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Blasting approaches to increase mine productivity and reduce greenhouse gas emissions in surface coal mining

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ABSTRACT

In response to concerns over greenhouse gas (GHG) emissions and an imposed cost in some jurisdictions, many mining houses have committed to reductions in their GHG emissions. However, mining faces particular challenges in this regard, notably from increasing strip ratios. Furthermore, mining activity around the globe is not expected to slow in the foreseeable future as mineral demand is driven up by the aspirations of rapidly-developing nations. Novel approaches will thus be needed if any reductions in energy consumption and GHG emissions of mining are to be achieved.

This paper presents some directions for the mining industry to pursue in order to reduce their GHG impact, focussing on the difference that blasting methods can make. Importantly, large productivity and revenue gains can also be realised from these methods.

Key directions considered here include optimising resource recovery and quality through:

- Reducing coal damage and loss from throw blasting
- Recovering thin coal seams
- Producing cleaner coal with less dilution

Blast design can also significantly improve the productivity of surface mining by:

- Improving muckpile shaping
- Improving mine equipment productivity
- Improving scheduling

We show how a particular blasting method can eliminate coal loss in overburden throw blasting and can lead to large increases in coal mine profitability. Thin seams that were previously wasted can also be recovered with this method. Furthermore, the method has been implemented to combine several separate drill and blast cycles into a single cycle, leading to productivity gains.

An illustrative example is given to show how increased coal recovery can increase revenues and more than offset any potential GHG emissions liabilities. Overall mine energy and GHG emission intensities can thus be reduced.

INTRODUCTION

The increase in the concentration of greenhouse gases (GHGs) in the atmosphere due to manmade emissions has been unequivocally established by extensive measurements around the world over many years. The principal GHG is carbon dioxide (CO_2), generally emitted as a product of combustion of hydrocarbon fuels such as coal, oil and gas. The second most important GHG is methane (CH_4), which usually constitutes the largest GHG emission from both surface and underground coal mines when it is released from the seams during mining. FIG 1 from the Intergovernmental Panel on Climate Change (IPCC, 2007) shows the measured atmospheric concentrations of these two principal GHGs, showing the sharp increases after 1900 due to rapid global industrialisation.

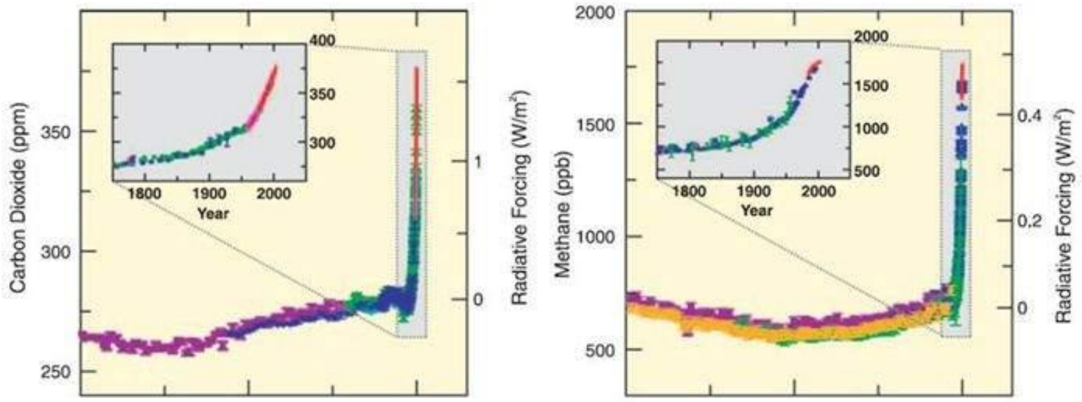


FIG 1 - Measured atmospheric concentration of CO_2 and CH_4 (reproduced from IPCC, 2007)

In parallel, the evidence for global warming and its link to increased concentrations of GHGs continues to mount. FIG 2 from Karl *et al*. (2009) shows the global atmospheric temperature fluctuations from the mean over the past 130 years with the recent CO_2 concentration superimposed.

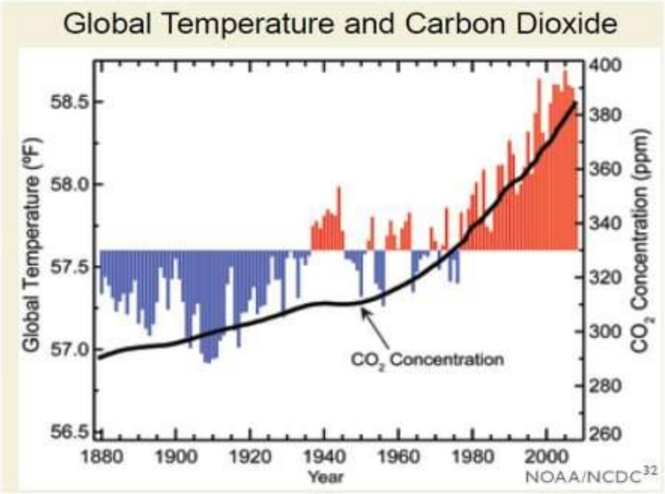
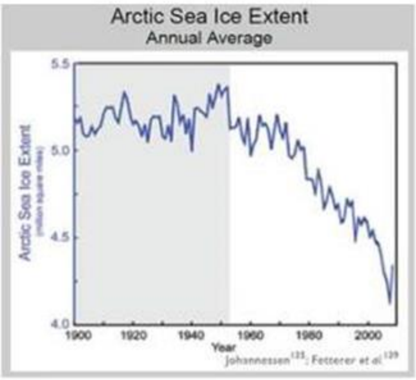


