of total resource extraction (according to a survey by The Freedonia Group, Inc.). Along with the demand for mining techniques, most large mining machinery

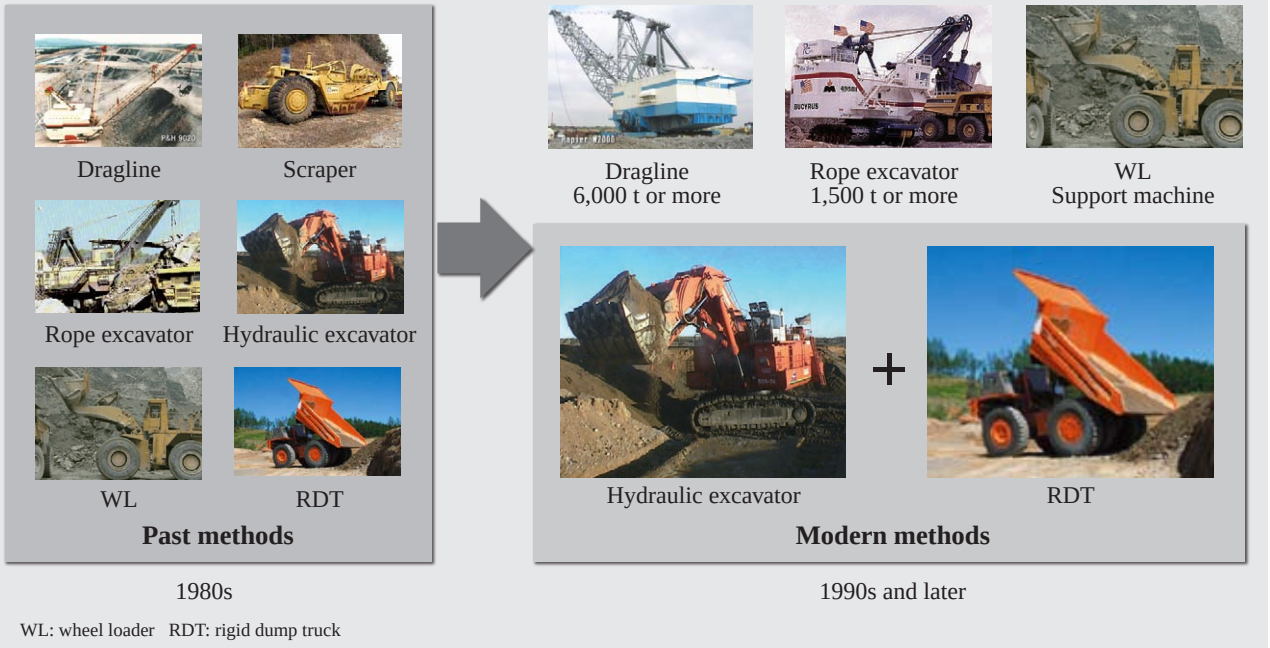


Source: http://www.angloamerican.com/
http://www.xstrata.com/

PGM: platinum group metals

Fig. 1—Planned Production Growth by Major Resource Companies.
The graphs show the planned expansion in production by two major resource companies, Anglo American and Xstrata.

was developed in the USA, and the large hydraulic excavators that arrived on the scene in the 1970s led to innovations in mining practices, to the point where the most common method now involves use of these machines in combination with dump trucks (excavator/dump truck mining). As expensive machinery such as draglines that are amortized over 20 years or more are unable to respond flexibly to the fluctuations of resource markets, it is anticipated that market demand for excavator/dump truck mining will continue to grow in order to cope with factors such as short-term (yearly) purchase contracts, global competition in resource prices (cost of production), and the speed of new mine development (see Fig. 2).



WL: wheel loader RDT: rigid dump truck

Fig. 2—Changes in Mining Practices.
As a result of improvements in the performance and reliability of hydraulic excavators, the most common form of opencast mining now involves use of these machines in combination with dump trucks (excavator/dump truck mining).

