View metadata, citation and similar papers at core.ac.uk brought to you by CORE
provided by Sydney eScholarship

THE UNIVERSITY OF SYDNEY

COPYRIGHT AND USE OF THIS THESIS

This thesis must be used in accordance with the provisions of the Copyright Act 1968.

Reproduction of material protected by copyright may be an infringement of copyright and copyright owners may be entitled to take legal action against persons who infringe their copyright.

Section 51 (2) of the Copyright Act permits an authorized officer of a university library or archives to provide a copy (by communication or otherwise) of an unpublished thesis kept in the library or archives, to a person who satisfies the authorized officer that he or she requires the reproduction for the purposes of research or study.

The Copyright Act grants the creator of a work a number of moral rights, specifically the right of attribution, the right against false attribution and the right of integrity.

You may infringe the author's moral rights if you:

- fail to acknowledge the author of this thesis if you quote sections from the work
- attribute this thesis to another author
- subject this thesis to derogatory treatment which may prejudice the author's reputation

For further information contact the University's Director of Copyright Services

sydney.edu.au/copyright

THE UNIVERSITY OF SYDNEY

Understanding success and failure in innovative Australian resource processing projects

Alan Tomlinson

A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

SCHOOL OF CHEMICAL AND BIOMOLECULAR ENGINEERING

31st March 2014

Student contribution declaration

I declare that this thesis contains no material which has been previously presented for the award of any other degree or diploma in any university or institution; and to the best of my knowledge, the material is original except where due reference is made in the text of the thesis.

Alan Tomlinson
March 2014

Acknowledgments

I would like to thank my supervisor, Associate Professor Ali Abbas, for his patience and good will during our long and challenging association. His support and good ideas have been vital. I would also like to thank my friends Dr Wayne Davies and Mr Jann Westermann for their unflagging interest and encouragement over many years and the evolution of the research.

Abstract

This thesis in concerned with the understanding of success and failure of innovation in resource processing, a sector that is central to the Australian economy. Decline in ore grade, complexity of available ore resources, increases in labour and capital cost, and increased market demand have driven innovation and larger resource processing projects. The outcomes from innovation investment have been disappointing, and not well understood. Innovation in Australian resource processing plants has now focused on incremental innovation and improvements in supply chain efficiency. This thesis aims to understand why so many large resource processing projects fail, and what factors have been critical in other projects that succeed. It proposes a new model for innovation investment, based on public domain data and an outsider view.

Five criteria are used in this thesis to classify success and failure of large resource processing projects; that (1) the project and firm made a profit, in failure the project made a loss, (2) the production in the first 36 months of operation is 90% or more of nameplate capacity, while a failure is less than 70%, (3) return on investment is below 105 months, failure above 105 months, average for successful projects is found to be 53 months,. (4) failure sees project and or firm fail, with the plant selling for less than 20% of cost, success sees the project continue to produce at close to capacity, and if sold was value at close to investment, and (5) the successful process is reproduced; in the case of failure it is not.

The thesis examines a sample of 67 resource processing projects in Australia initially valued at over $100 million each, over an 18 year interval between 1993 and 2010. The projects totalled $45.3 billion in value with 73% of classified as successful, while 15 projects failed. Four hypotheses are proposed and tested, each respectively relating to one of the following four factors; (1) Firm competence, (2) new process innovation, (3) government involvement in value adding, and (4) information asymmetry and strategic misrepresentation.

The first hypothesis states that project success was associated with firm competence. Most projects are classified as successful, and competent firms are found to be closely correlated with success. However, some otherwise successful firms had anomalous failures. Firms with low competence failed at large projects. Competent enough firms can fail where they lack the specific competence or motivation for a new process project.

The second hypothesis states that new process innovation is associated with project failure. Eleven of twelve projects based on new process innovation failed. In these cases radical process innovation is associated with large scale up that led to expensive failure. This is found to result in damage to future investor and corporate interests in such projects. No new process plants were built after 2005.

The third hypothesis states that successful government involvement in value adding processes is related to process maturity. It is found that government involvement is positive in projects with mature transformation processes like bauxite-to-alumina and alumina-to-aluminium resulting in successful projects over a long time period. However, the same involvement in new processing projects is found to be disastrous over a short time interval. Therefore, government involvement in value adding is found to be associated with failure, except with mature technologies, such as alumina and aluminium refineries.

The fourth hypothesis states that information asymmetry leading to strategic misrepresentation was associated with project failure. Information asymmetry leading to strategic misrepresentation explains the anomalous situation of otherwise competent firms failing at innovative projects. Information asymmetry could lead to benign or toxic outcomes depending how it is used. Strategic misrepresentation is found to be a significant factor in a number of high cost failures, which also encompassed government involvement, value adding and new processes.

A rigorous data collection methodology is conducted in this thesis and data is collected for each of the 67 projects based on availability in the public domain. Data is collected from annual reports, local and foreign government statistical data, trade publications, newspaper reports, institute meetings and publications, as well as through personal site visits.

Reference class forecasting is used to identify and group similar projects into the different classes of new process innovation (12 cases), gases transformed (8 cases), alumina and aluminium (11 cases), mineral sands (8 cases), noble metals (23 cases), and base metals projects (5 cases). An extensive set of distributional data for all projects is collected and used to identify causal (input) factors that correlate with success and failure, through financial calculations and cost and build performance measures.

Case studies are used to draw out fine details, explanations and understandings. Risk as predicted by indicators is found to be strongly correlated with project failure. For instance, a new team in Case 7, with little firm competence attempting a radical new process at large scale, failed severely. This case is an example of one carrying high risk as indicated by lack of competence, high level of Government involvement and investment as well as by multiple examples of strategic misrepresentation. While all other projects completed and produced some product; this particular failed case exhausted its capital and was only 5% complete. The process was never duplicated. In another (Case 8) it is learnt that investment of over a billion dollars and decades of incremental research and development resulted in a plant that was deeply uneconomic and capable of only 12% of nameplate capacity. The unusual factor was that it was built by an otherwise exceptionally successful firm. The successful innovation project (Case 40) was scaled up in stages, and was so successful it has been duplicated in nineteen other plants around the world. This success was also had the lowest cost at only $110 million, where many innovation failures typically cost over a billion dollars. Projects 7 and 8 were the two projects in the study to have direct government funding, with $400 million and $155 million respectively, and strategic misrepresentation was a feature of both. Project 40 benefited from Government indifference, and minimal involvement, and showed little asymmetric information and no strategic misrepresentation.

Operational investment models based on existing academic and government theory are proposed and tested. These are the firm competence model, based on the work of Prahalad and Hamel, the new process innovation model and the government involvement in value adding model based on published white papers and regulations, and asymmetric information model based on the work of Akerlof, Spence and Stiglitz, and work on strategic misrepresentation based on the work of Jones and Euske. Each has five measures with a success to failure axis.

An examination of developments after 2010, up to 2014 showed that investment in refining of resources had declined, and that production or ore concentrate was the preferred model, with minimum risk.

Recently the model of four decades of successful government involvement in alumina and aluminium refineries has faltered with commodity price changes, and plants have closed.