FIG 2 - Global atmospheric temperature fluctuations over the past 130 years with atmospheric CO_2 concentration superimposed (from Karl *et al.*, 2009)

In response to the increasing temperatures, physical manifestations of warming also continue to increase, including the rapid disappearance of Arctic sea ice and steady sea level rise. FIG 3a from Karl et al. (2009) and FIG 3b from Solomon et al. (2007) show the measured data for these phenomena.



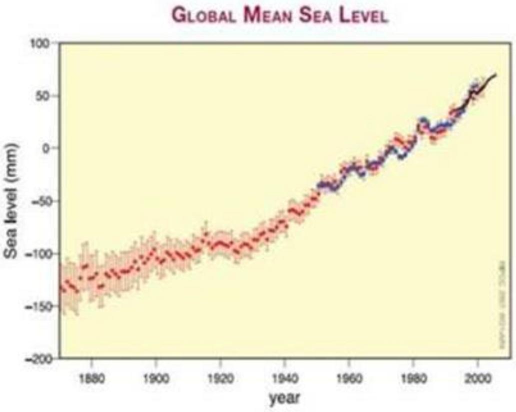


FIG 3a - Disappearance of Arctic sea ice (from Karl *et al.*, 2009) and

FIG 3b - Sea level rise (from Solomon *et al*., 2007)

MINING ENERGY AND EMISSIONS

The mining industry is a significant emitter of GHGs and in certain jurisdictions is coming under pressure from regulators to report and reduce its emissions to the atmosphere. Some regions have imposed a cost or tax on carbon emissions, with others introducing emission trading schemes. In addition, the increasingly prominent position in the public consciousness of this issue is adding to the demands for mineral producers to pay attention to it. While most major mining houses have set targets and initiated programs aimed at reporting and reducing their emissions, the lack of clarity from some governments over carbon pricing, the ongoing struggle for competitive position in the global market, economic instability and uncertainty and possibly 'fear of the unknown' are slowing any progress in this regard. The latter is perhaps most prominent in the coal industry, where an underlying fear of alternative energy sources might be driving a reluctance to acknowledge the problem. However, we contend that this is an issue that is here to stay well into the future and addressing it head-on is the only responsible option the industry has.

Surface coal mining utilises three principal sources of energy; diesel in mobile machinery, electricity in machines such as draglines, and explosives for fracturing and moving rock. Diesel combustion produces over three tonnes of CO_2 for every tonne of diesel consumed. Emissions from electricity generation vary according to the grid generation mix. For countries such as Australia, where coal is the predominant source of electrical power, the emissions are of the order of one tonne of CO_2 for every MWh consumed (Australian Greenhouse Office, 2008). Emissions from the detonation of explosives are of the order of one tonne of CO_2 for every five tonnes of explosives consumed. However, upstream emissions from the manufacture of ammonium nitrate can range from the equivalent of one to four tonnes of CO_2 for every tonne of explosives. For a fuller account of explosives and mining GHG emissions see Brent (2009). FIG 4 - Energy inputs and greenhouse gas emissions from surface coal mining typical of Australian conditions (from Brent, 2009) shows a schematic of major GHG emissions from surface coal mining, with magnitudes indicative of Australian black coal mining. Under carbon emission pricing schemes, mines could potentially be liable for these emissions. Seam gas, principally methane, constitutes the largest emission source. It must be noted that this gas will be emitted for any given quantum of coal that is exposed and disrupted, whether that coal is recovered as saleable product or wasted in the pit. Furthermore, energy consumption is dominated by overburden removal. This means that any additional coal that can be recovered from the mined pit will generally not require any significant change in overall energy consumption.

