Autonomous and remote operation technologies in Australian mining

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Centre for Social Responsibility in Mining

The Centre for Social Responsibility in Mining (CSRM) is a centre within the Sustainable Minerals Institute, University of Queensland, Australia. CSRM works with companies, communities and governments to respond to the socio-economic and political challenges brought about by resource extraction. The Centre's aim is to help build the capacity of these stakeholders to manage change in more effective ways. CSRM has global reach, with particular experience in Australia and the Asia-Pacific. For more information visit our website at: http:// www.csrm.uq.edu.au.

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CITATION

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EXECUTIVE SUMMARY

Autonomous and remote operation technologies are set to transform the Australian mining industry. These technologies will instigate a change in the nature of employment in the mining sector and as a result, the way in which mines interact with the communities in which they operate. Such a wide reaching transformation warrants the participation of an equally broad group of stakeholders in order to understand the scale and extent of potential implications and as a result, manage the transition with the best chance of sustainable success. This paper provides background information for a roundtable involving multi-disciplinary stakeholders to be held on 24 November 2011 and titled *Autonomous and remote operation technologies: harnessing the societal benefits for Australia*.

Project rationale

- Together, autonomous and remote operation technologies allow sophisticated integration of mining systems, delivering major efficiencies in production as well as fundamentally changing the mining process.

- The social dimensions of mining and their importance to ongoing operation are well known and are under continuing investigation within the fields of (*inter alia*) stakeholder theory, community relations, sustainable development, Social Licence to Operate (SLO), human rights, gender equality, social impact assessment and governance. If automation is to change the nature of mining, it will inevitably change the way mines interact with individuals and the communities in which they operate.

- This project aims to explore these social dimensions of autonomous and remote operation technologies in order to inform decision-making about the uptake and implementation of these technologies. Early consideration of potential social dimensions facilitates the identification of unintended consequences and potential societal benefits, allowing for their informed management.

- The roundtable will provide an opportunity for multi-stakeholder dialogue about the social implications of automation.

Autonomous and remote operation technologies in Australian mining

- The term automation generally refers to the full or partial replacement of a function previously carried out by human operators - either physically or mentally (Parasuraman et al. 2000; Thorogood et al. 2009:2).

- Autonomous and remote operation technologies represent different levels of automation, with autonomous systems representing the lowest level of human involvement and highest degree of automation (The Royal Academy of Engineering, 2009).

- Autonomous and remote operation technologies are being pursued to improve efficiency and productivity (in the context of declining quality of reserves), address the labour shortage and improve health and safety, working conditions and environmental performance (Rio

Tinto, 2008; CSIRO, 2009; Parreira et al. 2009; Bellamy and Pravica, 2010; Parreira and Meech 2010).

- Autonomous and remote operations feature in a number of visions for the future mine (Rio Tinto, 2008; CSIRO, 2011 and Anglo American, 2011).

- Most automation is currently concentrated on the component or subsystem level providing semi-autonomous operation, and is engaged on a small scale relative to the number of mines, processing plants and export facilities in Australia (Lynas and Horberry, 2011a).

- The strongest growth in automation is expected over the next 10 years and is expected to involve a gradual shift towards automation at the systems level and eventually leading to fully autonomous operation cycles (McAree and Lever, 2010).

- Opinion differs as to whether the most rapid growth in the uptake of these technologies will be in underground or surface mining.

Automation and the individual

- Despite decreasing levels of human involvement with increasing automation, humans continue to play an important role in systems operation, especially in terms of coping with unexpected situations (Lynas and Horberry, 2011a; Sheridan, 2002).

- Automation can introduce new sources of stress, such as information overload and boredom and new risks such as automation-induced complacency, over reliance on and poor understanding of automated equipment and poor communication and coordination between automated equipment and human operators, including human intervention during system failure. Such sources of risk have been observed across the aviation, transportation, medical, manufacturing, materials handling, nuclear power and processing industries by Lynas and Horberry (2011a).

Automation, employment and work culture

- Predictions about the workforce implications of automation range between significant reductions in a mine workforce and an ongoing need for on-site roles that will increase with industry growth (Grad, 2010).

- Our own discussions with industry representatives indicate a possible 30-40 per cent reduction in the mining workforce (50% reduction in operational roles) at those operations which adopt large-scale automation.

- Truck driving seems the most likely function to be carried out autonomously at a large scale.

- Bellamy and Pravica (2010) make a more significant estimate of a 75 per cent reduction in the overall workforce at BHP's Mouth Kieth nickel mine, as a result of fully automating the haul truck fleet (Bellamy and Pravica, 2010).

- Previous research by the Centre for Social Responsibility in Mining (CSRM) found that 50 per cent of Indigenous employees in an Australian mining operation occupied semi-skilled positions such as truck driving, followed by traineeships (20%), trades (12%), and administration (7%). This indicates that Indigenous groups, in particular, are likely to be significantly impacted by the large-scale uptake of automation.

- In other sectors, automation has introduced changes to the workforce culture such as a transition to flexible working conditions and a shift in the management style (Co et al. 1998; Laventhal et al. 2010).

- Autonomous and remote operation technologies may also present opportunities for other demographic groups (such as women and people living in larger regional centres) to participate in the mining industry – spreading the benefits of mining and increasing workforce participation in the mining sector.

Education skills and training

- Automation generally increases the complexity of a job and the skill level required (Co et al. 1998; Laventhal et al. 2010).

- This could present opportunities to build human capital by increasing the skills and quality of work for mining employees.

- Current projects in Australia, such as those being undertaken by the Mining Industry Skills Centre (MISC) and as part of a pre-conference workshop at the AusIMM Future Mining Conference 2011, are looking at the education and training requirements of automation as well as the future mine more generally.

- The CRC for Mining (through MISC) describes a Certificate III in Electrotechnology as the foundation qualification for supporting automation technologies. McAree and Lever (2010) advise that a seven to ten year timeframe is required to upskill existing workers to the capability of an Automation Technician (Certificate III in Electrotechnology). There is only a four to five year period before that role is in demand and there is currently no training package available to address this deficit (Dudley et al. 2010).

Business development, community investment and presence effects

- Business development opportunities associated with mining can provide important regional development opportunities (Rolfe et al. 2010). A diverse regional economy also has benefits

for a mine site therefore mines often take an active role in supporting local business development.

- The local business development and local employment prospects associated with mining are likely to change in the context of large-scale uptake of autonomous and remote operation technologies, as a result of associated changes in workforce structure and location and technical and professional service requirements. Local employment and business development are key factors in the value proposition to communities from mining.

- Mining companies often make other investments in communities to: facilitate community relations and maintain a desired quality of life for employees, ensure critical infrastructure and services are there for the mine to operate and to fulfil land use agreements. If the implementation of autonomous and remote operation technologies results in a change in employment and business development opportunities in regional and remote communities, this could have implications for the nature and scale of community investments.

- Under current policy arrangements, if automation results in a smaller resident workforce, this would generate a reduction in population-dependent government services and funding levels for regional communities (such as those relating to health and education). This creates a tension similar to that experienced with the increasing use of fly-in fly-out workforces at some mine sites in close proximity to regional communities.

Public acceptance and Social Licence to Operate

- The issues or changes associated with the uptake of automation, along with public perception of the technical risks, stand to influence public acceptance of the technology. This in turn could impinge on the Social Licence to Operate of a mine or industry more broadly, particularly where mines are seen as an important source of local employment and there are few other economic opportunities available (e.g. South Africa, Peru).

- Industrial relations will be an element of broader public acceptance of these new technologies. There have been examples of unions, as representatives of the workforce, not supporting automation in other sectors (Laventhal et al. 2010). Already, the Construction, Forestry, Mining and Energy Union (CFMEU) has expressed concerns about the safety risks of autonomous vehicles and implications for job creation (ABC News, 2011a; ABC News, 2011b; Kirkman, 2011).

- Earning a Social Licence requires, among other things, open communication among all stakeholders (Thomson and Boutilier, 2011). Studies relating to Technology Assessment also build a case for involving affected parties in the early stages of technology development to help address potential social risks and build public acceptance of new technologies (Franks and Cohen, 2011).

1.   INTRODUCTION

Autonomous and remote operation technologies are being pursued in the Australian mining industry with the multiple objectives of improving productivity, environmental performance and health and safety, as well as addressing labour shortages and reducing costs. The application of these technologies ranges from plans to fully automate and integrate entire operations to the incorporation of autonomous technologies (such as driverless trucks) into selected surface and underground mines (Grad, 2010). Evidence of the success of these technologies in terms of productivity improvements, health and safety, environmental performance and labour efficiencies is starting to emerge (CSIRO, 2009; Parreira et al. 2009; Bellamy and Pravica, 2010; Parreira and Meech, 2010).

To date, there has been little public consideration of the broader societal implications of autonomous and remote operation technologies. These are important considerations in the context of industry's commitments to sustainability and its Social Licence to Operate (SLO) as well as the future role of mining in regional development. Discussion about the development and application of these technologies appears to be taking place predominantly in the technical research and development and innovation domains. An exception is the work of Bellamy and Pravica (2010), which analyses the social and economic impacts of driverless haul trucks at BHP's Mount Kieth nickel mine. There has also been some consideration of the social dimensions of this technology change internationally through the work of Mottola and Holmes (2009) and Parreira et al. (2009).

Our discussions with industry representatives indicate that some major companies are starting to address the long-term training needs associated with autonomous and remote operations and incorporate the change in their own workforce planning. However, there are few examples of a broader dialogue emerging in the public domain involving stakeholders such as mining communities, training organisations, contractors, traditional owners and government. To date, this has been constrained because of sensitivities around the implication of the technology for the workforce, the highly competitive approach to the development of these technologies and the view that it's too early in the technology development process to open it to an external audience. This could be perceived as a lack of transparency, which threatens trust and limits the ability of stakeholders to adequately prepare for and benefit from the transition.

