1 LASC LONGWALL AUTOMATION: CASE STUDY

SUMMARY OF KEY FINDINGS

The key findings of this case study are that the CSIRO's research into longwall automation has:

- Improved underground longwall coal mine productivity by around 5 per cent. In present value terms, the stream of total net benefits attributable to CSIRO over the period from 2001-02 to 2028-29 is estimated to be some $3 billion in 2018-19 dollars under a 7 per cent real discount rate.
- Contributed to improving the working conditions and safety of coal mine employees. In addition to the social benefits associated with contributing to the reduced numbers of accidents and deaths, the costs that are avoided as a result are likely to save mining firms millions of dollars a year.
- Improved the accuracy of longwall mining operations and reduced the amount of waste rock that is mined along with the coal. This will lead to less environmental disruption from rock spoil stockpiles and reduced rehabilitation costs.

- The benefit cost ratio of the longwall automation project is over 60 when using a 7 per cent real discount rate.

1.1 Introduction

1.1.1 Purpose and audience

This case study was originally prepared in 2014 as part of a broader independent assessment of the impact and value delivered by CSIRO's research program. The case study assessed the economic, social and environmental impact of the Longwall Automation Steering Committee (LASC) Longwall Automation project.

This revision of the case study also provides an opportunity to present the developments in the science that underpins the longwall automation project and describes its development and ongoing commercialisation impacts. It also provides an ideal opportunity to revisit the outcomes and impacts from the deployment of the technology some five years after the initial case study was prepared.

Audiences for this report may include Members of Parliament, Government Departments, CSIRO, mining industry stakeholders and the general public.

1.1.2 Background

The longwall mining process centres on a shearing machine (the 'shearer') with large rotating cutting drums that is driven back and forth along a coal face. Significant 'slices' of coal are ground off with each pass of the shearer. The coal falls onto a conveyor system that carries it away from the mine face. The longwall mining process is currently used to supply approximately 90 per cent of the coal from underground mines in Australia.[1]

Ensuring a close alignment of the shearer to the coal seam is crucial to its performance. Failure to correctly align the mining equipment can lead to either process delays or some of the coal in the seam not being recovered and / or unwanted spoil (rock) being mined along with the coal. Any of these events reduces the efficiency of the mining process.

CSIRO developed and patented a technology to help automate longwall mining

In the past, ensuring the correct positioning of the mining machine required stopping it periodically and carrying out in situ manual adjustments of the machine's positioning. Doing so took time and involved miners working close to the coal face and machinery, which is an inherently riskier location for workers.

In the late 1990s CSIRO researchers developed and patented an enabling technology which demonstrated the potential to further automate the longwall mining process in a way that would improve mining efficiency, reduce the risk of potential accidents and injuries to workers.[2]

The key to the CSIRO's new technology was developing a robust method to measure the 3-dimensional position in space of the mining system underground, where standard localisation approaches such as the Global Positioning System (GPS) are not available. CSIRO used a single robust inertial navigation-based sensor mounted inside the protective body of the longwall shearer technology to provide a rugged positioning system for the machine.

Around the same time ACARP prioritised research to improve mining efficiency

CSIRO's research and patenting of its new technology coincided with a decision by the Australian Coal Association Research Program (ACARP) to give priority to research that could address a specific need identified by the industry, namely how to improve the efficiency of the longwall mining process. ACARP saw that automating the longwall mining process would drive significant improvements in efficiency and safety. As a result, ACARP subsequently took the decision to provide funding to CSIRO to support its R&D into the automation of longwall mining machines.

1.1.3 Project origins and inputs

The project was originally part of the then CSIRO's Energy Flagship program of research. The aim of the research program was to collaborate with industry, research organisations and government to create cost-competitive, low-emission energy technologies to plan for a secure and clean energy future in order to help Australia to protect and ensure its long term environmental, economic and social welfare. The stated goal of the then Energy Flagship was to:

Deliver by 2020 technology options and science that will enhance Australia's economic competitiveness and regional energy security while enabling the transition to a lower emissions energy future, by unlocking $100 billion of in-situ value from our energy resources and contributing 32 Mt p.a. of greenhouse gas abatements by 2030.[3]

Specifically, in relation to the coal mining theme of the Flagship, the then stated objective was to:

Develop coal mining automation technologies and facilitate the remote management of longwall mine operations in Australia, removing people from the most hazardous areas and increasing coal mining productivity that will lead to increased mineable resources by at least one billion tonnes by 2020.

The Longwall Automation project provides an excellent example of CSIRO's ability to deliver on its goals of enhancing productivity and providing a safer working environment in the coal mining sector in close cooperation with industry. Successful implementation of the technology has helped improve the productivity, competitiveness and worker safety of the Australian coal industry.

[1] https://www.csiro.au/en/Research/EF/Areas/Coal-mining/Mining-safety-and-automation/Longwall-automation accessed May 2019.
[2] https://www.csiro.au/en/Research/MRF/Areas/Resourceful-magazine/Issue-06/Longwall-automation-goes-global accessed May 2019,
[3] The restructuring of the CSIRO National Research Flagships in July 2014, led to a change to the goal of the Energy Flagship. The revised goal is: "*To develop, demonstrate and ensure deployment by 2020 of integrated low carbon pathways for Australia and alternative stationary and transport energy solutions that realise a reduction of Australia's CO2e emissions by >20Mtpa by 2030 and by >50Mtpa by 2050*".
The goal of the Energy Business Unit in 2016 is *'To deliver solutions by 2030 that will enhance Australia's economic competitiveness and regional energy security while enabling the transition to a lower emissions energy future. We will achieve this by unlocking $100 billion of in-situ value from our energy resources and contributing 32 Mtpa of greenhouse gas abatements."*

History of project

CSIRO developed a technology to advance automation of the longwall mining process in the late 1990s. The innovation that CSIRO subsequently patented allowed for the accurate measurement of the shearer position in three dimensions. This in turn, allows the machine operator to accurately position and guide a complete longwall mining system comprising an arrangement of powered supports and shearer. The innovation was made possible through the availability of a high quality Inertial Navigation Sensor (INS) that could be used in underground environments.

At the time, the deployment of the technology was expected to lead to improved mining efficiency, reduced risk of accidents and injuries to mine staff. Industry also clearly saw the potential of this technology to address the needs that the industry had already identified and in 2001 the LASC Longwall Automation project attracted funding support from the then Australian Coal Association's (ACA) research arm, ACARP.

The project was conducted by CSIRO's then Exploration and Mining Division with support from the Cooperative Research Centre for Mining Technology and Equipment.[4] The project was overseen by the Longwall Automation Steering Committee, which consisted of industry and ACARP representatives. The resulting research and technology provided a model of implementation and was regarded as an innovative success. The LASC research team now sits within the Coal Mining Research Program in CSIRO Energy.

ACARP has provided significant funding support to CSIRO's longwall R&D

Project inputs

ACARP provided two tranches of funding to CSIRO to support its ongoing R&D into longwall automation. The ACARP grants funded labour and operating costs.

— $3,237,000 (excluding GST) over a three-year period from 1 July 2001[5]

— $2,419,000 (excluding GST) over a two-year period from 1 April 2005[6]

CSIRO provided funding of approximately $1.5 million over the period of the initial ACARP grant. These funds covered the difference between CSIRO's full labour cost recovery and the labour charge made to ACARP.

As part of the second tranche of funding there was also additional cash (about $1 million) and in-kind support (some $1.5 million) provided to the project. In-kind support from mine operations included access to senior staff and open access to longwall production systems and mine ICT infrastructure. Longwall OEMs (original equipment manufacturers) made available mining equipment on which the CSIRO mining technology could be installed and tested. CSIRO also provided $555,000 in funding for the second stage of the project.

Table 1.1 shows CSIRO's costs associated with the longwall mining technology project and the sources of funds used to meet those costs. Since the end of the second stage of the project ongoing research has been funded from the royalty and licence stream received from companies who have licensed the technology.

TABLE 1.1 LONGWALL PROJECT: COSTS AND FUNDING (INCLUDING LICENCE PAYMENTS)

Period	Project expenditure	CSIRO funding[f]	ACARP funding	Other support	In kind support	Licence and royalty payments
	($M)	($M)	($M)	($M)	($M)	($M)
Stage 1 (2001-04)	4.737	1.5[b]	3.237	-	-	-
Stage 2 (2005-07)	2.969	0.55	2.419	1[a]	1.5[e]	-
2008-09	0.879 [c]	.672	-			0.225[d]
2009-10	0.430 [c]	-0.275 [g]	-			0.705 [d]
2010-11	0.495 [c]	-0.495	-			0.990 [d]

[4] http://www.longwallautomation.org/about-longwall-automation.html, accessed May 2019
[5], Research and Development Agreement between ACR and CSIRO, 2001
[6], Research and Development Agreement between ACR and CSIRO, 2005

Period	Project expenditure	CSIRO funding[f]	ACARP funding	Other support	In kind support	Licence and royalty payments
2011-12	0.555 [c]	-0.795[g]	-			1.350 [d]
2012-13	0.600 [c]	-0.780[g]	-			1.380 [d]
2013-14	0.485 [c]	-1.444 [g]	-			1.930 [d]
2014-15	0.380 [c]	-1.723 [g]				2.103 [d]
2015-16	0.560 [c]	-1.144 [g]				1.703 [d]
2016-17	0.456	-.950 [g]				1.406 [d]
2017-18	0.389	-1.390 [g]				1.779 [d]
2018-April 2019	0.600 (est.)	-0.583 (est.)				1.183[h]
TOTAL	13.535	-6.857 [g]	5.656	1	1.5	14.754

[a] Cash grant.
[b] In-kind support representing the difference between CSIRO's full labour cost recovery and the labour charge to ACARP.
[c] Around $3 million spent over period 2008 to 2013.
[d] CSIRO.
[e] Includes provision of OEM equipment and use of mines for testing.
[f] CSIRO funding from appropriations.
[g] A negative number signifies that some of the net IP revenue is available for other CSIRO coal mining research
[h] As at end April 2019.

