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## **Technology Futures Discussion Paper: Technology Assessment and the CSIRO Minerals Downunder National Research Flagship**

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### **For:**

CSIRO Minerals Down Under National Research Flagship



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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.csrn.uq.edu.au>.

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## EXECUTIVE SUMMARY

The CSIRO Minerals Down Under National Research Flagship aims to unlock Australia's future mineral wealth through transformational exploration, extraction and processing technologies. In this paper we outline the potential of Technology Assessment (TA) to improve the technologies under development within the flagship.

Section 1 outlines the rationale of the Technology Futures project which is a component of a broader multi-institutional research collaboration called the Minerals Futures Cluster Collaboration, between The University of Queensland, The University of Technology, Sydney, Curtin University of Technology, Central Queensland University and The Australian National University.

Section 2 examines the drivers of technological innovation in the minerals industry, discusses the relationship between technology and society and outlines the technologies under development in the Flagship. The Australian minerals industry faces a number of countervailing future uncertainties around declining resource quantity and grade, an increased demand for minerals, increased production costs and global competition, and more complex ores. Over and above these uncertainties concepts of sustainability have reshaped societal expectations and are placing further constraints on the resources necessary for mineral development such as water, energy and land.

Technology innovation will play an important role in meeting these challenges, however, even when technologies are designed with sustainability considerations in mind, such innovations are not always embraced by society. In Section 3 we explore the reasons why technologies may not find a receptive public, profile a series of case studies and draw lessons for future innovations. The concept of 'social license to operate' is introduced in section 4. Social license refers to an intangible and unwritten, tacit, contract with a society, or a social group, enabling a mining operation to enter a community, start, and continue operations. Further we examine the relationship between the state of social license and stakeholder behaviour and introduce the concept of *embedded conflict* to describe how technology design traits may lead to the absence of social license. We then explore the process of 'Social License by Design', which describes a design process that attempts to reduce social hazards or minimise potential social risk by involving designers and decision makers in considering the operational context of the designed product beyond the user or proponent.

In Section 5 we consider how technology assessment can address embedded conflict during the design phase of technology development. We do this by reviewing TA approaches and canvassing the challenges, constraints and opportunities of undertaking TA within innovation institutions.

# 1. INTRODUCTION

Technological change in the minerals industry is driven by the need to improve performance and efficiency against a 'triple bottom line' that considers, economic, social, and environmental criteria. Technological innovation is essential to meet sustainability goals and improve efficiency and has the potential to improve the public acceptability of mining projects. However, the adoption or transfer of new technologies may also result in considerable contestation. The mining industry depends not only on the availability of resources but also on the public acceptability of the technologies and methods employed to extract them.

Managing risk is important because ill-fitting technology can lead to considerable harm to the public, individual industries, specific mining processes and companies, mine employees as well as the environment. Social or environmental harm may lead to tangible and intangible costs to industry including reputational loss, costly retro-fitting and even the closure of an operation due to a loss of social license.

In this discussion paper we outline the possibilities and rationale for incorporating technology assessment into technology development within the CSIRO Minerals Down Under National Research Flagship. This report emphasises the need for technologists to consider, appreciate, participate and own the process of technology assessment. The technology assessment process should start in the research and design phase when there is still room for adjustments to be made to technologies without considerable loss of investment (Ravan *et al.*, 2009).

By assisting technologists to consider during the design process the social and environmental impacts, risks and opportunities, to community, industry and the environment, the success of a technology project can be enhanced - for all stakeholders<sup>1</sup>.

## 1.1. TECHNOLOGY FUTURES PROJECT

The Technology Futures project, being led by the Centre for Social Responsibility in Mining, is one of three streams of a broader program of research called the Minerals Futures Collaboration Cluster under CSIRO's Minerals Downunder Flagship. The Minerals Futures Cluster brings together CSIRO and four University-based research institutions, all of which have a strong track record of working in the minerals sector, to work on addressing the future sustainability challenges of the Australian minerals industry.

The broad aim of CSIRO's Minerals Downunder Flagship is to unlock Australia's future mineral wealth through transformational exploration, extraction and processing technologies. The Technology Futures project is a 3-year applied research project to develop technology assessment methods and tools and apply these within the MDU Flagship. More specifically the Technology Futures project fits within the MDU theme; Driving Sustainable Processing through System Innovation. The goal of this MDU theme is to develop "assessment methods and tools to evaluate the impacts of new technologies and the social and environmental cost to Australia." The Technology Futures Project aims to develop technology assessment approaches that, if adopted, will reduce the risk that emerging MDU Flagship technologies will result in future conflict.

The project will pilot technology assessment methods on two Flagship technologies and seek to build a legacy of technology assessment into the technology development process within

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<sup>1</sup> In this document we define stakeholders as anyone who can affect, or is affected by the technologies in question. A stakeholder includes those with a vested interest in the innovation such as technology institutes and development sponsors, as well as those who are directly or indirectly impacted.

the Flagship. The project will also develop tools to incorporate TA into internal CSIRO technology proposal, research and development processes. To achieve these goals, project staff will work closely with CSIRO personnel undertaking technology research and development within the flagship and involve these researchers in the assessments.

## **2. TECHNOLOGY INNOVATION IN THE MINERALS INDUSTRY**

### **2.1. WHAT IS TECHNOLOGY?**

The effectiveness of a particular technology depends not only on its mechanical or technical fitness, or its efficiency, but also on its uptake and/or acceptance in wider society (Christensen, 1997). Historically, technology was defined simply as machines or artefacts with specific and predictable external effects and technological innovation was seen as a result of 'technological trajectories' and the closed fields of interests of engineers and technological institutions (Geels and Schot, 2007). As such, technology assessment was seen to exist within the 'non-social' domain of technical expertise and the fields of science and engineering (Wynne 1988).

Now it is accepted that other components of society influence the technological sphere at multiple scales (Geels and Schot, 2007). In short, technological innovation and individual technologies themselves are influenced by the socio-technical landscape, an external environment, within which both society and technology shape and define each other sometimes with unintended consequences (Bijker, 1992; Geels and Schot, 2007; Guston and Sarewitz, 2002). In this broader, more integrated, realm, technology can be interpreted as including the social processes through which 'things', or artefacts, are constructed (Pinch and Bijker, 1984). Technological assessment must now consider the relationships which are intrinsic to technological innovation, as well as societal perceptions of risk, in order to ensure acceptance of new technologies and reduce the potential for future, costly, conflict.

Technologies and the products and services they produce or facilitate have a field of influence over which positive and negative impacts and risks are experienced or perceived. Whereas some innovations may be bounded, having a field of influence that is predictable, others may be unbounded, having effects that cross organisational boundaries into potentially contested domains (Harty, 2005). The field of technology assessment has grown in an attempt to predict and influence these impacts and, in essence, to control the direction of technological innovations.

### **2.2. DRIVERS OF TECHNOLOGICAL CHANGE IN THE MINERALS INDUSTRY**

Technology is continuously evolving due to two forces; firstly, the internal logic of science in which new knowledge always brings with it new technological possibilities, and secondly, the desire for increased efficiency (Braun, 1998). Changing human values and attitudes, as well as shifts in the character of accessible ore bodies, are re-defining notions of efficiency based on principles of sustainable development and, more recently, in response to climate change concerns. Technological innovations are thus increasingly likely to strive to maintain or enhance conditions for a viable industry, company or enterprise, which necessarily include innovation towards more efficient extraction and production techniques, decreased energy and water input, less waste output and fewer adverse environmental and social impacts, and increased social opportunities.

These are also key drivers for mineral technology innovation within the Minerals Down Under National Research Flagship (MDU). MDU is focused on researching and developing technologies which will sustain the medium to long term generation of wealth from the Australian mineral and mining services industries (CSIRO, 2009). MDU is exploring innovative technologies that address future uncertainties situated around declining resource quantity and grade alongside an increased demand for minerals. This paradox demands increased efficiency across the entire lifecycle of an operation, from the exploration phase through the mining and processing stages, and extending beyond the mine to rehabilitation and waste recovery and reuse.

Particular drivers of technological innovation towards greater efficiency recognised within the MDU flagship include:

- increasing production costs;
- mounting global competition;
- declining ore grades and increased handling of complex ores containing higher levels of impurities;
- increasing demand for larger quantities of ore; and
- increasing pressure from regulators and broader society to improve environmental and social performance and reduce energy consumption and water usage.

Giurco et al., (2009), in research conducted within the Mineral Futures Cluster within MDU, have expanded on these drivers of technological change. They identify key factors likely to shape the future of the minerals industry including:

- environmental sustainability and eco-efficiency (minimising environmental impacts at the operational level by increasing energy and water efficiency and decreasing ecological disturbance during the production cycle by, maximising the potential for reuse and recycling of materials);
- climate change mitigation and adaptation (reduction in energy inputs and emissions outputs, adaptation of mining processes and structures to cope with changing climatic and hydrological regimes);
- peak oil and peak minerals, where the increased costs of inputs such as water and energy are constraining the accessibility of reserves of oil and minerals ;
- higher community and societal expectations; and
- the reputational legacy of past operations (Giurco *et al.* 2009).