Table of Contents

Table of Tables

Acronyms

AB	Aditya Birla (Indian)
ABARE	Australian Bureau of Agricultural and Resource Economics
ABX	Barrick Gold Corporation (USA)
AGG	Anglo Gold Ashanti (South Africa)
AKL	Skardon River Kaolin
AL	Alcan (Canadian)
Alcoa	Alcoa Inc. originally Aluminum Company of America
AMC	Australian Magnesium Corporation Limited (2000 – 2005)
ANL	Anaconda Limited
ANM	ASX code for AMC
ASX	Australian Securities Exchange
AWAC	Alcoa World Alumina and Chemicals
AusIMM	The Australasian Institute of Mining and Metallurgy
BDG	Bendigo Mining N.L. (No Liability)
BHP	Broken Hill Proprietary Company Limited (before 2001)
BHP-B	BHP Billiton (after 2001)
BMX	Bemax Resources Limited
BPFL	Burrup Fertilisers Pty Ltd
COP	ConocoPhillips (USA)
CTR	Centaur Mining & Exploration Limited
ILU	Iluka Resources
JAP	Japanese consortium Furukawa 71.44% Nittetsu Mining 20%, Nissho Iwai 5.45% Itochu 3.11%
KOR	Korea Zinc
MIM	Mount Isa Mines (1924 – 2003)
NEM	Newmont Mining Corporation (USA)
NCM	Newcrest Mining Limited
ORI	Orica
OZL	Oz Minerals Limited
Pegasus	Pegasus Gold, Inc. (USA)
PSV	Perseverance Corporation

RIO	Rio Tinto Group
RSG	Resolute Limited
SPP	Stuart Oil Shale Project
Tiwest	Tiwest Joint Venture Tronox (US) and Exxaro (South Africa)
USGS	United States Geological Survey
WES	Westfarmers Limited
WMC	Western Mining Corporation (1933 – 2005)
WPL	Woodside Petroleum Limited
WVL	Windamurra Vanadium Limited
ZFX	Zinifex Limited

Chapter 1

Introduction

"Where observation is concerned chance favours the prepared mind." - Louis Pasteur

1. INTRODUCTION

1.1 Context of research

Australian wealth and prosperity is built on productive exploitation of our resources. Innovation in elaborately separating and transforming mineral and energy resources, the nation's largest chemical engineering endeavour, is not well understood. Innovation has changed, and is presently changing our main source of foreign income and investments. Innovation involves risks and failure, some predictable and avoidable, as well as profit and success.

My central question is "Why did innovation fail so often, and how could it succeed?"

To answer this and other related questions, an un-biased understanding based on a large data sample was considered and modelled over years. In this time evolution of projects in this field could be observed. The methods, models, and observations may be more widely applicable outside resource processing plants.

1.2 Rise and fall of innovation

Between January 1993 and December 2010, 67 resource processing plants valued at more than $100 million each were built in Australia.[1] $45.34 billion was invested, and 73% gave a commercial return. The failure of eleven of the twelve most innovative projects, wiping out $11.4 billion, transformed the investment outlook and challenged many widely held beliefs.

This research seeks to understand why so many innovative plants failed[2], and how others succeeded[3]. All these plants were subjected to extensive technical, financial, and managerial assessment and review by present methods[4]; yet 27% of this investment gave negative outcomes.[5] Businesses responded to expensive failure with avoidance, and profitable success with replication.[6]

The present methods of project evaluation are private, proprietary[7] and use data that is not publicly available, at the time of the project or later. These expert insider views of *"how it should work"* produced unacceptable results in too many cases. This normative model is used to estimates of the cost of defence equipment, public infrastructure, and rail transport. In these areas cost overruns, delivery delay and performance benefit shortfall are usually significant. The insider evaluation methods and outcomes are closed, and unavailable for public or academic review. Criticism or disclosure from within is not career enhancing.

The alternate view of that research is an outsider view of *“what does it actually do?”* over a longitudinal case study of all major projects in a reference group over 18 years, with 3 years more to observe outcomes. This descriptive model uses only public domain data available to the curious and persistent. It is an academic model in that it is open for all to see, use, criticise and enhance. The difference in viewpoint between the two views is essentially the “Is-ought problem” proposed by Hume in 1739.[8]

The failed projects included all but one innovative processing plant. These new process plants were built to elaborately transform increasingly low grade and or complex ores; and add value to abundant but otherwise intractable resources. The problem is described in the colourful quote: *“About the bravest thing anyone can do in Australia is to erect a green-fields mineral processing plant. They cost zillions of dollars; they take years to build; they blow up; the state-of-the-art process that was perfected in the laboratory mysteriously won’t work in the field; and the plants never, ever run right the first time you press the button.”* [9]

The willingness to innovate in process plant peaked in the 1995-2005 period, and as the above quote became commonly accepted wisdom, investment for innovative process plant stopped.

Cutler[10] states *“We have known for several generations that innovation pre-eminently determines our prosperity.”* Yet only one innovative technology mega project and a number of smaller niche and incremental innovations were successfully implemented in this time.[11] The failure of almost 99% of investment in innovative new process plants changed how the investment and innovation cultures interact.

1.3 Decline in grade

Metals have been extracted in Australia for more than 170 years. The easily recovered, rich ores were long ago worked out. There is a general trend of declining ore grade show in detail by Dr Gavin Mudd of Monash University, Mineral Policy Institute. [12] Gold grades have declined from greater than 50 g per tonne (or 50 ppm) of visible gold nuggets in the 1851 Gold rush , to present recovery of less than 1 part per million from huge volumes of hard rock, using complex mechanical and chemical process.

The decline in grade and the decline in ores that are easy to process mean that more energy and investment must be applied to extract smaller quantities of metal from larger volumes of increasingly difficult rock. To give a specific and recent example from the Cadia operations near Orange N.S.W. [13] the grade in the earlier accessed (2005) Ridgeway resource, at 1.75 g/t of Gold and 0.61% Copper was twice as rich as the later (2010) Cadia East resource with 0.81 g/t of Gold and 0.3% of Copper.

1.4 Links between grade, demand and innovation

Decline in grade has progressed at different rates for different resources:

Iron ore, coal, or natural gas have suffered little if any decline in grade over time, and increased demand has seen prices and profits increase. The leading Australian iron ore deposits, mostly in the Pilbara, require minimal beneficiation to meet export quality. The major coal basins of NSW and QLD are rich and located near railways linked to export ports. Coal extraction is not difficult; and requires only moderate beneficiation to reduce the ash content. These two minimally transformed resources represent more than half of Australia's mineral and energy exports at $96 billion in 2013.[14] This is up from $72 billion in 2009-2010. They are not considered in the case studies in this research as the processing is minimal, transforms the commodity only slightly, and adds limited value. They are however an element in the understanding as they represent the fastest growing share of the market, have yielded exception profit in the last decade, and are alternate options for investment, compared to mineral processing, with demonstrably low risk.

Natural gas requires compression, cooling and liquefaction to - 162° to be exported. The process of refining natural gas and concentrating it more than 600 times is relatively new, less than 50 years and complex engineering activity carried out at large scale. Thus it is included in this study.

Gold, copper, nickel, and cobalt suffered significant decline in grade in the 1993-2006 period. Silver, lead and zinc had relatively good grades but from more difficult to process ores. Commodity price increases (average 3.9 x over 18 years) as shown in Table 1, and strong demand encouraged investment. The increased value of the metal, with both declining grades and more intractable ores drove a trend to new processing innovations and mega projects. The project innovation was to enable extraction of metal from resources that were difficult to process with existing technology. Mega projects, designed to process huge volumes of low grade and difficult ores were the response.