SOURCE: CSIRO.

The first technology licensing agreements were put in place in 2007. The revenues received by CSIRO have been used to fund ongoing R&D to improve and further extend the initial research outcomes.

More recently CSIRO has begun to also receive payments for the operational and maintenance support that it provides to users of its technology. Those payments are shown in **Table 1.2**. This revenue has all come from overseas users of the technology.

TABLE 1.2 OTHER LONGWALL PROJECT REVENUE RECEIVED BY CSIRO

Year	Revenue ($)
2014-15	$96,517
2015-16	$93,942
2016-17	$71,374
2017-18	$329,310
2018-end April 2019	$496,742
TOTAL	$1,087,885

SOURCE: CSIRO PERSONAL COMMUNICATION APRIL 2019

The research funding agreement with ACARP specifies that once CSIRO has recovered its costs ACARP will receive a share of net intellectual property (IP) payments such as royalties. Moreover, through its partial funding of the longwall automation projects, ACARP is delivering on its primary mission, which is to create value for its members and stakeholders in the industry.

In 2008, CSIRO made its first royalty payment to ACARP under the agreement. The longwall automation project remains one of the few ACARP projects to have paid a royalty to ACARP. Licensing and royalty revenue and payments to ACARP are shown in **Table 1.3**.

TABLE 1.3 NET IP REVENUE FOR CSIRO'S LONGWALL MINING TECHNOLOGY

Year	Gross IP revenue	Payments to ACARP
	($m)	**($m)**
2008-09	0.225	0.020

Year	Gross IP revenue	Payments to ACARP
2009-10	0.705	0.008
2010-11	0.990	0.012
2011-12	1.350	0.020
2012-13	1.380	0.017
2013-14	1.930	0.031
2014-15	2.103	0.040
2015-16	1.704	0.027
2016-17	1.406	0.021
2017-18	1.779	0.034
TOTAL	13.572	0.230

Source: CSIRO.

1.2 Project activities

1.2.1 Activities prior to 2011

The longwall automation project utilised a wide range of CSIRO's skills and expertise. **Table 1.4** lists the key capabilities and summarises the activities undertaken for each of those capabilities.

TABLE 1.4 KEY CSIRO CAPABILITIES USED IN LONGWALL AUTOMATION PROJECT

CSIRO capability	Activity
Mining Engineering	Liaison with ACARP and collaborating mines, integration of automation systems onto longwall coal mining.
Geotechnical Engineering	Specification of control system performance and research into interaction of automation systems with ground conditions.
Electrical Engineering	Design of automation components, explosion protected enclosures and integration with OEM systems.
Mechatronic Engineering	Research into application of inertial navigation to the longwall guidance and automation problems. Implementation of the INS guidance solution.
Electronics Engineering	Design of guidance system components; embedded computer systems, hazardous area uninterruptable power supply systems.
Communications and Network Engineering	Design and implementation of wireless Ethernet for underground usage.
Process Control Engineering	Specification of Open Systems Architecture-based interconnection protocol for multi-vendor navigation and automation system components.
Software Engineering	Specification and development of embedded and user interface software for the automation and visualisation systems.
Mechanical Engineering	Design of mechanical systems and components for embedding automation system elements into OEM equipment and for installing stand-alone components on face equipment.
Geology and Geophysics	Input into specification of guidance system.
Project Management	Management of individual project components, co-ordination of overall project, reporting to ACARP Steering Committee.

Note: Only the key CSIRO capabilities are listed in the above.
SOURCE: CSIRO.

CSIRO research

The duration of the first stage of the project was three years. The aim of this first stage of the project was to assess the feasibility of using inertial navigation technology to accurately measure the position of a longwall shearer in three dimensions.

The research undertaken and subsequent technology developed during this stage of the project included automatic face alignment, sensors and software for automatic horizon control, open communication systems between longwall components, a robust information system to allow online 3D monitoring of the longwall system and various geotechnical monitoring systems.[7] The resulting technology allowed longwall mining equipment to operate automatically within pre-defined constraints.

Development and testing of prototype

Following the promising results of the first stage of the project ACARP provided a second tranche of funding to CSIRO to conduct additional R&D into the technology between April 2005 and March 2007. The aim of the second stage of the project was to allow the outcomes of the first stage to be tested and verified through large scale field trials. In addition, the extension sought to transform several technologies from laboratory concepts into demonstrable prototypes that would be ready for commercialisation. **Box 1.1** provides more information on the goals of the longwall automation extension project.

BOX 1.1 GOALS OF LASC LONGWALL AUTOMATION EXTENSION PROJECT: 2005 – 2007

The extension project had the following goals:

— **Longwall Automation System**: Install at three demonstration sites, make improvements to software quality to meet industry standards and develop and test new control strategies.
— **Shearer Position Measurement System**: implement an improved capacity INS-based system with resolution appropriate for real time horizon control and face straightening.
— **Horizon Control**: Develop and demonstrate to production standard:
  - improved horizon control compatible with Original Equipment Manufacturers' (OEM) control system
  - optical marker band
  - infra-red detection of strata
  - controlled traversing cut for a pre-determined path.
— **Technology Development**: Develop Landmark compatible technologies for:
  - gateroad convergence and shield pressure and convergence monitoring to production standard
  - coal flow optimisation and void detection to prototype standard.
— **Information System**: Develop and demonstrate production standard information systems for:
  - face management
  - operator interface
  - data management
  - training simulator.
— **OEM Commitment**: Commitment from participating OEMs to embrace Landmark Longwall Automation standards into their core products.

SOURCE: ACR & CSIRO 2005

Create a commercial product

The goals listed in **Box 1.1** were designed to enable a commercial longwall automation system to become available to Australian coal mines. That desired outcome was realised when the technology was licensed to five OEM firms. As part of the licensing agreement the licensees get access to a package of hardware designs, software and source code. This allows them to fit the technology to their own equipment. Importantly CSIRO's technology was always designed to be non-equipment

[7], 2005 Research and Development Agreement between ACR and CSIRO

specific so that any mining equipment manufacturer could incorporate the technology into their own equipment.

OEMs were given non-exclusive licences to the technology

The coal industry through ACARP and LASC required a non-exclusive technology licensing model so that the benefits of the industry-funded research would potentially be available to the industry from all major equipment suppliers. The equipment manufacturers recognised the strong interest and commitment of the industry to the technology and consequently accepted the non-exclusive licensing model. Support for this commercialisation model was reinforced by CSIRO's assurance that it would use a portion of its intellectual property revenue to provide technical assistance to manufacturers in the early developmental stages of the product. This commitment by CSIRO gave the mining equipment manufacturers the assurance they needed that they would be able to draw on CSIRO's experience to help minimise development costs and that the technology would continue to be supported and further developed and improved over time by CSIRO.

The inertial sensor currently used in the technology is supplied by an American company. The rest of the hardware and software was initially designed and built by CSIRO. However, more recently CSIRO has licensed a company in Canada to build the hardware to provide power to the sensor and to supply an embedded computer to get navigation information from the sensor to the mining machine.

Providing support to firms that bought the technology

CSIRO's continues to support users of the technology

As an R&D organisation, CSIRO's aim is to achieve full technology transfer to its licensees. In this case, to help ensure this outcome CSIRO provided technical support and advice to OEM licensees during the initial stages of the technology transfer. CSIRO also provided some initial support to mining companies. It is important to note that that support was provided through the OEMs rather than through any direct contract with the users. The aim was to provide CSIRO's support in partnership with the OEMs. By doing so, it was intended that the latter would gain the skills needed to provide the full suite of support services for the product they were providing to their mining company customers, without the need for any long-term CSIRO assistance.

However, OEMs and users of the equipment have continued to seek CSIRO's support for the operation and maintenance (O&M) of the longwall mining machines. The revenue flowing to CSIRO as a result of the support they provide in this area is shown in **Table 1.2**.

Ongoing activities

Research to further improve the technology and tech transfer is continuing

The first commercial-ready outcome of the initial research delivered a system that is capable of robustly providing optimal alignment between the mining machine and the coal face being mined. The current research is concentrating on better 'horizon control'. This technology enables the longwall mining machines to consistently vertically align themselves with the coal seam thus improving productivity by reducing dilution of the product.

While an INS-based implementation of horizon control was developed to a working prototype stage at the conclusion of the Extension Project and was included in CSIRO's original technology licensing agreement, the maturity and consequently the take up of this aspect of the technology has to date been more limited. CSIRO is continuing to develop this aspect of the technology.

Moreover, more sensitive methods of implementing effective horizon control based on directly sensing coal-rock interfaces at seam roof and floor using optical and thermal infra-red techniques, which were identified during the original projects, are currently also being developed. Further developments include radar-based coal thickness sensing along with digital seam models which take into account geological seam uncertainty and variability to provide more effective coal resource extraction management.

The longwall guidance methods developed during the Landmark projects have been transferred to continuous miner operations which are used to drive the underground roadways necessary to prepare for the longwall mining process. Currently, CSIRO is trialling pre-commercial installations of the technology in the field. This technology will significantly improve the speed of roadway development, which currently is a limiting factor in a number of longwall mines and will also enhance safety by removing miner operators from the vicinity of the machine and working face.

