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Examining safety and sustainability in longwall coal mining through case studies of disasters and reviewing global trends in environmental stewardship

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ABSTRACT
The coal mining industry has struggled recently with numerous operations being closed due to poor market conditions and profitability. In spite of these low prices however the industry is seeing longwall projects develop and continue operations, which seems to present an opportunity that can be economical and sustainable.
This paper examines longwall coal projects and what makes them successful. The topic of safety is a primary focus, with coal mining disasters highlighted and operational challenges addressed. It includes summary root-cause analyses that may serve as a risk register to highlight significant issues and challenges facing the industry.
The paper discusses sustainability and the influence longwall operations could have on the future of the coal industry, while also highlighting global trends in environmental stewardship and fossil fuel reduction.
KEYWORDS: Coal; Safety; Mine Disasters; Root Cause Safety Analysis; Fossil Fuels; Sustainability

1. CURRENT COAL DOWNTURN AND SLUMP RESILIANT LONGWALL MINES

The coal mining industry has been facing challenging operating conditions the past few years and in combination with a global shift towards renewable energy and a focus on sustainability, the viability of coal mining has been impacted. The effects of these conditions have been seen through the closure of numerous coal operations, the shelving of projects, and companies restructuring and selling assets to adjust to new market conditions.

The effects of low coal prices can be seen by looking at the traditionally active coal mining region of North East BC where 5 mines have closed and more than 1,300 employees are out of work. Communities such as Tumbler Ridge have been impacted, where the town’s mayor estimates its population has decreased from over 3000 to just 2000 (Cryderman 2015).

The severity of market conditions was highlighted in 2015 when Anglo American announced it would cut its workforce of 135,000 by 85,000 in response to continued low prices (Saunders 2015). Anglo also announcement its intentions to sell numerous assets and focus on priority assets. "Negative cash flow assets will either be closed, placed on care and maintenance or sold," Mark Cutifani, CEO Anglo American (Saunders 2015).

Despite low coal prices Anglo American announced that its longwall coal mines, Moranbah and Grosvenor, were not for sale and would continue operations (Saunders 2015). "Together with the additional material capital, cost saving and productivity measures announced, we are setting out an accelerated and aggressive strategic restructuring of the portfolio to focus it around our 'Priority One' assets, being those assets that are best placed to deliver free cash flow through the cycle and that constitute the core long-term value proposition of Anglo American," Mark Cutifani (Saunders 2015).

The statements from Anglo’s CEO highlight the advantages of longwall coal mines, primarily low operating costs, and the ability to stay cash positive during periods of low prices. Unfortunately, longwall mines are restricted by geological conditions and they require large up-front capital expenditures, however, once established a longwall mine can be very valuable.

2. SAFETY PERFORMANCE IN THE USA

The risks associated with underground mines are much greater than surface mines, which is evidenced by the higher accident and fatality rates in underground mines. In 2015 for example, the US coal industry had 11 fatalities, 7 of which were in underground mines, with 4 of the 7 attributed to roof or wall failures (CBC 2015). By reviewing the statistics from the Mine Safety and Health Association’s (MSHA) 2015 report, it is evident that in the USA citations and orders are generally being reduced. By reviewing Table 1 from MSHA 2015 it can be seen that with the exception of 2010, when the

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Upper Big Branch disaster occurred, the fatality rate has remained relatively constant around 0.016 fatalities per 200,000 hours worked, which is roughly 50% higher than in metal and non-metal mines. (If the Upper Big Branch disaster is excluded from 2010 figures, the fatality rate is approximately 0.152).

It is also interesting that the number of citations ordered is higher in coal mines, even though there are 6 times more metal and non-metal mines. Also, there are roughly 3 times as many workers at coal mines, which could be a contributing factor through issues with congestion and communication.

Table 1: Safety Performance at Coal Mines in the USA (MSHA 2015).

Coal Mine Safety and Health	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014***
Number of Coal Mines	2,129	2,076	1,944	1,973	1,871	1,701	1,632
Number of Miners	133,828	133,089	135,500	143,437	137,650	123,259	116,010
Fatalities	30	18	48	20	20	20	16
Fatal Injury Rate (per 200,000 hours worked)	0.0237	0.0148	0.0384	0.0148	0.0159	0.0176	0.015
All Injury Rate (per 200,000 hours worked)	3.89	3.69	3.43	3.43	3.16	3.11	3.11
Coal Production (Millions of Tons)	1,172	1,075	1,086	1,095	1,018	984	1,000
Citations and Orders Issued3	106,793	101,904	96,352	93,077	78,857	63,217	62,684
S&S Citations and Orders (%)	32%	30%	32%	31%	27%	26%	26%
Dollar Amount Assessed (Millions)	111.5	96.5	110.7	120.2	89.5	64.9	61.2

3. SAFETY PERFORMANCE IN CHINA

Coal mines are common in China because of how widely used coal is for energy production. From 2000 – 2015, approximately 70% of China's total energy consumption was from coal, and prior to 2000 it was even greater (Bloomberg 2015). However, mines in China have experienced many issues with safety and the future of coal mining in China is uncertain.