Key areas of technological innovation within the minerals industry in general are listed in Table 1. The Minerals Down Under Flagship is actively developing technology in a number of these areas focusing on locating and characterising ore bodies using predictive modelling services and geophysical detection methods, mine automation, more efficient extraction methods using leaching technologies and solute transport processes, creating value from processing waste streams, as well as increasing the water and energy efficiency of processing operations. Each of these developments will have profound implications on mineral futures as well as on the social and environmental landscape.

The drivers of technological innovation outlined above also have a geographical expression. With the most obvious ore bodies already under development, ores previously stranded by factors such as economics, logistics, policy, infrastructure or technology are now increasingly targeted for extraction. Future ores extraction operations will therefore tend to be located in increasingly complex circumstances: such as near population centres; under deeper regolith cover; close to sensitive environmental and social locations or places with high social and

ecological value; in more remote locations; in new regions; or where other land-uses are already present.



**Table 1: Areas of Technology Innovation in the Minerals Industry and Minerals Down Under Flagship.**

Focus	Technology innovation in the minerals industry	MDU Flagship research*
<b>Expansion of resource base</b>	<p><u>Exploration technologies to locate resources:</u></p> <p>Innovations in induced polarisation geophysics to see under regolith cover, regolith biogeochemistry, three dimensional mapping and improved processing of data.</p>	<p><u>MDU Goal:</u> Discover new resources under challenging Australian geological conditions</p> <p><u>Current focus:</u> Understanding ore body formation and evolution over time, enabling the spatial location of ore bodies using terrane-scale technologies including hyperspectral mineral mapping, and locating, mapping and characterising ore bodies in 3D.</p>
<b>New extraction methods</b>	<p><u>Unconventional technologies to access conventional resources:</u></p> <p>Coal seam gas, oil sands, oil shale, coal to liquids, automation of mining equipment, phytomining -plant based extraction of metals and minerals- and hydrometallurgy, including vat leaching, heap leaching of sulphide and oxide mineralogy and in-situ leaching.</p>	<p><u>MDU Goal:</u> Mine minerals in ways that increase productivity and improve safety and health through the next generation of safe, geologically intelligent Australian mining systems.</p> <p><u>Current focus:</u> The development of new leaching technologies for processing gold which could replace the use of cyanide as a reagent. Enhancing knowledge from drilling and delivering a wider range of high quality rock mass information for every bore hole drilled. New automated surface mining machinery with novel cutting systems that enable selective extraction and remote tele-operation to extract and remove people from hazardous areas of mining activities.</p>
<b>Improved extraction effectiveness</b>	<p><u>Technologies to maximise the extraction of ore at increasingly lower grades:</u></p> <p>In-situ and in-place leaching</p>	
<b>Access to remote and difficult ores</b>	<p><u>Technologies that improve the accessibility of ores:</u></p> <p>Key-hole mining and underground mechanical processing</p>	<p><u>MDU Goal:</u> Process ores that we currently know about but can't because they are too complex or low grade or stranded.</p> <p><u>Current focus:</u> Removal of impurities from Australian iron ores, pigment production from fine grained Murray Basin mineral sands, controlled leaching of low-grade and refractory nickel, copper and gold ores, in-situ leaching technologies, non-entry underground mining at increasing depths, high in-situ rock stress and elevated temperatures.</p>
<b>Processing of complex ores</b>	<p><u>Technologies to extract resource from ores with impurities and in complex mineralogies.</u></p>	

**Reduction of side-effects:**Technologies that reduce by-products, and environmental impacts:

Thorium reactors may produce energy with decreased security risks, carbon capture and storage/sequestration may capture greenhouse gas emissions from fossil fuels, mine methane drainage may reduce fugitive emissions from coal mining, biomass blast furnace reductants may replace coal in the coking of iron-ore, improved amenity from noise reduced mine trucks, and end of pipe technology to reduce waste emissions.

**New waste management and rehabilitation methods**Innovations in waste management and rehabilitation:

Deep sea tailings placement that is argued to improve the feasibility of operations in steep or limited terrain unsuitable for conventional tailings; paste and thickened tailings methods that can drastically reduce water loss to tailings and improve tailings stability; desalination and reverse osmosis can increase water management options; and phytoremediation, the use of plants to treat environmental problems, can improve rehabilitation outcomes.

**Recovery of resources from wastes**Technologies that allow for ore to be recovered from the reprocessing of mine waste:

Recycling, mineral stewardship and product stewardship can recover resources after use (e.g. tantalum from mobile phones, aluminium from beverage containers). These technologies may provide an economic opportunity to rehabilitate historical sites into stable landforms.

**Utilisation of wastes as resources**Extraction and processing waste streams may be alternate source of resources.

Fly ash for use in cement; and red mud, a by-product of aluminium production, for use as a soil conditioner.

MDU Goal: Dramatically reduce the environmental footprint of the sector

Current focus: Technologies for reducing greenhouse gas emissions (focusing on iron and steel industries) and freshwater usage. Projects include development and application of 'green' biomass grown in salinity prone areas. The treatment and reuse of plant/tailings water including surface permeable barriers and high intensity ion exchange.

Maximising resource utilisation towards zero waste and emission. Geopolymer based products from fly ash and residues converted into building materials such as green concrete.

Advanced predictive thermodynamic models for metallurgical accounting of minor elements enabling the development of new practices for

MDU Goal: Sustain and grow the mining technology services sector

Current focus: Creating value from processing waste streams minimising atmospheric pollution.

<b>New and expanded markets</b>	<u>Innovations and technologies that create new markets for conventional resources and demand for new resources:</u>  Electric drive vehicles which have the potential to expand the market for fixed energy production. Battery components, and advances in mobile telecommunication have increased demand for tantalum and niobium.
<b>Expansion of service infrastructure</b>	<u>New infrastructure that makes resources more economic to develop:</u>  The proximity of a resource to rail, ports, electricity, natural gas etc is a major factor in the economics of extraction and processing.

\* MDU focus areas adapted from MDU literature including 'Unlocking Australia's future mineral wealth' (2008a), 'Securing Australia's future ore reserves' (2008b), 'Driving sustainable processing through system innovation'(2008c), 'Transforming the future mine'(2008d), 'Discovering Australia's mineral resources' (2008e) and 'Highlights from the first year of operation' (CSIRO, 2009)

### 3. PUBLIC ACCEPTANCE OF TECHNOLOGY

#### 3.1. WHY DO TECHNOLOGIES FAIL TO WIN ACCEPTANCE?

Technologies may fail during design or implementation for many commercial, technical, social, political and environmental reasons. Despite the ability of technological innovation to deliver greater efficiencies, emerging technologies are not always embraced by society. This research project is concerned with the question of why some technologies do not meet public acceptance. Public concerns may arise over the environmental and social risk of new technologies and these concerns tend to differ across geographical and cultural boundaries, and also through time, reflecting local ideals and values. From this social perspective, technologies may fail because:

- there are unintended or unmanageable side effects;
- the costs 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 or the intended context;
- the inputs for the technology restrict its application or are contested (including water, energy and economic inputs); and,
- stakeholders hold values about the landscape in which a technology is situated that is incompatible with the technology or the development of the resource.

Factors affecting societal concerns mirror the drivers of technological change outlined earlier. As societal values increasingly reflect the ethics of sustainable development there is public and regulatory demand for greater production efficiency. More than this though, societal concerns over, and experiences of, mining activities can be personal and are likely to change through time as people's personal values, ideals and needs shift. As such, judgments about emerging processes are often based on perceived threats or opportunities measured against factors that an individual considers important. These potential threats or opportunities constitute the *risk* of a technology.

## INTRODUCTION OF THE CANE TOAD – A SHORT SIGHTED INNOVATION

The introduction of the cane toad, *Bufo marinus*, to Australia in 1935 is a prominent example of an innovation where the research phase failed to effectively identify and incorporate the actual social-environmental reality and where the innovation has led to severe and widespread unintended effects.

Based on a successful introduction in Puerto Rico, where the cane toad was apparently effective at bringing infestation of the cane beetle (*Dermolepida albobirtum*) under control, the cane toad was introduced in Australia from specimens collected in Hawaii. Initially more than 100 specimens were released in North and Central Queensland in 1935 before the Commonwealth Department of Health temporarily banned further introductions due to environmental concerns. A study into the feeding habits of the toad, completed in 1936, overturned the ban and led to large scale releases.

### Critiques of the process

Use of the cane toad as a biological control has been critiqued as ill- thought out and badly planned. Warnings against its introduction were disregarded (Kinghorn, 1938 and Froggatt, 1936) and the environment into which the cane toad was introduced was poorly understood. There are a few hypotheses put forward as to why the cane toad failed as a biological control agent. Cane beetles live high up the sugar cane stalks and cane toads, being unable to reach the beetles, soon began preying on other native species. Others argue that the cane toad sought denser cover in vegetated areas beyond the cane field. Nevertheless the cane beetle remains as a pest in Australian cane fields and, as warned, the cane toad has become a pest in its own right to the extent that it is listed as a key threatening agent under the *Environment Protection and Biodiversity Conservation Act 1999*.