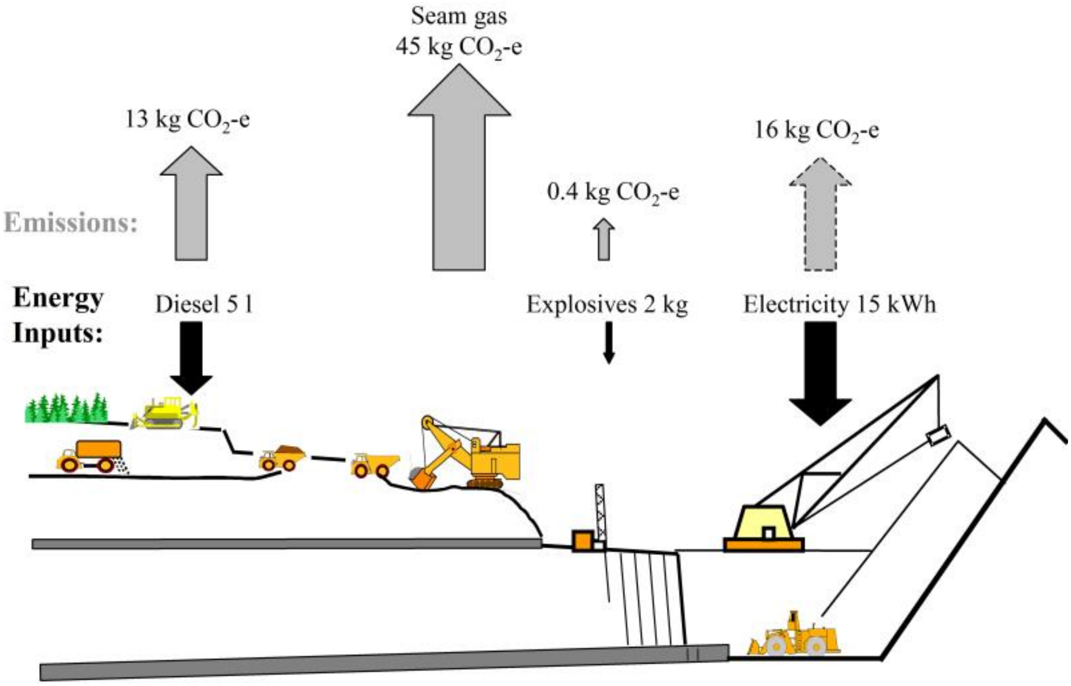


FIG 4 - Energy inputs and greenhouse gas emissions from surface coal mining typical of Australian conditions (from Brent, 2009)

CHALLENGES FOR THE INDUSTRY

Mining faces two inherent challenges in reducing energy consumption and GHG emissions, perhaps uniquely as an industry. The first is that shallower mineral deposits are, in general, mined first. This means that over time, as strip ratios increase, the energy input and associated emissions to recover the same quantity of mineral inevitably increase. This was demonstrated for the case of surface coal mines in the 2006 annual report by BHPBilliton Mitsubishi Alliance (BMA, 2006), see FIG 5.

The second challenge, usually more applicable to metalliferous mines, is that mineral grades and quality generally also deteriorate as higher grades are mined out. Again this means that inputs and emissions increase over time for a given quantity and quality of product recovery.

Apart from finding new shallower or higher grade deposits, these challenges seem to be almost insurmountable for the industry if it is to meet targets for reducing energy consumption and emissions. The problem remains whether the emissions are expressed in terms of absolute emissions or per tonne of mineral (FIG 5). The latter normalisation is known as the emissions “intensity”.

The coal industry plays a vital role in Australia's economy. It is the nation's largest export earner valued at AU$55 billion in 2008-09 and employs more than 137,000 people directly or indirectly (Morris, 2011). There is thus a natural reluctance to contemplate carbon pricing or any GHG reduction mechanism that is feared might have a negative impact on the industry.

Here we present some options that the surface coal mining industry can employ to achieve reductions in energy and emissions while maintaining or increasing mineral output. They are all based on blasting and in many cases do not require additional energy inputs. We show that the use of new blasting methods coupled with advanced blast designs and products can deliver substantial improvements to mine productivity and energy and GHG emission profiles.