Based on the experience of introducing automation technologies in other sectors as well as industry commentary on its application in Australian mining, we expect that the large-scale uptake of autonomous and remote operations technologies would reduce employment in some roles while creating other new roles and requiring the development of new skills. Already, the Australian mining industry is preparing for this transition as evident in work by organisations such as the Mining Industry Skills Centre's (MISC) Automation Skills Formation Strategy.[1] However, combined with the move to co-locate workers in centralised remote operation centres, this has potentially significant implications for semi-skilled and unskilled workers who live in regional and remote areas and are not geographically mobile (particularly Indigenous employees). There are also likely to be changes in the ways mines interact with the communities and regions in which they operate.

This project aims to initiate consideration of the wider societal implications of the large-scale uptake

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[1] The Mining Industry Skills Centre's Automation Skills Formation Strategy (ASFS) is a Department of Education and Training (DET) initiative seeking ways for industry and key stakeholders to collaborate on workforce planning and workforce development initiatives specific to an industry, community or future technologies. http://www.miskillscentre.com.au/our-services/workforce-planning-initiatives/automation-for-success.aspx

of autonomous and remote operation across a broader group of stakeholders. Its intent is to identify potential unintended consequences or 'embedded conflict' as well as opportunities to build human and social capital and inform the development of strategies to harness the societal benefits of this technology change.[2] Stakeholder participation in a dialogue about these issues itself will help to contribute to these aims. In particular, we are interested in the overall change in employment levels and structure and the particular effects this will have on different demographic groups such as women, Indigenous people and members of regional and remote mining communities.

This work focuses on the application of autonomous and remote operation technologies in surface mining operations for bulk commodities such as iron ore while drawing examples from underground operations and other minerals. This is because these forms of mining account for the majority of people employed in mining now and into the future (based on current projections) and also represent an area of potential future growth in the uptake of autonomous and remote operations technologies.

This work also serves as an application of a Technology Assessment (TA) process, called Social License in Design, being developed to assess the social and environmental implications and improve the sustainability outcomes of new technologies being developed under the Commonwealth Scientific Industrial Research Organisation (CSIRO) Minerals Down Under Flagship program (Franks and Cohen, 2011) (See Appendix A).

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TEXT BOX 1.1: PURPOSE OF THE ROUNDTABLE EVENT – AUTONOMOUS AND REMOTE OPERATION TECHNOLOGIES: HARNESSING THE SOCIETAL BENEFITS FOR AUSTRALIA

24 November 2011
The Australian Museum
Sydney, Australia

This paper provides background information for a multi-disciplinary roundtable event, titled Autonomous and remote operation technologies: harnessing the societal benefits for Australia. The roundtable provides an opportunity to discuss the social implications of autonomous and remote operation technologies outside a technical audience and at an industry level, with respect for the commercial sensitivities of individual companies' approach. It initiates a multi-stakeholder process of identifying opportunities to build social and human capital through the implementation of autonomous and remote operation technologies and to identify possible management strategies to address unintended consequences.

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[2] Embedded conflict describes technology design traits that have the potential to manifest into conflict at some point during implementation but once sunk into a landscape, mining technology can be difficult and costly to retrofit (Franks *et al.* 2010).

2. AUTONOMOUS AND REMOTE OPERATION TECHNOLOGIES IN AUSTRALIAN MINING

Together, autonomous and remote operation technologies are transforming Australian mining. While these two streams represent different levels of automation, together they allow sophisticated integration of mining systems delivering major efficiencies in production as well as fundamentally changing the mining process. These technologies also have a similar, and compounding, influence on the mine workforce and the communities in which mines operate. Both technological trends create new activities in the workplace, require higher order skills, remove particular roles (absolutely or from a particular location) and create new ones. The societal consequences of both autonomous and remote operation technologies are being considered in this project.

2.1. AUTOMATION AND AUTONOMOUS OPERATIONS

The term automation generally refers to the full or partial replacement of a function previously carried out by human operators - either physically or mentally (Parasuraman et al. 2000; Thorogood et al. 2009:2). The main objective of automation is 'to control the behaviour of dynamic systems and emulate the maximum physical and intellectual human capacity to improve productivity through increased accuracy' (Parreira *et al.* 2009:2). The development of automation technology depends on advances in other information and communication technologies such as those outlined in Box 4.1. It can be applied to a range of mechanical, sensing, data processing and communication processes (Sheridan, 2002) to components of a system (e.g. a valve) or complete systems (e.g. a dragline) (Lynas and Horberry, 2011a).

TEXT BOX 4.1: TECHNOLOGIES UNDERPINNING DEVELOPMENTS IN AUTOMATION

- **Communication technology**
  Advances in communication technology have enabled larger amounts of data to be transmitted with limited latency (time delay) over greater distances and with increased reliability (e.g. digital video compression and the adaptation of wireless Ethernet (Madhavan, 2001)).

- **Sensing technology**
  Advanced sensing technologies that are robust enough to operate in the mine environment are used for monitoring equipment health, operation and location (e.g. two-dimensional radar and terrain and local-area mapping).

- **System processes**
  The development of increasingly sophisticated systems processing and control capacity along with increasing computer processing power to enable management and analysis of mine-wide information systems, including protocols for exchange of data between different systems.

- **Navigation and imaging technology**
  Navigation and imaging technology (e.g. high precision GPS in the open pit situation and two-dimensional radar imaging in the underground situation) to enable machines to know where they are (relative navigation).

Automation can be achieved at differing degrees. The terms direct control, supervisory, automatic and autonomous systems describe a continuum of increasing levels of automation and decreasing human intervention (The Royal Academy of Engineering, 2009). Riley (1989) defines automation levels as combinations of 'intelligence' and 'autonomy' varying along two dimensions.   Automation with high levels of autonomy can carry out functions with only initiating input from the operator and at the highest levels, the functions cannot be overridden by the human operator (Parasuraman, 1997 in Lynas and Horberry, 2011a).

Despite the ability for decreasing levels of human involvement, various authors stress the continuing importance of the human. Lynas and Horberry (2011a) note examples where automation fails because the role of the person performing the task is underestimated, particularly the ability to compensate for the unexpected or in their ongoing role in data entry. Sheridan (2002) also argues automated systems often lack the flexibility of humans needed to handle unanticipated situations.

Automation technology is used across a range of process-based industries including manufacturing, food and beverage production, water and waste management and power generation and in the petrochemical, pharmaceutical and metals and mining sectors. The automotive industry in particular has applied automation to achieve major improvements to productivity and product quality (Yeung, 2004).

In the mining sector, automation has been used over the past 50 years to enhance efficiency, remove operators from hazardous environments and to improve the accuracy and reliability of data collection and processing to inform environmental management and minerals processing. It has been applied to both the machinery and equipment used in the mining process (such as drilling, blasting, loading and hauling) as well as to monitoring, control and communications systems and planning and design tools (Lever and McAree, 2003:9). Driverless technology was first used throughout Europe and the United States in the 1960s and 1970s (Konyukh, 2002 in Lynas and Horberry, 2011a). Automated drills were also developed in the United States during this time (Bellamy and Pravica, 2010). However, more recent developments have created autonomous operations requiring no human intervention, along with the integration of automated components increasing coordination and efficiency.

2.2.   REMOTE OPERATIONS

The use of automation in mining has also involved various forms of remote control. This is where machines and processes are monitored and controlled at a location remote from the activity. This includes remote operation (e.g. drilling performed by workers using a joystick at a distance) and direct tele-operation (e.g. controlling the mining process from a computer in a control room) (Parreira and Meech, 2010). These forms of remote control have enabled operators to be located in safer environments as well as the centralisation of functions bringing together normally disparate control systems and placing personnel supervising those systems in close proximity to one another. This ability enables greater awareness of the status of each component part of an operation, enhancing the integration of information available and providing a view of the whole operation.

Remote control ore-extraction machines were in use underground in the 1970s (Lynas and Horberry, 2011a). However, these were controlled by operators on the surface. Now, with the increasing capacity of communication systems, advanced sensing technology, systems processes, navigation and imaging technology, the location of remote control centres is becoming possible at greater distances from mine sites. In some instances, such as underground load-haul-dump (LHD) machines, the use of tele-remote systems is being superseded by autonomous navigation (Nebot, 2007). In these cases, monitoring can still be performed remotely.

2.3. INTEGRATION THROUGH AUTONOMOUS AND REMOTE CONTROL TECHNOLOGIES

The increased control and accuracy achieved by reducing human input through automation enhances the potential for integrating information and delivering coordinated processes for improved efficiency. The integrating function of remote control technologies also captures the benefits of the control and accuracy achieved with autonomous equipment, especially where it interacts with other equipment (manned or autonomous) by providing a framework to manage the interaction (Lever and McAree, 2003:13). Figure 1 depicts an interpretation of this relationship.
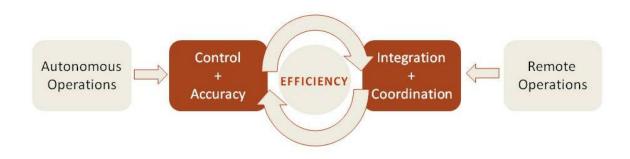

Figure 1: Together autonomous and remote operations deliver efficiency gains.

Through integration, components of the overall mining system can be managed as part of the whole and in the knowledge of the conditions of the other components. This enables efficiencies where discrete parts of the process – such as mining, processing, transporting and export – interact. For example, rates of mine processing depend on the rate at which ore is delivered by the mine. With integration, processing operations and milling rates can be adjusted to account for changes in the rates of mine production. Similarly, rail operations can dispatch more trains when a peak in demand for loading ships is anticipated.