### Unintended consequences

The properties of the toad that make it a candidate for agricultural pest control are also the same properties that make the toad an exotic pest in its own right. Cane toads are prolific breeders and voracious predators and source their diet from a wide range of dead and living matter. Not only do they prey on native species but they out compete other species and are poisonous at all stages of their lifecycle from egg to adult. As such native animals such as quolls, goannas, some species of snake, freshwater crocodiles and native fish are most at risk from cane toads. Recent studies have shown cane toads also prey on chicks of ground nesting birds (Boland 2004) and are known to transmit diseases such as salmonella (Invasive Animal CRC, 2007). The result of cane toad invasion is an initial rapid decline in frog eating native animals in the area (Catling *et al.*, 1999) and a failure for some species to regain their pre-invasion population densities. Cane toads have now spread through northern NSW, the Northern Territory including through Kakadu National Park and Arnhem land, and have reached as far west as the Kimberley region in Western Australia travelling at a rate of 27-50 km/year (Molloy and Henderson, 2006). Newly colonised areas in the NT can experience toad densities of 2000 toads/hectare (Invasive Animal CRC, 2007).

### Lessons for Future Innovations

There are lessons that can be learnt from innovations that fail to effectively identify and incorporate the social-environmental reality beyond the laboratory, what we might call *cane toad* innovations. Successful technology development necessitates a good understanding of the innovation (the behaviour of cane toads and cane beetles in the laboratory), the intended environment (the Australian cane field), and importantly the interaction between the two in a controlled real world context prior to widespread implementation (whether the cane toad actually eats the cane beetle in a real Australian cane field). Furthermore it also requires consideration of the how the innovation/technology performs under foreseeable and non-ideal contexts (for example, the behaviour of the cane toad beyond the cane field i.e when it reaches sensitive native ecosystems).



## THE CARMEN DE ANDACOLLO CASE – A TECHNOLOGY INAPPROPRIATE FOR ITS CONTEXT

The Andacollo Copper Project, Chile, is operated by Carmen de Andacollo. The mine is currently owned by Canadian mining company Teck, after it acquired the operations from Aur Resources in August 2007. The mine is located in the community of Chepiguilla, around 2 km from the city of Andacollo and 55 km from La Serena, in Region IV, Chile. Chepiguilla is within the city limits of Andacollo. Work on the mine began in 1996. The project is a heap leach copper operation that processes copper oxide and supergene (weathering produced) sulphide ore. The extraction and processing consists of mining the ore material in an open cut operation and arranging this ore into a '*lixiviación*' pile where a solvent is applied to dissolve the copper minerals before collection and further processing.

The leaching piles of the Andacollo Copper Project are located just 200 m from homes in Chepiguilla. They cover an area of 520,000 m<sup>2</sup> and have a height of 60 m (*Juntos de Vecinos – Chepiguilla et al., 2001*). The sulphuric acid '*lixiviant*' is applied to leach the ore utilised spray technology. The community representative body complained of health problems as a result of the mining operations, particularly respiratory illnesses due to the contamination by dispersion of the sulphuric acid spray. They further argued that pollution from the mine caused their trees to dry up and for the fruits to become ill and acidic (at interview, 2003). Other environmental concerns included the noise pollution from blasting so close to the community.

The health impacts of the spray were eventually confirmed by the Coquimbo Health Service (Corvalán and Alvear, 2003) and breaches in air quality criteria were confirmed by internal company reports witnessed by one of the authors. The direct impact of the pollution was accompanied by a change in community identity. Before the mine community members considered Chepiguilla the 'greenhouse' of Andacollo, "We had nice fruits and trees, clean water and people from other places used to come and relax and sightsee" (at interview, 2003). The community valued their amenity even while they were located in a region with a long history of small and large scale mining and associated pollution. The loss in amenity mobilised the community members. The issues of pollution from the leaching process were brought to the attention of the company and Chilean government authorities without resolution.

### What went wrong?

Prior to the development, in 1994, a voluntary Environmental Impact Assessment (EIA) was submitted by the then owners Canada Tungsten. The project was approved under the Environmental Framework Law however, the regulations to guide the approval process had yet to be adopted by the state when approval was granted by the authorities. A number of environmental criteria were thus not applied in this case, including public participation in the EIA process (*Juntos de Vecinos – Chepiguilla et al. 2001; Padilla, 2005*). The location of the heap leach piles was also given approval despite the fact that part of the area was within the city limits and zoned as residential. The municipal authorities were notified of this irregularity by the local community representative body. While the authorities acknowledged the illegality of the location of the mine, the city master plan was modified to administratively resolve the issue without resolving the environmental and social impacts (*Juntos de Vecinos – Chepiguilla et al. 2001; Padilla, 2005*).

Following escalation of the conflict the project operators suspended leaching in the region closest to the community and, on the order of the Coquimbo Health Service, adopted an alternate drip system for acid application instead of the original spray technology (OLCA, 2004). These changes significantly reduced the scale of the impacts.

The spray leaching technology, while appropriate in other circumstances, was incompatible with the location of the leaching piles so close to community. Technology assessment and impact assessment that included the participation of stakeholders may have identified the criteria necessary for implementation of the chosen technology and provided a better understanding of the local context. Such assessments may have prompted the initial selection of an alternative leaching system.

### 3.2. TECHNICAL AND SOCIAL RISK

**Technical risk** refers to risks that arise as part of project development or the risk of project failure due to engineering, manufacturing, and technological processes. This area of risk management is most familiar to managers, technical personnel and researchers working within the minerals processing industry (Barclay *et al.* 2009). We argue here that individuals involved in the design, development and implementation of new technologies must think beyond simply the technical risk component of technologies to consider the social risks of new technologies.

A **social risk** is the potential for an existing or planned project to have an adverse impact on individuals or groups or, conversely, to be impacted by them. Social opportunities refer to the potential for mining to generate beneficial outcomes, such as economic and community development and employment.

The definition of social risk is often narrowly defined to refer only to the risk experienced by project proponents (see Barclay *et al.*, 2009). We argue that the social risk to a project is intrinsically linked to the risk faced by project stakeholders, especially members of the communities in which technologies operate or affect. This feedback loop operates such that when social harm and costs are experienced or perceived to be experienced by stakeholders they may raise the social costs to proponents and thus increase the risk of project failure. Thus the impacts of technologies, or indeed the perceived risk of technologies, to society or the environment, must also be considered as components of social risk.

By minimising the risk of social harm to the community, the risk of social disruption to the technology proponent is also reduced. Similarly, by improving the opportunities for communities and other stakeholders the opportunities for the technology proponent are enhanced.

To understand social risk, it is also important to understand the generation of social impacts. A **social impact** is something that is experienced or felt (real or perceived) by an individual, social group or economic unit (Slootweg *et al.*, 2001; Vanclay, 2002, 2003). Social impacts are the effect of an action (or lack of action). Social impacts can vary in type and intensity, and over space and time. New technologies alter the mining-social landscape thus creating social impacts that may be either positive or negative or both simultaneously.

Environmental impacts also have social implications. Mining activities can result in changes to community amenity, health or the availability and quality of water and land. Impacts can be direct, such as the impact of noise and dust, or result from indirect pathways, for example, road fatalities resulting from increased traffic in a nearby town servicing a mine. Impacts often accumulate and interact such that they trigger or become associated with other impacts. Cumulative impacts arise from the compounding activities of a single operation or multiple mining and processing operations, as well as the interaction of mining impacts with other past, current and future activities that may or may not be related to mining (Franks, Brereton and Moran, 2009).

The fear of an action can often be as important a generator of impact as the action itself. Perceptions of risk are subjective and public understandings do not necessarily correspond with scientific perspectives. It is also unwise to assume that stakeholders all share a similar perception of what is or is not acceptable risk and indeed what constitutes risk at all. There are a number of reasons for this. Non-technical factors, such as personal value systems, previous experience, levels of trust in information sources and methods, and openness to change, all influence how individuals and communities perceive and respond to change (Franks,

forthcoming). This makes it hard to predict or indeed measure community risks without consulting the community in some way or understanding the cultural context.

Recognising that perceived risk is a fundamental component of the social impact of technologies forces one to reconsider risk evaluation being conducted solely from the technical perspective that most technologists and engineers possess. Risks are not always concrete and risk is always measured and assessed differently by individuals. The assumption, sometimes held by proponents of technology, that community concerns are unscientific and thus unfounded can be counterproductive to the uptake and acceptance of technologies. Differing standards of acceptable risk within specific areas of the minerals industry itself are proof that even scientifically based risk identification is subjective. Consequently scientifically based regulations sanctioned by government or industry are not always sufficient to meet public concerns. Science itself is often contested. As such it is unwise to assume that sufficient technical information and education, alone, is bound to sway public opinion. A more effective approach is to design technologies that are reflective of stakeholder values.

Perceptions of social risk can have profound and costly impacts on technologies whether the risks become realised or remain as potentialities. Social impacts and perceptions of risk have the potential to disrupt the application of certain technologies through, for instance, negative publicity, delays in obtaining regulatory approval, increased litigation, substantial reputational damage and, in extreme cases, loss of the 'social license to operate'. The industry uptake of a technology may also be impacted by perceptions of risk. We return to these issues in section 4.

**THE STUART OIL SHALE PROJECT – A TECHNOLOGY POORLY UNDERSTOOD**

The Stuart Oil Shale project was a joint venture between an Australian company, Southern Pacific Petroleum/Central Pacific Minerals, and a Canadian based multinational, Suncor, to commission a \$250 million experimental oil shale plant and mine near the Central Queensland port city of Gladstone, Australia (Sinclair Knight Merz, 1998). Oil shale is a sedimentary rock that is mined for the production of fossil fuels. Airborne emissions released from the project led to health complaints and community opposition, with the conflict contributing to the eventual closure of the facility, hundreds of millions of dollars in lost capital, many hundreds more lost in potential future production, and lost income and benefits to the community. The declaration of the region as a 'state development area' by the Queensland Government resulted in the closure of the nearby Targinnie community and the resumption of their properties. Recent attempts by the successors of the Stuart Project to develop another Central Queensland deposit were met with a 20-year moratorium by the State government, a direct legacy of the original conflict (Queensland Parliament, 2008).