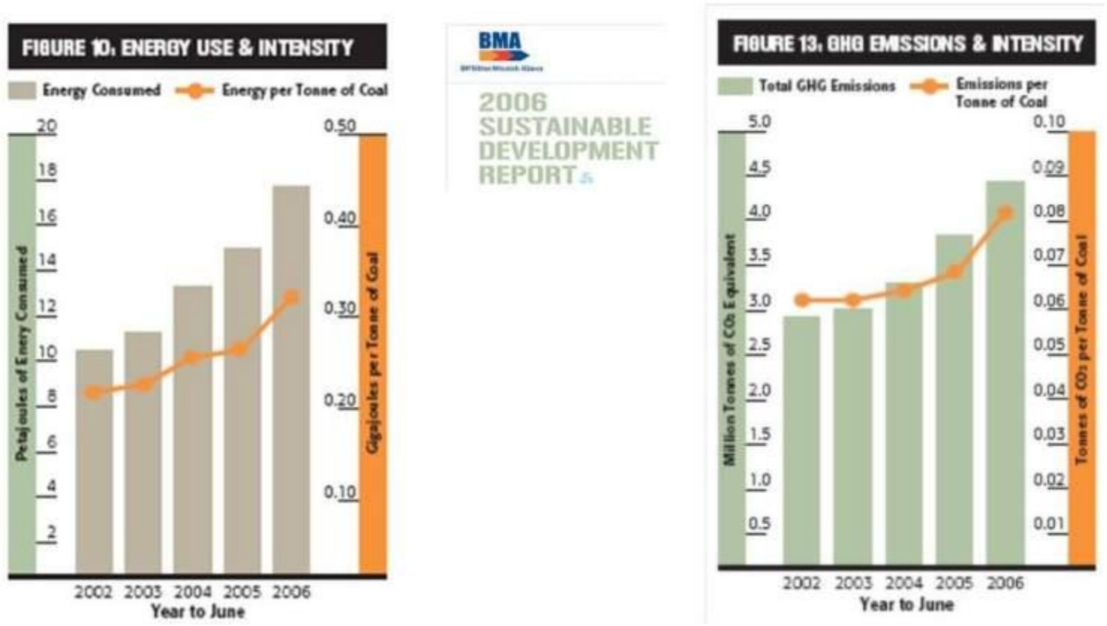


FIG 5 - Energy use and GHG emissions and intensities as reported by BMA (2006)

RESOURCE RECOVERY AND DILUTION CONTROL

Coal loss from blasting is a serious problem. In Australia it has recently been stated that one in every ten coal mines is completely wasted due to these losses (Australian Coal Association Research Programme, 2011). This coal is lost in the spoil in the pit, largely from the blasting process. Major coal loss mechanisms include coal roof, floor and front edge loss during throw blasting. Coal damage and dilution from blasting are further problems (for example Kanchibotla *et al.* 1999). Coal damage and loss mechanisms during throw blasting that have been observed by the authors and others include:

- Excessive overburden throw carries the coal edge with it. This commonly happens with overly 'aggressive' throw blast designs, as percentage throw has traditionally been one of the measures of blasting efficiency.
- The spatial movement of overburden during the throw blast as the rock mass moves laterally across the coal seam. This tends to damage and dilute the coal roof.
- Falling rock impact the seam during the course of the throw blast. Again, this leads to coal roof damage and dilution. Often, a plume of coal dust is visible during the later stages of the blast, frequently from the back of the blast. It has been observed that these blasts result in this kind of coal damage.
- The use of inappropriate bulk explosives immediately above the coal seam can be a cause of coal damage. The presence of excessive energy in the explosive column close to the seam will lead to damage and dilution.
- Insufficient stand-off distances between the explosive charge and the coal commonly lead to coal damage and losses.

- Initiation timing also appears to play a vital role. For example in a throw blast situation in the absence of free end-walls a ‘V’ initiation is often used to create the initial opening after which the initiation front is ‘turned’ around to a ‘row-by-row’ situation to maximise throw. Such a blast is shown in FIG 6. Coal plumes were observed some time into the blast. The exposed coal roof was surveyed and contours were constructed, revealing the formation of trenches up to 3 m wide and 1 m deep in the coal. Similar excessive coal losses have been observed in many such cases. It has also been observed that wherever the coal edge has moved, trenches almost parallel to such edge movement are evident in the remaining coal (see FIG 11 and FIG 12).

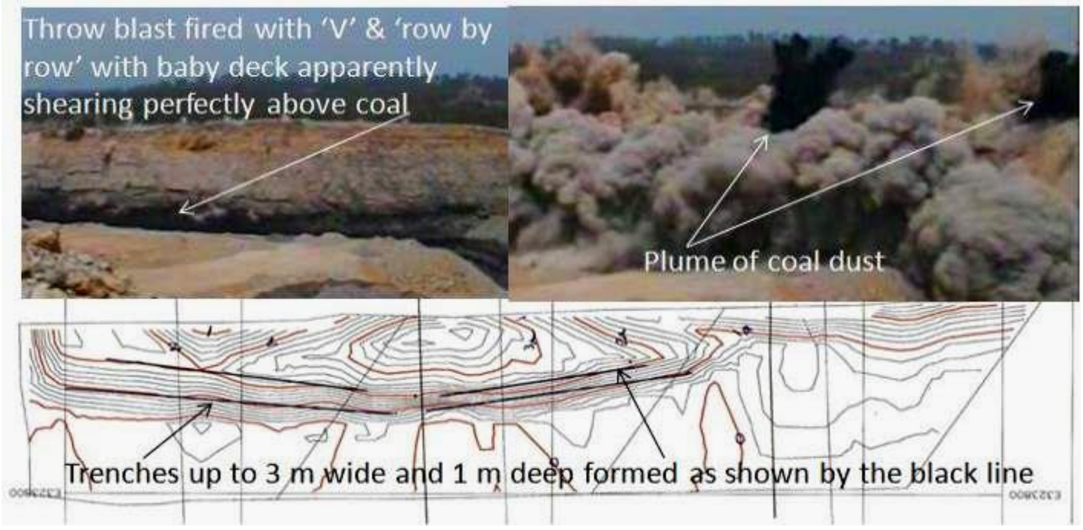


FIG 6 - A throw blast with baby decks, 'V opening and row-row timing' which resulted in visible coal plumes and serious coal loss shown by contours in exposed coal roof (bottom)

Another source of significant coal loss is the deliberate decision not to recover thin seams, as the additional effort to separately drill, blast and mine these seams is often considered too onerous, costly and disruptive to mine schedules. FIG 7 shows an example of such seams.