The licensing and technology transfer model was reviewed in 2016. The existing technology licensing agreements (TLAs) between CSIRO and all licensees are based on an initial licence fee per installation and a continuous 5-year royalty period thereafter. The industry's circumstances have changed since the original negotiations. The impacts on mines from tighter financial operating conditions and long-term interruptions to production for economic reasons post the 'mining boom' of the late 2000s were not envisaged by CSIRO or licensees when the licenses were initially set up. Consequently, a more flexible model licencing approach, which provides for a lower, more regular licence cost structure and more flexible arrangements for interruptions to mine operations is the basis of a new licensing model. The new approach adopts a 12 month per-product licence fee. The licence can be renewed annually for as long as required and will apply for the lifetime of the product. The annual fee gives the rights to use the patented LASC technology in the product together with access to the LASC software. The licences are flexible and transferrable, meaning that a licence can be used at different locations and may be stopped and started as operational needs change.

Moreover, the implementation of the technology is being modified, to move to a more common software licensing structure based on distribution of protected software rather than the current open-source model. The new model, which is in line with contemporary software system licensing approaches, has been developed following incremental enhancements to the technology and offers a higher level of IP protection for the international market.

1.3 Project outputs

1.3.1 Key outputs of the project

The main output of the longwall project is the enabling technology that provides significantly higher levels of automation for the underground longwall mining process. The technology consists of the hardware and software necessary to automatically operate and monitor the longwall mining equipment (see **Box 1.2**).

CSIRO also provides technical support (through the OEMs) to companies who install the automated mining machinery.

1.3.2 Key publications

CSIRO also published some 25 papers (4 journal articles and 21 refereed conference papers). Examples of some of the papers with the greatest impact in the field are provided below:

— Ralston, Jonathon; Hargrave, Chad; Dunn, Mark. *Longwall automation: trends, challenges and opportunities*. International Journal of Mining Science and Technology. 2017; 27:7.

— Reid, David; Ralston, Jonathon; Dunn, Mark; Hainsworth, David. *Longwall Shearer Automation: From Research to Reality*. In: J. Billingsley and P. Brett (eds.), editor/s. Machine Vision and Mechatronics in Practice (2015). Springer-Verlag Berlin Heidelberg 2015; 2015. 9.

— Ralston, JC, Reid, DC, Dunn, MT, & ... (2015). *Longwall automation: Delivering enabling technology to achieve safer and more productive underground mining*. International Journal of Mining Science and Technology, Elsevier

— Ralston, Jonathon; Hargrave, Chad; Dunn, Mark. *Mining Automation: Challenges and Opportunities*. In: The 9th International Symposium on Green Mining; 27-30 November 2016; Wollongong, Australia. University of Wollongong and China University of Mining; 2016. 8.

1.3.3 Patents

The following patents have been taken out covering the LASC technology.

— Reid, David Charles; Ralston, Jonathon Carey; Hargrave, Chad Owen; Dunn, Mark Thomas; Reid, Peter Bryan; Thompson, Jeremy Patrick. (2015). System and method for controlling a mining machine

— Reid, David Charles; Ralston, Jonathon Carey; Hargrave, Chad Owen; Dunn, Mark Thomas; Reid, Peter Bryan; Thompson, Jeremy Patrick. (2015). Improved mining machine and method of control

— Reid, David Charles; Ralston, Jonathon Carey; Hargrave, Chad Owen; Dunn, Mark Thomas; Reid, Peter Bryan; Thompson, Jeremy Patrick. (2015). Mining machine

— Hainsworth, David William; Reid, David Charles; Reid, Peter Bryan; Dunn, Mark Thomas. (2015). Navigation of mining machines

BOX 1.2 OUTPUTS OF LASC LONGWALL AUTOMATION PROJECT

The primary outputs of the LASC Longwall Automation project consist of four licensed technologies:

— ***Shearer Position Measurement System (SPMS)*** – Hardware and embedded software mounted on the shearer and application software that resides in generic networked platforms. The SPMS hardware's purpose is to measure and communicate the 3D position of the shearer to the face data network. The off-shearer applications then process the raw SPMS information to provide both industry standard data streams and user-accessible displays of face and/or floor profiles. The purpose of this technology is to measure the path of the shearer.

— ***Automated Face Alignment*** – Software whose functions are to manage transfer of recommended position corrections (RPCs) to the OEM powered roof support control system and to provide a user interface to the automatic face alignment system for:

... entry of designed face alignments

... display face alignment information

... management and monitoring of system performance.

The purpose of this technology is to keep the roof supports and the cutting face straight.

— ***INS-Based Automated Horizon Control*** - This technology comprises software whose functions are to Manage transfer of horizon information to the OEM shearer control system and provide a user interface to the horizon control system for:

... entry of designed cutting horizons

... display roof and floor horizon information

... management and monitoring of system performance.

The purpose of this technology is to keep the shearer cutting in the seam.

— ***Automated Creep Control*** – This technology comprises hardware and software components. The hardware component is a pair of scanning laser-based sensors mounted adjacent to the main gate that measure the cross-gate road creep distance of the main gate drive hardware. The software component displays and logs creep measurement values and computes corrections to add to basic face alignment RPCs to implement creep control. The purpose of this technology is to keep the longwall support equipment centred in the roadway.

In addition, there are the following outputs that assist in implementing the LASC technologies above.

— ***Reference Designs*** – Documentation describing the design of all system components to implement the above technology solutions. This information has been issued to all licensees.

— ***Open System Communications*** – Specifications for implementation of industry-standard communications protocols to interconnect the LASC and OEM system components necessary to implement the above technology solutions. These specifications are available on-line at www.longwallautomation.org.

Cross-face wifi communications – Implementation details for cross-face wireless Ethernet communications. This information was made freely available through publications and individual advice to OEMs.

SOURCE: CSIRO

1.3.4 Awards and public recognition

In 2004 CSIRO was awarded the ACARP Research and Industry Excellence Award for the initial longwall automation project (July 2001 – July 2004).

The LASC Longwall Automation Research Team won the 2015 CSIRO Award for Impact from Science. The award was given for:

…developing LASC, a mining equipment automation technology based on inertial navigation that has generated significant improvements to the productivity of Australia's longwall coal mines and the safety of people who work in them.[8]

In 2016 the Longwall Automation Research Team was awarded the CSIRO Sir Ian McLennan Award. The award citation stated that the award was given for:

… the development of LASC, a mining equipment automation technology based on inertial navigation that has generated significant improvements to the productivity and safety of Australia's longwall coal mines.[9]

The success of this project has been a significant factor in the strength of the ongoing collaborative relationship between CSIRO and ACARP. While CSIRO's contribution to the ACARP research portfolio covers a broad capability and science base, its track record in longwall automation has resulted in ongoing research funding in other projects related to that domain of around $1 million a year being provided to CSIRO by ACARP following the completion of the longwall automation projects

In 2019 the research team was nominated for the PM Science Prize for Innovation based on the research and commercial impacts of the technology on the underground mining industry.

1.4 Status of Outcomes and Impacts

1.4.1 Nature of Outcomes and Impacts

Outcomes

The primary outcome of this project is the commercialisation of technologies that enable a higher level of automated operation of underground longwall mining equipment. The technology was delivered to the industry as an integral element of longwall mining equipment rather than an optional add-on. ACARP required that the technology could not be exclusive to a single manufacturer. CSIRO has argued that, being an R&D entity, it would not be able to sustainably support the technology directly in the field indefinitely.

As part of the licensing agreement CSIRO has assisted OEMs with the technology roll out

The equipment manufacturers recognised the level of interest and commitment from the industry and subsequently accepted a non-exclusive licensing model. The commercialisation model was reinforced by CSIRO's assurance to use a portion of its intellectual property revenue towards the provision of technical assistance to manufacturers in the early stages of the product. This commitment by CSIRO gave mining equipment manufacturers the assurance they needed that they would avoid any additional development costs and that the technology would continue to be supported and further developed and improved over time by CSIRO.

The assistance provided to commercialisation partners early in the technology transfer process has proved to be very successful. Early implementation of the technology delivered good performance due in part to support from CSIRO. This enhanced the reputation of the technology and has increased customer confidence in longwall automation. It is highly likely that this has accelerated the level of market penetration achieved to date.

CSIRO has subsequently employed this approach in the commercialisation of its Sirovision and NEXSYS products.[10] [11]

The LASC Longwall Automation project has provided licensed OEMs with an opportunity to sell a successful new product, delivering increased business and revenue for those OEMs

Uptake has been extremely rapid

The adoption of the technology has been outstanding. To date, CSIRO's longwall automation technology has been adopted in 24 of the 33 longwall mines in Australia. This represents around 72

[8] https://csiropedia.csiro.au/csiro-medal-for-business-excellence/ accessed May 2019.
[9] https://csiropedia.csiro.au/sir-ian-mclennan-award/#SirIanMcLennanAward-2016, accessed May 2019
[10] Sirovision was developed through collaboration between Datamine and the CSIRO. The technology allows remote and safe capture of geological features in mines while avoiding costly disruption to production activities. Mapping of geological and geotechnical features is supported, along with automatic recognition of mineralogy. Sirovision can also be used to identify safety hazards in open pits and underground environments.
[11] Nexsys allows underground coal mines to interrogate vast amounts of digital information from a variety of sensors and systems throughout the mine. The system analyses this integrated data to provide real-time risk management and decision support for control room operators, including automatic triggering of response plans if it discovers a hazardous condition.

per cent of operating longwall coal mines in Australia. The generally accepted view within the industry is that a maximum of 80 per cent of the longwall coal mines in the Australia are candidates to use mining machines which incorporate CSIRO's longwall mining technology. CSIRO expects to capture this share of the Australian market by 2021.