Table 1 Commodity price increase and changes over 18 years of study (ABARE)

Commodity	Dollar	Jan 1993	Dec 2010	Increase	In study	Grade change	Extraction
Alumina	Aust	$252.84	$315.65	1.25	Yes	little	similar
Gold	U.S.	$329.01	$1,393.51	4.24	Yes	much lower	complex ores
Iron ore	Aust	$29.12	$119.56	4.11	No	little	simple
Met Coal	Aust	$68.53	$186.22	2.72	No	little	simple
Oil	U.S.	$16.17	$87.56	5.41	No	little	deeper water
LNG		Commercial	Confidential	~ 8-10	Yes	little	deeper water
Copper	U.S.	$2,262.62	$9,147.26	4.04	Yes	much lower	difficult
Lead	U.S.	$437.66	$2,412.93	5.51	Yes	moderate	complex ores
Zinc	U.S.	$1,061.40	$2,280.93	2.15	Yes	moderate	complex ores
Silver	U.S.	$368.43	$2,934.90	7.97	Yes	moderate	complex ores
Nickel	U.S.	$5,932.80	$23,454.29	3.95	Yes	much lower	complex ores
Zircon	Aust	$195.22	$1,123.37	5.75	Yes	lower	harder

Decline in grade has been managed historically by technological innovation; which led to increased productivity, increased output, and often a decline in metal price, which most disadvantaged the operators who did not have the new process. Four new processes are described to illustrate how new technology enabled the processing of lower grades or complex and difficult ores.

The 1887 MacArthur Forrest Process for gold extraction by dilute cyanide solution enabled the economical extraction of gold from ores where it is in low grades and or small particles. Till then gold extraction sought visible gold, nuggets that could be picked by hand or separated by gravity. Most gold extracted today is in low parts per million, and in pockets measured in microns. This new process quickly adopted increased gold production significantly and transformed the industry.

The development and improvement flotation technologies have evolved over many years. In 1897 the brothers Frank and Stanley Elmore[15]purchased the Glasdir Copper mine in North Wales, and installed an early type of flotation processing plant. In Australia C.V. Potter in 1901 and G.D. Delprat in 1902 independently invented new processes where naturally occurring chemicals such as fatty acids and oils were used as flotation reagents in a large quantity to increase the hydrophobicity of the valuable minerals. However their process was not successful in scale up implementation at the Broken Hill mines.[16] In 1906 Belgium-born chemist, Auguste De Bavay patented his 'skin' or 'film' flotation process and opened what was to become the first successful plant at Broken Hill. In 1909, De Bavay started the public company, Amalgamated Zinc (De Bavay's Ltd), and enlarged the plant at Broken Hill to use the flotation process on the materials from the tailings dumps. This was very profitable, as the ore was already extracted and available at low price.

Progressive incremental advances in flotation have been applied to a wide variety of materials to be separated. The flotation process is essential for separation of small portions of valuable materials from gangue in a low grade ore. The interesting detail is that vigorous commercial competition between small firms enabled this new and vital technology to rapidly evolve and be widely implemented in a decade.

Two radical innovations transformed mineral processing and enabled the production of cheap, strong and lightweight aluminium, and its precursor alumina.

The Bayer process for alumina production from bauxite was invented in 1887 by Karl Bayer, an Austrian working in St Petersburg. He sought to develop a method to produce alumina; to be used as a fixing agent in the dyeing of cotton. In 1888, Bayer patented his four-stage Bayer process of extracting alumina from bauxite ore, which is much the same as used today.

The alumina process supplied the feedstock for the Hall-Heroult process; invented independently in France and America in 1886. Both inventors were 23 years old, both worked on their own inspiration on modest family funds, in makeshift laboratories. The developed a complex process that with a few improvements is in use today. Together these two radical innovations, from three amateur industrial scientists transformed the world. They saw the price of Aluminium metal declined by 80% as a result, yet that led to mass utilisation and profit.

By comparison with modern process research, the researchers had tiny budgets, primitive facilities, and worked incredibly fast, with very limited support. Their processes; as described in patents, worked first time, scaled up progressively, and over the next 124 years have evolved by incremental improvements.

Decline in grade, and or increased complexity in available ores; at a time of increased demand, encouraged a wave of process innovation for processing more difficult resources. These innovative process plants were built, with one exception, in a decade between 1995 and 2005. They were built in remote locations, at large scale, with blown out investments. They all failed and destroyed their investor’s capital and confidence.

The viability of innovative processing plant and future investment are dramatically affected by how well the plant performed. When reaching design performance is long delayed, expensive in extra costs, and never achieved, future investment is at risk. Investors burned by innovation failure avoid repeating their pain.

1.5 Three Gaps in knowledge

Three pertinent gaps in knowledge are identified:

There are no “outsider view” studies of factors that influence success and failure of large resource processing projects.

There is an opportunity to evolve new theory in firm competence, innovation success models, interactions of government in value adding processes and strategic misrepresentation in mega projects.

There is a need to build a wide and deep database in a project class on which to base methods and theory. The database should have enough examples to be statistically robust, and over a time frame long enough to see trends.

1.6 Four Research Hypotheses

Four hypotheses are proposed and investigated in this thesis:

That at project success was associated with firm competence. The hypothesis is in the positive as most projects succeeded, and the majority of firms were variably competent enough. Firms with low competence failed at large projects. Competent enough firms can fail occasionally for other reasons.

That new process innovation was associated with project failure. The hypothesis is in the negative as most projects, eleven of twelve, failed. In these cases radical process innovation was associated with large scale up. That led to expensive failure; which has damaged investor and corporate interest in such projects in the future.

That successful government involvement in value adding processes was related to process maturity. The hypothesis is in the positive as government involvement in mature transformation processes like bauxite to alumina and alumina to aluminium have been successful over a long time period, whereas the same involvement in new process projects was disastrous over a short time interval.

That information asymmetry leading to strategic misrepresentation was associated with project failure. The hypothesis is in the negative as information asymmetry leading to strategic misrepresentation was the explanation for the anomalous situation of otherwise competent firms failing at innovative projects.

1.7 Three Research objectives

Three thesis objectives are:

To understand why some (~ 27%) projects failed, and other (~73%) succeeded. The understanding is expressed by simple models that should be explanatory and predictive.

To examine each of four hypotheses; that seek to explain why failure was so frequent and to indicate how success might be better managed.

To answer “Why did innovation in resource processing plant fail so often, and how can they succeed?”

1.8 Research viewpoint

The research viewpoint is important, and will be expanded on in the literature search, and the methodology. Project evaluation, and outcome forecasting has traditionally been an insider expert working with confidential data. The failure of 15 projects lost ~ $12.5 billion dollars. All had "bankable feasibility" studies using existing (insider) methods. The majority of this loss was to outsider shareholders and taxpayers.

An insider is an actor within the system, where approving a project has a financial reward. An outsider is an observer, where approval or disapproval of a project is of no consequence.

The insider has access to much more data, the outsider has access only to some data, and much of it only well after the event. However as the outside data is often "what actually happened", it may, in a model be more useful.