Prior to the construction of the development, public community meetings were held in association with the Stage 1 EIS. The impression the community held about the development, derived from the community information sessions and communication materials produced by the company, was that the project would not pose any risks to the community. One resident of Yarwun described the characterisation of the project as "you won't even know we're here" (Noonan, 2002). A communications document to the community, separately confirmed at interview by multiple interviewees, stated that 'you won't hear us, see us or smell us'. Project proponents believed, based on laboratory scale pilots, that the technology did not pose environmental or social risk.

While the proponents of the project may not have anticipated adverse impacts, characterising the risks of the project in this way was not consistent with information on the process of oil shale extraction and processing available at the time (Graham, 1980), nor with the eventual practice of the plant. The understanding that proponents had about the technology based on experimental results under optimal conditions was inconsistent with the actual performance in its operational context. Airborne emissions from the plant resulted in health impacts for the local Targinnie community, including irritation of mucous membranes (tingling lips and tongue, dry and irritated throat, burning skin, sore and stinging eyes, runny nose, sinus problems), headache and nausea. These health impacts were confirmed by field officers of the Environmental Protection Agency who on multiple occasions were forced to withdraw from the field due to health effects (Qld EPA, 2001).

Operational changes later reduced the scale of emissions; however, the community conflict continued and was a major factor behind the abandonment of the project. Understating the potential impacts of the project created a false impression, distorting expectations. The less than frank assessment offered during the early community engagement process became an ongoing point of contention and exposed the proponents to a potential breach of trust when impacts were eventually experienced. The loss of trust, furthermore, left a lasting legacy that hampered resolution of the conflict when emissions were later reduced.

The case demonstrates the importance of effective characterisation of technology and its potential waste streams in all possible operating conditions (ideal and non-ideal) prior to implementation and the negative legacies created when trust is breached.

### DEEP SEA TAILINGS PLACEMENT AT MINAHASA – A CONTESTED TECHNOLOGY

Deep sea tailings placement (DSTP) is a type of submarine tailings disposal where mine waste is discharged into the ocean at depth. The technique is based on the assumption that the waste is; physically contained by the ocean thermocline and will not be re-mobilized in surface water, chemically contained by the alkalinity and reduced oxygen of seawater, and is geographically stable after deposition in ocean depressions or canyons. DSTP is not a common process but where it is possible it is increasingly being considered, such as in circumstances where land is restricted in rugged terrain or islands, where precipitation exceeds evaporation and excess water needs to be discharged from a tailings dam, or there is risk of earthquakes. One place where DSTP was practiced is at a now closed gold mine operated by Newmont Minahasa Raya in Sulawesi, Indonesia.

#### Environmental and Social Risks and Impacts

Proponents of DSTP argue that the technique is advantageous because tailings stored at depth are more stable both physically and chemically, upfront capital and operating costs are lower, metal mobilisation is inhibited, there is a lower risk of contamination of freshwater systems surrounding mines, there is a reduced terrestrial footprint, and the technique is more visually aesthetic (Poling, 2002). There remains a lack of peer-reviewed and independent scientific studies to verify these assumptions, a situation acknowledged by some advocates of the technique (Poling, 2002) and the findings of the MMSD (2002). There are also some significant disadvantages and risks of DSTP. Environmental impacts can include the creation of a benthic footprint, topographic alteration of the sea floor, the release of leachable toxins and residual chemicals, or impacts on fisheries and other socio-environmental impacts on communities that rely on the ocean. According to Poling (2002), an advocate of the practice, DSTP can lead to acute and chronic toxicities, bioaccumulation, and habitat alteration.

#### Controversy at Minahasa

Controversy surrounding DSTP at Newmont's Minahasa Mine led to international media coverage, including on the front page of The New York Times, and public and government scrutiny over Newmont's operations at Minahasa and their other international sites. Local opposition to the mine was organised around perceived risks of pollution from DSTP as well as a number of other issues, including inadequate land compensation. Although local opposition began before the mine commenced operation, the global controversy ensued during preparation for closure in 2004 when claims were made that a baby from a coastal fishing village, Buyat Pantai, died as a result of mercury contamination. As media coverage increased local fishermen found it more difficult to sell their fish for fear of contamination and the majority of Buyat Pantai community were voluntarily relocated with the help of non-government organisations. Impacts to the company from the controversy include local government injunctions, which forced the mine to close several times, the arrest of several mine employees (with charges later dropped) and litigation. One of the largest company costs was the reputational damage sustained by Newmont as global media portrayed them as responsible for the death.

#### Lessons from Minahasa

Results of independent investigations did not find elevated levels of mercury in Buyat Bay. Despite these findings, community opposition led to international media coverage and legal interjection. This case study illustrates the very real capability of communities to link with non-government and media organisations to mobilise opposition to mining technologies based on both the perceived and real risks of technologies. A community relations review commissioned by Newmont indicates that the controversy may have been averted if Newmont's approach with key stakeholder groups was more strategic rather than working to establish relationships after the controversy had gained momentum (Smith and Feldman, 2009). The case also demonstrates that in the presence of contested science and the absence of public trust of a technology, there is a higher likelihood that stakeholders will be sceptical of the operations and for adverse impacts to be perceived. In such situations proponents have little validated evidence to point to once controversies ensue. The interrelationship between operational conduct and technology as factors affecting public acceptability are discussed further in section 4.2.



## 4. SOCIAL LICENSE TO OPERATE AND TECHNOLOGY

Social license to operate refers to the intangible and unwritten, tacit, contract with society, or a social group, which enables a mining operation to enter a community, start, and continue operations (Joyce and Thomson, 2000). Social license to operate is not an agreement between communities and mines that can be formalised in any way but, rather, must be thought about as a descriptor of the state of the relationship between the mining proponent and the community in which the mine is operating and, therefore, as a process of continual negotiation. Increasingly the minerals sector is realising that, whilst necessary, compliance with statutory environmental regulations is often insufficient to meet societal expectations of environmental and social conduct and thus extra activities must be undertaken to foster social license (Bridge 2004).

Social license is a complement to regulatory licenses but is not a product that can be granted by civil authorities, political structures or even the legal system (Solomon *et al.* 2008). Despite a relationship of influence existing between government acceptance of certain technologies/industries and public opinion, the two are by no means synonymous with each other. Community acceptance and support of a project may be withheld despite government approval and can also inform regulatory procedures and affect government approval.

Social license to operate can only be sought from project stakeholders (those affected by, or that can effect, the technology, operation or event). The process by which social license is expressed is contextually specific, dynamic and non-linear. This means that community perceptions of mining activities that affect them depend on the community and operation at hand and can change through time. It is therefore difficult to determine whether a new technology will gain social license until the technology is implemented. It also means that social license to operate can be withdrawn at any stage in the operation if the community becomes concerned about the operation or disenfranchised from the process.

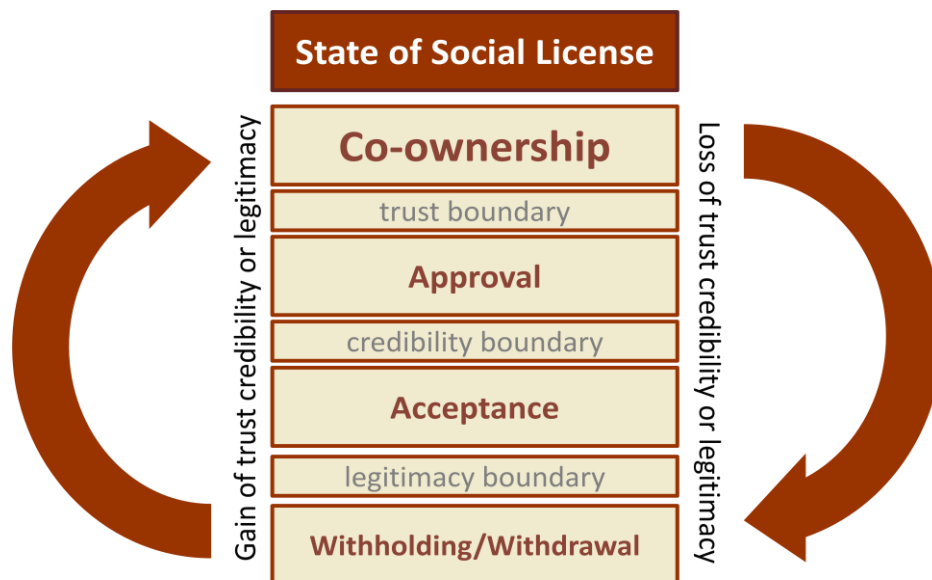
Technological traits can have a profound effect on the establishment or maintenance of a social license. At one level, acceptance of a technology is based on perceptions of the risk of that technology; for example, social license can be influenced by whether the technology is considered to be harmful, benign, beneficial or essential. These categories are not mutually exclusive however. Perceiving a technology as essential does not necessarily mean that an individual would accept that technology in their local area. Examples include controversies over the construction of mobile telecommunication towers in residential areas and or near schools. The overlap exists because attitudes towards technologies are ultimately bound up in both individual's aspirations as human beings (Tiles and Oberdiek, 1994) and personal perceptions of risks associated with the technology. Technological components are but one factor in the social license albeit a very important factor.