The industry itself has played a large part in the rapid uptake of the LASC technology through the close involvement of the LASC industry steering committee in the design of research projects. This has ensured that the research was directed towards generating the solutions that the industry needs. As a result of the participation of the major mining companies during the demonstration phase, the industry was able at an early stage to translate the technical IP generated by CSIRO into value for their operations. This generated an enthusiastic market for the technology outcomes of the LASC project.

International adoption

The LASC technology is also being used in Norway, US and China. One longwall mining machine is operational in Norway, one in the US and 10 in China. The latter two markets are expected to grow considerably:

— In the case of the US, CSIRO expects to have five mines using its technology by the end of 2019 and 36 by the end of 2025

— In the case of China, CSIRO expects 23 mines to be using its technology by the end of 2019. With some 1,500 long wall underground mines the market for CSIRO's technology in that country could be considerable.

Impacts

Benefits of the technology include improved productivity and safety

The LASC Longwall Automation project has had a range of impacts. **Table 1.5** summarises the social, environmental and economic impacts to date.

The main beneficiaries of the project include: equipment manufacturers who benefit through the sale of the technology; mining companies who save on operating costs and achieve greater productivity; and employees of mining companies who install and use the technology through safer working conditions.

The LASC Longwall Automation project has also had several unintended benefits. The most significant of these is the decreased time required for maintenance of mining equipment in mines that use CSIRO's longwall automation technology. This has occurred due to the need to ensure that all parts of the mining operation, including equipment-specific automation technology developed by individual equipment manufacturers are fully optimised to maximise the benefit of this technology. As a result, all machines are consistently operating in a manner that optimises their performance. This results in fewer stoppages, better alignment in the workloads of the various components of the mining operation and optimal maintenance of machinery. While precise information on the productivity gain due to the automated longwall mining technology is difficult to obtain due to the commercially sensitive nature of such information, it is broadly accepted within the industry that adoption of LASC Longwall Automation technology has increased peak productivity by around 10 per cent. However, the major benefit to the industry of LASC has been greater consistency in operations because of the factors described above, which, with other enhancements has generated a long-term productivity improvement in the order of 5%.

The extremely rapid adoption of the technology by Australian underground coal mines is an excellent indication that mine operators expect that the productivity gains will ensure that the return on investment for installing the technology will be very attractive. That productivity gain results from several factors, including:

— significantly reduced down-time for periodic realignment of the longwall face

— less waste rock (spoil) being produced during the mining process

— optimisation of the operation of all other elements of the mining operation that is required to ensure that full benefits of the longwall mining technology can be captured. This results in improved equipment performance due to more consistent and optimal rates of production and a resultant reduction in the frequency of machinery maintenance that is required.

TABLE 1.5 OUTCOMES AND IMPACTS OF CSIRO LONGWALL MINING TECHNOLOGY

Outcome / impact	Detail
Economic	
Technology Adoption Category: New products or services Reach: Global	The new technology has been widely adopted by OEM suppliers of underground mining equipment. Licencing agreements have been entered into with six major global OEMs (Caterpillar, Joy, Nepean, Eickhoff, Kopex and China Coal Technology and Engineering Group (CCTEG)). To date, CSIRO's LASC Longwall Automation technology has been installed in 24 longwall mines, or about 72 per cent of total underground coal mines in Australia.
Reduction in operating costs Category: New products or services Reach: Global	The technology contributes to lower operating costs and has increased returns from export earnings. The technology reduces costs associated with shearing of spoil rock. It also reduces environmental management and remediation costs, as there is less waste rock to be processed, stored and (ultimately) remediated.
Higher productivity Category: New products or services Reach: Global	The technology is estimated to deliver productivity increases of up to 10 per cent peak due to: timely maintenance to ensure peak performance of other parts of the overall mining operation; less shearing of spoil rock; lower levels of volatility in machinery activity; and lower risk of accident and injury. This has resulted in less work stoppages and greater efficiency of the overall mining operation.
New model of industry collaboration and commercialisation developed Category: Management and productivity Reach: National	As part of the commercialisation of longwall automation technology, CSIRO developed a new model for collaborating with OEMs. Under that model OEMs accept a non-exclusive licensing arrangement and CSIRO undertakes to provide a certain number of hours of training and support during the first phase of commercialisation. This gives the OEMs confidence that they can draw on CSIRO's skills to help minimise the costs of any further technology development and commercialisation. This model of industry collaboration for the commercialisation of new technologies has now been applied in several other CSIRO projects.
Environmental	
Reduced environmental footprint Category: Sustainable industry development Reach: Industry	The improved accuracy of the underground mining equipment reduces the amount of unwanted rock (spoil) that is mined along with the coal. Spoil reduces product quality and ultimately requires processing and disposal. It also allows high-quality, low-ash product to be preferably extracted, leading to reduced emissions for steel making and energy production. One form of disposal is to store the rock in above ground spoil dumps. There are potential environmental impacts associated with spoil dumps, such as runoff. Less spoil means a smaller spoil dump and a reduced impact on the environment.
Social	
Increased coalminer safety Category: Life & Health + Safety Reach: Industry	Employees of mining firms are required to manually adjust the large machines where automation is not installed – thereby increasing the likelihood of an accident or injury. Automation of some of the longwall mining processes has removed miners from noisy, dusty and hazardous areas.

SOURCE: ACIL ALLEN CONSULTING, CSIRO 2008 AND CSIRO 2014A

Industry sources suggest that the cost of lost production can be as high as $1,000 a minute.[12] While this figure is likely to vary significantly from mine to mine, it provides an indication of the scale of benefits that can result from the productivity gains directly attributable to the use of the automated longwall mining technology and the system-wide efficiencies that use of this technology encourages.

1.4.2 Counterfactual

Limited prospects for a competing technology to emerge before 2030 are limited

In 1994, CSIRO reviewed the global research effort to develop technologies to help automate and control Longwall mining equipment. The review showed that research was mainly being done by government research institutions, for example in the United States (US), United Kingdom, Japan, France and South Africa. However, at that time there had been few useful outcomes from any of that research.

It is of course possible that other individuals or organisations might have developed similar technologies over time. However, it is difficult to determine when such technologies might have emerged in the absence of CSIRO's activities. ACIL Allen notes that the CSIRO technology is used in over 70 per cent of the automated underground coal mining equipment in use in Australia today, and its use in overseas mines is increasing rapidly.

CSIRO's technology is recognised as world leading

One of the licensees, Caterpillar, had previously developed advanced software and control systems to automate the motion of longwall shields to implement face alignment and continued to develop this system while the Landmark projects were being conducted. However, this system suffered from the lack of an effective sensor to measure the position of the longwall shield units. This problem was only overcome by measurement of the shearer position using CSIRO's LASC technology. Therefore, this OEM is able to offer a longwall automation product that requires only one technology from the LASC family, which when linked with their OEM system can achieve state-of-the-art face alignment performance.

Other automation developments have been produced by shearer manufacturers during the period of location along the face have also resulted in considerable productivity improvements. These advances have been able to achieve higher levels of effectiveness through integration with LASC control.

This provides strong support for the view that CSIRO's technology is still regarded as being the best available over 10 years after it was first commercialised. Consultations with CSIRO and another industry stakeholder suggest that there is still no other automated longwall mining technology that might compete with CSIRO's technology on the horizon.[13] For the purposes of our economic analysis we have assumed that no competitor to CSIRO's longwall technology will emerge over the next ten years.

CSIRO continues to carry out research to continually improve the longwall mining technology and any incremental technology improvements that are developed are passed on to its licensees. As long as CSIRO continues to support the further development of the technology it is likely to retain its high level of acceptance and use within the industry. If CSIRO ceased efforts to further developing the technology, then we estimate that it would take the industry roughly five years to catch up to CSIRO's current research position in this technology. It would then take a further five years to commercialise the competing technology.

One industry participant noted that the large and growing number of firms using the CSIRO's technology will make it more difficult for new entrants to capture market share. They also noted that CSIRO's technology could be used in a range of other underground applications.[14]

1.4.3 Attribution

CSIRO's ground-breaking innovation in this area was to recognise and subsequently demonstrate that the position of all the relevant components in the longwall system could be inferred accurately from a 3D measurement of the position of the shearer component. This is the crucial element of the

[12] Estimate based on information from http://www.whitehavencoal.com.au/narrabri-mine/ that states that saleable coal production was 7.0Mt in FY2017. If we assume that operations are ongoing for 24 hours every day then this implies the mine is producing some 13 tonnes of coal every minute. At $100 a tonne this would be worth $1,300 a minute.
[13] Personal communication CSIRO and industry, April and May 2019
[14] Personal communication May 2019

intellectual property covered by CSIRO's patents. CSIRO also implemented a robust, highly accurate method based on inertial navigation to make the necessary 3D measurement of shearer position. The LASC system currently relies on a high-performance inertial navigation system developed in the US to measure the shearer position. However, the inventive step in LASC technology is the use of the measured shearer position to infer the location of the other longwall components and any form of position measurement could in theory be used.

ACIL Allen understands that CSIRO is now the recognised world leader in automated longwall mining, with little or no serious competition from other researchers for the last two decades. Certainly, no competitive technology solutions have surfaced in the market and no major technology developments have been reported in the literature. OEMs are regularly in communication with CSIRO regarding the implementation status of further LASC developments and have approached the organisation to undertake further underground automation research.

While funding from ACARP (particularly the second tranche of funding) was integral to commercialising the technology that organisation conducted no actual R&D activities itself. However, the management role undertaken by ACARP through the Steering Committee and the facilitation of a co-ordinated industry-wide development and testing process meant that the technical IP generated by CSIRO was fast-tracked to a mature stage, capable of generating value for the industry, which accelerated the market for the LASC technology.

We have attributed 60 per cent of the impacts to CSIRO's R&D efforts.