Resource Boom and Changes at Mining Companies

Faced with difficult business conditions, the mining industry underwent a period of consolidation, involving mergers between mining companies, during the mining slump that ran from the 1990s to the early 2000s. Prices subsequently rose rapidly in response to a sharp increase in demand for resources from China and other emerging economies, allowing mining companies to reap large profits and leading to a further burst of investment and new mine development around the world. This resulted in an international shortage of personnel that prompted mining companies to involve equipment manufacturers and suppliers in the joint operation of mines, and led to demand for solutions such as for machinery operation and maintenance.

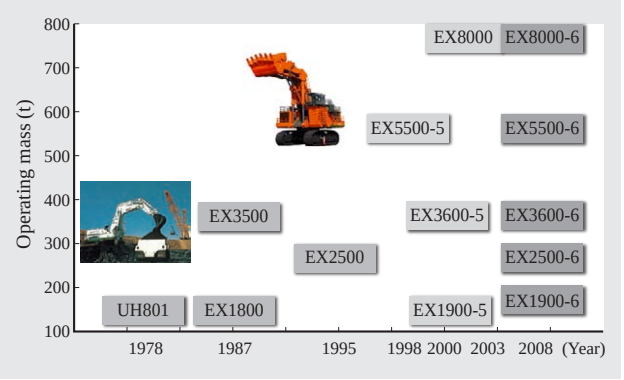


Fig. 4—Hydraulic Excavator Product Range and Development History.
Starting with the UH801 developed in the 1970s, Hitachi Construction Machinery has established a range of hydraulic excavators for the mining industry that extends up to the EX8000 with an operating weight in the 800-t class.

HISTORY OF MINING MACHINERY

Hydraulic Excavators

Hydraulic excavators were first developed in Europe in the 1950s. In Japan, Hitachi released the first hydraulic excavator based entirely on Japanese technology in 1965. Called the UH03, it had a gross weight of 8.7 t and a bucket capacity of 0.35 m^3 (see Fig. 3).

Following on from the UH801 released in 1979 (operating mass: 157 t, loading bucket capacity: 8.4 m^3), Hitachi Construction Machinery released a series of progressively larger machines over the next 25 years, culminating in the EX8000-6 in 2005 (operating mass: 811 t, loading bucket capacity: 40 m^3). Not only were the machines designed from the outset to deliver work performance and reliability, Hitachi Construction Machinery also placed an emphasis during this period on incorporating feedback from the market. The numerous improvements that resulted gave the machines a strong reputation for reliability in particular and gained a large market share. Fig. 4 shows a history of hydraulic excavator development for the mining industry together with the Hitachi product range.

Including the UH801, the models in the figure are used in a total of 72 countries around the world, with cumulative shipments of approximately 1,500 machines. The electric excavator described below was developed by Hitachi Construction Machinery in the 1970s, with the number of machines shipped getting a boost in 2001 thanks to a large order from the Kingdom of Thailand. Total shipments to date have now reached 45 excavators.

Fig. 3—First Hydraulic Excavator Based Entirely on Japanese Technology (UH03).
Developed in 1965, the UH03 was the first hydraulic excavator based entirely on Japanese technology. An example is on display at the Tsuchiura Works of Hitachi Construction Machinery Co., Ltd.

Dump Trucks

Hitachi has developed various series of dump trucks, dating back to the development in 1971 of a truck with freight mass in the 190-t class by Euclid (now Hitachi Construction Truck Manufacturing Ltd.) in Canada. The base for dump truck development was subsequently shifted to Hitachi Construction Machinery. The EH3500ACII dump truck released in 2008 had freight mass in the 190-t class and featured the latest IGBT AC drive made by Hitachi, Ltd. This was followed in 2010 by the 220-t EH4000ACII series of dump trucks (see Fig. 5).