Nebot and Baiden (2007) refer to the benefits of integration in the following way:

> *"...the key to successful management of the overall mining system is to understand how component systems can work together and to devise technology to allow these elements to function as part of the overall system. Specifically in mining, mine sites consist of personnel, vehicles and machines that have to be allocated according to the best geophysical knowledge available, market conditions and financial constraints. The real-time availability of information such as ground conditions, ore-body morphology and grade distribution will make high fidelity simulation of systems essential to rapidly adapt to the dynamics of the actual circumstances. The full integration and analysis of systems will also be of fundamental importance to develop the concept of distance mining."*

2.4. DRIVERS FOR AUTONOMOUS AND REMOTE OPERATION TECHNOLOGIES IN MINING

Mining operations are increasingly adopting and continuing to develop autonomous and remote operation technologies with the multiple aims of improving efficiency and productivity (in the context of declining quality of reserves), addressing labour shortages and improving health and safety, working conditions, and environmental performance (Rio Tinto, 2008; CSIRO, 2009; Parreira *et al.* 2009; Bellamy and Pravica, 2010; Parreira and Meech 2010).

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Autonomous technologies deliver a range of productivity gains. In terms of driverless vehicles, removing the variability of human performance increases the efficiency of machine utilisation through reduced idling and consistent driving speeds improving fuel efficiency (Ashley, 1995; Bennick, 2008 and Murphy, 2011). Machine utilisation is maximised as there is less down-time associated with breaks and shift changes (Bellamy and Pravica, 2010). The costs associated with physical damage resulting from human error, such as collisions and tyre wear, are also removed (Ashley, 1995; Caterpillar, 2011; Kral, 2008) and other productivity gains arise from being able to reduce the distance allowed between operating vehicles (Bellamy and Pravica, 2010) and reduced maintenance (Kral, 2008).

The safety gains arising from automation and remote operation include removing people from hazardous and inhospitable working environments (CSIRO, 2009:2). For example, workers are not exposed to the risk of mine collapse during excavation in underground mines (Parreira *et al.* 2009) and drill operators are removed from one of the most dangerous environments in the industry (Moore, 2009). The potential for injuries to occur when operators access or egress from machines or through head-to-head or head-to-tail collisions, is also reduced (Ashley, 1995).

In Australia, autonomous and remote operation technologies can also provide a solution to the growing labour shortage, particularly in the more remote mining regions. This is an important contextual driver in Australia as a skilled labour shortage is identified as a major constraint for industry. Rio Tinto's Head of Innovation stated that "at any given time Rio Tinto Iron Ore has at least 600 open positions and this problem will be magnified in the future" (Cribb, 2008:13). In the Pilbara, automation and remote operation provide a means of meeting increased production demands "without having large issues about how to get more and more people into remote locations, or the costs to bring them there and how to keep them safe" (Tom Albanese, Rio Tinto Chief Executive in Rio Tinto, 2009a). This sentiment was also expressed by Neville Power, Chief Operating Officer at Fortescue Metals Group (FMG) who commented that "one of the key growth challenges we face is around availability of people and the need to best utilize this valuable resource" (Williams, 2011).

There is support for automation as a contributor to productivity, safety and labour efficiency gains from the corporate level, the site level, original equipment manufacturers and research and development organisations (Dudley *et al*., 2009). Our interviews with industry and related researchers indicated that companies' share prices may also have contributed to organisational support for automation in the past, in an attempt to alter the perception of mining as a low-tech industry. Companies are now understandably determined to capitalise on their investments in developing autonomous and remote operation technologies.

2.5.   VISIONS OF THE FUTURE MINE

The quest for an increasingly technological approach to mining is captured in the various expressions of visions for a future mine. These visions encompass multi-faceted strategies to address future challenges in mining such as declining ore grades, the increasing remoteness of mines and the increasing importance of the social and environmental constraints that mining operations face, as documented by Giurco *et al.* (2009) and Ernst &Young (2011). Autonomous and remote operations in particular feature in a number of visions for the future mine (Rio Tinto, 2008; CSIRO, 2011 and Anglo American, 2011).

In its description of the future mine of 2030, CSIRO (2011) envisages that:

> *"...High power laser and plasma drilling is more common than it was in the 2020s. Logging and measuring while drilling are standard, with feedback to intelligent control systems for drill rigs. Semi-autonomous moles are guided with pin-point accuracy and are used to drill*

multi-lateral bore holes from a parent borehole. Sampling boreholes themselves are now very small in diameter, and down-hole probes measure elemental and mineralogical compositions in real time. Remotely controlled semi-autonomous rigs are able to move around in mines or in the field. Many mines are controlled from major centres. Operations are fully automated, highly selective and host minimal local support staff. Geologically 'intelligent' autonomous mining systems are capable of mining ore selected for grade, and are able to sort ore as it is mined. Deep ore mining systems keep people isolated from the hazardous activities of drilling, explosive placement, access construction and ore haulage..."

CSIRO, 2011

In 2008, Rio Tinto released its own vision for the future mine under its *Mine of the* Future™ program. Rio Tinto envisages the future mine as one where:

"...humans will no longer need to be hands on as all this equipment will be autonomous - able to make decisions on what to do based on their environment and interaction with other machines. Operators will oversee the equipment from the remote operation control room."

Rio Tinto, 2008

Rio Tinto's intention for its *Mine of the Future*™ program is captured in the following quote:

"Rio Tinto is changing the face of mining... We're aiming to be the global leaders in fully integrated, automated operations. It will allow for more efficient operations and directly confront the escalating costs associated with basing employees at remote sites, giving us a competitive advantage as an employer along the way."

Tom Albanese, Chief Executive, Rio Tinto (Rio Tinto, 2008)

In 2010, Anglo American released a vision for the future mine – *The 2030 Mine*. This vision included technology roadmaps and technology development action plans. The concept was used to define future technological requirements, across different commodities and encompass the entire value chain from exploration to beneficiation (Anglo American, 2011). There is, however, little detail in the public domain about *The 2030 Mine*.

While these visions are set some time in the future, several mining companies operating in Australia are already implementing varying degrees of autonomous and semi-autonomous operations.

2.6. CURRENT STATUS OF AUTONOMOUS AND REMOTE OPERATION IN AUSTRALIA

Levels of automation currently very considerably across mine sites – from minimal (e.g. machinery operated remotely from the surface), to partial (e.g. wash plant maintained by a central control room) to fully autonomous or integrated operations (e.g. trucks, diggers and rail fleets operated autonomously from a remote location off site). An example of fully autonomous and integrated operations is Rio Tinto's *Mine of the Future*™ program, which is one of the world's largest civilian robotics projects and the first attempt at a completely integrated system (Grad, 2010). Lynas and Horberry (2011a) observe that most automation is currently concentrated on the component or subsystem level providing semi-autonomous operation, and is engaged on a small scale relative to the number of mines, processing plants and export facilities in Australia. Text Box 4.2 summarises some examples of how autonomous and remote operation are being implemented in Australia.

TEXT BOX 4.2: EXAMPLES OF AUTOMATION AND REMOTE OPERATION IN AUSTRALIAN MINING

- **Rio Tinto's** *Mine of the Future™* program was launched in 2008 and includes an ambitious program to fully automate it's iron ore operations including remote control blast hole drills, tele-remote controlled rock breakers, driverless haul trucks, driverless trains to carry ore to port, tele-remote controlled ship loaders and integrating the operations of 14 mine sites and two ports as an integrated single large scale processing system (Rio Tinto, 2011a). This technology is critical for supporting RTIO's projected increase in production in the Pilbara of achieving up to 320 Mtpa in the coming years (Cribb, 2008).

  This ambitious program is supported by a corporate commitment to being the global leader in fully integrated, automated mining operations, leading to greater efficiency, lower production costs (especially those associated with basing employees at remote sites) and a stated aim to provide more attractive working conditions that will help Rio Tinto to recruit and retain staff in the highly competitive labour market (Rio Tinto, 2008).

  As part of its strategy, Rio Tinto has also invested in the creation of the Rio Tinto Centre for Mine Automation, in collaboration with the Australian Centre for Field Robotics at The University of Sydney (Rio Tinto, 2007).

  In 2008, a full-trial of autonomous and remotely operated equipment was established at the West Angelas open pit iron ore mine in the Pilbara. Automation components included driverless trucks (Komatsu's Autonomous Haulage System), remotely operated drilling and blasting, automated train systems and remote train loading functions.

  In June 2010, Rio Tinto opened an Operations Centre in Perth that can control Rio Tinto's rail systems, infrastructure facilities and port operations in the Pilbara. The operation involves 200 controllers and schedulers and about 230 technical planning and support staff (Rio Tinto, 2010).

  In 2011, Rio Tinto first announced that its fleet of driverless haul trucks would double and would be deployed at Rio's Yandicoogina mine, following the two year successful trial at the West Angelas mine where greater efficiency was achieved (Mining Engineering, 2011). By November, this outlook changed to a 15-fold expansion of its original form with Rio Tinto announcing that it would increase the size of its autonomous haul truck fleet to 150 trucks (40% of its fleet) by 2015 (Rio Tinto, 2011d; O'Brien, 2011).

- **Newcrest's** Cadia Valley operations in Orange, New South Wales (NSW) involve both open cut and underground mining of several extremely large but relatively low grade gold and copper ore bodies. Newcrest is currently establishing a tele-remote control centre, in which up to 300 people could work or train, in the town of Orange - a regional centre in NSW 25 kilometres (km) from the operation and 250km from Sydney (Shields, 2010). The project is not expected to reduce labour costs as extra IT personnel and electrical support are expected. According to Tony McPaul – General Manager, Cadia Valley Operations - the decision to locate the remote operations centre in Orange is largely influenced by the relationship the company has with the region and is a demonstration of Newcrest's commitment to the region (at interview, 2010).