FIG 7 - Wasted thin coal seams

IMPROVING RESOURCE RECOVERY THROUGH BLASTING

Reducing coal damage and loss from throw blasting

A great deal of work has gone into reducing blast-induced coal damage and loss over many decades with mixed success. Practices known as ‘ski-jumping’ (Marton, 1988), ‘baby decking’ (Kanchibotla and Scott, 2000), buffering (Kanchibotla and Scott, 1999) and the use of variable stand-off distances have been attempted. However, due to the erratic nature of many coal formations, adopting a standard blasting practice for the entire mine may not provide the desired protection. Where there are variations in the geotechnical properties of the coal and rock strata immediately above and below the coal seams, the wetness of the seams, the geometry, the cohesion between layers and the type and design of the blasting method it is not surprising that variable results are often produced.

As an example, several attempts were made to reduce coal loss during throw blasting at a large mine in central Queensland including baby decking or buffering with a very large buffer of dump material compacted in front of the coal seam. A combination of both techniques was also applied. Despite all efforts unacceptably high coal losses remained (Goswami *et al*., 2008). This stemmed from the widely held belief in the industry that a properly constructed large buffer is all that is required to minimise coal loss. , This is not the authors’ experience: by way of an example, FIG 8 shows a buffer completely covering the coal seam and extending the entire width of the void, a method that still resulted in coal losses in excess of 20% (result shown in FIG 11).

FIG 8 - Throw blast with a baby deck and a large buffer which resulted in significant coal damage and loss

The introduction of the Stratablast^{TM} technique at this mine was able to eliminate these coal losses completely (Goswami *et al*., 2008) as a major application of this method, hereafter referred to as the ‘new method’, is in such single seam throw blasts that are particularly prone to coal loss. With the technique, a ‘coal protection’ layer is introduced as a second blast underneath the throw blast, with both blast layers being part of the same single cycle of drilling, loading and blasting. The bottom layer is fired in stand-up mode, several seconds after the completion of the upper throw blast. As such, it provides a layer of intact stationary rock ‘capping’ the underlying coal seam during the progression of the throw blast, completely eliminating the possibility of any coal loss. The subsequent firing of the stand-up blast layer occurs underneath the stationary throw blast muckpile. Confinement by the upper muckpile ensures that the stand-up blast cannot displace any coal, merely fragmenting the rock cap to allow for its excavation later.

Another benefit of this technique is the protection of the coal seam from excessive damage caused by falling rock in the throw blast. FIG 9 shows the output of the SoH blast model for a conventional throw blast and the new method in the same strip in a mine in the USA. It can be seen that extensive cracking and damage occurs in the coal seam (shown as the green layer) due to the conventional throw blast, while the new method shows only slight coal damage. Protection is provided to the coal seam by the overlaying layer of intact rock during the throw blast phase.

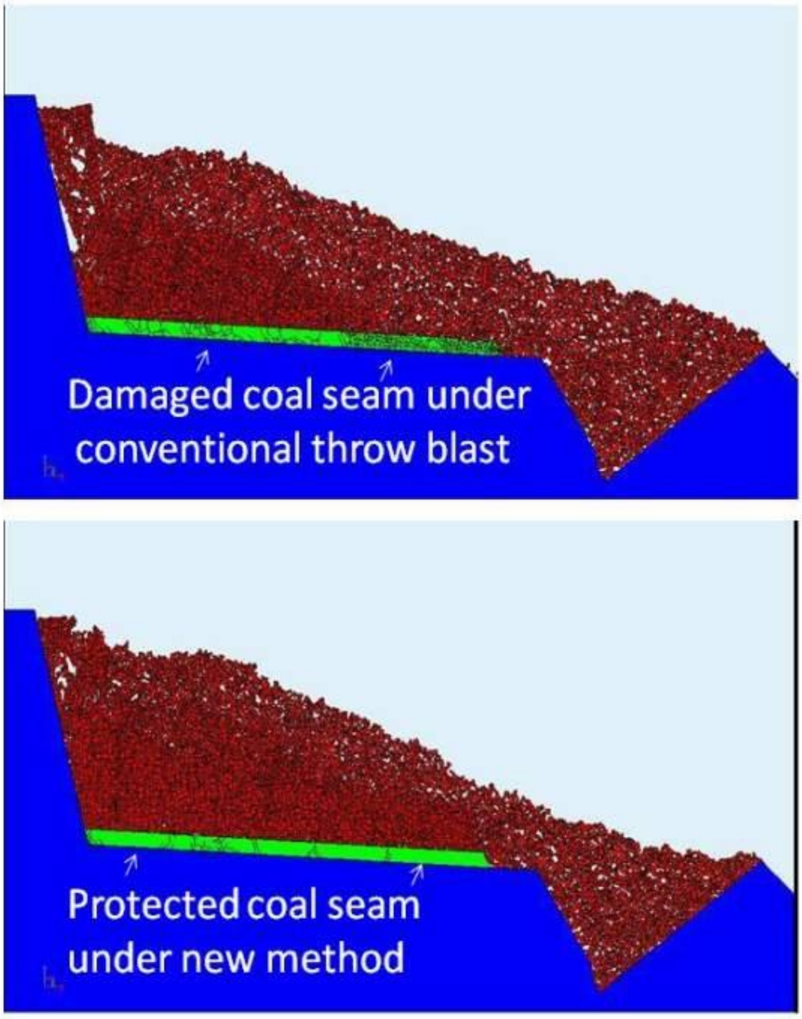


FIG 9 - SoH model showing damage due to conventional throw blast (top)
compared to the new method (bottom)