While other companies have been selling mining dump trucks since the 1970s, most models used either mechanical drive systems with automatic gearboxes or direct current (DC) electrical drive systems in

Fig. 5—EX5500-6 and EH4000ACII in Operation.
The EX5500-6 and EH4000ACII shown here are at a coal mine in eastern Australia.

which the engine drives a generator to produce an alternating current that is then rectified to drive the electric traction motors. Hitachi, Ltd. has a long and successful experience in the development of electric drive systems for trains and other vehicles, so although Hitachi Construction Machinery was a late arrival to the dump truck market, it was able to achieve an ideal match between chassis and electric drive through their joint development of an AC drive system for dump trucks. The result was a high level of both driving and operational performance.

More than a hundred EH3500ACII and EH4000ACII trucks are already in use in 11 different countries where they have a high level of utilization, including some that have already clocked up more than 20,000 hours of operation.

Having a range of hydraulic excavators and dump trucks for the mining industry allows Hitachi Construction Machinery to sell these as a package, and it will be necessary in the future to provide more comprehensive support so that customers can operate their mines even more efficiently.

DUMP TRUCK DEVELOPMENT

The EH3500ACII and EH4000ACII models that emerged out of a joint development with Hitachi, Ltd. use an AC drive system in which the engine drives a generator that supplies power to latest IGBT inverter from Hitachi, Ltd. The inverter in turn controls the AC electric motors that drive the vehicle. Table 1 lists the specifications and Fig. 6 shows the configuration of the AC drive system used by the vehicles.

The objectives of the joint development with Hitachi, Ltd. of the chassis and electric drive system were as follows.

(1) A high level of driving and operational performance achieved by matching the chassis and electric drive system.
(2) Improve quality by moving production to Japan.
(3) Enhance truck capabilities by using technology from ultra-large hydraulic excavators.

In addition to utilizing technology from Euclid, a company with a long history of dump truck manufacturing, and adopting reliability design techniques honed on ultra-large excavators, Hitachi Construction Machinery also offered performance guarantees. Regarding the specific technologies that play a core role in dump trucks, Hitachi Construction Machinery established proprietary technologies by working with Hitachi, Ltd. on joint development through all stages from initial design through to final testing. They also developed machines based on the same concepts by sharing these technologies across

TABLE 1. Specifications of EH3500ACII and EH4000ACII.
The table below lists the specifications of the EH3500ACII and EH4000ACII dump trucks.

	EH3500ACII	EH4000ACII
Nominal payload (t)	168	222
Capacity (m^3)	111	153
Net machine mass (t)	141	162
Target vehicle mass (t)	309	384
Engine	Cummins QSKTA-50CE	Cummins QSKTA-60CE
Engine output (kW)	1,491	1,864
Length (m)	13.51	14.28
Width (m)	8.99	9.54
Height (m)	6.77	7.36
Maximum speed (km/h)	56	56
Tire size	37.00R57	46/90R57

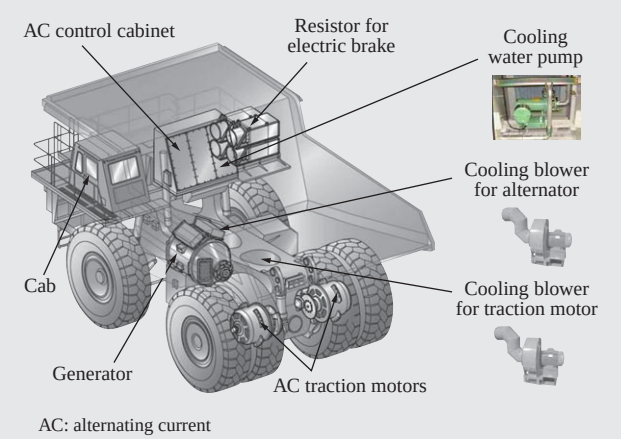


Fig. 6—Configuration of Dump Truck with AC Electric Drive.
The diagram shows the component parts of the AC electric drive system on the EH3500ACII dump truck.

other classes of dump truck. Designing most of the key components used in the trucks themselves and bringing production in-house allowed feedback from the field to be incorporated, sped up parts supply, and facilitated sharing of parts across models.