TEXT BOX 4.2 (CONTINUE): EXAMPLES OF AUTOMATION AND REMOTE OPERATION IN AUSTRALIAN MINING

Automation in this context still employs some, although fewer people in the loading cycle. The remote operations centre will be capable of controlling and/or monitoring more than one site in Australia, including the Telfer open pit and underground operations in Western Australia, and possibly sites overseas. Among other things, it is expected to reduce traffic between the mine and town, reduce the requirement for Personal Protective Equipment (PPE) and introduce scope for flexible working hours.

- **BHP Billiton** is working on the implementation of autonomous truck haulage, blast hole drills and remote control shovels for its expansion project at the existing copper/gold operations at Olympic Dam in northern South Australia (BHPBilliton, 2011). The implementation of the autonomous trucks at the new open pit mine will be done in collaboration with Caterpillar. BHP Billiton has been working with Caterpillar since 2003 when the Olympic Dam mine reported a 40 per cent increase in productivity by using two LHDs of Caterpillar's underground automation system MINEGEM (CSIRO, 2008). In relation to its Pilbara iron ore operations, BHP has indicated that it too will move to have a remote operations centre in Perth, similar to Rio Tinto's (Chambers, 2011).

- **Newmont** is engaged in a staged program of automation at Boddington, Western Australia (approximately 130km south east of Perth). Boddington is a large, long life, low grade, open cut gold mine with operating life of 24 years. In a presentation at the Automation Conference in Perth March 2010, a Newmont representative identified a shortage of skilled labour as a motivation for automation and indicated that Newmont's aspiration is to remove all workers from the pit – a 'peopleless pit' (Clough and Tan, 2010). Alongside this vision, Newmont has also entered into a voluntary Community Partnership Agreement with the local native title applicant through the South West Aboriginal Land and Sea Council. Under the agreement, Newmont supports the employment of 100 Aboriginal people throughout the life of the mine (Newmont, 2010).

- **Fortescue Metals Group** signed a Memorandum of Understanding with Caterpillar and WesTrac in July 2011 to implement autonomous vehicles at its Solomon iron ore mine in Western Australia. Caterpillar and WesTrac will provide product and technology implementation, consulting and change management services, technicians and support personnel, as well as operate the complete autonomous system once it is implemented. An initial fleet of 12 autonomous trucks will be deployed in 2012 and a fleet of 45 are expected by 2015 (Williams, 2011).

2.7. OUTLOOK FOR AUTONOMOUS AND REMOTE OPERATION TECHNOLOGIES IN AUSTRALIAN MINING

While increases in the scale and distribution of autonomous and remote operations are expected in Australian mining, there is a great deal of uncertainty in the potential rate and extent of uptake. The strongest growth in automation is expected over the next 10 years (McAree and Lever, 2010). This is expected to involve a gradual shift towards automation at the systems level, as the reliability of autonomous equipment is enhanced, and the integration of semi-autonomous subsystems eventually leading to fully autonomous operation cycles such as dig, load, haul and dump (McAree, 2009). Full automation is very unlikely; envisaging humans either on the machines, controlling them remotely or even in fully autonomous systems, there would always be the need for a human (Goddard, 2011).

Ultimately, the uptake of autonomous and remote operation technologies will depend on individual companies' investment decisions, in the broader context of global economic conditions and Australia's evolving competitive advantage in resource investment (Giurco, 2009) as well as the compatibility of the technologies with specific mine sites and different socio-political contexts, including government support and regulatory requirements.

Opinion is somewhat divided within the mining sector as to whether the future of autonomous and remote operation will be in surface or underground mining technologies. For the next decade, large scale open pit automation trials are expected to gain momentum (Bellamy & Pravica, 2010) and key activities are likely to focus on incrementally delivering autonomous rock loading. Underground mining is seen by others to be better positioned for the uptake of new mining technologies (Goddard, 2011). For underground applications key activities will be directed to enhance situational awareness supporting operator decisions to improve energy efficiency and mine vehicle safety.

To maximise the potential of autonomous and remote operation technologies, McAree and Lever (2010), have identified the following areas that must be addressed:

- Control strategies must be developed to enable automated machines to operate interdependently with other equipment;
- Situational awareness capabilities must evolve to the point where they can replace the many and varied functions performed by human operators;
- Technologies are required that enable effective integration of automated machinery into mine systems; and
- Workforce skills must be enhanced to operate and support autonomous equipment.

Social considerations are also an important dimension to the future success of autonomous and remote operation technologies. The development of automated systems in other sectors has been associated with a considerable number of unanticipated problems and failures largely related to breakdowns in the interaction between human operators and automated systems (Sarter et al. 1997 in Lynas and Horberry, 2011a). This could include aspects of workplace culture, education and training and health and safety. Other social dimensions requiring consideration include stakeholder perspectives and perceptions of risk and the disproportionate employment impacts on specific groups within society.

3. SOCIAL IMPLICATIONS OF AUTONOMOUS AND REMOTE OPERATION TECHNOLOGIES IN AUSTRALIAN MINING

This section draws on the limited publicly available information to inform the consideration of potential social implications of autonomous and remote operation technologies. Issues are grouped according to the ways in which mines interact with people and the communities in which they operate, namely: employment; business development opportunities; education and training; community investment; 'presence effects'; and public or stakeholder attitudes towards the operation. Our view of the way a mine interacts with the community in which it operates is shown in Figure 2.

Figure 2. Mine-community interactions

Firstly, the implications of automation in other sectors and mining examples are considered to inform the scoping of potential social implications that may arise in an Australian mining context. The Pilbara region in Western Australia will be used to explore these issues in context, while acknowledging its uniqueness in terms of remoteness, scale of projected resource development and dependence on the resources industry. In particular, the implications of autonomous and remote operation technologies for the Pilbara need to be considered in the context of its potential to transition from being a localised economy with a narrow economic base to a more diverse regional economy.

3.1. AUTOMATION IN THE WORKPLACE AND SOCIETY

There is an opportunity to learn from the application of automation in other sectors and elsewhere in the mining sector to inform the consideration of the social implications of autonomous and remote operation technologies in Australian mining.

Central to a discussion about the social dimensions of autonomous and remote operation technologies, is the way in which humans directly interface with the equipment. At the human level, the introduction of automation requires higher order skills and additional training. The development of the skills and expertise required to implement and maintain automated equipment has been identified as a particular challenge in the adoption of automation in other sectors (Wilson, 2010).

Automation can also introduce new sources of stress, such as information overload and boredom and risks such as skill-degradation, automation-induced complacency, over reliance on and poor understanding of automated equipment and poor communication and coordination between automated equipment and human operators, including human intervention during system failure. Such sources of risk have been observed across the aviation, transportation, medical, manufacturing, materials handling, nuclear power and processing industries by Lynas and Horberry (2011a) as part of the 'human factors' component of this project.[3]

Ultimately, the introduction of automation eliminates some jobs and skills while creating others (Rico, 1966; Phitchinis, 1983). In relation to automated information technology, opportunities existed mainly for highly educated or skilled workers (Huang, 2009). However, in a review of the impacts of automation in manufacturing, Rico (1966) found that automation did not dramatically change the level of employment. There was a significant movement of people within the company with some jobs being eliminated and others being created with the new jobs largely being filled internally by displaced employees (Rico, 1966).

Research by Co et al. (1998 in Lynas and Horberry, 2011a) also identified that advanced automation in the manufacturing sector resulted in changes to the technical complexity of the job and skill level required. In this case, a fear of being made redundant and changes to the workforce culture were associated with automation. Cultural changes included the way management viewed its work and the morale and performance of the workers. Co et al (1998) identified that the introduction of advanced technology required a shift from a 'didactic' to a 'participative' management style as managers were required to interact with higher-educated and higher skilled workers.

At the Patricks Wharf facility in the Port of Brisbane, autonomous straddle carriers are used to load, unload and move shipping containers between ships and the port loading area and are operated from a control room in Sydney. According to Durrant-Whyte et al (2007), this system was initially developed to address low productivity associated with a highly unionised workforce in Australian ports and has since enhanced productivity and reduced maintenance costs (Durrant-Whyte et al, 2007). The transition to automated loading and unloading of ships by programmed robotic cranes and driverless vehicles globally has been cited as creating workforce challenges, such as the need to upgrade skills as well as a transition to flexible working conditions (Laventhal et al., 2010).

The changes in work requirements and workplace culture outlined require a careful change management process or risk a rejection by the traditional workforce. The introduction of new technology to the resources industry in particular must overcome a well established culture and mindset (Lynas and Horberry, 2011a).

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[3] Human Factors is the application of behavioural and biological sciences to the design and integration of tasks, machines and human – machine systems. It is concerned with understanding the interactions among people and the other elements of a work system in order to optimize human well being, safety and overall system performance.

With the emphasis on changing work systems to suit people, rather than requiring people to adapt to systems, Human Factors looks at the world with a focus on the capabilities, limitations, motivations, behaviours and preferences of people. Training is seen as a necessary complement rather than just designing and deploying equipment based on a technology-centred approach (Horberry et al. 2010). It aims to maximize efficiency, effectiveness, quality, comfort, safety and health by ensuring that systems are designed and implemented based on an operator-centred approach (Horberry et al. 2010).