Recovering thin coal seams

As overburden depths increase, production pressures mount. Mining of multiple coal seams is thus often not attempted as the larger number of mining cycles becomes too onerous and costly. The application of through-seam blasting where seams are separated by a few to several metres is recommended in many cases. Where more complex multi-seam situations arise, particularly where free faces are involved or throw blasting is employed for dragline operations, more complex methods such as the new method have been successfully used to blast several layers in a single blast cycle (for example Goswami et al., 2006). The uppermost overburden is usually blasted to maximise throw whereas the interburden and coal layers are blasted in stand-up mode. The movement of all these layers has to be controlled to avoid edge loss due to the throw section of the blast and damage and dilution to the other coal layers within the stand-up section of the blast. The process requires knowledge of the exact location of the coal seams, and knowledge of the rock properties at the roof and floor of the coal seams (to ascertain stand-off distances and the correct explosive energy where required). FIG 10 shows a schematic of this method to recover a seam that was previously wasted.

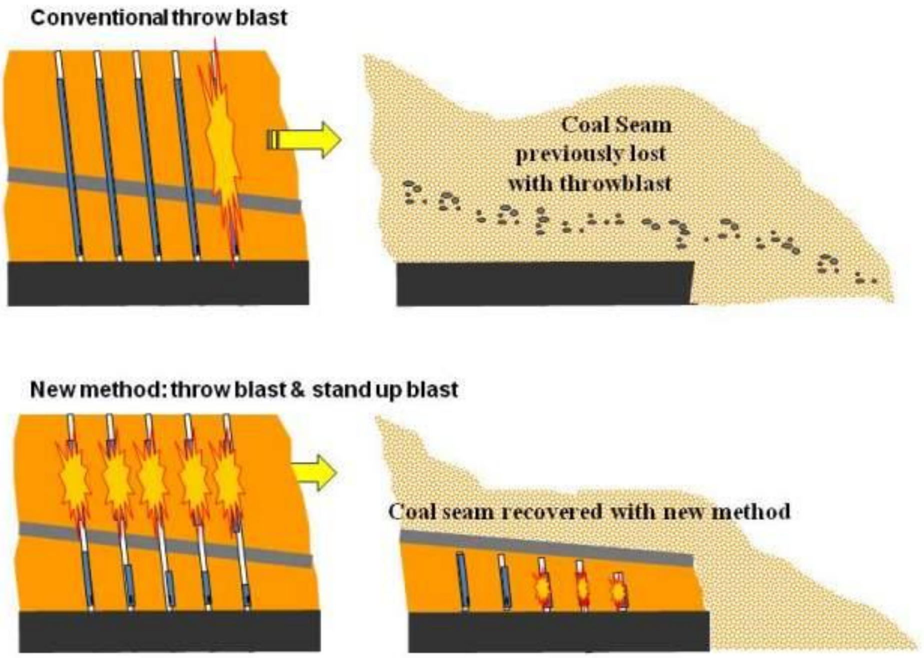


FIG 10 - Recovering a thin coal seam that would be wasted by conventional throw blasting

Coal seams as thin as 160 mm have been successfully recovered by careful blast design and adopting suitable excavation techniques. While coal from such thin seams does not always meet the required quality specifications, substantial additional revenue may result. Goswami *et al.* (2010) presented a case study of recovering thin coal seams.

Producing cleaner coal and generating additional revenue

We propose that the production of cleaner coal from the pit should receive more attention from the industry as it would save further wastage during the washing process. This again increases resource recovery and reduces overall mine GHG intensity while increasing revenue.

Often, core samples are collected from the exploration holes drilled at a large grid size to construct a geological coal model. In many cases, the quality and quantity of future coal production is estimated from these models. Sales contracts may even be entered into on this basis, well before the mining process commences. After exposing the coal, further sampling is carried out. Almost always there are major discrepancies between the geological models and the coal actually recovered, both in terms of quality and quantity. Accurate reporting and accounting of coal therefore remains questionable.

In Queensland and New South Wales (NSW), mine sites without access to a washing plant sell coal on the basis of spot sampling. Depending on the coal quality, they negotiate an agreed price from the customer or sell it on the spot market. Any improvements in % ash, moisture content and volatile matter will attract substantial value.