Information compiled by Askci (2013) indicates that China's coal production accounted for roughly half of global production from 2012 to 2014. This high production rate contributes to higher accident rates in that because of scarcity, marginally profitable deposits are exploited and small margins can cause operators to take greater risk. These risks could include failing to implement certain safety measures to reduce costs.

An article by Xi (2015) highlights China's poor safety record and cites that in 2009 China had the highest number of fatalities globally, with 2,631. The figures indicate that total fatalities in China have been decreasing, but fatalities per unit produced are still 15 times greater compared to figures from US mines.

However, though there are a significant number of safety incidents and fatalities in Chinese mines, research by Chen and Zhao (2012) indicates that the majority of accidents can be attributed to ownership. The research divides China's coal mines into 3 types including state-owned, local, and private enterprises.

State-owned refers to mines controlled by China's federal government. These mines are large, have high yields and production rates, are highly mechanized, and have generally strong safety records. Local refers to mines controlled by the local government without influence from the state, and are generally smaller than state-owned mines. Private refers to mines that are individually owned and operated without influence from the government. These mines are relatively small, with low yields and production rates, low level of mechanization, and have very poor safety records (Zhang et al., 2007).

Table 2: Safety Incidents in Chinese Coal Mines from 2001 – 2010 (Chen and Zhao, 2012).

Coal Mine Ownership	Number of Accidents	%total accidents	%total casualties
Private Enterprise	6911	87.7	90.2
Local government	938	11.9	9.2
State government	35	0.4	0.6

These statistics indicate that state-owned mines account for less than 1% of incidents, with the majority occurring in mines that are privately owned. However, relative values can be misleading and investigating total fatalities shows a significant number occurring at state-owned coal mines. A contributing factor to this is the sheer number of mines, where in 2008 for example, there were 16,000 active Chinese coal mines. However, a telling statistic of how bad times were previously is that in 2001 to 2005 China had on average 6,000+ fatalities annually (MAC 2006).

Recent reports indicate that annual fatalities, which peaked in 2002 at over 7000, have been decreasing with less than 1000 reported in 2014 (Lelyveld, 2015). However, figures show that

China's coal industry is still experiencing severe risks and there is discussion about the validity of reporting by the Chinese government.

China Cuts Coal Mine Deaths, But Count in Doubt.

In a 2006 article for the Jamestown Foundation research organization, energy expert Jianjun Tu argued that official reports understate the real totals, "as mine owners routinely falsify death counts in order to avoid mine closures or fines."

The highest accident category of 30 or more deaths automatically triggers an investigation led by the State Council, or government cabinet, the Hong Kong-based China Labour Bulletin said.

In what may be the worst recent case involving the accident definitions in 2013, a State Council probe found that operators in northeastern Jilin province understated the death toll from a gas explosion to avoid falling into the 30-or-more category.

The Babao Coal Mine Co. reported 28 deaths and 13 injuries from the accident, although the real death toll reached 36 (Lelyveld 2015).

A good example of strong safety at a Chinese coal mine is the Daliuta mine owned by ShenHua Group. The Daliuta mine was the world's largest underground coal mine in 2011 and at the time of reporting the mine had an ongoing record of 7 years of safe production with no fatalities (Daliuta 2011).

The Chinese coal industry faces many challenges with safety, and the high number of accidents and fatalities highlights the need for improvement and transformation. Overall, it seems state-owned mines can have safety performance comparable or superior to mines in the USA, but it is difficult to separate these from the local and private mines.

4. LONGWALL DISASTERS: CASE STUDIES

Sadly, there are numerous cases of underground coal disasters throughout history. It seems to be a repeating cycle. Below are three summaries of root cause investigations.

4.1 Soma Mine Disaster (Turkey)

On May 13, 2014 an electrical malfunction created an explosion and fire in the Soma coal mine in Eynez, Turkey. An analysis of the disaster is outlined in the report by Kilic (2014). A fire started in the mine shaft which rapidly depleted oxygen and also created smoke. Smoke was blown into the mine and resulted in 301 miners dying of carbon monoxide poisoning, and 162 others being injured.