In a relevant example from the mining sector, Malcolm Scoble[4] said of INCO's Sudbury LHD and Drilling Automation program that "beyond developing the new technology, there are many related social, training, and union issues that remain to be addressed - operating the new technology requires an adaptable, trained workforce" (Ashley, 1995). This statement was made in 1995. In 1998, INCO's automation program was withdrawn because of insufficient teamwork across the organization including between internal research and development groups with divergent philosophies and a lack of support from head office (Mottola and Holmes, 2009 in Parreira *et al.* 2009).

Studies are now being done at The University of British Columbia (Vancouver, Canada) to ensure the success of autonomous mining by focusing on the integration of people, technology and process through strategies such as executive sponsorship, stakeholder assessment, teamwork and internal communications (Mottola and Holmes, 2009). See Box 5.1 for more information.

The need for engagement in the transition to autonomous and remote operations extends to broader groups of stakeholders such as those representing regional development interests, Indigenous communities and traditional owners, environmental values, education and training organisations and mining communities and governments. Parreira *et al*. (2009) note that:

> "...to be successful, an automation project must identify and analyse levels of interest, expectation, priorities and influence of stakeholders in the early stages, as well as, develop a management plan which incorporates quality control, risk management, communication plans, and exit strategies. Furthermore, managing stakeholder expectations through the executing and closing project phases is integral".

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[4] Former director of the mining engineering program at McGill University (Montreal, Canada) and former head of the UBC mining engineering department (Vancouver, Canada).

TEXT BOX 5.1: THE SOCIAL DIMENSIONS PLAY OUT IN MINE AUTOMATION: THE CASE OF INCO

In 1993, Canadian Inco (now part of Vale) was working on a program to incrementally convert mine equipment into tele-operated and, later, autonomous systems. The drivers were to: overcome the challenge of an ageing workforce; reduce the costs of transporting people to and from the mining area; save time during each work shift; reduce capital costs as fewer machines and workers would be needed underground; and lower the cost of safety and environmental systems as miners would not be exposed to high temperatures, diesel fumes, and mine gases underground (Ashley, 1995).

Inco engineers successfully operated scoop trams, trucks, drills and other equipment by remote control. Among the first tele-operated technologies to be developed were an automatic haulage truck (AHT) and a tele-operated load haul dump truck (LHD). Multiple-machine control using the tele-operation station was also tested. Inco demonstrated the feasibility of one person operating two LHDs from the surface, LHD efficiency even improved by 25 percent per machine through reduced idle time. Operating errors were also reduced and it was expected that each operator would be able to direct three machines simultaneously (Ashley, 1995).

Inco tried to take the needed precautions to materialize the mine they had envisioned. Inco even developed an expert system to aid AHT novice operators and successfully faced the challenges in communication infrastructure that emerged during the trials (Ashley, 1995). But in the end, INCO's Sudbury LHD and Drilling Automation program was withdrawn in 1998 because of insufficient teamwork across the organization, between internal research and development groups with divergent philosophies, and because of a lack of support from head office (Mottola and Holmes, 2009).

Back in 1995, Malcolm Scoble noted that "beyond developing the new technology, there are many related social, training, and union issues that remain to be addressed - operating the new technology requires an adaptable, trained workforce" (Ashley, 1995). Studies are now being done at The University of British Columbia (Vancouver, Canada) to assure the success of autonomous mining by focusing on the integration of people, technology and process; and exploring critical success factors, like executive sponsorship, stakeholder assessment, teamwork and internal communications (Mottola and Holmes, 2009 in Parreira *et al.* 2009).

3.2. EMPLOYMENT

There are mixed messages about the expected impact of autonomous and remote operations technologies on employment within the Australian mining sector. While autonomous technologies reduce human input to the operation of mines, new roles are likely to be created in the observation, servicing and maintenance of autonomous and remotely controlled equipment. Without clear numbers around the type and location of these new roles, predictions range between significant reductions in a mine workforce and an ongoing need for on-site roles that will increase with industry growth.

A Rio Tinto Manager has stated that there are still many people in the (automated and remotely controlled) mines, observing and supervising the operations and that there is likely to be more people in the mines than there are currently (Grad, 2010). However, there are visions for the future mine which openly aim to reduce the number of people at the mine site. In a series of interviews with mine automation technology specialists, Lynas and Horberry (2011b) identified a common

theme of concern amongst interviewees about job security and fears that automation would change or replace jobs.

3.2.1. Workplace health and safety

Improved working conditions and workplace health and safety are being promoted as important drivers in the development of autonomous and remote operation technologies. As mentioned, the automation of drilling was motivated from a health and safety perspective, with drilling being one of the most dangerous activities in mining and automation providing an opportunity to remove workers from this environment (Moore, 2009).

Any improvements in health and safety will be important in the mining industry which has one of the highest incident rates of work-related injuries and fatalities in Australia. In 2009, the fatality rate in mining was over twice as high as the national average for all industries (Workplace Relations Minister's Council, 2009), with 2395 workers' compensation claims (for injuries and fatalities) made in the mining industry in 2008-09 (Safe Work Australia, 2011a). In 2009-2010, there was some improvement with 6 fatalities (3.5 per 100,000 workers) in the industry (Safe Work Australia, 2011b). Three of these occurred in Western Australia although not in the iron ore sector (Department of Mines and Petroleum, 2011).

The mining industry has made improving safety and health its top priority (Minerals Council Australia, 2011) and automation may play a role in achieving this objective. In the three years to 2009, vehicle incidents were the most common cause of fatality in the mining industry, accounting for 35 per cent of fatalities (WRMC, 2009). With driverless trucks the autonomous technology most likely to be taken up at a large scale, this presents a good alignment between technology and industry need.

Lynas and Horberry (2011) identify some health and safety issues that could arise with the introduction of automated systems, including system failure causing injury and the release of toxic or flammable materials or significant damage to surroundings. They also note other safety issues that accompany operator workloads and fatigue. The safety of autonomous technologies, especially where they interact with manned vehicles, has been identified as a concern for the Construction Forestry Mining and Energy Union (Kirkman, 2011).

One health and safety aspect that has been discussed less in public is the risk of failure or malfunction of autonomous equipment and the potential for catastrophic events. This will be important in gaining regulatory approval for new autonomous operations and for any autonomous equipment potentially operating outside the controlled environment of a mine, such as driverless trains. It is also likely to be important to mining communities and the broader public in their own perception of the level of risk associated with these new technologies and therefore their acceptance (or rejection) of it.

3.2.2. Potential reduction in the size of the workforce

A number of functions are being targeted for autonomous or remote operation including drilling, blasting and train driving. However, truck driving seems the most likely function to be carried out autonomously at a large scale. This focus is important because haul truck drivers constitute the occupation employing the most people on-site in large open pit mines (Bellamy and Pravica, 2010). Therefore, automation of truck driving stands to make the greatest impact in addressing the labour shortage. However, this highlights that it is a particular group within the workforce profile that are faced with a change in the nature of their work.

There are few estimates of the potential workforce impacts of autonomous truck driving. Our own conversations with industry representatives indicate a possible 30-40 per cent reduction in the workforce, as a result of halving the number of in-pit roles in an open-cut mine. Bellamy and Pravica (2010) make a more significant estimate of a 75 per cent reduction in the overall workforce at BHP's Mouth Kieth nickel mine, as a result of fully automating the haul truck fleet (Bellamy and Pravica, 2010). They acknowledge that an increase in maintenance personnel accompanied the reduction in machine operators at El Teniente copper mine in Chile following the introduction of automated load-haul-dump machines. Notwithstanding, Bellamy and Pravica (2010) predict that automation will culminate in a reduction in population of remote mining towns, a decrease in the lower skilled labour requirements for the mining sector, an increase in fly-in fly-out mining operations and remote control centres in larger cities – reducing employment overall in the sector (Bellamy and Pravica, 2010). Parreira and Meech (2010) also identify a reduction in the number of truck drivers and an increase in personnel required for maintenance.

Other roles, including ongoing site-based, entry-level roles that are not likely to be automated, such as those relating to site rehabilitation, road building and other site works, are expected to continue to grow as a result of industry expansion.

3.2.3. Opportunities through the creation of new roles

There is wide acknowledgement of the new roles that will be created with autonomous and remote control operations. The work of Parreira *et al.* (2009) focuses on the opportunity this presents to build human capital by increasing the skills and quality of work for mining employees through the creation of such roles. These roles could include console operators, controllers, schedulers, operational planning, logistics and support roles, mine planning and maintenance. In remote control centres, fly-in fly-out maintenance crews working with highly-skilled on-site observers via enhanced communication and visualisation technologies. Some predictions are for an increase in the need for tradespeople and electrical technical support. Walsh (2010) predicts an increase in information technology (IT), business, systems and logistics skills.

The Cooperative Research Centre for Mining (CRC for Mining), through its work with MISC, makes a conservative estimate of 190 qualified new automation support staff (at the trades level) being required each year to fill a total of 1500 positions over 15 years to sustain the implementation of automation in Australian mining (Dudley *et al*, 2010).

These new roles are likely to primarily exist in capital cities. This may create opportunities for others to enter the mining workforce such as those not able to fly-in fly-out (FIFO), drive-in drive-out (DIDO) or work long sifts (e.g. women). Codelco's Gabriela Mistral (Gaby) open pit mine located in Antofagasta in Northern Chile, was the first mine in the world to operate 100 per cent Komatsu autonomous trucks and is currently the operation with the highest percentage of women employees (23 per cent) in the Chilean mining industry (Codelco, 2011). It may also stimulate workforce participation in the mining industry among older workers. According to the General Manager at Newcrest's Cadia Valley operations, some employees are looking forward to the planned transition to partially autonomous and remotely controlled operation in order to extend their working life (at interview, 2010).

This higher level of skills required for these new roles (Lynas and Horberry, 2011b) is discussed in Section 3.5 (Skills, education and training).