An indication of how good the vehicles are is that they achieve brake and hill-climbing performance among the best in their class by using the same high-voltage IGBT modules from Hitachi, Ltd. that are used in railway control systems. Similarly, because the vehicle control and AC drive control systems were jointly developed by Hitachi, Ltd. and Hitachi Construction Machinery, they are able to take advantage of sensor technology and the high-speed control characteristics of the AC drive to perform detailed vehicle control. Developed for vehicle stability control, this control technology can be used to assist with the driving safety of the dump trucks, to reduce the driver's workload, and to reduce the load on the vehicle.

The aspect of development that took the longest time was tuning the vehicle and AC drive control. By combining desktop simulations with field trials, Hitachi Construction Machinery was able to establish a pattern for this tuning work, which is expected to improve significantly the efficiency of future development. Performing the work on the overall control of the vehicle within Hitachi enhanced their ability to respond to future development requirements such as optional enhancements or the next generation of models. Working together with Hitachi, Ltd. also made development faster.

The frame was modified to use bolts to fasten the cab support instead of the welds used previously. This was done to eliminate the need for on-site welding as well as to improve the reliability of the fastening and to simplify local assembly (see Fig. 7).

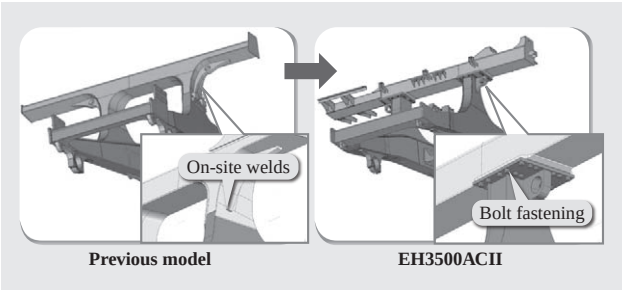


Fig. 7—Split Frame Configuration (Bolt Fastening Structure). The figure shows the frame structure on the EH3500ACII dump truck that can be split apart. This was done to improve reliability and reduce the amount of local assembly work.

FUTURE MINING MACHINES

The rapid rise in the price of oil is behind demand for better productivity (cost/t), and the electrification of mining machinery is seen as one way of achieving this. Electrification is also important for environmental reasons and active steps are being taken toward adopting trolley-assist for dump trucks and electric drive for hydraulic excavators.

Trolley-assisted dump trucks only receive electric power from overhead contact lines when they are loaded and driving uphill, at which time they are powered by AC motors instead of their diesel engine. This provides significant fuel savings and improves productivity by allowing the trucks to drive uphill faster than they could using their diesel engines.

Electric-hydraulic excavators, in contrast, by substituting an electric motor for the diesel engine with which they are normally fitted and by receiving electric power from a cable, use this electric motor to drive all operations. As most mines already have electric power infrastructure, the major benefits of electric-hydraulic excavators are that they can significantly reduce running costs and cut CO_2 emissions.

Trolley-assisted Dump Trucks

Trolley-assisted dump trucks use a pantograph fitted to the top of the vehicle to receive electric power from overhead contact lines installed on uphill sections. Because this power is used to drive the AC motors, the engine can be idled during those times when a power supply is available. The trolley box fitted on the right side of the vehicle is used to control switching between trolley mode and engine mode. At locations where no overhead lines are installed, such as at loading and unloading sites or downhill sections, the vehicle powers itself using its engine to generate electric power in the same way as a conventional dump truck (see Fig. 8).

To date, trolley-assisted dump trucks have been most widely used in southern Africa (see Fig. 9).