Judicious washing decisions can also be made on whether it is necessary to wash the coal as the final yields from the washing plant can reduce the overall recovery by as much as 35% (Australian Mining Services, 2001). Moisture contents may also increase due to washing. Reducing these wash plant coal losses and the final product moisture content by avoiding washing can thus add enormous value.

Whether washed or not, any reductions in ash and moisture content have environmental benefits in addition to the revenue and cost benefits. Ash and moisture add to transport and handling burdens per tonne of coal. Coals with higher ash and moisture content have lower heating values and produce power at lower efficiencies, thus having a higher GHG impact for power generation (Sharma *et al.*, 2001).

The new method has been found to not only recover significantly more coal but also to improve recovered coal quality by reducing in-pit dilution with waste. If well-controlled blasting practices are implemented and the coal is excavated with the proper equipment then the quality of final product coal can be improved. Very important to the success of the new method is the attention paid to all aspects of blast design. These all have a role to play in affecting coal loss and quality, the latter by reducing dilution. The following aspects are considered to be important:

- Locating the top and bottom of all coal seams along the blast block. This is usually done with natural or induced gamma logging at regular intervals so that the physical position along with geological disturbances and undulations can be predefined.
- Determining rock properties immediately above the roof and below the floor of all the coal seams (about 3 to 4 metres). This helps the blast designer to decide stand-off distances, which usually vary along the blast, as well as to locate explosives energy where required. Importantly, this information is used to design the timing of the blast such that adverse effects of ‘V’, ‘zip’ and ‘row-by-row’ firing are minimised. Multiple point initiation has been adopted in the new method and has delivered successful outcomes.
- The above also leads to consideration of the accuracy of timing. It is well known that non-electric initiation systems have an inherent timing spread or scatter. The actual delay between two charges might vary anywhere up to about 40 ms. This scatter depends on the products and the actual delay - usually longer delays have a larger scatter and the down hole delay scatter dictates the actual inter-hole delay. By comparison, electronic detonators provide almost exact firing times; with scatter generally ± 0.01%. This detonator accuracy in turn controls the energy release of bulk explosives which drives the ultimate rock mass movement. Without precise control, it is not possible to control the rock movement which drives throw and displacement of the rock and coal.
- The rock condition immediately below the coal seam is often overlooked. This is believed to play a significant role. For example, if the floor of the coal is soft (such as saturated mudstone or shale), excessive explosive energy can push the coal down into the floor thereby diluting the coal. Conversely, if the floor comprises competent rock (such as conglomerate) then the possibility exists for the coal to move out horizontally (or laterally) and thus to be lost in the spoil. As discussed earlier it has been observed by the authors that often such lateral movement resulting in coal edge loss is associated with the formation of trenches in the coal almost parallel to the coal edge loss. FIG 11 shows such trenches in a blast that had substantial edge loss under the spoil pile. FIG 12 shows both a trench in the coal and the edge loss.

FIG 11 - Coal loss with the formation of deep trenches, despite use of buffering and baby decks

FIG 12 - Formation of trenches parallel to coal edge movement

Many blasts using the new method have been fired since its introduction and the coal recoveries have generally been accounted to be in excess of 95%, commonly 100% (for example Goswami *et al.*, 2008 and Goswami *et al*., 2010).

INCREASING THE PRODUCTIVITY OF SURFACE MINING

Muckpile shaping

The explosive energy can be used to tailor a muckpile shape that would make a dragline or truck and shovel operation more productive. Successful attempts have been made to create ramps for dragline access, thus minimising dozer push requirements. These methods, usually based on specific explosive loading and initiation design, can be used to 'stand-up' muckpiles to suite particular equipment such as excavators, shovels or loaders.

Conversely, maximising throw, especially for dragline operations, has been reported many times, especially by using appropriate electronic delay sequences (for example Brent, 2002; Brent *et al.*, 2003; Brent and Noy, 2005). This does not require any additional explosive energy input, merely well-crafted timing designs.

Another area which requires optimisation in multiple pass dragline excavation is rehandle. For a discussion of muckpile volumes and relationships to coal exposure rates, see Brent and Noy (2009). The rehandle volume can be significantly influenced by the blast design.

Improving machine productivity

The coal industry has sponsored many research programmes over the past two decades, largely through the Australian Coal Research Programme (ACARP) in Australia, which have resulted in productivity gains. For example the Australian coal mining industry has gained at least 10% improvement in dragline productivity since 'bottom line' research and development, initiated with the assistance of ACARP commenced in the 1990s. This equates to a value of around AUS$2 million per dragline per year or AUS$150 million per year for the Australian coal mining industry as a whole (ACARP, 2008).

Improving the ease with which the muckpile can be excavated, commonly known as the 'diggability', would further add to these productivity gains. In this regard, blast design can be modified to produce muckpiles of varying degrees of swell or tightness.

Combining multiple bench operations into fewer benches and reducing the number of drill, blast and load cycles can also increase overall equipment productivity and can reduce machine movement time. Optimising haul distances by bringing the waste dump closer to the excavating machinery, designing for dual-side shovel loading, use of appropriate buckets and optimising the dump height for the dragline based on boom height, reach and swing angle are other areas that can be modified to increase productivity and achieve savings. In most cases, such productivity gains will be associated with reduced energy consumption and thus GHG emissions per unit of coal produced.