### 4.1. STATE OF SOCIAL LICENSE

Thomson and Boutlier (forthcoming) have identified various levels of strength in social license 'contracts' meaning various levels of social approval and acceptance of the mining operation. At the lowest level the relationship between the community or a network of stakeholders and the operation is one of acceptance only. The community 'puts up' with the operation. A higher level of social license is reached when the community explicitly approves of and encourages the continuation of the operation. The highest level is achieved when a community perceives the operation to be integral to their communal identity and values and therefore feel a sense of co-ownership over the operation. An example is when residents willingly identify, are proud of, and encourage their town's identity as a mining town.

Stronger levels of social license are gained as an operation establishes legitimacy, credibility and finally a lasting and affective level of trust (Thomson and Boutlier, forthcoming). The strength of social license can also be reversed as trust, credibility and legitimacy are impacted or lost, leading eventually to the community withdrawal of the social license, or withholding of the social license to begin with, as shown in 1. It is important to note that processes of strengthening and or weakening social license relationships are not linear and thus a state of 'co-ownership' can rapidly deteriorate to a state of 'withdrawal' if a problem of significant scope arises. This is why a social license must be thought about as a process of continual negotiation rather than as a legal contract with defined clauses and actions for involved parties. In the following section we discuss the relationship between a social license and stakeholder behaviour and the consequences of a loss of social license to operate.

**Figure 1: Levels of social license and conditional boundaries (adapted from Thomson and Boutilier, forthcoming).**



## 4.2. SOCIAL LICENSE TO OPERATE AND STAKEHOLDER BEHAVIOUR

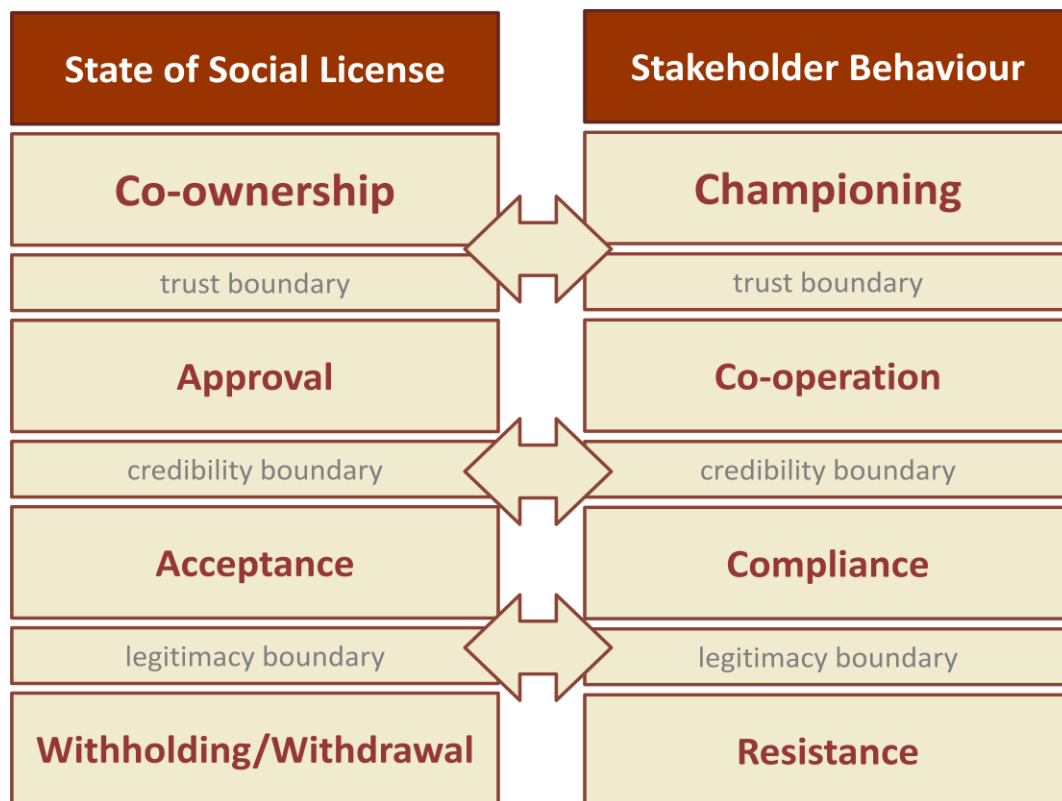
A study conducted on the closure of 800 Australian mines between 1981- 2006 found that only 25% of closures were due to exhaustion of reserves and the other 75% were closed prematurely (Laurence, 2006). Many factors force the premature closure of mines including economics, commercial decisions, technical and environmental issues, as well as community opposition. Examples of Australian mine closures where community opposition was a major factor include Timbarra gold mine in NSW which closed in 2001, the Stuart Oil Shale Project in Gladstone which was abandoned in 2004, and the Jabiluka Uranium Mine in the NT which was never allowed to progress into the production phase of operation (Laurence, 2006; Franks, 2009). These examples represent mining projects in which social license was never achieved.

Building on Thomson and Boutilier (forthcoming) we argue that the state of the social license can be directly linked to stakeholder behaviour and vice versa. If a project, or its technological components, is considered untrustworthy, lacking credibility and illegitimate then a

community may actively, or passively, resist that project. Conversely, if such social capital exists a community may actively champion a project (see Figure 2). When talking about stakeholder relationships it is necessary to state that those directly located in the vicinity of an operation (communities of place) as well as those with a legitimate but perhaps less immediate interest (communities of interest) are both critical informants that shape the nature of social license.

The strength and resilience of the relationship between an operation and its stakeholders will influence the response of stakeholders to events, and, as such, the ease with which social license may deteriorate or be withdrawn. This can be thought of as the resilience in the relationship. The more robust the relationship the more it takes for the social license to be withdrawn.

**Figure 2: Relationship between the state of a social license and stakeholder behaviour (adapted after Thomson and Boutilier, forthcoming)**



Research by Nelson and Scoble (2006) has identified conditions that industry personnel consider critical to acquiring and maintaining, and we argue, strengthening, social license. These include maintaining a positive corporate reputation, understanding the cultural and historical context of the community and operation, educating local stakeholders about the project and ensuring open communication among all stakeholders (Nelson and Scoble 2006). The conduct of the mining company is, evidently, of critical importance especially in fostering trust in mining-community relationships. However the nature of the mining technology employed by an operation in its particular political, geographical, geological, and social context is a fundamental issue not identified by Nelson and Scoble (2006).

Establishing and maintaining, as well as losing social license is influenced by both the nature of the operation in its landscape context as well as the conduct of the operators or industry.

Technologies and technological processes are irretrievably linked to both the operation and the operator's behaviour (see Table 2).

**Table 2 Factors affecting the state of the social license to operate**

	Factor affecting social license to operate	Example
<b>The nature of the operation in its landscape context</b>	Operational traits	The use of contextually appropriate technologies or processes.
	Extraction of particular resources (minerals)	Uranium mining is controversial due to concerns about health and environmental impacts and because of the use of the resource in weapons.
	Mine inputs	Water in mining and minerals processing and energy for mining, minerals processing and transport.
	The scale and location of the operation	Underground/ open cut; size and production.
	Mine pollution and amenity	Dust, water quality, noise.
	Sense of place/community	Location and accommodation of workforce.
	Access and transportation	Fly-in Fly-out, trucks travelling through town.
<b>Operational conduct</b>	Land-use and landscape resources (Franks, 2007).	Conflicting land use, competition over resources and how these are defined.
	Cultural and historical context of the community and operation (Nelson and Scoble 2006).	Social profiling, past experience.
	Level of stakeholder education about the project (Nelson and Scoble 2006).	Public relations.
	Level of communication among stakeholders (Nelson and Scoble 2006).	Risk communication, transparency, mutual reciprocity (see for example Stehlik, 2005; Browne <i>et al.</i> , 2009).
	Presence or absence of consent for resource development (Franks, 2007; Laplante and Spears 2008)	Indigenous (traditional owner) consent, and the consent of sovereign states.
	Community economic development and wealth capture in regional mining communities	Local training and employment, post-mining legacies and infrastructure (CSIRO, 2004).
	Corporate reputation (Nelson and Scoble 2006).	Trustworthy conduct.

Research in progress by the Centre for Social Responsibility in Mining in collaboration with the Corporate Social Responsibility Initiative at the Harvard Kennedy School is collating global case studies of disruptions to mining projects, both temporary and permanent, to understand the economic, reputational and social costs encountered by companies when social license is lost or alternatively never achieved. Economic costs are only a component of the total costs experienced and are reflective of the costs experienced by proponents only. Nevertheless they point to tangible disincentives for operations when a social license breaks down. These costs range from the need to invest in tighter security, or public relations, to technological or project

modifications, as community opposition against an operation mounts. For example costs may relate to material damage to equipment or property, increased security or insurance costs, loss of productivity, loss of capital, personnel costs and also social or environmental compensation.