Investigations revealed the mine was a "Death Trap" with numerous cases of gross negligence. A root cause analysis by Kilic (2014) and Ultas (2014) found:

1. There was no refuge chamber in the mine and workers were not provided functioning gas masks.
2. There were faults in the electrical system and many issues found in the weeks prior to the accident.
3. Plans for the electrical layout were not sent to regulators for inspection and approval.
4. The mine's gas sensors had not been inspected
5. The ventilation system did not meet requirements and there wasn't an adequate supply of fresh air or removal of polluted air.
6. Workers were unable to exit the mine because exit routes were being used for production, and because no escape plan had been created.
7. The communication system used in the mine was not suitable for an underground mine.
8. Production was 2.5 times greater than originally planned with more workers were present. However, the ventilation system was not adjusted to provide the increased volumes of clean air required.
9. Employees were not trained adequately before beginning their work.

The Kilic report concluded with "Our group is of the opinion that there were many negligent practices, and that this accident was avoidable."

4.2 Upper Big Branch Disaster (USA)

On April 5th, 2010, the Upper Big Branch Mine in West Virginia exploded and killed 29 miners, making it the worst mining disaster in the US since 1970. As outlined by McAteer et al. (2011) the methane and coal dust explosion is believed to have been ignited by a spark created as a shearer cut into the sandstone roof at the mining face. The shearer was equipped with water sprays designed to douse flames like these at the point of ignition, however, the investigation found that the water sprays were ineffective because they had either been removed or were clogged with dust.

McAteer et al. (2011) determined the root causes to be:

1. Water sprinklers and methane detectors were not properly maintained and failed to extinguish the small ignition that led to the massive explosion.
2. Massey failed to remove accumulated coal dust which allowed the explosion to propagate.
3. The ventilation system did not function adequately, allowing explosive gases to build up well beyond safe levels. Stoppings and seals had been removed that could have controlled the spread of fire, but instead blocked the mines escape route.
4. Many pieces of faulty equipment indicated that maintenance of safety equipment was not a priority. A misaligned conveyor belt allowed coal dust to accumulate at the face and created a huge

hazard.

Massey Energy had a history of incidents prior to this disaster with 25 other workers being killed in Massey mines from 2000 to 2010 (Stickeler, 2012). The unsafe conditions were well known and in 2009 26 citations were issued for coal dust accumulation and for failure to adequately apply rock dust. In the 15 months prior to the incident, the mine received 40 citations with the majority classified as substantial.

Massey received federal indictments and as outlined by Biggers and Nelson 2010, the company entered into guilty pleas for 10 criminal violations of mine safety and agreed to pay $2.5 million in fines. Also, over 1,300 citations were issued which resulted in another $1.7 million in civil penalties. In 2015, former Massey Energy CEO Don Blankenship was found criminally guilty for a conspiracy to willfully violate the Mine Safety and Health Act.

4.3 Jiangjiawan Coal Mine Dsaster (China)

On April 19, 2015, 24 miners were killed at the Jiangjiawan mine when a shaft flooded (Mkaq, 2015). 247 workers were inside the mine when the accident occurred, of which 223 made it out safely while 3 trapped workers were rescued (Mkaq, 2015).

According to Mkaq, on April 14, water flow increased very suddenly at the mining face but the mine didn't stop production to investigate the hazard. Instead, the mine continued production by installing pumps to drain the water, rather than evacuating workers. On April 19, the flooding accident occurred at the mining face, and 24 miners were killed.

The Mkaq 2015 report determined root causes as:

1. The Mine failed to take effective measures when water flow increased suddenly at the mining face and did not respond to the new risks adequately.
2. Failed to evacuate workers effectively when water flow increased at the mining face.
3. Controlled caving in the gob area created fractures in the rock above the coal seam. The fractures allowed surrounding groundwater to flood into the working area very rapidly.
4. Detailed exploration was not conducted prior to mining, which caused the accumulated water above the active mining face to go undetected until its inflow.

5. IS COAL MINING WORTH THE RISKS?

It is clear that there are risks associated with longwall coal mining and past disasters can be heeded as warnings to its dangers. However, there are many cases of successful longwall operations and with proper planning these mines can be successful.

In the case studies outlined in this paper all of the disasters were preceded by cases of negligence. In hindsight it is easy to identify the root causes, but tragically the problems did not receive the necessary attention, and focuses of production and profitability surpassed safety and sustainability.

Current and future coal mines are greatly affected by each disaster and it raises the question "are coal mines, particularly underground coal mines, worth the risk?" The global shift towards renewable and clean energy, along with increasing focuses on environmental and social stewardship has impacted all fossil fuel projects and it is challenging to generate positive attitudes and excitement about projects.

Coal's decline is perhaps best illustrated by the Dow Jones U.S. Coal Index, which has decreased more than 95% from 2011 to 2016 (Finance, 2016). Clearly times are tough, and a fundamental shift seems to be occurring with alternative energy looking to replace fossil fuels.