1.9 Research methods

The research methodology is based on building an extensive database and examining it for patterns. The data is examined in three layers, all drawing on existing academic research and theory.

The first is data shown in a positional layout with multiple parameters as in reference class forecasting. The selection criteria for the relevant reference class depends what type of outcome one seeking to predict or explain, from the outcomes of the prior projects. The distribution shows the extremes, the median, and clusters. The probability distribution may be ranked by a number of criteria. This is covered in detail in the literature search chapter, and in practical utilization in the methodology chapter. In brief it asserts that human judgement on future outcomes is often biased and there is insufficient regard to distributional data of past similar projects.

The second layer is improper linear modelling; which is also covered in detail on pages 43-44. It also seeks to avoid bias in human cognition by utilisation of simple and uncorrected rating of selected parameters. This modelling is the basis of the parameters used in positional ranking, and in the predictive and explanatory hypotheses.

The third layer is selected case studies that compare and contrast the extremes and a median example for better understanding.

1.10 Thesis structure

This thesis is structured as follows:

Chapter 2 reviews the literature which is the body of knowledge used as the foundations of the ideas, models and methods in this thesis.

Chapter 3 examines and explains the models for firm competence, new process innovation, government involvement in value adding and information asymmetry leading to strategic misinformation.

Chapter 4 explains the methodology used is this thesis. It covers indicating factors and performance measures used in the models and distributional displays.

Chapter 5 explores the first two hypotheses of Firm Competence and New Process innovation.

Chapter 6 explores the second two hypotheses of Government involvement in value adding and Information asymmetry leading to strategic misrepresentation.

Chapter 7 reviews the findings of Chapters 5 and 6 and suggests further research.

Chapter 2
Literature review

"*If I have seen further it is only by standing on the shoulders of giants*" - Isaac Newton

2. LITERATURE REVIEW

This chapter first reviews existing literature and practice in resource project evaluation, which has an insider viewpoint. It then reviews the fundamental differences between descriptive and normative viewpoints, or the outsider and insider views. An examination of the development of simpler economic models to visualise large data sets over time is followed by economic theories dealing with decision under uncertainty. The back ground of literature for the four hypotheses is then covered, looking at Core competence, new process innovation, government involvement in value adding and strategic misrepresentation.

2.1 Resource project evaluation - the insider view

Project evaluation can be viewed from either an "insider" or "outsider" view, these might equally be as normative (or what ought to be) and descriptive (what is).

Resource project evaluation has historically been an "insider" study, with a small number of experts. Ed Merrow, the founder and CEO of Independent Project Analysis, Inc. (IPA[17]), was one of the earliest and most persistent researchers. His work in the field began at RAND in 1978 and has evolved into a firm that specialises in advice on Megaproject activity across the oil, minerals, and chemical industries in all parts of the world.

US oil production began falling in 1969[18], and with the 1973 Yom Kippur War the price of oil rose sharply[19]. This lead to the building of a range of innovative processes plants for extracting oil from shale and tar sands. These new technology plants absorbed public research dollars but made little contribution to oil supply. The U.S. Department of Energy wanted to know why, and engaged RAND Corporation to investigate the problem. [20]

In the late 1990's and early 2000's innovative projects with great potential to add value to Australian resources under-performed and failed, in much the same way. Edward W. Merrow[21] and co-workers started production of a series of papers[22] between 1978 and 1989. These are shown in Table 2 Merrow and co-workers laid the foundations for later studies of innovative project failure. This work was looking at the projects built in urgent response to the First Oil Crisis of 1973-4. These projects, shown in Table 3, consumed invested funds and made almost no short term contribution to oil sufficiency.

Merrow observes a rule of alternate fuel commercialisation[23]. It applies equally to new process development and is adopted in this study. *"Successful commercialisation of a technology ultimately depends upon only one factor: profitability. No matter how actively the government promotes a technologies introduction, commercialisation will not occur if industry cannot obtain positive return on its investment comparable to what other investment opportunities offer." The plants had been un-commercial primarily due to significant cost increases and poor technical performance."* Merrow is stating the obvious, but an obvious that is sometimes overlooked. All private investment in resource processing attracted investment based on making a profit. There is a development of research by RAND shown in Table 2, which is the seed for the "insider" project evaluation now conducted by IPA. It is a good model for "outsiders" to understand and to copy key features. Profit is a parameter of every model in this thesis.

Table 2 RAND Papers on pioneer plant problems

Year	Title
1978	Constraints on the commercialization of oil shale
1979	A review of cost estimation in new technologies
1981	Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants
1983	Cost growth in new process facilities
1983	Pioneer plants study users' manual
1984	Linking R&D to problems experienced in solids processing
1986	A quantitative Assessment of R&D Requirements for Solids Processing Technology
1987	An application of the pioneer plants study methodology to first of a kind MHD central station
1988	Trends in attrition of high quality military recruits
1988	Understanding the outcome of megaprojects
1989	An analysis of cost improvement in chemical process technologies

In his second paper[24] Merrow notes the disconnection between initial cost estimate, and the cost growth till some projects were cancelled incomplete. The interesting anomaly is Syncrude Canada Ltd who has modified and expanded the plant near Fort McMurray in the Athabasca Tar Sands, and today produces 13% of Canada's oil requirements.[25]

Table 3 shows all pioneer plants suffered cost growth. One located in Canada went on to succeed, and be duplicated. Canada is today the largest supplier of oil to the United States, delivering around a million barrels a day by pipeline from Tar sands. The objective of the program, oil supply to USA from new resources and processes in the long term succeeded.

Table 3 RAND studies showing cost growth in pioneer plants

Project Title	Cost Growth	Cancellation Stage	Comments
Shell Tar Sands	350%	Preliminary	Two estimates
El Paso SNG	300%	Preliminary	Three estimates
Occidental shale oil	330%	Definitive	Three estimates
Wesco SNG	240%	Budget	Two estimates
Syncrude Tar Sands	300%	Completed	Plant started September 1978
Great Plains SNG	180%	Definitive	Two estimates
Colony Oil Shale	230%	Definitive	four estimates
Baltimore Solid Waste	160%	Completed	Unsatisfactory operation
Barnwell Reprocessing	200%	Completed	No start up due to problems
GE Reprocessing	230%	Completed	Plant failed to operate

Merrow comments: *"little systematic analytical work has been published on the question of cost estimation error for public works and large private sector construction projects."* This is very much the situation for many types of projects in Australia today. He continues *"Such private venture data and analysis that does exist, to our knowledge, have not been published and remain proprietary".*

The idea that the assembly of such confidential data for systematic analysis would yield knowledge and understanding is core concept, which is much later developed by Merrow into a business. To my knowledge there are no academic or public domain models, and it is the aim of this thesis to create one.

The 1981 paper "Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants" is the cited inspiration for most studies that followed.

Firstly Merrow identifies the linkage between innovation and failure.
"By hypothesising (and later demonstrating) that unproven technology is related to cost growth and performance problems, we are ***not*** *suggesting that innovation is "bad". Although the estimates for an innovative process plant may grow far more than those for a conventional counterpart, the innovative plants may still cost considerably less than the technology it replaces. Even if that innovative plant performs poorly, it may ultimately pay a handsome profit to the innovating company if the subsequent units (employing what has then become demonstrated technology) perform well."* (p13)

Innovation, particularly radical innovation with a new process fails often. But when it succeeds it can deliver the objective, transform the industry, and yield sustained high profits.