Participating mines contributed greatly to the success of LASC technology demonstration programs, contributing in-kind support and taking on risk to incorporate experimental technology into their core revenue-generating operations. Similarly, OEM firms supplied mining machines as test beds for the CSIRO technology, and provided in-kind input to modify their longwall products to accommodate LASC hardware and to provide appropriate software interfaces to their control systems. However, none of the above participants conducted any actual research into the LASC automation technology.

ACIL Allen would therefore argue that 60 per cent of the current impacts with respect to longwall mining technology should be attributed to CSIRO's research and development efforts, with coal mining companies/ACARP and OEMs collectively accounting for 40 per cent of the current impacts of the technology.

1.4.4 Adoption

Five OEMs have adopted the technology in their mining machines

The close involvement of OEM equipment suppliers and participating mines in the second stage of the R&D program helped ensure the relatively rapid commercialisation of the technology. The first commercial installations of mining machines using CSIRO's automation technology occurred in 2008. The firms that have adopted the CSIRO technology for use in their mining machines are: Joy Global; Eickhoff; Kopex; Nepean; Caterpillar; and CCTEG.

Almost three quarters of Australian underground coal mines use the technology

Longwall mining accounts for approximately 90 per cent of the 70 million tonnes of underground coal that is annually mined in Australia. In Australia 24 out of a total of 33 longwall mining systems are currently operating with CSIRO's automation technology. Gaining such a large market share in the short time since the technology was first licensed is an extremely rapid technology adoption rate.

However, the rate of growth in market penetration is expected to slow going forward. CSIRO anticipates that the market share of LASC Longwall Automation technology will peak at around 80 per cent in 2021. This is because some underground coal mines are not suitable candidates for adoption of the longwall automation technology.

The technology is now also being marketed overseas

In 2012, the technology was contracted for installation in a mine in the US and has been installed in another mine in Norway in late 2014. One commercialisation partner is actively pursuing the US market and CSIRO expects continued growth in this market over the next 10 years. This would represent a considerable expansion of use of the technology. The production of coal from US longwall underground coal mines in 2012 was around 166 million tonnes a year, more than twice Australia's average production from underground longwall coal mines over the last five years.

China is seen as another major potential market for the longwall automation technology. The International Traffic in Arms Regulations (ITAR) were a major barrier to the adoption of the technology in that country. The longwall automation technology employs advanced inertial positioning sensors.

The manufacturer of the sensor used by CSIRO also supplies the same sensor to the US defence force and it is therefore subject to ITAR. As a signatory to ITAR, Australia is required to abide by its conditions on the sales of dual use technology. OEM firms were therefore unable to sell mining machines containing the inertial positioning sensor to mining firms in China. However, CSIRO has sourced existing non-ITAR technology and has developed and commercialised a low cost non-ITAR inertial navigation solution which has overcome these international market limitations.

There are already ten mines in China using CSIRO's technology and CSIRO expects that number to increase to 18 by the end of 2019. Given that China has around 1,500 long wall underground coal mines, the Chinese market for CSIRO's technology could be considerable. For the purposes of our analysis we have assumed that the number of mines using the technology increases by five mines a year over the next ten years.

1.5 Assessment of impacts

1.5.1 Impacts to date

The commercialisation of CSIRO's longwall automation technology has had a range of economic, environmental and social impacts.

The introduction and deployment of LASC technologies provided the coal mining industry with a powerful, extensible automation platform. This has provided the industry with confidence and traction to support ongoing innovations, including providing technology vendors and third-party automation specialists with new opportunities to provide additional value-add services.

Economic impacts

New products and services

The fact that over 72 per cent of Australia's underground coal mines have switched to using mining machines that incorporate the CSIRO technology strongly suggests that the mining industry's view was that the likely productivity improvements would be significant.

The introduction and deployment of LASC technologies provided industry with a powerful, extensible automation platform. This outcome has provided the industry with the confidence to pursue further innovations. This includes providing technology vendors and third-party automation specialists with new opportunities to demonstrate how they can provide additional value-add services.

Better management and productivity

The main economic impact of CSIRO's automated longwall mining technology flows from the improved productivity of the underground mine. Those benefits would have begun to flow from the date the first automated mining machine was put on the market in 2008. The benefits flow to coal mining firms.

The technology is conservatively estimated to improve productivity by 5 per cent

Importantly, not only is there a direct improvement in productivity due to the automation of the longwall mining system, but there is also an indirect benefit due to the need to ensure that the operations of all other elements of the mining process are optimised in order to fully realise the benefits of the CSIRO technology. Hence, the use of LASC Longwall Automation technology encourages wider system efficiencies beyond the immediate productivity gains that result from the use of the technology itself. The fact that all the mining equipment is operating at, or close to, an optimal level helps reduce ongoing maintenance costs and leads to more consistency in the longwall operation.

Obtaining first-hand information about the productivity improvements achieved by mines using the CSIRO technology is difficult as that information is regarded as highly commercially sensitive. A common figure for the productivity improvement among industry insiders is around 10 per cent peak, with the consistency in overall operation obtained leading to an average of around 5 per cent. Industry participants spoken to as part of preparing this case study supported the estimate of a 5 per cent productivity improvement.

The value of Australian coal exports over the last few years has increased to more than $60 billion a year. Consequently, a productivity improvement of 5 per cent would suggest that the potential increase in the value of exports as a result of this technology could be of the order of billions of dollars.

See also the discussion in Section 1.5.

Environmental benefits

Environmental benefits associated with the use of the CSIRO automated mining technology are principally a reduction in the amount of spoil that is mined along with the coal. There is an environmental benefit associated with the need for less above ground storage area to store the spoil. The benefits flow to coal mining firms.

There are also likely to be some economic benefits associated with the reduction in the amount of spoil. The main ones would be:

- Reduced costs for separating spoil from coal
- Reduced rehabilitation costs.

Rehabilitation costs can be considerable. Information on the Oresome Resources website suggests that the cost of rehabilitating spoil dumps is around $25,000 a hectare.[15] Another source states that rehabilitating waste rock dumps costs closer to $50,000 a hectare.[16] Adjusting this figure for movements in Consumer Price Index (CPI) since 1995 suggests that the cost of rehabilitating a rock spoil dump could now be over $80,000 a hectare.

Recent Queensland government statistics on coal production, for the year ended March 2014, report that the percentage of saleable coal from total raw coal production was 81 per cent for open cut mining and 63 per cent for underground mining, the remainder being spoil or 'ash'.[17] This is a significant difference. Some factors in the production of spoil are common to both mining methods but a major difference is the better identification of seam boundaries that is possible in open cut versus underground mining. A conservative assumption would be that on average, the percentage of saleable underground coal could be increased by 10 per cent through effective identification of seam/rock boundaries. In Queensland in the year ending March 2014, this would equate to reducing the amount of spoil that had to be first dealt with then rehabilitated by some 4 million tonnes. If the extraction cost of the coal was $40/tonne, then this would represent a saving to the industry of over $150 million/year in production costs alone.

However, the improved horizon control that is necessary to help reduce the amount of spoil that is mined along with the coal is part of the work that is still underway, and we have therefore not included the reduction in spoil as a benefit at this point in time.

Social impacts

The main social impact from the implementation of the technology is improved worker safety since the use of automated mining machines reduces the amount of time that workers have to spend at the mine face to monitor and adjust the alignment of longwall mining machine and the coal seam. As LASC Longwall Automation removes the need for a worker to be in the mine wall to monitor a longwall mining machine, it also reduces that worker's exposure to noise and dust. The benefits flow to mine employees and mining firms.

An April 2008 report on mine fatalities found that between 1980 and 2008 there were 1005 fatalities in Australian coal mines. Of these 919 (over 91 per cent) occurred in underground mines. This is an average of almost 33 deaths a year in underground coal mines.[18]

Safe Work Australia publishes information on fatality rates (deaths per 100,000 employers) for a range of occupations. The fatality rates for coal mining between 2003 and 2016 are shown in **Figure 1.1**.

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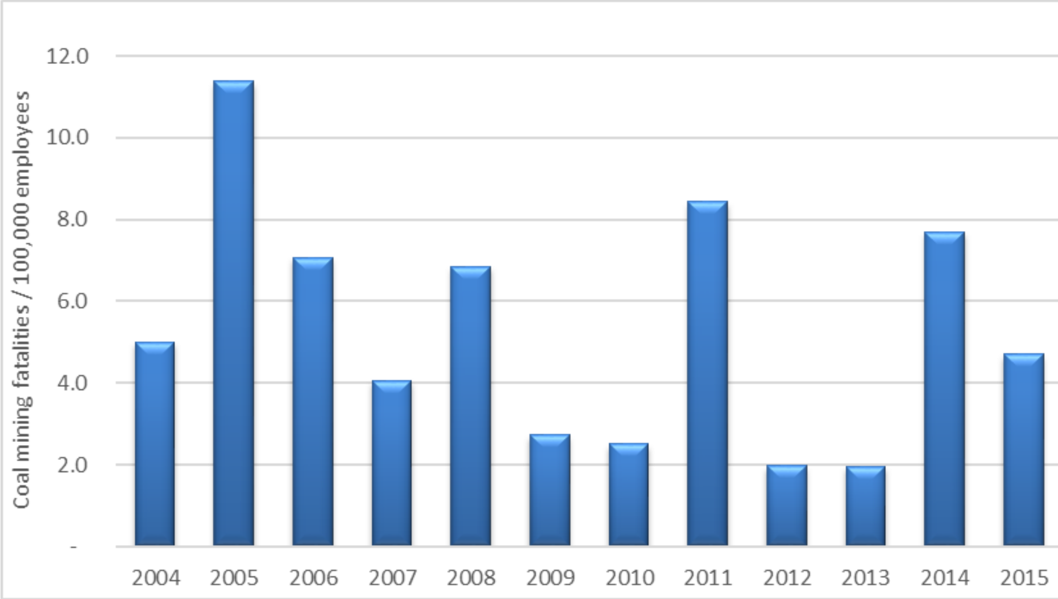
[15] Oresome Resources, http://www.oresomeresources.com/resources_view/resource/powerpoint_minesite_rehabilitation accessed August 2014

[16] *Lateral Thinking on Mine Site Rehabilitation*, David J Williams, University of Queensland, Australian Geomechanics, December 1995

[17] See: http://mines.industry.qld.gov.au/assets/coal-stats/quarterly-reports/Quarterly%20coal%20report%20for%20the%20three%20months%20ended%2031%20March%202014%20FINAL%20v1.0.pdf.