3.2.4. Labour shortages in Australian mining

With current growth projections, a reduction in truck drivers may not necessarily result in an overall reduction in the mining industry workforce but a reduction in employment growth. The largest increase in jobs in the mining sector over the next four to five years is expected to occur in the metal ore and coal mining sectors, which already employ the majority of the mining workforce.[5] An additional 10,400 and 8,900 jobs are required by 2014-15 in the metal ore and coal mining sectors respectively (SkillsInfo, 2010). The majority of employment growth will be for machinery operators and drivers (an additional 21,372 by 2015, from 2008) and technicians and tradespeople (an additional 15,080 by 2015, from 2008) (National Resources Sector Taskforce, 2010).[6]

Autonomous and remote operation technologies are promoted as a means for industry to achieve current growth requirements and overcome the significant labour shortage faced by the Australian mining sector as well as the increasing challenge of attracting workers to remote locations where the cost of living is high (Chamber of Minerals and Energy Western Australia, 2011). In effect, in the Australian context – and in the short to medium term - autonomous technologies seem likely to reduce the additional jobs created through growth rather than lead to a net reduction in employment levels in mining.

In Western Australia, there has been a record capital expenditure in minerals and energy projects of $173.5 billion in the year to April 2011 and a continuing labour deficit is projected into the future (New *et al.* 2011).The majority of this growth is planned for the Pilbara region where an additional 34,000 workers will be required in 2012 (Chamber of Minerals and Energy Western Australia, 2011). Overall, the Western Australian resources sector could be short 36,000 tradespeople, particularly electricians, by 2015 (National Resources Sector Taskforce, 2010).[7]

Increasing workforce participation is identified as one of the priority strategies for meeting labour demand in the mining sector (National Resources Sector Taskforce, 2010). Currently, the mining sector has a lower proportion of its workforce from 15-19 year olds (1.6 per cent of the workforce, compared to 6.9 per cent for all other industries) and a lower proportion of its workforce in over 65 years of age (1.3 percent compared to 2.3 per cent for all other industries). The mining industry has the lowest share of part-time employment (3.1%) and the second lowest share of female employment with females making up 13.2 percent of the mining industry workforce in the year to February 2010. These statistics are attributed to the remoteness of mining sites, the physical demands of the work and a lack of compatibility between the demands of the business such as fly-in fly-out and family responsibilities (SkillsInfo, 2011). The move to autonomous and remote operation technologies may present opportunities for other demographic groups to participate in the mining industry – spreading the benefits of mining and increasing workforce participation in the mining sector.

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[5] These sectors are currently also the major employers within the mining sector, with 37.4 % (56,600 workers) and 28.1% (42,500 workers) of the mining workforce employed in these sectors in February 2010 (SkillsInfo, 2010).

[6] The extent to which these projections have accounted for influence of uptake of autonomous and remote operations technologies is unknown.

[7] The extent to which these projections have accounted for influence of uptake of autonomous and remote operations technologies is unknown and would presumably depend on the extent to which individual companies' own internal human resource planning processes have accounted for this trend (given this data is based partly on data provided by individual companies to the Chamber of Minerals and Energy Western Australia).

3.2.5. Employment for Indigenous Australians living in remote and regional communities

Employment in the mining sector is an important source of regular income and opportunity for Indigenous Australians living in regional and remote communities in mining regions. These include opportunities to improve skills and occupational mobility as well as creating positive role models for young people and building human capital (Brereton and Parmenter, 2008). The promise of employment opportunities has also increasingly become a component of the land access agreements established between traditional owners and mining companies (Brereton and Parmenter, 2008). The majority of these opportunities exist in entry-level jobs (unskilled or semi-skilled) like truck-driving or plant operator positions, roles that are the focus of automation.

This concentration of Indigenous employees in semi-skilled and trade-based roles was evident in research conducted by Tiplady and Barclay (2007) (see Table 1). This finding is also supported by research undertaken by CSRM at the University of Queensland indicating that 50 per cent of Indigenous employees within an Australian mining operation occupying semi-skilled positions such as truck driving, followed by traineeships (20%), trades (12%), and administration (7%).

Table 1: Occuptaional breakdown of Indigenous employment across 10 Australian mines

Employment category	Male	Female	Total	Of Indigenous workforce
Semi-skilled; operators	578	89	667	56.6
Trade	82	3	85	7.2
Administration	4	73	77	6.5
Supervisor	31	2	33	2.8
Technical	19	2	21	1.8
Graduate	1	1	2	0.2
Professional	7	7	14	1.2
Specialist	5	2	7	0.6
Superintendent	8	0	8	0.7
Manager	5	0	5	0.4
Traineeship	100	60	160	13.6
Apprentice	96	4	100	8.5
Total	936	243	1179	

Source: Brereton and Parmenter, 2008 (adapted from Tiplady and Barclay, 2007)

If the number of machine operator positions is to decline to the extent anticipated – ranging from 50 to 75 per cent - and these positions are replaced by higher skilled roles on-site or in capital cities, then there is a need to consider how Indigenous employees in remote and regional communities will be impacted. What opportunities will continue to exist on site? What skills will these roles require and what training plans are in place? What pre-requisite skills will potential employees need to be in contention for these roles?

Unless adequate training takes place and on-site or regional roles are aligned with the available skills-base, there may be a risk to Indigenous employment in mining regions where automation and remote operation are taken up. This would appear to be at odds with industry goals to increase workforce participation among Indigenous people for Indigenous community development and as a means of addressing the labour shortage faced by Australian mining.

Current initiatives aimed at increasing Indigenous participation in the mining industry include Rio Tinto Iron Ore's target of 20 per cent Indigenous employment by 2015 and a local target of 14 per cent Pilbara Aboriginal employment in iron ore Pilbara residential jobs (Rio Tinto, 2011b); the Australian Employment Covenant – to which Fortescue Metals and other mining companies are signatories (Australian Employment Covenant, 2011); programs such as the North West Queensland Indigenous Resources Industry Initiative (NWQIRII) and the Bowen Basin Indigenous Participation Partnership; and partnerships between the Federal and State Governments and the Queensland Resources Council (QRC) (in which BHP Billiton, Xstrata and MMG Century are participants). These initiatives encourage Indigenous employment in the resources sector through education, training and work-readiness. It is unclear how organisations involved in these initiatives are preparing for a transition to autonomous and remotely operated mines.

3.3. BUSINESS DEVELOPMENT

The presence of a mining operation within a regional economy can present business development opportunities through the procurement of goods and services from local businesses and the discretionary expenditure of employees as well as the associated flow-on benefits from these transactions (Rolfe *et al*, 2010). Some mining companies seek to actively support local business development to capture the benefits of a diverse regional economy such as enhanced access to goods and services, access to a diverse labour pool and enhanced quality of life for residential employees.

It is difficult to get an overall picture of the importance of local procurement to the national and regional economies and to Indigenous communities as data pertaining to the local spend of mining operations is difficult to obtain and is often not publicly available. While some sites may record such data, often this is done on the basis of the invoice postcode, which can represent a local outlet for a larger state, national or international firm. What is known, is that local companies can have difficulty in meeting the scale and governance requirements of large, multi-national mining firms. Local discretionary expenditure by employees has also been seen by regional communities as an important opportunity that has been lost in the increasing use of FIFO practices (Storey, 2001).

The business opportunities that mining presents can also be an important source of economic activity for Indigenous communities. In recognition of this, business development opportunities are increasingly becoming part of land access agreements between traditional owner groups and mining companies (Brereton and Parmenter, 2008). Business development opportunities are also a critical component of the Australian Government and Minerals Council of Australia (MCA) Memorandum of Understanding (MOU) and the Queensland Resources Council and Queensland Government partnership on Indigenous participation in the mining industry.

 As an example of the scale of these opportunities, Rio Tinto Iron Ore plans to exceed its 2010 target of a total spend with Aboriginal businesses of $180 million in 2011 (Rio Tinto, 2011b). One particular example of such a contract in 2011 saw Rio Tinto award $184 million in Indigenous joint venture contracts associated with its Hope Downs 4 mine in the Pilbara (Perthnow, 2011). In another recent agreement with Indigenous groups in the Pilbara, Rio Tinto committed to contracts worth $300 million with Indigenous companies (Clear, 2011; O'Fairchaelleagh, 2010).

Despite a lack of information around the nature and extent of local business opportunities, this can be expected to change following the large-scale uptake of autonomous and remote operation technologies. For example, there is likely to be a reduction in the flow-on benefits associated with a mine workforce if the bulk of the workforce is not based or operating in the region. As one example of the potential flow-on impacts of automation, Bellamy and Pravica (2010) estimate that if driverless haul trucks were fully implemented across all mines surrounding Mount Newman by 2026, employment in the BHPB iron-ore mining town would fall from 2593 to 2255, creating a flow on reduction in the district's resident workforce of 20% (Bellamy and Pravica, 2010).

Further, the nature of the supply chain would change with an increasing need for highly technical professional and operational support services. Mining companies already contract automation support providers (Dudley *et al.* 2010). It is unclear whether such service providers are likely to locate themselves in regional areas or to what extent new or existing suppliers are involved in and being prepared for the transition to automation. Part of the solution to creating business development opportunities in regional areas associated with automation will include overcoming existing barriers to business development such as remoteness, lack of infrastructure and limited labour availability. For example, local business development (through an increase in local supply chain competition) is a critical step in the Pilbara evolving from a localised economy to a more diverse regional economy. Therefore how autonomous and remote operation technologies influence this aspect of regional development will be critical to the Pilbara's future.