Because most trolley-assisted dump trucks in the past have used electric motors and other key electrical components made by companies like Siemens AG or General Electric Company, together with pantographs produced by local suppliers, there has been a limit to how well systems could be put together to provide the best reliability for the vehicle. In response, Hitachi Construction Machinery has been able to deliver highly reliable trolley-assisted dump trucks by jointly developing all parts of its products in collaboration with other companies in the Hitachi Group. Other

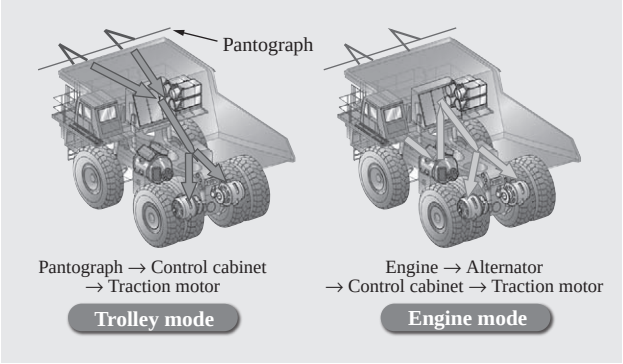


Fig. 8—Power Flow in Trolley-assisted Dump Truck.
The diagrams show the flow of power in an EH3500ACII trolley-assisted dump truck during trolley mode and engine mode respectively.

Fig. 9—EH3500ACII Trolley-assisted Dump Truck.
This EH3500ACII trolley-assisted dump truck was supplied to a copper mine in the Republic of Zambia in Africa.

advantages include being able to conduct on-site tuning as appropriate, and being able to respond quickly by providing a single point of contact for service and support.

By consolidating these group synergies, Hitachi has won an order for 24 trolley-assisted dump trucks from the Republic of Zambia and is currently preparing the first truck for operation at the customer's site.

Trolley-assisted dump trucks have the following advantages over conventional models.
(1) Lower fuel consumption
(2) Better hill-climbing performance
(3) Lower engine maintenance costs
(4) Lower CO_2 emissions

In the case of fuel consumption, for example, assuming the vehicles are making round trips on a road with a 10% gradient, trolley-assisted dump trucks use roughly half as much fuel as conventional dump trucks. Furthermore, while the speed of an engine-powered dump truck traveling fully loaded up this 10% gradient would be about 11 km/h, trolley-assisted dump trucks can travel at approximately twice that speed. This shortens the travel time between loading and unloading sites, resulting in higher production per truck than for conventional dump trucks.

Regarding maintenance costs, because the engine can be idled while the dump truck is operating in trolley mode, the load on the engine is reduced. Assuming a typical case of 60,000 operating hours, an engine-powered dump truck would require three engine overhauls during this time compared to only two for a trolley-assisted dump truck. Considering the load on the environment, the reduced load on the engine also limits the CO_2 emissions from the trucks themselves.

In other words, adopting trolley-assisted dump trucks has major benefits for both production and the environment.

Electric-hydraulic Excavator

Although electric-hydraulic excavators currently make up less than 10% of hydraulic excavator shipments to the mining industry, the number of electric machines has roughly doubled in the last two to three years and it is anticipated that demand for this configuration will continue to grow in the future.

Electric-hydraulic excavators have the following advantages over engine-powered models.
(1) The electric power they use costs less than diesel.
(2) Lower overhaul costs
(3) No CO_2 emissions from excavator itself
(4) Does not require consumables such as engine oil and filters.
(5) Low noise and vibration

In particular, because their total running costs are about one-half those of engine-powered models, electric excavators can help cut costs for customers in countries or regions where the price of fuel is high. Fig. 10 shows an example worksite that uses an electric excavator.

Electric-hydraulic excavators required a continuous supply of electric power.

The disadvantages of this configuration include a requirement for electric transmission equipment, and the difficulty of moving from place to place, depending on the availability of cables.