6. GLOBAL SHIFT FROM FOSSIL FUELS

In November 2015 the government of Alberta announced that by 2030 they plan to close all 18 of the coal-fired power plants that generate around 55% of the province's electricity, with two-thirds of that power replaced by renewable sources (Wilt, 2015).

Alberta's decision follows a trend of moving away from coal, which is highlighted by comments made by the Environmental Protection Agency (EPA) administrator Gina McCarthy. "We know in the U.S. that we are transitioning away from coal because coal is no longer marketable. We have cleaner natural gas, and we have opportunities for low-carbon sources like renewables and using energy efficiency to lower energy demand." (Henry 2015)

The UK has also pledged to close all 12 of its coal power plants by 2025, and research by Levey (2015) found that "to achieve the international goal of limiting global warming to less than 2°C above pre-industrial revolution averages, the least expensive way of doing so is to close a significant number of coal power stations by 2030". Also, the Levey research shows that some of the lowest cost scenarios involve eliminating coal power by 2030, even if that means shutting down generators earlier than planned.

However, demand in Asia still makes coal mining feasible and using safe and sustainable methods is paramount for coal to be an option. The New York Times reported in 2015 that China has underreported its use of coal. "China Burns Much More Coal than Reported, Complicating Climate Talks" said Lin Boqiang, a Research Director at Xiamen University (Smith, 2015). While in India a senior government official explained "Paris climate deal won't affect plans to double coal output," and that India still plans to double coal output by 2020 because no alternatives are available (Wilkes and Das, 2015).

Coal reserves in Asia are slowly depleting and more remote deposits are being mined with advanced technology. With North American mines shipping coal to Asia, a global connection is already in place. This promotes coal's development in North America even if there is no local market. Demand in Asia can be expected to continue because of the high costs of alternatives, and the infrastructure already established in North America facilitates opportunities for Asian companies to extract coal from overseas.

Ontario phased out coal fired power plants in 2014. The transition's costs and challenges are explained in the report by Cundiff (2015). The cost for Ontario to transition to alternative energy was estimated at $9.2 Billion. These prices were relatively high, as much as 3.5 times for solar and 2.0 times for wind compared to the US average, because infrastructure was not already established and private power generators with higher prices were relied upon. These high costs were rebuked by presenting cost savings through less pollution, including savings of over $1 Billion in Health Care and improved productivity. Savings of $10 Billion were estimated when accounting for loss of life, pain, and suffering.

However, it seems Asia will be coal dependent until prices for alternatives become more competitive. The transition away could be initiated by prices increasing through depleted reserves, higher extraction costs, or relying on imports, however, because many places are phasing out coal, and sustained low prices indicate an oversupply, it seems that Asia's transition away could be driven by environmental stewardship.

Pollution has been a major problem in China and though costs are accounted differently in each country, if Ontario was able to show that up to $10 Billion could potentially be saved annually by eliminating coal power plants, China could be able to show exponentially higher savings because its population is roughly 100 times greater than Ontario's and its pollution levels are much more severe.

7. LOOKING AHEAD: FOCUSING ON SAFETY AND SUSTAINABILITY

Longwall coal mining is common in China and applying the method to deposits in more places seems like a natural progression. However, the current coal mining industry faces risks with regards to safety, sustainability, and economics, and aligning a coal project within a larger framework of long-term growth and development can be challenging.

An operating coal mine can stimulate an economy locally and regionally by providing many high paying jobs and numerous opportunities for indirect employment. Once a longwall coal mine is established its operating costs are relatively low and it is more capable of staying cash positive during a downturn compared to other methods, and this is very advantageous for long term stability and overall sustainability. Advances in clean coal technology also provide the opportunity to increase efficiency and reduce pollution, particularly in regions that do not have access to viable alternative energy sources.

Alternatively, there are many risks associated with longwall coal mines and it is critical to identify the contributions and impacts a project may have. The risk of a mining disaster is always present, and even though safety practices have advanced the industry has a long and sad history of disasters. Statistically, coal mines have injury and fatality rates approximately 50% higher than metal and non-metal mines, and the increased risks need to be considered (MSHA, 2015). The increased risk could potentially be offset with comprehensive safety programs, and the costs funded through the lower operating costs and increased margins. There are also environmental risks, such as pollution, waste, subsidence, and impacting water resources, which can greatly affect the local region, while extracting fossil fuels impacts pollution levels and global warming. Understanding these risks is critical before developing a project, along with identifying and reviewing project specific risks.

There are many opportunities and benefits of having a mine operating, particularly when the coal mining industry has been struggling, but concerns over safety, local and regional participation in the project, and long-term viability remain. Finding a balance is key and keeping safety at the forefront is critical if coal mines are going to be successful in future.

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