3.4. PRESENCE EFFECTS

A mine and its workforce (resident or FIFO/DIDO) creates other regional development opportunities through their presence. A commonly used example in terms of regional infrastructure is the presence of an airstrip in a town or community where there may otherwise not be the scale necessary to warrant such infrastructure. This could represent an investment by a mining company or a local government trying to attract or support a mining operation.

Where a workforce includes residential employees, the inclusion of these workers and their families in local population numbers can mean a town or area attracts additional government services or funding. Population-driven jobs also emerge due to the need to service the workforce and their families. This growing population creates the compounding effect of population growth and associated population-driven employment. Likewise, a reduction in the mine workforce can lead to a withdrawal of government services or funding (Storey, 2010) and a reduction in population-driven jobs.

If a transition to autonomous and remote operations reduces the on-site workforce (residential or FIFO), there is the potential for significant impacts on regional development opportunities in regional and remote mining communities.

The Pilbara Industries Community Council (PICC), in its 2010 report, *Planning for resources growth in the Pilbara: revised employment and population projections to 2020*, predicts a population increase to a resident population of 61,086 in 2015 and 62,500 in 2020 on the basis of projected increases in the resource-related workforce (Waller, 2010). These projections are used by the Western Australia Planning Commission (Waller, 2010). Under the Western Australia State Government's 'Pilbara Cities Initiative', Karratha and Port Hedland are planned to be developed into cities with populations of 50,000 supported by Newman as a sub regional centre with a population of 15,000 (Pilbara Development Commission, 2011). It is not clear how the transition to large-scale autonomous and remote operations technologies would affect these objectives and projections?

These and other regional development issues will be considered further in the regional economic analysis and further work being conducted as part of the project.

3.5. SKILLS, EDUCATION AND TRAINING

The forecast creation of new roles and changing nature of employment arising from autonomous and remote operations will drive new needs in education and training supporting the mining sector. There are current projects in Australia, such as those being undertaken by MISC, that are looking at the education and training requirements of automation as well as the future mine more generally. This project will be informed by those projects, with the roundtable providing an opportunity to gain a deeper understanding of future directions.

The MISC project is specifically concerned with the changing skill requirements and education and training needs of the majority of mine workers in trades and operational roles. The mining industry provides important employment opportunities for people with only school level qualifications and these groups represented 36.9 per cent of the mining industry workforce in May 2009. Tradespeople, with Certificate III or IV qualifications represented 33.5 per cent (SkillsInfo, 2010). While automation presents opportunities for mine workers to develop new knowledge and skills (Parreira *et al.* 2009), this project is particularly concerned with those workers who may not be geographically mobile or do not have the pre-requisite skills for the opportunities that arise with autonomous and remote operations. Is it possible for the industry to bridge the gap between current entry-level skills and those required as pre-requisites to undertake more advanced training or to meet the skill requirements for the new roles created under autonomous and remote operations?

Lynas and Horberry (2011b), identify that remote operators will basically need to possess a higher order of skills than currently required by on-site operators and the technology will require a more multi-skilled workforce overall (Lynas and Horberry, 2011b). In their paper, they identify a number of skills and aptitudes that are likely to be required of operators and maintenance personnel in the implementation of autonomous and remote operation technologies (See Table 2).

The CRC for Mining describes a Certificate III in Electrotechnology as the foundation qualification for supporting automation technologies. Certificate III is already an established path of entry to the industry and prepares people to work on electrical and electronic equipment in mining. In the context of their prediction of the number of positions required in the coming years, McAree and Lever (2010) identify a skills deficit emerging in the supply of automation support staff at the trade level. McAree and Lever (2010) advise that a seven to ten year timeframe is required to upskill existing workers to the capability of an Automation Technician (Certificate III in Electrotechnology) yet there is only a four to five year period before that role is in demand and there is currently no training package available to address this deficit (Dudley *et al*, 2010).

This acute training need exists within an industry that does not have a strong record for providing training in these sections of its workforce. The resources sector to date has not trained as many apprentices as its level of trade-related employment would suggest (National Resources Sector Taskforce, 2010), despite formal qualifications becoming more important with the increasing complexity of machinery and operations (SkillsInfo, 2010). This may be starting to change with MISC's announcement of Accelerated Skilling Hubs to prepare for increased demand from 2014 (MISC, 2011).

These Accelerated Skilling Hubs will harness serious gaming technologies, simulation techniques and automation to rapidly skill workers in a 'centre of excellence' environment which can be located regionally, or in any major capital city. The hubs will have the capability to completely redefine and radically transform how people are skilled for the industry and incorporate training such as the

Targeted Technology Introduction Module (TIIM) which provides for a diverse range of automation and system integration training and skills development outcomes (MISC, 2011). There are also examples such as Rio Tinto's Kuttajin Borne training centre in Perth. This centre opened in June 2011 and will manage the increased flow of trainees and apprentices working in the Pilbara iron ore industry over the next decade. It will be the principal training base for Rio Tinto's Perth-based and FIFO employees, Perth-based apprentices and remote train operators (Rio Tinto, 2011c).

Table 2: Skills required by operators and maintenance personnel for autonomous and remote operations technologies

Operators	Maintenance Personnel	
Remote	On-site	Remote
- Need to maintain a knowledge-based behaviour to inform decisions about a course of action in new/unexpected conditions - Balance trust in technology while not being overly-reliant on it - High mental concentration - High level of dexterity - Ability to cope with repetitive tasks - Ability to integrate multiple sources of information - Ability to use and understand computer software - Ability to interpret visual data - Ability to work in confined spaces with extended periods of time looking at computer screens	- Ability to relay information and execute instructions under guidance - Knowledge of technology/computer use - Fault finding - Mechanical knowledge (eg fitters and turners)	- Diagnosis skills - Interfacing with on-site (potentially lower-skilled) personnel - Knowledge of technology/ computer use

Source: Lynas, D. and Horberry, T., (2011b)

3.6. COMMUNITY INVESTMENT

Mines choose to invest directly in communities for a range of reasons - to maintain good relations with communities and their Social Licence to Operate, make communities a better place to live and work for their employees, ensure critical infrastructure and services are there for the mine to operate and to fulfil land use agreements. In its Reconciliation Action Plan, Rio Tinto acknowledges that it invests directly in communities because mining is a capital intensive industry unable to provide sufficient employment to support broad-based economic and community development (Rio Tinto, 2011b). In 2010, Pilbara-focussed Rio Tinto Iron Ore invested a total of $5.9 million (including in-kind contributions across community education and work readiness, health, cultural, environmental and other social service/infrastructure projects (Rio Tinto, 2010).

In the past, community investments have predominantly consisted of sponsorships and donations as well as one-off investment to local infrastructure or events. Now, mining companies are increasingly taking a partnership approach to community investments and strategically investing in community infrastructure with the aim of building longer-term sustainable communities through shared responsibility and community self-determination. One significant change has been in the nature of

land use agreements with traditional owners where Rio Tinto has moved towards a new model of investing in local communities, by sharing the revenue generated by its mining activities. In a recent agreement with Indigenous groups in the Pilbara, Rio Tinto will direct a 0.5 per cent share of revenue to Indigenous communities. This will constitute several billion dollars over the 40-year life of the mines in question (Clear, 2011).

Will a change in the employment and business opportunities for regional and remote communities trigger a change in the voluntary investments mining companies make in the communities in which they operate?

3.7. SOCIAL LICENCE TO OPERATE AND PUBLIC ACCEPTANCE

In the interest of earning and maintaining the industry's Social Licence to Operate and maximising the potential for the successful development and implementation of autonomous and remote operations, a dialogue with a broader group of stakeholders than has been engaged on this issue to date is warranted. This will contribute to building trust in mining and technology development companies, developing an understanding of the technology and its requirements and helping stakeholders who will have an interest in or be impacted by the technology to prepare for the transition. This more open and transparent approach also presents an opportunity to identify ways to build human and social capital through the transition, in a manner that enables the benefits to be distributed equitably across the existing mining workforce, potential employees and mining communities.

One dimension of public acceptance is the response of the workforce and in particular, unions, to these new technologies. Unions and mining management have had a chequered relationship in Australia. There was significant industrial action against mining companies in the 1980s followed by a period of companies dealing directly with their workforce through individual contracts. In 2011, the Construction, Forestry, Mining and Energy Union (CFMEU) negotiated a collective agreement with Rio Tinto to cover rail workers, marking their return to the Pilbara region after a period of 20 years (Hannan, 2011). This agreement directly addressed the implications of autonomous technologies, with rail workers retaining existing allowances in the event of the introduction of driverless trains (Hannan, 2011). Fortescue Metal Group's announcement to introduce driverless trucks received a different response with the CFMEU seeing the technology as a threat to jobs and a safety risk (Kirkman, 2011).

> 'Fortescue have promoted indigenous employment opportunities and here they are removing opportunities for unskilled workers, whether indigenous or other, by bringing in the automation of their trucking fleets.'
>
> Gary Wood, Mining and Energy Secretary, CFMEU (Kirkman, 2011)

4. NEXT STEPS

The roundtable event on 24 November will involve a series of presentations, a facilitated discussion and a scenario planning activity to help identify potential impacts of the large scale uptake of autonomous and remote operation technologies as well as strategies to build social and human capital through a transition to these technologies. This event will be followed by further research, the regional economic analysis and follow up interviews. This research will inform the identification of strategies to help industry and stakeholders prepare for the transition and maximise the human and social development opportunities (through employment, business development, education and training, presence effect and community investment). The work will also be reported as an application of the Social License in Design process to autonomous and remote operations technologies in Australian mining (see Appendix A).