### **4.3. EMBEDDED CONFLICT AND ‘SOCIAL LICENSE BY DESIGN’**

We now explore the relationship between social license to operate and technology innovation and development. We are directly concerned with the degree of reflexivity of technologies (see Schot and Rip, 1996), or the ability of technologies and technologists to examine the limitations of technological trajectories and processes, and incorporate external perspectives and social values into the design of technologies. Such transition pathways have elsewhere been labelled co-evolution (Rip, 2006) and co-construction (Misa et al., 2003) and are understood as the outcomes of alignments between developments at multiple levels from individual technologists to interplays between individuals and the socio-technical landscape (Geels and Schot, 2007).

Here we introduce the concept of *embedded conflict* to describe how technology design traits may lead to the absence of social license to operate. Embedded conflict refers to the idea that the design traits of a technology have the potential to manifest into conflict at some point during implementation. Conflict may or may not manifest depending on the future social and environmental context. In this sense a potential social impact or risk may be triggered or ‘switched on’ in the future.

Conflict can be embedded in technology because, once sunk into a landscape, mining technology can be difficult and very costly to retrofit – so, to some extent, the future outcomes are set within the technology. Moran (1974) observed that the power dynamics between companies, governments and host communities shifts once capital has been sunk within a landscape due to the relative inflexibility of modifying, moving or withdrawing mining technology. Moran’s ‘balance of power’ model explains the shifting dynamics in the context of foreign investor and host country relationships but the model is broadly applicable for understanding company community relationships when a new technology is implemented.

Moran (1974) observed that to encourage investment a host government may offer concessions to mining companies, particularly where the risks of such investment are high. In such a case the host government is motivated to see their natural resource potential realised and to generate revenue, employment and associated services. At this stage, an investor has a monopoly control over the ability to create a working operation (human and financial capital and the potential to produce built capital) from the host country’s ore reserves. This and the uncertainty over whether the operation will return an investment place the bargaining strength initially on the side of the investor.

Once the investment is made and the mining technology is embedded within a landscape the host country is in a position to renegotiate. The bargaining power shifts with the reduced uncertainty and risk experienced by the investor now that the project has experienced success and the skills and built capital are transferred into the domain of control of the host government. In this way Moran’s model explains the observed phenomena of host governments successfully leveraging better outcomes through renegotiated resource contracts.

The same can be true for host communities. Prior to the implementation of a new technology, host communities can lack the bargaining power to influence the shape of operations. They



are largely in the hands of the state as to whether a mine goes ahead and the conditions under which it proceeds and they may lack the technical skills and resources and, depending on the legislative context, the opportunity to effectively participate in the decision making process. Before implementation the costs experienced by host communities may also be intangible and the reaction to impacts may be different then when they are actually experienced. This final point is particularly acute for new technologies where host communities are unfamiliar with the technology and there are no analogous examples to draw experience.

Once the technology is implemented, disruptions to operations can be very costly due to lost production time and host communities can leverage this to raise the social costs to developers if they perceive that they are disproportionately experiencing the costs, rather than the benefits of a project. The bargaining power is with host communities if they are motivated enough to disrupt operations. But unlike the renegotiation of a resource contract the technology itself is difficult to change – in this way conflict can be embedded<sup>2</sup>.

Franks (2007) and Boege and Franks (forthcoming) have observed that the operational decision making of mining companies are constrained by commercial and production imperatives. Despite secondary values such as commitments to Corporate Social Responsibility the primary interest of a mining company in a particular location is based on the occurrence of the ore deposit that can be extracted and marketed for profit. The economic and technical constraints of modifying production processes once implemented can therefore lead companies into confrontation with stakeholders<sup>3</sup>.

It is for these reasons that it is crucial to consider the future operational context within the design of technology. The idea of embedded conflict, and also the idea of designing technologies to prevent embedding conflict in their design, has precedent in recent work in Occupational Health and Safety (OHS) on the area of Safety in Design (also known as Safe Design, or Prevention through Design). The Safety in Design approach attempts to eliminate OHS hazards, to those who make and use technologies, within the design phase of technologies rather than addressing safety issues through retrofitting technologies (Horberry et al., in press). Safe Work Australia (2009, cited in Horberry et al., in press) defines Safe Design as:

*... a design process that eliminates OHS hazards, or minimises potential OHS risk, by involving decision makers and considering the life cycle of the designed-product.*

*A Safe Design approach will generate a design option that eliminates OHS hazards and minimises the risks to those who make the product, and to those who use it.*

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<sup>2</sup> Embedded conflict relates to but is significantly different from the concept of technological 'lock-in'. Technological 'lock-in' refers to the processes which limit technological innovation and encourages technological development toward defined pathways proscribed by existing technological regimes. For example, engineering or institutional frameworks that narrowly define the nature of and solutions to technological problems will effectively exclude the production of technologies that address problems in unique ways (Dosi, 1982). Another component of technological 'lock-in' refers to the idea of increasing returns to adoption locking inferior designs into the market place (Perkins, 2003). Commonly used examples include the QWERTY keyboard (David, 1985) and, although outdated, the VHS video recorder compared to Betamax (Arthur, 1990). Embedded conflict interacts with, but differs from, the concept of technological 'lock-in'. The interplay exists because the macro level forces that shape the forms of technological 'lock-in', when realised in certain contexts, may result in conflict. In certain cases, therefore, technological 'lock-in' can be a factor contributing to embedded conflict.

<sup>3</sup> Tushman and Anderson (1986) refer to a similar process in arguing that technological change (or, we add, the application of existing technologies in new environments), can either support or undermine the competencies or values of the proponent. The difference between a positive and negative outcome for the proponent can depend on the organisation's adaptability, sunk costs, and other macro constraints (Tushman and Anderson, 1986).

We propose that appropriate technology assessment methods can help facilitate “Social License by Design”. Building on the Safe Design definition, Social License by Design describes a *design process that attempts to reduce social hazards or minimise potential social risk by involving designers and decision makers in considering the operational context of the designed product beyond the user or proponent*. In the following section we outline technology assessment methods that could be used to facilitate Social License by Design by increasing technologists understanding of future landscape contexts and stakeholder values.

## 5. TECHNOLOGY ASSESSMENT

### 5.1. IS THERE A ROLE FOR TECHNOLOGY ASSESSMENT?

Technology assessment during the design phase of technology development can help to understand and reduce the potential for conflict to be embedded within the design of a technology and to understand the circumstances in which a technology is contextually appropriate.

The uptake of Technology Assessment (TA) by industry and government has been slow in Australia, despite a number of very prominent examples where technologies have attracted controversy when implemented. In the Australian minerals industry in situ leaching of uranium, the development of oil shale, and by products such as alkaloam are examples of technology that has been the subject of public controversy. In at least one case, opposition resulted in the abandonment of the development (Barclay *et al.*, 2009). A current Australian Research Council-funded project, *Technology Assessment in Social Context*, is seeking to advance technology assessment in Australia, particularly in the area of nano and food technologies. There is a need to extend such approaches to the development of technology in the Australian minerals industry.

Technology assessment has a long history as a method to inform research, development and decision-making. Since the 1970s the United States Office of Technology Assessment provided technology analysis for the US congress to guide policy. The Office was disbanded in 1995, but the Federation of American Scientists hosts an archive of published material (<http://fas.org/ota/>). The European Union continues to undertake such analyses through the European Parliamentary Technology Assessment Network and the Science and Technology Options Assessment. In 2007 the European Union introduced regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) that requires industry to assess and manage the risks of chemicals.

The term Technology Assessment has been used in a number of ways, across various fields and in association with a wide variety of methodologies. In particular, the term has been applied to:

- Market research for technology development to maximise market potential (Un and Price 2007; van den Hende, Schoormans *et al.* 2007)
- Strategic technology selection for companies or organisations to use internally to maximise revenue (Pretorius and de Wet 2000; Jolly 2008)
- Technology selection for societies or governments to optimise societal benefit and acceptance and reduce adverse impacts (Einsiedel, Jelsoe *et al.* 2001; Assefa and Frostell 2007; Raven, Jolivet *et al.* 2009)
- For companies to plan their investment in technology development (Hoffmann, McRae *et al.* 2004; Azzone and Manzini 2008)

- Assessment of social or environmental impacts of technology (Jischa 1998; Dewulf and Van Langenhove 2005).

Technology assessment to assess the development of mining technologies for the Minerals Down Under Flagship of the CSIRO could usefully draw from the last of these listed applications. Our focus here is on assisting the developers of technology to identify, communicate and resolve real and perceived social risks of the technology in the context of its application. This process aims to improve the environmental and social outcomes from the technology, as well as the potential for social acceptance. Improving the environmental and social outcomes of a technology should not be seen as a merely providing a 'social solution' but rather as providing a better technology (on both social and technical grounds) and thus fostering considerable competitive advantage (Nowotny, 2006).

## 5.2. APPROACHES AND TOOLS OF TECHNOLOGY ASSESSMENT

In literature regarding technology assessment there is no generic methodology agreed upon; rather it is argued that each technology and context requires the latitude to apply appropriate techniques to the specific situation (Coates 1976; Wood 1997). In addition, there is potentially variable perception of technology assessment and its importance and structure, depending on the country and culture (Chen 1979). With this in mind the current review was performed with consideration to minerals technology development.