Secondly Merrow lays out the model followed by most subsequent studies; the multi factor data base of around 50 similar projects.

"Each of the 44 chemical process plants sampled is characterised by over 400 separate items. Participating companies voluntarily provided proprietary data underwritten non-disclosure agreements with The RAND Corporation." (p19)

The concept of building a database with items of data for all projects is like gather a new form of data in a census. This applies as much to insider as outsider studies, and is adopted in the methodology used in this thesis.

Thirdly Merrow proposes *"Measures of technological change"*

- *The number of process steps that were new at commercial scale*
- *The scale up of the plants from prior units*
- *The percentage of estimated capital investment in the new steps*
- *Whether the plant represented the first time the technology had been used commercially in North America*
- *The extent to which heat and materials balance equations were known on the basis of data from prior plants as opposed to being calculated on the basis of theory or simply unknown at various points in the project (p25)*

These parameters are incorporated in this Australian study. Specifically the scale up from a prior successful unit is one of five parameters of the innovation model. The number complexity of new process steps are another.

In "A quantities Assessment of R&D Requirements for Solids Processing Technology" (1986) this multi factor database is described as a "Parametric approach" …
"Parametric analysis statistically links the characteristics of entities to some defined

outcome measures, such as commercial plant performance. The statistical links are derived from historical experience, e.g. a database describing many projects."

Parametric analysis of data collected into a systematic matrix has many practical similarities with reference class forecasting. It differs in that it is an inside, expert, proprietary system. The problem of using only private information is that the study is restricted to "insiders" who pay for the data. Apart from a silhouette of a good model it does little to assist with public understanding, examination and criticism. However it is a good model for the methodology of this thesis.

Building on Merrows' foundation, Terry McNulty[26], developed 4 "Category" model[27] based on 41 Copper plants built between 1965 and 1995. These included 13 sulphide floatation concentrators, (which are the least challenging for ore and plant) 7 inorganic chemical plants, (which were a variety of techniques to treat poly-metallic ores) 6 copper and nickel smelters (as in North America the two are often found together, whereas copper gold is more common in Australia) 8 hydrometallurgical plants (biologically assisted heap leach, agitated leaching, and autoclaving) 7 hydrometallurgical oxide plants.

This model was later extended with a 5th Category which described the Western Australian Murrin-Murrin (Anaconda) Nickel plant. This is reasonable as the Murrin-Murrin plant was a hydrometallurgical oxide plant, with comparable process to those considered for copper gold and copper nickel. The other reason for adding the 5th category was that category 5 is category 4 taken to the most egregious excesses. The very promotional project owner, a theme in many 1990's business sagas, was possibly more focused on mining the share-market than the ore body. The problems of misstated ore reserves, ore grades, final value, or included elements that made the process more difficult were apparently largely ignored.

The plant owner and operator that made limited input to engineering, showed their inexperience, and might have influenced the construction firm to appoint a "B" team to manage the work. This lead to serious engineering deficiencies, which went unknown and unresolved till the process plant, became operational. Incorrect materials specifications; were the final and spectacular evidence of very limited technical and managerial competence. When a process involved dissolving ore in hot sulphuric acid, it would be wise to ensure that the materials in contact with the acid and abrasive ore residue were resistant to both. The valves were not; and quickly failed. Table 4 shows 5 levels which range from least risk in Series 1 to most risk in Series 5. This is utilised in the improper linear models shown in Sheet 3 of Appendix. The Series showing risk from highest to lowest is also an indicator of probable performance.

Table 4 1 to 5 Series categories by Mc Nulty

Series 1	Mature technology, Mature, experienced project owner, Standard types/sizes of equipment, Thorough pilot testing of risky unit operations.
Series 2	If licensed, one of the first licensees, Prototype equipment, Incomplete pilot testing, Non-representative sample, Severe process conditions, Insufficient attention to materials handling or other standard unit operations.
Series 3	Limited pilot testing, some important steps ignored, Mineralogy poorly understood, Product quality ignored, Serious design flaws, Fast track; increased risk ignored, Inexperienced management, Unforeseen product price decline.
Series 4	Process chemistry poorly understood, Equipment downsized or design criteria compromised to cut capital, Very complex flow sheet with many interdependent unit operations, Only continuous tests were for demonstration purposes, No safety margins.
Series 5	Most of Series 3 and 4 flaws, plus Very promotional project owner, Little owner input to engineering, Serious engineering deficiencies, Misstated reserves, Incorrect materials specifications.

To which Doug Halbe[28] added a financial analysis for the Series above and the percentage of nameplate capacity of plant below, for a hypothetical gold mine[29]. A Gold mine (without intractable ores) is a rather standard operation, with long established processes, utilising existing plant with well-known performance characteristics. Table 5 shows a linkage between risk factors and financial outcome for 41 copper plants and for Murrin-Murrin PAL Nickel Cobalt HPAL plant (Case 3 in the Appendix). This is also developed in more detail in the Hypotheses in Chapter 5 and 6, and in sheets 4, 5, 6 and 7 of the Appendix.

Table 5 Halbes' financial outcomes for the different series, showing profit or loss estimates.

Category	Net present value
Series 1	$ 209 million
Series 2	$ 110 million
Series 3	- $ 25 million
Series 4	- $ 240 million

Every mine in Halbe and McNulty's study is designed for a regular extraction capacity of a certain grade of ore. This ore is fed to a process plant tailored to process the volume and grade. This "nameplate capacity" is the performance of the plant; when fed the quality of ore that it was designed for. The name plate capacity is usually set at an output of metal processed and refined to a widely accepted market specification.

However it might better be defined as the mass or volume of materials that can be processed as an input. A plant that could process 600,000 tons of ore a month, to produce 20,000 ounces of gold a month is constrained by the input. If fed ore at twice the grade it might be capable of producing 40,000 oz. a month; but if half the grade, then only 10,000 oz. a month can be produced.

In Table 6 data shows lowest indicator risk projects were fastest to reach plant design capacity. Highest risk projects performed worst at reaching nameplate capacity. The measure of output over first 36 months as a percentage of nameplate capacity is taken as a parameter 13 in the Hypothesis studies.

Table 6 Output from series process plants as percentage of nameplate capacity

	6 months	**12 months**	**18 months**	**24 months**	**30 months**	**36 months**
Series 1	80%	100%	101%	103%	105%	106%
Series 2	50%	78%	90%	95%	97%	97%
Series 3	40%	60%	75%	78%	80%	83%
Series 4	21%	37%	44%	55%	56%	57%
Series 5	10%	18%	30%	46%	60%	70%

Chris Twigge-Molecey of Hatch and Associates points out that the funding for R&D or industrial design are but a very small percentage[30] of an innovative project, yet if they are not excellent, the project must be in trouble[31]. He promotes the idea that the design and construction contractor must also be the technology developer, and thus take responsibility for project success. An extra 5-10% on budget, AND the plants reached name plate quickly might transform innovation in mineral processing. This concept is taken into the innovation model in Chapter 3.

The example from Halbe shows this, as do a number of projects in the case study, where the initial planning did not appear very professional, and a difficult start up followed. In one large Australian project (Case 1) the proposed start date shifted 2 years, and was then late, the cost went from $750 million in 1995, to $1.5 billion in 1996, $1.7 billion in 1997, and $2.4 billion in 1998.