[18] DPI, 2008, NSW Department of Primary Industries, International Mining Fatality Database - Project Report, Patrick MacNeill, April 2008.

FIGURE 1.1 FATALITY RATES FROM COAL MINING [UPDATE]



SOURCE: SWA 2014

The technology improves worker safety

The data in **Figure 1.1** shows a clear decline in fatality rates over time. The average fatality rate between 2004 and 2008 was almost 7 deaths per 100,000 workers per year. However, for the period between 2009 and 2016 the fatality rate almost halved to an average of around 3.75 deaths per 100,000 workers per year. This coincides with the period during which the use of CSIRO's automated mining technology became increasingly adopted by underground coal mining firms in Australia.

The data in **Figure 1.1** includes any mining related deaths in open cut coal mines. This makes it difficult to argue that the observed decline in fatality rates is due to the introduction of CSIRO's automated mining technology. However, the fact that historically coal mining fatalities have almost exclusively been in underground coal mines provides some confidence that the technology is at least contributing to improved worker safety.

Finally, it is worth noting that much of CSIRO's ongoing work is aimed at further refining the technology to provide additional safety benefits. These will be progressively released to licensees when they are ready for commercialisation. The importance of improving mine safety is illustrated by **Box 1.3**. The information it contains illustrates how avoiding the death of a mine employee can have significant economic benefits as well as the obvious social benefits.

BOX 1.3 THE IMPACT OF A COAL MINE FATALITY

The process of underground roadway development uses a continuous mining machine to form the openings for subsequent longwall activities. This involves operating the miner under short sections of temporarily unsupported roof. While serious incidents of roof failure are rare, significant human and social costs are borne if a serious accident or fatality occurs.

To help overcome this hazard, CSIRO is continuing to extend the impact of their ongoing longwall navigation solutions to adapt their inertial guidance technology for use on a continuous mining machine. Using this navigation solution, the continuous miner is now able to be more accurately guided without the need for direct human intervention. Reducing or removing the need for people to be in the immediate vicinity of the mining will make major improvements towards preventing mining accidents in the future.

While the major concern over any accident will always be injury or loss of life, there are also considerable economic costs associated with accidents. The statistical value of a life alone is $4.5 million. In addition, industry sources suggest that the cost of lost production due accidents is around $1,000 a minute, although this varies significantly from mine to mine. Based on this figure, one day of lost production would cost the mining company $0.72 million (assuming the mine operates twelve hours a day).

If a coal mine fatality caused the mine to be shut down for a week, then the total cost of such an event would be of the order of $5.2 million.

SOURCE: DISCUSSIONS WITH CSIRO OFFICIALS

1.5.2 Potential future impacts

There have been several sales of longwall mining equipment incorporating CSIRO's automation technology to overseas mining firms. One system has been sold in the US and one in Norway. Initially ITAR was a barrier to deployment of the CSIRO technology to China. In addition, while non-ITAR high quality inertial systems could be used, they are not cost-effective due to the cost models of mining in China. However, CSIRO has now developed a low-cost inertial navigation solution using commercial-grade inertial sensors, which has allowed it to support commercialisation partners entering the Chinese market and develop new licensing opportunities there

The LASC innovations are now providing a technology platform to support the *next* generation of mining automation development by enabling a longwall operation to be fully remotely operated from a surface control station. Achieving a remotely operating longwall is seen by the industry as the number one priority to provide a step-change in personnel health, productivity, environmental sustainability and emissions. Current and emerging LASC technologies will provide an important means to achieve this goal.

The nature of benefits from overseas sales would be similar to those experienced in Australia. The majority of those benefits will accrue overseas. The initial benefit that will accrue to Australia will be a revenue stream to CSIRO from licensing fees and royalty payments, accompanied by a mixture of tangible and intangible benefits through export of its capability to conduct further research projects built on the reputation of this technology. Successful implementation of LASC technology in the Chinese industry which currently experiences more challenging mining conditions than in Australia will also lead to future benefits in Australia. The valuable knowledge and experience gained in dealing with automation in challenging conditions will be directly applicable to Australian mines as seams become thinner and deeper in the future.

CSIRO has identified several other potential uses for the underground inertial guidance sensor technology it has developed. It is applicable to a range of industries – particularly those involving excavation activity with mobile equipment where access to alternative guidance methods such as Global Positioning Systems are unavailable. CSIRO is currently working on other underground mining and tunnelling applications such as continuous miner and tunnel boring machine guidance. A continuous miner guidance system has been demonstrated in underground production conditions. The first commercial installation is expected to be commissioned in 2019.

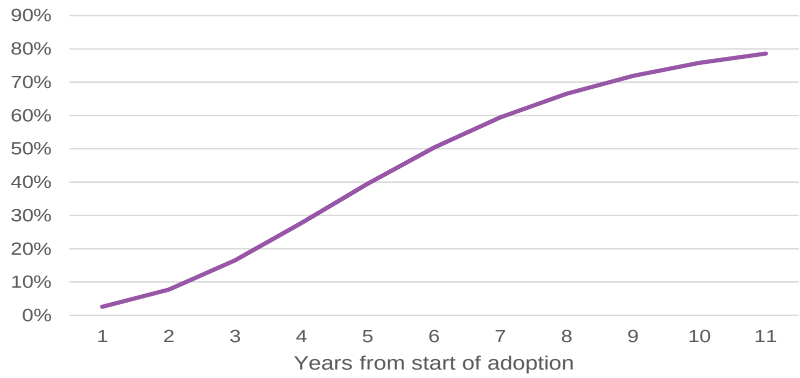
1.5.3 Cost Benefit Analysis

Assessment of benefits

Assessing the benefits of longwall automation developed by CSIRO requires estimating the historical and future increase in production relative to the Base Case where the development and adoption of longwall automation technology is delayed until at least 2030 in the absence of CSIRO's R&D.

The assumed rate of adoption of CSIRO's longwall automation technology in underground coal mining is shown in **Figure 1.2**. This is based on information from CSIRO that, as of early 2019, 24 out of the 30 underground mines in Australia have adopted (or are in the process of adopting) the technology and that, ultimately, approximately 80 per cent of all underground coal mining in Australia will be utilising the technology.

FIGURE 1.2 ADOPTION OF LONGWALL AUTOMATION IN AUSTRALIAN UNDERGROUND COAL MINING



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SOURCE: ACIL ALLEN

The estimated tonnage of underground coal production in Australia between 2001-02 and 2012-13 is shown in the third column of **Table 1.6**. This is based on ABS statistics on black coal production in Australia (see the second column in the table) and advice that about 22 per cent of black coal mining in Australia takes place underground.[19]

Using the adoption rate assumed previously and the assumption that longwall automation results in a 5 per cent productivity improvement (based on studies such as the December 2008 report that Heuris Partners prepared for CSIRO titled 'ACAP Extension 2010-2015 Case Studies'[20]), ACIL Allen has estimated the production that would have occurred in the Base Case between 2008-09 and 2028-29 without the CSIRO-developed longwall automation technology (that is, the 'baseline' production level). This is shown in column 6 of **Table 1.6**.

TABLE 1.6 CALCULATION OF ADDITIONAL VALUE OF COAL PRODUCTION ENABLED BY LONGWALL AUTOMATION

Year	Actual black coal production	Estimated underground coal production	Adoption rate of CSIRO innovation	Adoption rate of substitute technology	Baseline production	Additional production	Australian coal price	CPI (Dec)	Real price of coal	Value of additional production
	kt	kt	%		kt	kt	$/tonne		2018-19 $	2014 $
2001/02	273,236	60,112	0%	0%			32.31	75.4	48.90	0

[19] Minerals Council of Australia, personal communication August 2014

[20] The Heuris Partners study suggests that longwall automation enables the elimination of string lines that disrupt production twice a day, resulting in an increase in the baseline cutting rate by 130 tonnes per hour. In addition, longwall automation enables a further 5 per cent increase in the cutting rate, resulting in a combined productivity gain of approximately 13.7 per cent.