The main types of TA have been summarised elsewhere by Van Den Ende et al. (1998) as:

1. Awareness TA: forecasting technological developments and their impacts, to warn for unintended or undesirable consequences.
2. Strategic TA: supporting specific actors or groups of actors in formulating their policy or strategy with respect to a specific technological development.
3. Constructive TA: broadening the decision process about technological development to shape the course of technological development in socially desirable directions.
4. Backcasting: developing scenarios of desirable futures and starting innovation processes based on these scenarios.

Constructive TA is well suited to technology assessment within R&D institutions. Guston and Sarewitz (2002) argue that constructive TA has three particular analytical components these being socio-technical mapping, early and controlled experimentation and identification of unanticipated impacts, and communication between technology proponents and the public. These components allow social aspects to become additional design criteria of technologies (Schot et al., 1992) thus avoiding embedding conflict into design traits.

Another useful review of methods and tools has been performed by Tran and Daim (2008) who classify TA methods by user type (see Table 3). Risk assessment, integrated TA and emerging technologies assessment tools specifically are likely to be useful for assisting technology developers.

**Table 3: Tools and methods for technology assessment (Tran and Daim 2008)**

	In the public decision-making domain	For business and non-governmental uses
<b>Tools and Methods</b>	<ul style="list-style-type: none"> <li>• Impact analysis</li> <li>• Scenario analysis</li> <li>• Risk assessment</li> <li>• Decision analysis</li> <li>• Emerging technologies</li> <li>• Structural modelling and system dynamics</li> <li>• Environmental concerns and integrated TA</li> </ul>	<ul style="list-style-type: none"> <li>• Cost-benefit analysis</li> <li>• Measures for technology</li> <li>• Scenarios and Delphi</li> <li>• Road-mapping</li> <li>• Decision analysis</li> <li>• Surveying, information monitoring, new technology assessment</li> <li>• Mathematical and other synthesis methods</li> </ul>

Roessner and Frey (1974) breakdown the available and essential methods into the following categories:

1. Methods for systematic description of technologies and the physical and social setting into which these technologies will be introduced
2. Methods for making predictive statements about the consequences of a new technology
3. A variety of “aids to structured thought” as ways to structure tasks, identify relevant variables and explore assumptions made about relationships among variables
4. Methods to coordinate and manage the activities of a large number of professionals from a number of different disciplines and fields

Table 4 provides a description of some of the many and varied technology assessment tools and methods.

**Table 4: List of methods that can be applied to technology assessment. Modified after Franks (forthcoming).**

<b>Methods useful in Technology Assessment</b>	
<b>Data gathering</b>	
<b>Case Study</b>	Case study research involves the "detailed examination of an aspect of a historical episode to develop or test historical explanations that may be generalisable to other events" (George and Bennett, 2005, 5). Case study research is at a scale and depth that favours the identification of causal relationships and the tracing of processes (Gerring, 2004). In the context of technology assessment case studies of similar technologies can provide valuable data on potential issues that may arise, however, where technology is novel and where analogous situations are not available case study research is limited.
<b>Choice Modelling</b>	An experimental technique used in economics to frame tradeoffs between different options. The technique estimates the value of options by revealing how respondents are willing to trade them. Information is usually gathered through surveys.
<b>Interviews</b>	A method of primary data collection that consists of in-depth questioning. Interviews may vary according to the type of informant, the type of medium (telephone or face-to-face, individual or group), the setting and recording, and the type of questioning (structured, semi-structured, and unstructured).
<b>Stakeholder Analysis</b>	<p>Stakeholder analysis consists of the identification of stakeholders; analysis of their underlying attitudes and motivations; a determination of which stakeholders are most significant; an understanding of their networks and relationships; and the development and implementation of an engagement plan. A stakeholder is anyone who can affect, or is affected by, an action.</p> <p>Targeted consultations (or focused plans) may need to be developed for each stakeholder, especially vulnerable groups. Stakeholders have varying degrees of power, legitimacy and interest in an issue or a project. They may include communities that may be located in the vicinity of mining operations, employees, shareholders, financial institutions, indigenous peoples, non-government organisations (NGOs), trade unions, governments and their departments. Stakeholders also include people within resource companies that may be important to the planning, development and implementation of the action.</p>
<b>Strategic &amp; Regional Assessments</b>	Strategic assessments are assessments done at the scale of a policy, plan or program, while regional assessments may be at the scale of a minerals or resource province, catchment, or political jurisdiction. Strategic and regional assessments may be undertaken during, or prior to, the establishment of a new type of industry, extraction method, or exploitable resource. The advantage of such approaches are that they: facilitate the early identification and resolution of potential issues when there is the flexibility to make changes; provide an opportunity for longitudinal and



	<p>comparative research; may more effectively identify existing and potential cumulative impacts; may explicitly link assessment to regional planning and reporting; and can establish baseline and regional datasets that assist the development of region-wide monitoring efforts.</p> <p>A strategic assessment can be the most appropriate form of assessment for regions involving multiple stakeholders or complex, large-scale actions</p>
<b>Surveys</b>	<p>A form with questions used to solicit information from a statistically significant group of respondents. Surveys may be used in SIA to provide data on the characteristics and opinions of a population and may vary according to the choice and wording of questions, the type of instrument (e.g. mail-out, telephone or face-to-face), the sample size and sample frame.</p>
<b>Social and Regional Profiling</b>	<p>A process to collect relevant primary and secondary data about a community. The profile is a detailed description of the community, environment and economy of a region and provides insight into values, priorities and trends. A social baseline is an appraisal of the current state of a community or social group including a consideration of trends.</p> <p>Knowing the community assists in anticipating how people might respond to change. Understanding communities involves an analysis of their relationships and networks, and the values that may shape attitudes and behaviours. Profiling includes analysis of demographic patterns and trends, population characteristics, ethnicity and culture, the local economy, labour market, land-use and ownership patterns, social and political organisation, family and community organisation, health, nutrition, disease, community infrastructure and services (housing, health, childcare etc.), expectations and concerns community members have about the project, community 'needs' and desired futures and the capacity to meet these needs, and the vulnerability of social groups.</p>
<b>Social Mapping</b>	<p>A process for identifying and recording the meaning and values ascribed to landscapes by social and cultural groups.</p>
<b>Focus Groups</b>	<p>A group interview method where a facilitator poses questions to generate discussion among participants.</p>
<b>Analysis</b>	
<b>Cost Benefit Analysis</b>	<p>An economic technique that compares the costs and benefits, usually quantified in monetary terms, for scenarios with and without an action.</p>
<b>Cost Effectiveness Analysis</b>	<p>An economic technique that compares the cost effectiveness of alternative options for achieving an outcome, and is used to identify the alternative with the lowest direct financial cost.</p>
<b>Impact Pathway Analysis</b>	<p>A process-mapping exercise used to predict the pathway of impacts resulting from an action. The method prompts insights into the direct and indirect impacts of actions and their interaction. Also known as change mapping.</p>
<b>Input Output Analysis</b>	<p>Input output analysis investigates the relationships and interdependences of an economy through an analysis of the flow of resources. It considers the inputs to industry, transfers between sectors, household consumption and the outputs of goods produced.</p>

<b>Life Cycle Assessment</b>	Life Cycle Assessment (LCA) is a widely recognised method of assessing the impacts of a process or product over its whole life cycle, and has been applied to different minerals processes (Stewart 1999; Stewart 2001; Stewart and Petrie 2006; Norgate, Jahanshahi et al. 2007). LCA has been used as a tool in environmental assessments for many years, but perhaps the most important contribution of life-cycle thinking, is the concept of stewardship of a product across its life cycle. It has been shown that a systems approach (as used in LCA) is valuable in discovering opportunities for development, financial savings and improvement of environmental performance (Bossel 1999). Over recent years, there have been moves to incorporate cost and social factors into LCA (Labuschagne and Brent 2006; Jeswani, Azapagic et al. 2010).
<b>Scenario Analysis</b>	Scenario analysis is a tool to anticipate change under different plausible future situations. Scenario analysis assists the development of a proactive policy response through the testing of assumptions. Scenario planning can assist organisations to prepare for unplanned activities. If conducted with communities, scenario planning can help to inform the public of risks and manage expectations.
<b>Sustainability Assessment and Metrics</b>	<p>Sustainability assessment is akin to technology assessment, in that it is a term that covers a broad range of methodologies with no set or agreed approach. Sustainability assessment examines a technology, plant or process in the light of sustainable development criteria or metrics, to attempt to identify improvements or impacts on environmental, social and economic bases. Sustainability assessment is often applied to technology, and has been undertaken for a variety of minerals industry technologies (McLellan, Corder et al. 2007). Engineering or physical sciences approaches tend to dominate the sustainability assessment literature, especially in regards to technology assessment where numerical approaches are often sought to provide some perceived higher level of certainty than qualitative descriptions (Jischa 1998; Hoffmann, McRae et al. 2004; Dewulf and Van Langenhove 2005).</p> <p>The measurement of sustainability is a concept that has led to the development of various general and empirical sets of metrics or indicators which can be applied to assess new technology. These metrics have been developed for specific industries (Azapagic 2004) or industry more generally (Azapagic and Perdan 2000; Tallis, Azapagic et al. 2003; Pinter, Hardi et al. 2005; GRI 2006). However, the significant omission from all of these metrics is that they do not directly incorporate the specific environment or community in which the technology or plant is located (Xun Jin 2004; Diniz da Costa and Pagan 2006; Durucan, Korre et al. 2006). (Rather, there is an implicit or generalised connection through the selection of appropriate metrics.)</p>
<b>Trend Analysis</b>	The collection and analysis of historical and contemporary data to inform the prediction of the future.
<b>Social Risk Assessment Workshops</b>	A participatory technique to identify, prioritise and respond to the social risks and opportunities faced by an organisation or communities. Through a facilitated workshop, key stakeholders determine the consequence and likelihood of each identified risk and develop controls to avoid, mitigate or enhance priority risks. Also known as social risk and opportunity analysis