A Canadian expert in pressure acid leaching plants, was has been called into the post mortem, and partial resuscitation of 3 laterite nickel plants[32]. His papers shows multiple design and construction shortcomings.[33] Table 7 shows three projects, and their production over time. The results indicate that they would be in Series 5 as shown in Table 6.

Table 7 Production of Nickel at three HPAL laterite process plants

HPAL	6 months	12 months	18 months	24 months	30 months	36 months
Bulong	12%	45%	42%	69%	46%	65%
Cawse	25%	45%	88%	76%	88%	Closed
Murrin Murrin	8%	12%	29%	42%	59%	66%

The conclusion from examining these insider studies is that they include excellent measures to be adopted and incorporated into the methodology used in this thesis.

2.1.1 Infrastructure project evaluation - an outsider view.

Public infrastructure evaluation, selecting which projects will be funded to implement the policy and social objectives of the Government, have traditionally been chosen by insiders with an insider view.

Yet such public infrastructure; railways, road, tunnels bridges and dams often cost more than the budget plan, take longer to build that projected, under-deliver benefits and payback investment more slowly than promised.

A study[34] of 258 transportation infrastructure projects, over a 70 year time frame, worldwide, shows the regular inaccuracy of construction cost estimates measured as the size of cost overrun. For rail, the average cost overrun is 44.7 percent measured in constant prices. For bridges and the tunnels, the equivalent figure is 33.8 percent, and for roads 20.4 percent.

The Treasury of the United Kingdom[35] are aware of the problem and state:

"There is a demonstrated, systematic, tendency for project appraisers to be overly optimistic. To redress this tendency appraisers should make explicit, empirically based adjustments to the estimates of a project's costs, benefits, and duration ... It is recommended that these adjustments be based on data from past projects or similar projects elsewhere."

The benefits proposed to justify, or pay for the projects are even more inaccurate[36].
"For rail, actual passenger traffic is 51.4 percent lower than estimated traffic on average.
This is equivalent to an average overestimate in rail passenger forecasts of no less than
105.6 percent. The result is large benefit shortfalls for rail. For roads, actual vehicle traffic is on average 9.5 percent higher than forecasted traffic. We see that rail passenger forecasts are biased, whereas this is not the case for road traffic forecasts. The difference between rail and road is statistically significant at a high level. Again the standard deviations are large, indicating that forecasting errors vary widely across projects."

The following observations hold for traffic demand forecasts:
• 84 percent of rail passenger forecasts are wrong by more than ±20 percent.
9 out of 10 rail projects have overestimated traffic.

Governments who approve and fund rail projects have a policy problem when the cost and the benefit are projected so poorly.

"Misrepresentation about costs, benefits …and the related cost overruns and benefit shortfalls - are a problem for the following reasons:
They lead to a Pareto-inefficient allocation of resources, that is, waste.
They lead to non-democratic decisions.
They lead to delays and further cost overruns and benefit shortfalls.
They destabilize policy, planning, implementation, and operations of projects.
The problem is getting bigger, because projects get bigger.

The policy implications are equally clear: Lawmakers, investors, and the public cannot trust information about costs, benefits, and risks of large infrastructure projects produced by promoters and planners of such projects. There is a strong need for reform in policy and planning for large infrastructure projects[37]."

The construction of railway links, roads, bridges and tunnels in NSW appears to have all the characteristics Flyvbjerg describes. Some investors in toll roads have seen their investment destroyed, and are thus may withdraw, or demand much higher risk premiums. The state government has proposed many rail projects, but delivered few, as they cost so much more than budgeted and take so long to complete.

There are many similarities between resource processing mega projects and public sector transport projects. The analysis, concepts and methodology used by Flybjerg are uniquely well suited for this research study and are largely adopted.

2.2 Descriptive and normative

Project evaluation can be viewed from either an "insider" or "outsider" view. Decision theory may similarly be descriptive (what is) or normative (what ought).

The normative or prescriptive outlook is concerned with identifying the best decision to take, assuming the "insiders" are ideal decision makers who are fully informed, fully rational and without bias, and in possession of models that have perfect accuracy. The some highly developed tools are called decision support systems.

The Descriptive or positive outlook looks at what people actually do, and how systems actually work. This considers the inputs and outputs, of what was proposed and what was actually delivered. This "what ought to be - what is distinction was first noted by David Hume.[38]

In "The Methodology of Positive Economics[39]" Milton Friedman argues that economics should be free of normative judgments for it to be respected as objective. He argues that normative judgments frequently involve implicit predictions about the consequences of different policies. He further argues that useful economic theory should be judged primarily by it's:

a.) Simplicity in being able to predict at least as much as an alternate theory, although requiring less information.

b.) Fruitfulness in the precision and scope of its predictions and in its ability to generate additional research lines.

A normative (or regulative) view is:

1.) Based on implicit or explicit moral beliefs or value judgements.
2.) Prescriptive, as in "What should be, or ought to be".
3.) "Relating to an ideal standard or model."
4.) Where desired ethical or political goals or outcomes are important.
5.) Often faith based preconceptions of good and bad.
6.) Often an insider or expert view…to enhance their control.
7.) Assumes an ideal decision maker who is fully informed, able to compute with perfect accuracy, and is fully rational.
8.) What a system should do…design and specification.
9.) Rules based and imply a command structure.

A descriptive (or positive) view is:

1.) Descriptive in that it only describes what happens.
2.) Describes "what is or as it is."
3.) Encompasses all human flaws and imperfect knowledge or competition.
4.) Outcomes are measured.
5.) How the economy works in practice.
6.) Often an outsider or consumer view…to enhance their utility.
7.) Observes actual decision makers, who may be poorly informed, biased, self-interested and emotional.
8.) What a system actually does…performance and cost.
9.) Is potentially more critical of existing decision makers and participants.

Einhorn and Hogarth[40] pose two questions. Why are normative theories so prevalent in academic publication, and why would no other branch of science tolerate rules of "what should be" that are so different to what actually happens.

They note that "much of decision research concerns evaluating and developing ways for improving behaviour", which in the past was more ethics or religion than science. They conclude with a plea to "adopt a broader perspective …investigating topics not usually treated in the decision literature, creativity, problem solving, and concept formation." They conclude with the statement "we believe that psychologists can best contribute to decision research by elucidating the basic psychological process underlying judgement and choice."

This work, based on a descriptive or outsider viewpoint, will be based on information available in the public domain to an outsider.

2.3 Economic models and theories

An economic model is a simplification, based on empirical observations, of past human behaviour. The ultimate goal is to discover more accurate understanding of economic relationships in the real world.[41]

An economical model is similar to a road map, in that it omits details, and emphasises specific points of interest, that enable an endeavour to be completed successfully.[42]

Varian[43] proposes modelling economic activity that has not been studied previously, working out if it has value, taking a different approach than previously, building the model then simplifying till "everything should be as simple as possible…but no simpler."[44]

An economic model may be casual or econometric[45]. Observing that petrol is usually cheaper on Tuesdays is casual, building a table of retail petrol price changes over a year is econometrics. A series of linked casual observations can suggest an economic model, which is then made econometric with the collection of data.