Year	Actual black coal production	Estimated underground coal production	Adoption rate of CSIRO innovation	Adoption rate of substitute technology	Baseline production	Additional production	Australian coal price	CPI (Dec)	Real price of coal	Value of additional production
2002/03	271,613	59,755	0%	0%			25.31	77.6	37.21	0
2003/04	280,753	61,766	0%	0%			26.09	79.5	37.45	0
2004/05	300,034	66,007	0%	0%			52.95	81.5	74.13	0
2005/06	303,431	66,755	0%	0%			47.62	83.8	64.84	0
2006/07	321,391	70,706	0%	0%			49.09	86.6	64.68	0
2007/08	322,163	70,876	2.6%	0%			65.73	89.1	84.17	0
2008/09	335,630	73,839	7.8%	0%	73,553	285	127.10	92.4	156.95	44,799,530
2009/10	363,330	79,933	16.5%	0%	79,277	656	71.84	94.3	86.93	56,994,643
2010/11	344,400	75,768	27.8%	0%	74,731	1,037	98.97	96.9	116.53	120,837,961
2011/12	362,709	79,796	39.5%	0%	78,249	1,547	121.45	99.8	138.85	214,766,670
2012/13	396,095	87,141	50.4%	0%	85,001	2,140	96.36	102.0	107.80	230,708,387
2013/14	430,200	94,644	59.4%	0%	91,913	2,731	84.56	104.8	92.07	251,415,535
2014/15	445,800	98,076	66.5%	0%	94,918	3,158	72.76	106.6	77.88	245,943,378
2015/16	437,000	96,140	71.9%	0%	92,804	3,336	81.67	109.4	85.96	286,789,589
2016/17	443,000	97,460	75.8%	0%	93,901	3,559	95.78	110.0	99.35	353,592,276
2017/18	439,100	96,602	78.6%	0%	92,949	3,653	122.71	112.1	124.90	456,236,626
2018/19F		102,791	80.0%	0%	98,838	3,954	160.79	114.1	160.79	635,678,897
2019/20F		105,283	80.0%	0%	101,233	4,049			109.11	441,805,085
2020/21F		107,774	80.0%	0%	103,629	4,145			109.11	452,260,890
2021/22F		110,266	80.0%	0%	106,025	4,241			109.11	462,716,694
2022/23F		112,758	80.0%	0%	108,421	4,337			109.11	473,172,498
2023/24F		115,249	80.0%	0%	110,817	4,433			109.11	483,628,303
2024/25F		117,741	80.0%	0%	113,212	4,528			109.11	494,084,107
2025/26F		120,233	80.0%	0%	115,608	4,624			109.11	504,539,912
2026/27F		122,724	80.0%	0%	118,004	4,720			109.11	514,995,716
2027/28F		125,216	80.0%	0%	120,400	4,816			109.11	525,451,520
2028/29F		127,707	80.0%	0%	122,796	4,912			109.11	535,907,325

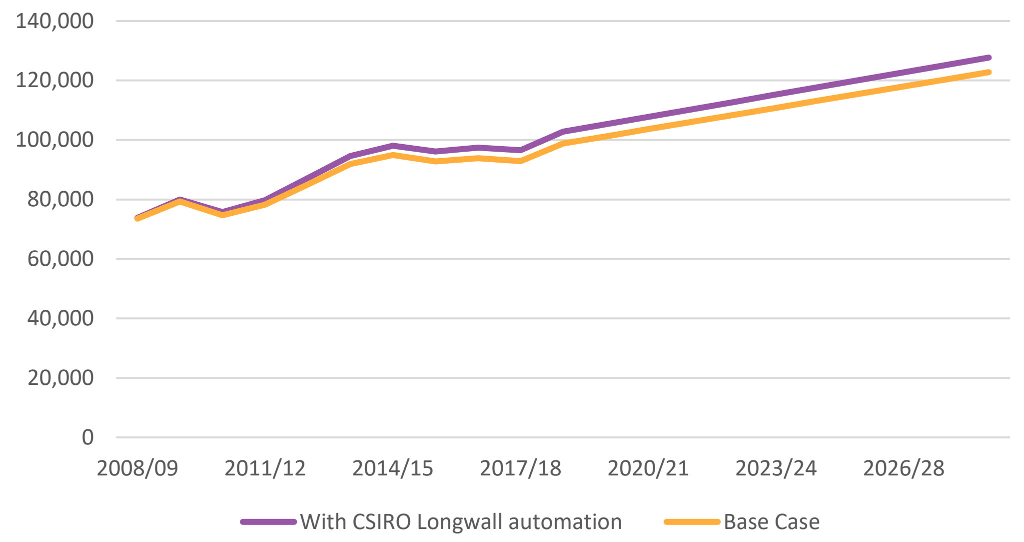
SOURCE: ACIL ALLEN

The baseline production level for the years 2013-14 to 2028-29 is estimated by fitting a linear trend to the historical data on underground coal production between 2001-02 and 2007-08 combined with the estimated baseline production between 2008-09 and 2017-18 and extrapolating from this fitted line.

The projected production level for 2013-14 to 2028-29 with the CSIRO longwall automation technology is then calculated by combining the following information: the baseline production level for the years 2013-14 to 2028-29; the adoption rate of the CSIRO technology discussed previously; and the assumed 5 per cent productivity gain (shown in column 5 of **Table 1.6**). Based on discussions with CSIRO, it is unlikely that substitute technology would develop before 2030 in the absence of CSIRO's Longwall research.

A comparison of the production level in the Base Case and the production level with the CSIRO longwall automation technology between 2008-09 and 2024-25 is presented in **Figure 1.3**.

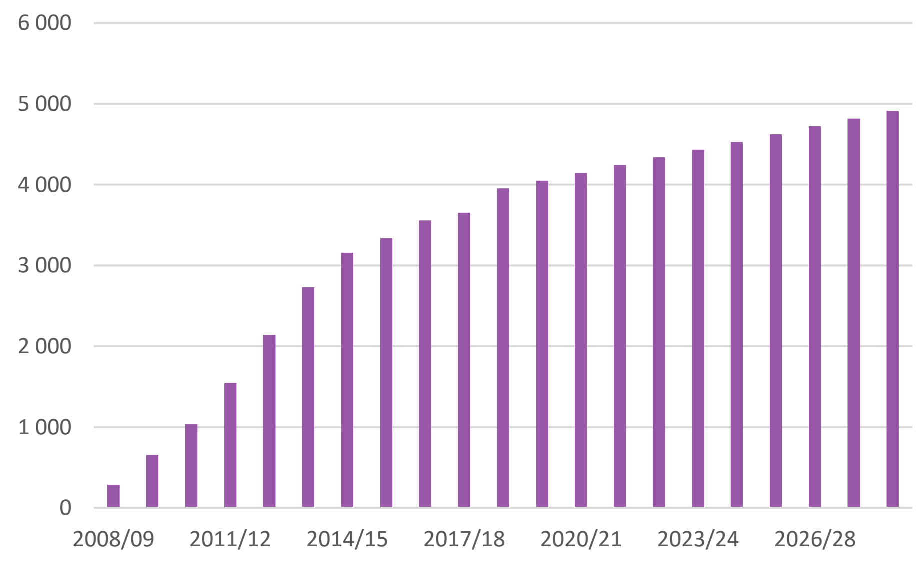
FIGURE 1.3 UNDERGROUND COAL PRODUCTION IN AUSTRALIA IN THE BASE CASE AND WITH CSIRO LONGWALL AUTOMATION TECHNOLOGY: 2008-09 TO 2028-29 (IN KILO TONNES)



SOURCE: ACIL ALLEN

The estimated increase in historical and future underground coal production in Australia due to CSIRO's longwall automation technology is shown in column 7 of **Error! Reference source not found.**and illustrated in **Figure 1.4**. This is calculated by subtracting the baseline production level from the actual production level for the years 2008-09 to 2017-18 and the projected production level for the years 2013-14 and 2028-29.

FIGURE 1.4 ADDITIONAL COAL PRODUCTION IN AUSTRALIA DUE TO CSIRO LONGWALL AUTOMATION TECHNOLOGY: 2008-09 TO 2028-29 (KILO TONNES)



SOURCE: ACIL ALLEN

Estimating the value of the additional production (the final column in **Table 1.7**) requires using the historical time series on the average coal price in Australia (adjusted for CPI inflation to bring the price in each year to equivalent 2018-19 dollars) and the projected Australian coal price for 2019-20 to

2024-25. This projected price is assumed to be the average historical price between 2009-10 and 2018-19 in equivalent 2018-19 dollars.

In addition to increased black coal production due to productivity enhancements made possible by longwall automation, the benefits to Australia also include future licence and royalty revenues from overseas mining firms. Estimates of these benefits, based on data provided by CSIRO, are shown in **Table 1.7**.

TABLE 1.7 PROJECTED FUTURE LICENCE AND ROYALTY REVENUES FROM OVERSEAS MINES

Year	Number of Chinese mines	Licence fee per Chinese mine	Number of US mines	Licence fee per US mine	Total revenue
2018-19	13	45,000	1	75,000	660,000
2019-20	18	45,000	5	75,000	1,185,000
2020-21	23	45,000	11	75,000	1,860,000
2021-22	28	45,000	16	75,000	2,460,000
2022-23	33	37,500	21	75,000	2,812,500
2023-24	38	37,500	26	75,000	3,375,000
2024-25	43	37,500	31	75,000	3,937,500
2025-26	48	37,500	36	75,000	4,500,000
2026-27	53	37,500	36	75,000	4,687,500
2027-28	58	37,500	36	75,000	4,875,000
2028-29	63	37,500	36	75,000	5,062,500

SOURCE: CSIRO

The total benefits of longwall automation also include an expected reduction in mining accidents. It is assumed that 1 death is avoided each year between 2011-12 and 2028-29 as a result of the adoption of the longwall automation technology (see column 2 of **Table 1.8**) and that the Value of a Statistical Life is $4.5 million in 2014-15 dollars (based on a 2014 Guidance Note on the Value of Statistical Life by the Australian Government Office of Best Practice Regulation, adjusted for CPI inflation between 2014-15 and 2018-19). It is also assumed that a mining death would result in the stoppage of production at the affected mine for 2 days. CSIRO estimates that each minute of lost production costs $1,000, as discussed previously in this case study. It is assumed that the mine would normally be operating 12 hours per day.

Total benefits attributable to CSIRO is $3 billion in present value terms

As ACIL Allen does not have detailed and specific information on additional input costs that might be associated with the increased production enabled by longwall automation (such as higher operational costs and transport costs), it is conservatively assumed that such additional costs would reduce total benefits by 10 per cent. The resulting net benefits are shown in the penultimate column of **Table 1.8** Finally, it is assumed that 60 per cent of these net benefits are attributable to CSIRO (see the final column in Table).