	(Evans, Brereton et al. 2007). Risk assessment has also been examined in the specific context of technology futures analysis (Koivisto, Wessberg et al. 2009).
<b>Decision Making Processes</b>	
<b>Citizen Juries</b>	Citizens' juries involve the selection of a representative sample of the community to consider a particular issue. Representatives are usually randomly selected, briefed in detail on the background of an issue, and able to call expert witnesses on a subject. The jurors deliver a judgement in the form of recommendations or a report.
<b>Consensus Conferences</b>	Consensus conferences involve the gathering of a selected group of citizens to learn about a given technology and question the technologists on their concerns. The process typically involves a number of workshops, with approximately 15 citizens participating. Consensus conferences are particularly popular among European technology assessment advocates (Lee Kleinman, Powell et al. 2007), although it has been demonstrated as having some success within an Australian context (Einsiedel, Jelsoe et al. 2001).
<b>Delphi Technique</b>	The Delphi technique consists of a group of people (often a panel of relevant experts or professionals) who make judgement and express their opinions on an issue. These opinions are elicited via multiple rounds of surveys or questionnaires (referred to as iterations), with controlled feedback between each round to inform the group members of the opinions of their colleagues (Rowe and Wright 1999). This process of communication is designed to allow group members to review their opinions in light of what they have learnt from other participants (Jain <i>et al.</i> 1993:204). After several rounds of questionnaire iterations, a final judgment or consensus is made based on the statistical average (mean/median) of the participants' opinions (Rowe and Wright 1999; Jain <i>et al.</i> 1993). The key features of the Delphi technique are: anonymity (achieved through the use of questionnaires), iteration, controlled feedback and statistical aggregation of a group response).

### 5.3. CHALLENGES OF UNDERTAKING TECHNOLOGY ASSESSMENT WITHIN INSTITUTIONS

To date technology assessment has been mostly conducted by parliamentary TA institutions or consultants. There has been little written about technology assessment being conducted internally within innovative technology institutions with the participation of the technologists themselves. Whilst championing the benefits of TA being conducted in partnership with technology proponents, we recognise that there are some challenges associated with undertaking TA within technical institutions. These include:

- future technologies may not be well defined and thus knowledge on their potential impacts is variable;
- the reflexivity of an individual technology/technologist is variable, meaning there may actually be little room for alteration of the technology or the technologist may be unable to imagine how or why to alter a technology;

- many TA tools call for the imagining of a hypothetical future context which is highly complex;
- early application of TA may mean that there may not be tangible, readily identifiable, stakeholders to engage with; and conversely, if stakeholders are engaged and the project does not proceed then there may be challenges managing stakeholder expectations of project development;
- technical scientists may not appreciate or value tools originating from the social sciences due to historical disciplinary divisions; social scientists may lack the technical skills to understand the technology and its implications; and communication barriers may exist due to differences in language and discourse;
- the timescale and timing of assessment may not complement technology development processes, such that the assessment may stretch project timeframes, resources and personnel and the information uncovered during the assessment cannot be incorporated into the development process.

Russell (pers comm.) has furthermore identified that the communicative skills and broad and critical perspectives needed to conduct TA may clash with the focused perspective that scientists may possess; that the necessary research and communication skills, time and resources may not be possessed by technologists; and that conflicts of interest may arise for individuals and institutions undertaking TA within technology institutions. Such critiques stem from a conflict over ideas about who is most equipped to make decisions about technologies and the implications for the public.

We argue that social science professionals skilled in social assessment methods are well placed to facilitate TA in collaboration with technologists, however the constraints of such an approach must be acknowledged. Technologists possess a power to transform future landscapes through their innovation yet simultaneously are not exposed to the values and perspectives of the public. The involvement of both technologists and stakeholders is therefore critical. Technological expertise is needed to think about and modify technologies to account for social perceptions of risks. Public opinion, in turn, is needed to identify those risks which may seem irrational to technically oriented experts but nevertheless can result in very real conflict and impacts. Institutional TA performs a valuable and unique function in that those who can directly affect technologies (i.e. scientists and engineers) become privy to aspects of their projects that they may not have previously envisioned (Stirling, 2008).

TA within institutions is not a substitute for public policy focussed TA agencies. It is unreasonable to expect that professionals undertaking and assisting technology assessment within institutions will have the same scope or remit to critically appraise technology as public policy focussed technology agencies. The institutions and professionals developing technology quite naturally have a stake in the success of the innovation. Instead, the purpose of TA within institutions should be to enable the technologist to undergo a learning process about the technology under study and reflexively apply this learning to the design of the technology. In this way the focus is not to provide recommendations to be adopted, but to expose technologists to the context in which the technology will be situated and encourage reflection and incorporation of such values, perceptions and realities.

Constructive TA seeks to affect technological developments by incorporating values and ideas that may exist outside of the concerns of narrowly defined technological trajectories. Drawing on Beck's notion of reflexive modernisation (Beck et al., 1994; Beck et al., 2003) Voß and Kemp (2006) argue that to avoid unintended consequences and second-order problems the isolated

perspectives in which problems are often addressed must be widened to include external filters of relevance. They argue that constructive TA is a way of creating interaction between various rationalities and taking into account the complexity of social, technological and ecological interrelationships (Voß and Kemp, 2006). Such an approach is deemed reflexive in that social rationalities are reflected in technological outcomes but also in that technologies (and technologists) are forced to reflect inwardly on, and hopefully transcend, the factors (structures) that shape technological pathways (see Rip, 2006; Stirling, 2006).

#### **5.4. OPPORTUNITIES THROUGH BUILDING TRUST**

The general public depends on information from scientific experts and government agencies when making decisions about and accepting and using new and emerging technologies (Barclay *et al.* 2009; Flynn 2007). If an impact or risk becomes realised in light of a new situation or context, then stakeholders may come to believe that they were misinformed about the impacts of the operation or technology, thereby igniting considerable mistrust and resulting in reputational damage to the operating company or industry. If the product/process fails to meet public (or industry) expectations, or has side effects that the public were ill- or misinformed about, then the potential for social conflict is heightened and the reputation (and take-up) of the technology and its proponents are diminished. As discussed previously, loss of social license to operate can be a costly impact resulting, sometimes, in the premature closure of a project.

The development and implementation of technologies with consideration of public concerns provided the opportunity for the technology proponent to obtain a measure of the public trust in the technology and this enhances the prospect of success. This measure at the outset of technology implementation is of course conditional. If the public is trusting at the outset but the technology turns out to be untrustworthy (in that it causes unacceptable impacts at some stage in its lifecycle) then social license may be revoked. In such cases the possibility of rebuilding public confidence cannot be guaranteed. Positive mining-community relationships thus need both a trusting participant (the public) and a trustworthy object (i.e., the specific technology or institution in question) (Stirling 2008).

As seen above trust and reputation are critical components of the social capital needed to ensure operational longevity. Trust and reputational assets are cumulative and co-dependent and must be developed and maintained within the early stages of each operation (Thomson and Boutlier, forthcoming). As trust increases the willingness of the public to absorb the consequences of decisions made by the decision-makers (those designing or implementing technologies) also increases (Hansen, 2006:575). Likewise if trusting relationships between decision-makers and those affected by decisions are established in the early phases the time taken to achieve social acceptance, approval and eventually co-ownership, of new technologies may be reduced which can in turn enable technological advancement to continue (see Assefa and Frostell, 2007). In this sense a trustworthy reputation is a rare and valuable resource facilitating competitive advantage (Tuck *et al.* 2005).

Trust is strengthened and reputational assets are enhanced through TA in the design phase by:

- identifying and accommodating community concerns from the outset;
- including the participation of stakeholders; and
- ensuring that community concerns are acted upon.

It is important to note that if community concerns and stakeholder aspirations are sought by technology proponents, and then dismissed or ignored, or the community is not informed via

reporting mechanisms that their concerns were heard fairly then the potential exists for trust, in both the proponent and the process of TA itself, to be eroded.

## **6. CONCLUSION**

This paper has discussed the challenges and benefits for undertaking TA within the CSIRO Minerals Down Under National Research Flagship. Technological innovation in the minerals industry is essential to meet sustainability and increase efficiency and has the potential to improve the public acceptability of mining projects. Mining technology once sunk into a landscape can be difficult and very costly to retrofit. It is for this reason that it is crucial to consider the future operational context within the design of technology.

Technology assessment during technology development can help to understand and reduce the potential for conflict to be embedded within the design of a technology and to understand the circumstances in which a technology is contextually appropriate. We argue that TA within innovation institutions, such as the CSIRO Minerals Down Under Flagship should be focussed on enabling the technologist to undergo a learning process about the technology under study and its future context and reflexively apply this learning to the technology design. The next stage of the project will be to pilot TA on two technologies under development within the Flagship to further develop methodologies and demonstrate the efficacy of the approach.

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