Data is collected at a particular interval, and is like a snapshot. Data collected over time at regular intervals enables a longitudinal study, like a movie. In a movie change and direction may be observed.

The first systematic collection of numerical data was probably in Egypt well before the great pyramids were built 4,580 years ago. The purpose was to enable a ruler, or ruling class to understand what resources were available to them, and what responsibilities they might need to manage in hard times. Data was probably collected for population numbers, residence location, age, gender and the productivity of the region.

This would be used for estimating taxation levels, as taking 1/10 of available wealth might be unlikely to lead to higher collection costs (civil revolt). The data was also valuable for managing military service, without depriving farms of too much labour, and causing famine. As much of the tax was taken in grains, held in temples, civil harmony could be maintained in a famine by the ruling elite.

A Census in China taken in 2 AD showed the population at 13 million[46]. The Roman Census was conducted every 5 years to provide a register of citizens and their property[47]. This enabled taxation and registration of property. The word census comes from the Latin word “censere” meaning “estimate”.

In 1085 William the Conqueror "had deep speech with his counsellors and sent men all over England to each shire to find out what or how much each landholder had in land and livestock, and what it was worth[48]." This enabled the tax administration of the Kingdom, as whatever wealth existed was recorded in the Domesday Book. The Domesday Book and earlier Censuses recorded “What Is”, so as the ruler may take a realistic financial slice. Too high a tax burden engenders revolt by those with nothing to lose. Too light a burden diminishes the ruler’s power, and leaves resources available for a revolt.

Jean Baptiste Colbert[49] commented "The art of taxation consists in so plucking the goose as to obtain the largest amount of feathers with the least possible amount of hissing."

The use of census and estimate to determine what wealth might be extracted (without insurrection) was advanced by William Petty’s 1654 survey of Ireland[50]. Petty based his ideas on efficient methods of land survey, and estimates of the most productive use that may be made of it. Land that had a value per measure could be “paid” in lieu of wages to victorious solders, or sold to defray other English Civil War (1642-1651) expenses.

From the collected data and statistics, he also reached radical conclusions. He recognised that the total economic contribution put in by the ordinary workers represented the majority of the wealth creation of the economy. Yet much of it was outside the money economy, and could only be taxed in kind. Thus he recommended consumption taxes in kind, rather than poll taxes in cash.[51]

Petty's survey goes a step further than its assigned task[52], in that it is not just a catalogue of "what is" but estimates value of "what could be". The data starts to project patterns that were unimaginable before, enabling Petty to take the third step to "what are the best ways of achieving what may be".

A census is the basis of rational civil administration, in that it shows "what is". With reference to earlier census "what is" can be compared to "what was", and in a longitudinal model, projected forward to what might be. Data, viewed as it is in this context, without a bias of "what should be" is useful for scientific understanding, prediction and management.
This work uses a census like approach to collecting data, with a similar outlook to William Petty.

2.3.1 Life expectancy - data into prediction.

In 1662, John Graunt published "Natural and Political Observations Mentioned in a following Index and Made upon the Bills of Mortality". This work was a compilation of weekly bills of mortality, and enabled an estimate of probability of cause of death in a locality at a time. But it did not include age at death.

A fellow member of the Royal Society Edmund Halley added birth and death data from the Prussian town of Breslau[53], and was able to work out the probability of death at any age; producing the first life table.

By a longitudinal study (the collection of the data over many years), of a complete set, or reference class, meant that accurate prediction could be made for life insurance or annuities. The purchaser received the highest potential benefits, and the company a low and manageable risk. Previously insurance typically for cargos carried at sea were set at a premium more by guess work, and what the market would bear than probability.

Life Insurance based on mathematical probability rather than intuition followed in 1743. Robert Wallace and Alexander Webster applied their spreadsheet calculations to the sum a Scottish minister would need to pay during his lifetime to insure an adequate income for his widow and children if he was died early. The total of ministers with a "living" (income from the church) at that time was 930. Over a 20 year period, it was found that 27 a year died, 18 leaving a widow and 5 children without a widow[54]. The challenge was to predict future demand for payment, based on the past reference class so as to set the premiums just sufficient to not burden the participating clergymen. As the capital and interest was only sufficient to meet the expected claims, the expected growth (uptake by clients) also has to be worked out.

The original quill, ink and parchment spreadsheets survive, and are an inspiration to use similar methods. They calculated that by 1765 they would have capital of £ 58,348. Both men lived to see "Scottish Ministers' Widows' Fund" with a free capital of £ 58,347 in that year.

This is probably the first and finest example of careful "reference class forecasting", and was the seed for growth in insurance and pension investment. Scottish Widows[55] has today more than £ 100 billion under management.[56]

Conclusion: Case studies of all cases in a class, over a period of time will yield far more robust data. The larger the data set and the longer time over which they are considered the better the prediction. In the years 1743-65 Wallace and Webster were able to calculate future expenditure with accuracy difficult to imaginable in any public or private undertaking today over a 22 year period. Their error was 0.000017%. In contrast the collapse of HIH Insurance in March 2001 saw a loss of $5.3 billion in assets from a total of $7.8 billion under management, or 68% "error".[57] [58] This was Australia's largest corporate collapse, and involved extraordinary incompetence and criminality. Government involvement via the regulatory system of checks, also failed. The risks that HIH were taking were known to insiders and some outsiders.

"The corporate officers, auditors and regulators of HIH failed to see, remedy or report what should have been obvious. And some of those who were in or close to the management of the

group ignored or, worse, concealed the true state of the group's steadily deteriorating financial position."[59]

In 1743 honest and capable people are able to produce excellent predictions using simple spreadsheet data based analysis. From 1997 to 2001 dishonest and incapable people, without an outsider overview were capable of extensive economic damage. Simple methods of reference class forecasting applied to understanding the success or failure of resource plant or financial firms might achieve a similar outcome, enabling investments to be made with less risk. Government involvement, incompetence, and behaviour that may be found to be illegal are a factor in failures.

2.4 Reference class forecasting and non-linear models

2.4.1 Reference Class Forecasting

Whilst practical actuarial methods very similar to reference class forecasting have been in use in life insurance for more than 267 years, the theory is more recent. Reference Class Forecasting (RCF) evolved from Prospect Theory, which is a descriptive decision theory.

Kahneman and Tversky[60] developed an alternative descriptive model of decision making under risk, which they called prospect theory. They noted *"In particular, people underweight outcomes that are merely probable in comparison with outcomes that are obtained with certainty. This tendency, called the certainty effect, contributes to risk aversion in choices involving sure gains and to risk seeking in choices involving sure losses. In addition, people generally discard components that are shared by all prospects under consideration. This tendency, called the isolation effect, leads to inconsistent preferences when the same choice is presented in different forms. An alternative theory of choice is developed, in which value is assigned to gains and losses rather than to final assets and in which probabilities are replaced by decision weights. The value function is normally concave for gains, commonly convex for losses, and is generally steeper for losses than for gains. Decision weights are generally lower than the corresponding probabilities, except in the range of low probabilities. Overweighting of low probabilities may contribute to the attractiveness of both insurance and gambling."*

The accurate weighting of risk is rarely precise, and ranges between optimistic overconfidence and insufficient consideration of probable outcomes. In these situations there is a tendency to underestimate the costs, completion times, and risks of planned actions, whilst tending to overestimate the benefits of those same actions. This is evident in many of the failed projects in this study.