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APPENDIX A: TECHNOLOGY ASSESSMENT

A.1 MINERALS FUTURES RESEARCH CLUSTER COLLABORATION

The Minerals Futures Research Cluster Collaboration is a collaborative research program being undertaken by CSIRO and four Australian universities to address the future sustainability issues of the Australian minerals industry. It is part of CSIRO's Minerals Down Under National Research Flagship (MDU), a broader research program seeking to develop technologies to unlock Australia's future mineral wealth through transformational exploration, extraction and processing technologies. The Cluster includes three research streams – Commodity Futures, Technology Futures and Regional Futures.

This work is part of the Technology Futures stream being led by the Centre for Social Responsibility in Mining, to develop Technology Assessment (TA) tools and methods to assess the social and environmental impacts of new technologies. These tools and methods are intended for use in reducing social and business risks and improving the sustainability outcomes of new technologies developed under the MDU Flagship program (Franks *et al.* 2010). This contributes to the MDU theme: Driving Sustainable Processing through System Innovation, which aims to develop "assessment methods and tools to evaluate the impacts of new technologies and the social and environmental cost to Australia."

Social License in Design is a particular approach to Technology Assessment being developed through the Technology Futures stream. It seeks to address the future social challenges and opportunities of a technology under development by considering the potential performance of the technology in its future operational context and accounting for the perspectives and values of potential stakeholders and decision makers (Franks and Cohen, 2011).

This project will apply the Social License in Design process under development to autonomous and remote operation technologies in the Australian mining sector.

A.2 TECHNOLOGY ASSESSMENT

Technology Assessment is a process for considering the implications of a new technology during the design phase, when there is still scope to make modification to address any issues identified. This reduces the potential for losses associated with retro-fitting or technology failure (Raven *et al.* 2009 from Franks *et al.* 2010). The process ultimately aims to increase the likelihood of successful implementation of new technology.

While autonomous and remote operations technologies are already in use across several Australian mine sites, undertaking a Technology Assessment is still a valuable exercise because there are further developments taking place and a level of uncertainty about the future uptake across the industry. Hence there is a need for information to assist industry stakeholders, particularly training providers, contract labour suppliers, regional and remote communities and policy makers, to prepare for the further development and uptake of autonomous and remote operations technologies. There are also management decisions concerning the implementation of these technologies that lie ahead for resource companies that could be informed by the consideration of potential social implications.

Franks and Cohen (2011) outline a process for Constructive Technology Assessment (CTA) in the form of a broader framework that can be informed by a range of research methodologies (see Figure A.1). CTA is used to shape the course of technological development in socially

desirable directions by broadening the focus of the decision-making process (van den Ende *et al.* 1998).

What type of assessment?	What is the technology?	Where will it be implemented?	Who will it affect?	How will it affect them?	What is the magnitude?	What can be done?
Scope technology assessment • Resources • Degree of reflexivity • Stage of technology development • Level of assessment • Desire for public involvement	**Scope technology design characteristics** • Drivers and constraints • Options/ alternatives • Current picture of the technology under development	**Scope and profile: anticipated social and geographical context** • Identify the target resource or industrial application and understand the features	**Scope and profile stakeholders** • Determine values, concerns and expectations through methods, such as interviews, focus groups, etc.	**Forecasting risks and opportunities** • Imagine possible and not impossible outcomes • Propose controls (design out, mitigate, enhance, offset, constraints on implementation, risk communication • Identify knowledge gaps and confidence	**What is the magnitude?** • With reference to each stakeholder	**Review controls (management options)** • Design out, mitigate, enhance, offset, constraints on implementation, risk communication

Figure A.1:   Social License in Design – potential issues for consideration during Constructive Technology Assessment.
(Source: Franks and Cohen, 2011)

While this project applies the Social License in Design framework to autonomous and remote operation technologies, it also serves as a form of Awareness TA which, as described by van den Ende *et al.* (1998) involves forecasting technological development and their impacts to warn for unintended or undesirable consequences. In this case, some degree of forecasting is required as there is little information in the public domain or available from industry about the future social and workforce implications of autonomous and remote operation technologies. The approach taken in assessing autonomous and remote operation technologies incorporates consideration of both unintended consequences and potential opportunities and societal benefits that require explicit management to be captured.

Specific research methods being used to inform the assessment of autonomous and remote operation technologies include regional economic analysis and aspects of scenario planning (also scenario analysis). These activities are informed by desk-top research, a series of stakeholder interviews, attendance at specialist conferences over a period of three years and this roundtable. The roundtable discussion will verify information collected for the purpose of the scoping exercise as well as forecasting risks and opportunities (see Figure A.).

A full report on the application of the Social License in Design framework to autonomous and remote operation technologies will be produced upon the completion of the project. A specific paper outlining the findings of the roundtable discussion will also be produced, along with a report intended to inform stakeholder decision making in preparation for further development and roll-out of autonomous and remote operations technologies in the Australian minerals industry.

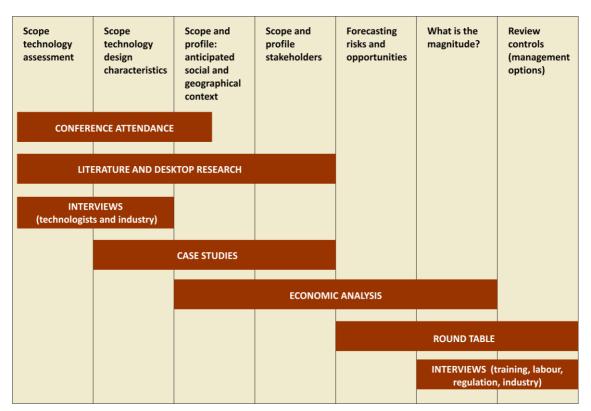| Scope technology assessment	Scope technology design characteristics	Scope and profile: anticipated social and geographical context	Scope and profile stakeholders	Forecasting risks and opportunities	What is the magnitude?	Review controls (management options)
CONFERENCE ATTENDANCE						
LITERATURE AND DESKTOP RESEARCH						
INTERVIEWS (technologists and industry)						
	CASE STUDIES					
		ECONOMIC ANALYSIS				
				ROUND TABLE		
				INTERVIEWS (training, labour, regulation, industry)		

Figure A.2: Research activities informing the Social License in Design process.

A.3 SOCIAL DIMENSIONS OF TECHNOLOGY CHANGE

The social implications of technology change can occur at the individual, workforce, community and societal level. These may include implications for personal and public health and safety, new risks for catastrophic events, changes in work practices and conditions as well as changes in the type, number and location of jobs and economic returns to communities. These changes may have positive, negative or neutral effects and may also require an adjustment process for different stakeholder groups and will influence stakeholder responses to the technology.

Public acceptance of a new technology is also a social dimension of technology change. This dimension is influenced by responses to the issues outlined above, as well as stakeholder trust in the organisation or technology in question, their perception of risk and the consistency of the change with stakeholder values such as environmental and cultural values.

Where new technologies do not have public support as a result of real or perceived negative impacts or a lack of trust, credibility or legitimacy, this can lead to tangible and intangible costs to industry such as reputational loss, delays in regulatory approval, retro-fitting, disruption to production and even the closure of an operation due to a loss of social license to operate (Franks and Cohen, 2011).[8] Recent examples of technologies attracting public opposition in

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[8] Social License to Operate refers to the intangible and unwritten, tacit, contract with society, or a social group, which enables an operation to enter a community, start, and continue operation – a concept that has become increasingly acknowledged and applied in the mining sector (Thomson and Boutilier, 2011 in Franks and Cohen, 2011). Obtaining and maintaining the social license requires maintaining a positive corporate reputation; understanding the cultural and historical context of the community and

Australia include the hydraulic fracturing process used in coal seam gas operations (because of its real or perceived impact on groundwater tables), wind farms and genetically modified foods (because of real or perceived impacts on health and well being). Examples of Australian mines that were closed because of community opposition include Timbarra gold mine in New South Wales, the Stuart Oil Shale Project in Gladstone and the Jabiluka Uranium Mine in the Northern Territory (Laurence, 2006 and Franks *et al.* 2009). While mine closure is an extreme example, all of the outcomes of public opposition could jeopardise the successful implementation of a new technology. Franks *et al*. (2010) provide a useful list of reasons why technologies fail from a social perspective (see Text Box 3.1).

TEXT BOX A.1: WHY TECHNOLOGY FAILS FROM A SOCIAL PERSPECTIVE (Franks *et al.* 2010)

- There are unintended or unmanageable side effects
- The cost and benefits of a technology project are disproportionately experienced
- The intrinsic activity or product the technology is facilitating is not supported by stakeholders
- The technology itself is not supported by stakeholders
- The technology does not perform the intended function
- The intended function of the technology is perceived to be not needed
- The context in which the technology is implemented does not match the design specifications of the intended context
- The inputs for the technology restrict its application or are contested (including water, energy and economic inputs)
- Stakeholders hold values about the landscape in which a technology is situated that is incompatible with the technology of the development of the resource.

It is also possible to build public support for technology change and reduce the potential for future conflict through a process of understanding stakeholder values and developing ways for new technologies to be used in a manner consistent with those values. This requires being transparent with stakeholders about the development of new technology as well as sharing information about the benefits and management of any potential risks associated with new technology.

Constructive TA seeks to use dialogue and interaction with technology developers to incorporate social aspects as additional design criteria for technology development to influence the design process (Schot, 1992 and Schot and Rip, 1997 in Franks and Cohen, 2011). The process aims to develop an understanding of the values, perspectives and background of potential stakeholders and anticipates likely stakeholder responses to a new technology (Franks and Cohen, 2011). The objective is then to reduce the uncertainty associated with novel or emerging technologies and shaping the technology in response to these issues (Franks and Cohen, 2011).

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operation, educating local stakeholders about the project and ensuring open communication among all stakeholders.

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