Scheduling

Most mines have long, medium and short term planning and scheduling in place. However, fluctuating mineral pricing and demand often forces operations to adopt selective mining. This usually disrupts the planned mine schedule resulting in unnecessary machine movements within the pit. There will also be occasions when the dragline has to travel several kilometres (or miles) to remove interburden after the completion of coal excavation. These machine movements can be avoided by adopting methods such as the one advocated here where several layers can be blasted as one blast event. This avoids unnecessary machine movement resulting in productivity gains, cost savings and reductions in energy consumption and thus GHG emissions. Goswami and Brent (2010) presented a case study of productivity gains from combining multiple benches on steeply dipping coal seams into single blast cycles.

THE POTENTIAL

A medium-sized Australian open cut coal mine might typically recover a 5 m thick coal seam to yield a total production of 5 Mt per annum at a stripping ratio of 1:6. Based on the GHG intensity reported by BMA (2006), such a mine would emit the equivalent of approximately 410 kilotonnes of CO_2 annually, from energy consumption and seam gas emissions. At a carbon emissions price of AUS$25 per tonne of CO_2 this mine could potentially be liable for in excess of AUS$10 million annually.

As an example of improved recovery using our blasting methods, a mine in the Hunter Valley of NSW had a thin coal seam (maximum thickness of 240 mm and average thickness of 200 mm) in the interburden. This thin seam was wasted throughout the length of the strip. The strip length was 1800 m and the strip width was 60 m. This meant around 30,000 t of coal was being wasted per strip. At prevailing coal spot prices of around AUS$200 per tonne this coal was worth around AUS$6 million. As the mine averaged four strips per year the annual potential extra revenue that could be generated from recovering this thin seam was AUS$24 million. This additional revenue would easily pay for the entire mine’s carbon pricing liability. Of course, the coal also becomes a usable energy resource and reduces the need to mine additional coal elsewhere. This thin seam was in fact recovered using the new method. For the typical mine mentioned above, this would effectively reduce its stripping ratio to 1: 5.75.

We propose that there is enormous potential for mines to recover much of the coal that is currently lost, simply through the implementation of improved blasting methods. This can be achieved through recovering thin coal seams that are now wasted, reducing throw blasting losses and reducing dilution. A combination of all three of these methods is possible at several sites. As demonstrated above, the additional revenue derived from the extra coal can more than pay for a mine’s entire carbon pricing liability.

Importantly, the additional coal becomes a usable energy resource and reduces the need to mine coal elsewhere. Other mining liabilities and environmental impacts such as land and water use are thus saved. Waste coal that is not dumped in the spoil also cannot undergo spontaneous combustion or slow oxidation, a further environmental concern for many pits and yet another source of GHG emissions. Reduced spontaneous combustion was recognised as a benefit of the new method by the mine reported in Goswami *et al*. (2010).

Improved machine productivity, through any of the methods discussed earlier, will further add to the revenue gains and reductions in energy and emissions intensities.

CONCLUSIONS

The surface coal mining industry faces several challenges, notably increasing strip ratios. Surface coal mining is further challenged by GHG issues and a potential cost associated with GHG emissions. We have presented a case for blasting methods that can increase coal recoveries, and mine productivity and profitability. In general, these methods require little or no change to the mining energy inputs and overall mining activity and area mined. The increased coal recovery can lead to substantial revenue gains, more than offsetting the total potential mine GHG emission costs, and lead to reductions in mine energy and GHG intensities.

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FIGURE CAPTIONS

FIG 1 - Measured atmospheric concentration of CO_2 and CH_4 (reproduced from IPCC, 2007)

FIG 2 - Global atmospheric temperature fluctuations over the past 130 years with atmospheric CO_2 concentration superimposed (from Karl *et al.*, 2009)

FIG 3a - Disappearance of Arctic sea ice (from Karl *et al.*, 2009) and

FIG 3b - Sea level rise (from Solomon *et al*., 2007)

FIG 4 - Energy inputs and greenhouse gas emissions from surface coal mining typical of Australian conditions (from Brent, 2009)

FIG 5 - Energy use and GHG emissions and intensities as reported by BMA (2006)

FIG 6 - A throw blast with baby decks, 'V opening and row-row timing' which resulted in visible coal plumes and serious coal loss shown by contours in exposed coal roof (bottom)

FIG 7 - Wasted thin coal seams

FIG 8 - Throw blast with a baby deck and a large buffer which resulted in significant coal damage and loss

FIG 9 - SoH model showing damage due to conventional throw blast (top) compared to the new method (bottom)

FIG 10 - Recovering a thin coal seam that would be wasted by conventional throw blasting

FIG 11 - Coal loss with the formation of deep trenches, despite use of buffering and baby decks

FIG 12 - Formation of trenches parallel to coal edge movement