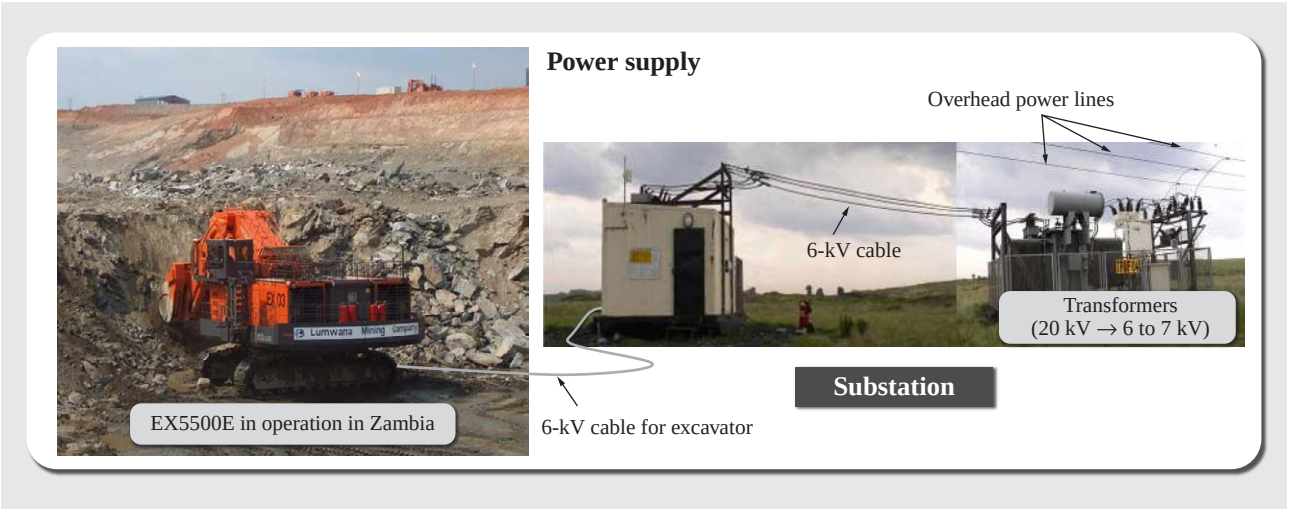


Fig. 10—Electric Excavator Worksite.
Electric power from a generation plant is stepped down by transformers to 6 to 7 kV and supplied to the electric-hydraulic excavator.

Nevertheless, for mining developments that face a tradeoff against environmental problems, electric-hydraulic excavators have superior environmental performance (place less of a load on the environment), and their running costs deliver great benefits to customers in mines where the power supply infrastructure is already in place.

As of the end of 2011, most deliveries of electric-hydraulic excavators had been to Asia, Africa, the Russian Federation, and the Commonwealth of Independent States (CIS) region. However, it is anticipated that demand from the Americas will also grow in the future as exhaust emission laws become more stringent.

While factors such as temperature and altitude mean that many mines around the world present hydraulic excavators with a harsh operating environment, Hitachi Construction Machinery aims to achieve even greater results by overcoming the problems associated with selling into many different regions.

CONCLUSIONS

This article has recounted the history of mining machinery made by Hitachi Construction Machinery, and described both recent developments and future mining machinery.

Meanwhile, there is strong demand from the market for improvements in mine production efficiency, including a need to maintain high levels of utilization, not only through machine reliability, but also through the establishment of a robust post-sales support system.

In addition to the conventional approach of making further improvements in machinery quality, Hitachi Construction Machinery is also taking active steps to strengthen its support system for machinery operating at mines. The aims include use of mining information and communication technology (ICT) to reduce machine downtime and to implement preventive maintenance by obtaining timely information from sensors embedded in the machines and detecting faults preemptively.

In the future, Hitachi Construction Machinery Co., Ltd. intends to advance beyond being a supplier of individual machines so that it can offer solutions that help achieve efficient operation across all aspects of mining.

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