In present value terms, the stream of total benefits attributable to CSIRO over the period from 2001-02 to 2028-29 is estimated to be $3.01 billion in 2018-19 dollars under a 7 per cent real discount rate.

TABLE 1.8 ESTIMATION OF TOTAL BENEFITS OF LONGWALL AUTOMATION ATTRIBUTABLE TO CSIRO, 2001-02 TO 2028-29

Year	Deaths avoided	Value of lives saved	Avoided down time due to mine death	Total benefits	Total benefits net of increased operational and transport costs	Total net benefits attributable to CSIRO
		2014 $	2014 $	2014 $	2014 $	2014 $
2001/02	0	0	0	0	0	0
2002/03	0	0	0	0	0	0
2003/04	0	0	0	0	0	0

Year	Deaths avoided	Value of lives saved	Avoided down time due to mine death	Total benefits	Total benefits net of increased operational and transport costs	Total net benefits attributable to CSIRO
2004/05	0	0	0	0	0	0
2005/06	0	0	0	0	0	0
2006/07	0	0	0	0	0	0
2007/08	0	0	0	0	0	0
2008/09	0	0	0	44,799,530	40,319,577	24,191,746
2009/10	0	0	0	56,994,643	51,295,178	30,777,107
2010/11	0	0	0	120,837,961	108,754,165	65,252,499
2011/12	1	4,500,000	1,440,000	220,702,167	198,631,951	119,179,170
2012/13	1	4,500,000	1,440,000	236,643,884	212,979,496	127,787,698
2013/14	1	4,500,000	1,440,000	257,351,032	231,615,929	138,969,557
2014/15	1	4,500,000	1,440,000	252,256,384	227,030,745	136,218,447
2015/16	1	4,500,000	1,440,000	292,939,028	263,645,125	158,187,075
2016/17	1	4,500,000	1,440,000	359,719,147	323,747,232	194,248,339
2017/18	1	4,500,000	1,440,000	462,621,433	416,359,290	249,815,574
2018/19F	1	4,500,000	1,440,000	642,771,136	578,494,022	347,096,413
2019/20F	1	4,500,000	1,440,000	448,925,583	404,033,204	242,419,815
2020/21F	1	4,500,000	1,440,000	460,056,387	414,050,748	248,430,449
2021/22F	1	4,500,000	1,440,000	471,112,191	424,000,972	254,400,583
2022/23F	1	4,500,000	1,440,000	481,920,496	433,728,446	260,237,068
2023/24F	1	4,500,000	1,440,000	492,938,800	443,644,920	266,186,952
2024/25F	1	4,500,000	1,440,000	506,957,104	453,561,394	272,136,836
2025/26F	1	4,500,000	1,440,000	514,975,409	463,477,868	278,086,721
2026/27F	1	4,500,000	1,440,000	525,618,713	473,056,842	283,834,105
2027/28F	1	4,500,000	1,440,000	536,262,017	482,635,816	289,581,489
2028/29F	1	4,500,000	1,440,000	546,905,322	492,214,790	295,328,874

SOURCE: ACIL ALLEN

Assessment of costs

The nominal R&D costs associated with CSIRO's development of the longwall automation technology (discussed previously in the case study) are reproduced in the second column of **Table 1.9**. Adjusting for CPI inflation, these costs in 2018-19 dollars are shown in the third column of the table.

It is assumed that machines with longwall automation are only installed when the previous machines are replaced due to wear and tear, and that a machine with CSIRO longwall automation technology costs $100,000 in 2018-19 dollars more than a machine without this technology. The useful life of a machine is assumed to twenty years. The incremental capital costs of the machines with longwall automation technology are shown in the penultimate column of **Table 1.9**. Total incremental costs are shown in the final column of the table.

The stream of total incremental costs associated with longwall automation over the period from 2001-02 to 2028-29 is estimated to be $50.19 million in 2018-19 dollars in present value terms under a 7 per cent real discount rate.

TABLE 1.9 TOTAL INCREMENTAL COSTS ASSOCIATED WITH LONGWALL AUTOMATION, 2001-02 TO 2028-29

Year	Nominal R&D costs	Real R&D costs	Incremental capital costs of automated longwall machines	Total incremental costs
	$	2018-19 $	2018-19 $	2018-19 $
2001-02	1,184,250	1,792,081	0	1,792,081
2002-03	1,184,250	1,741,275	0	1,741,275
2003-04	1,184,250	1,699,659	0	1,699,659
2004-05	1,184,250	1,657,950	0	1,657,950
2005-06	1,823,000	2,482,152	0	2,482,152
2006-07	1,823,000	2,401,897	0	2,401,897
2007-08	1,823,000	2,334,504	19,251	2,353,755
2008-09	897,349	1,108,090	58,209	1,166,299
2009-10	430,197	520,525	124,055	644,579
2010-11	495,197	583,096	208,135	791,231
2011-12	555,197	634,749	296,505	931,254
2012-13	600,197	671,397	377,686	1,049,083
2013-14	485,510	528,594	445,661	974,256
2014-15	404,995	433,489	499,065	932,554
2015-16	560,119	589,572	539,225	1,128,796
2016-17	455,762	472,749	568,534	1,041,293
2017-18	389,322	396,268	589,489	985,757
2018-19F	0	0	600,000	600,000
2019-20F	0	0	600,000	600,000
2020-21F	0	0	600,000	600,000
2021-22F	0	0	600,000	600,000
2022-23F	0	0	600,000	600,000
2023-24F	0	0	600,000	600,000
2024-25F	0	0	600,000	600,000
2025-26F	0	0	600,000	600,000
2026-27F	0	0	600,000	600,000
2027-28F	0	0	600,000	600,000
2028-29F	0	0	600,000	600,000

SOURCE: ACIL ALLEN

Key cost-benefit analysis results

Benefits net of research and other costs that are attributable to CSIRO are equal to $2.96 billion

The Net Present Value (NPV) of CSIRO's longwall automation technology over the period from 2001-02 to 2028-29, calculated by subtracting the present value of total incremental costs from the present value of total incremental benefits, is estimated to be $2.96 billion in 2018-19 dollars between 2001/2 and 2028-29 under a 7 per cent real discount rate.

The project has a BCR of 60 under a 7 per cent real discount rate

The Benefit-Cost Ratio (BCR) of CSIRO's longwall automation technology, calculated by dividing the present value of total incremental benefits by the present value of total incremental costs, is estimated to be 60.1 when using a 7 per cent real discount rate.

The internal rate of return of CSIRO's longwall automation technology, the discount rate that would make the NPV exactly zero, is estimated to be 64 per cent.

Sensitivity analysis

Should the increase in productivity enabled by longwall automation be 10 per cent instead of 5 per cent, the BCR increases to 117.4 while the NPV rises to $5.84 billion in 2018-19 dollars, both under a 7 per cent real discount rate.

If 40 per cent of benefits are attributed to CSIRO instead of 60 per cent, the BCR decreases to 40.0 under a 7 per cent real discount rate. NPV falls to $1.96 billion in 2018-19 dollars under the same real discount rate.

If the adjustment of benefits for increased input costs is 20 per cent instead of 10 per cent, the BCR decreases slightly to 53.4 while the NPV falls to $2.63 billion in 2018-19 dollars, both under a 7 per cent real discount rate.

1.5.4 Impact pathway diagram

This case study uses the evaluation framework outlined in the CSIRO Impact Evaluation Guide. The results of applying that framework to the longwall automation project are summarised in **Figure 1.5**.

FIGURE 1.5 LONGWALL AUTOMATION – IMPACT DIAGRAM

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
▪ ACARP grant ▪ CSIRO funding ▪ In kind support from OEMs ▪ Cash grant ▪ In kind support from mining firms ▪ CSIRO IP (patents) ▪ Other IP (inertial guidance sensor from US) ▪ In-kind support from Cooperative Research Centre for Mining Technology and Equipment	▪ CSIRO research and development ▪ Development and testing of prototypes ▪ Supporting the development of a commercial product ▪ Providing support to firms buying the technology	▪ Sensing and guidance hardware and software for installation in OEM automated longwall mining machines ▪ Patents ▪ New model of industry collaboration and commercialisation developed	▪ New products and services – commercialised sensing and guidance hardware and software for installation in OEM automated longwall mining machines ▪ Negotiation and signing of licensing agreements ▪ Widespread adoption of new mining technology by underground coal mining companies. ▪ New model of industry collaboration has since been applied to other projects. ▪ IP revenue ▪ Export revenue	▪ Better management and improved mining productivity ▪ Increased production of coal ▪ Gains in overall system efficiencies ▪ Fewer stoppages and more consistent production levels ▪ Increased coal export earnings ▪ Export revenue from hardware and software sales ▪ Lower operating costs ▪ Reduction in risk of mine worker injuries ▪ Reduced environmental footprint due to smaller waste rock dumps ▪ Lower remediation costs ▪ Reduced emissions through higher grade resource extraction

SOURCE: ACIL ALLEN

1.6 Acronyms

ACA	Australian Coal Association
ACARP	Australian Coal Association Research Program
BCR	Benefit-Cost Ratio
CPI	Consumer Price Index
CSIRO	Commonwealth Scientific and Industrial Research Organisation
INS	Inertial Navigation Sensor

IP	Intellectual property
ITAR	International Traffic in Arms Regulations
LASC	Longwall Automation Steering Committee
NPV	Net Present Value
OEM	Original Equipment Manufacturers
RPCs	Recommended Position Corrections
SPMS	Shearer Position Measurement System
US	United States of America