The reaction to searing financial loss is then an emphasis on certainty, where projects are chosen for the certainty of outcome, rather than a balance of risk to reward. This has been the response to innovation in mineral processing in Australia since 2006.

Dan Lovallo and Daniel Kahneman[61], acknowledging earlier work[62] outlines a 5 step method. *Making a forecast using the outside view requires planners to identify a reference class of analogous past initiatives, determine the distribution of outcomes for those initiatives, and place the projects at hand at the appropriate point along that distribution.*

1.) ***Select a reference class.*** *Identifying the right reference class involved both art and science. You usually have to weigh similarities and differences on many variables and determine which are the most meaningful in judging how your own initiative will play out. If you're a manager at a chemical company that is considering building an olefin plant incorporating a new processing technology, you may instinctively think that your reference class would include olefin plants now in operation. But you may actually get better results by looking at other chemical plants built with new technology. The plants outcome, in other word, may be more influenced by the newness of its technology than what it produces. The key is to choose a class that is broad enough to be statistically meaningful but narrow enough to be truly comparable to the project at hand.*

2.) ***Assess the distribution outcomes.*** *Once the reference class is chosen, you have to documents the outcomes of the prior projects and arrange them as a distribution, showing the extremes, the median and any clusters. Sometimes you won't be able to precisely document the outcomes of every member of the class. But you can still arrive at a rough distribution by calculating the average outcome as well as measuring the variability.*

3.) ***Make an intuitive prediction of your projects position in the distribution.*** *Based on* *your own understanding of the project at hand and how it compares with the projects in the reference class, predict where it would fall along the distribution. Because your intuitive estimate will likely be biased the final two steps are intended to adjust the estimate in order to arrive at a more accurate forecast.*

4.) ***Assess the reliability of your prediction.*** *This step is intended to gauge the reliability of the forecast you made in step 3. The goal is to estimate the correlation between the forecast and actual outcome, expressed as coefficient between o and 1, where 0 indicates no correlation and 1 indicates complete correlation. In the best case, information will be available on how well your past predictions matched the actual outcomes. You can then estimate the correlation based on historical precedent.*

5.) ***Correct the intuitive estimate.*** *Due to bias, the intuitive estimate made in step 3 will likely be optimistic – deviating too far from the average outcome of the reference class. In the final step you adjust the estimate towards the average on your analysis of predictability in step 4.*

Flyvbjerg[63] proposes: *More specifically, reference class forecasting for a particular project requires the following three steps:*

(1) Identification of a relevant reference class of past, similar projects. The class must be broad enough to be statistically meaningful but narrow enough to be truly comparable with the specific project.

(2) Establishing a probability distribution for the selected reference class. This requires access to credible, empirical data for a sufficient number of projects within the reference class to make statistically meaningful conclusions.

(3) Comparing the specific project with the reference class distribution, in order to establish the most likely outcome for the specific project.

Thus reference class forecasting does not try to forecast the specific uncertain events that will affect the particular project, but instead places the project in a statistical distribution of outcomes from the class of reference projects. In statisticians' vernacular, reference class *forecasting consists of regressing forecasters' best guess toward the average of the reference class and expanding their estimate of credible interval toward the corresponding interval for the class.*

Flyvbjerg has evolved reference class forecasting as a tool to understand and manage public transport infrastructure projects in Europe.[64]

Optimism Bias is discussed in a paper by Lovallo & Kaneman[65] which links in with the "very promotional project owner" described by Mc Nulty. They comment "when pessimistic opinions are suppressed, while optimistic ones are rewarded, an organisations ability to think critically is undermined".

This is a comment heard anecdotally in with engineers who had worked on some of the large projects; that beyond a point where the decision has been made, any criticism was a "career limiting move." From this point it is only one step to changing the numbers so that the project continues to look good, which is the situation Flyvbjerg describes in "Rationality and Power"[66]. In this in depth case study the seemingly innocuous choice of locating a bus interchange in the centre of town, causes the individuals who want to push through the decision "defining reality" to ensure their goal is achieved.

This means whatever lie must be told, whatever data must be altered to ensure the project proceeds as planned is an acceptable cost. But how are such unreal costing and over blown benefit passed through the maze of specialists and consultants who handles the technical and reporting on a project? According to Flyvbjerg[67] they realise that unless they are part of this process the job will not progress and they will get no work, or the job might progress and someone else more accommodating will get the work. They all have a vested interest in the project being approved. In a recent paper Flyvbjerg[68] calls this practice "the survival of the un-fittest", those who told the greatest lies got the most reward.

The work of Merrow, Kahneman, Lovallo and Flyvbjerg may be synthesised onto a five step model for understanding large volumes of data describing resource projects in Chapter 4.

2.4.2 Improper linear models

Improper linear models are described by Robyn Dawes[69] as *"Improper linear models are those in which the weights of the predictor variables are obtained by some non-optimal method; for example they may be obtained on the basis of intuition, derived from simulating a clinical judge's predictions, or set to be equal."*

The original work in this area was by Paul Meehl[70] in his book Clinical vs. Statistical Prediction: A Theoretical Analysis and a Review of the Evidence" In this he argued that numerical methods of data combination outperformed expert clinical judgements.

A year earlier (1953) Virginia Apgar[71] had published her paper on "a new method of evaluation of the newborn infant." Here she proposed the now famous and universally adopted APGAR test. It has five parameters and three levels of degree from greatest risk on the left to least risk on the right. This is shown below in Table 8.

Table 8 APGAR Test

Post birth criteria	*Score of 0 (greatest risk)*	*Score of 1*	*Score of 2 (least risk)*
Skin colour / complexion	Blue of pale all over	Acrocyanosis, blue at extremities, body pink	No cyanosis, body and extremities pink
Pulse rate	Absent	< 100	> 100
Reflex irritability	No response to stimulation	Grimace / feble cry when stimulated	Cry or pull away when stimulated
Muscle tone	None	Some flexion	Flexed arms and legs that resist extension
Breathing	Absent	Weak, irregular, gasping	Strong lusty cry

Here the addition of judgements on the five factors will give a score between 0 and 10. 7 and above is a baby that is at low risk. Below 3 is a baby at high risk of neurological damage without urgent medical attention.

Similar predictive factors and measures are used in the work of Halbe and McNulty[72], which used 5 classes (series) of project types, from lowest risk to highest risk. In this model the most experienced (and least risk) type projects were series 1, and the least experienced (and most risky) projects were series 5. The model was developed based on proprietary data for 41 case studies of resource processing plants constructed after 1965 and before the mid 1990's.

Daniel Kahneman[73] devotes a chapter to Intuition vs. Formulas, and notes that he instituted such a five step grading system over five factors in 1966 for evaluating new recruits into the Israeli Army, that is still in use. The five models shown in Table 12 in Chapter 3 and the 4 distributional tables shown on sheets 4 to 7 in the appendix follow this form and principal.

2.5 Core Competence

The modern academic concept of "core competence" is first developed in 1991 by Prahalad and Hamel.[74] Two quotes illustrate the ideas: *"Such a competence will be difficult to replicate as it rests on deeply held cultural norms and draws on employees' tacit knowledge of tasks and processes."* and *"a core competence is a combination of complementary skills and knowledge bases embedded in a group or team that results in the ability to execute one or more critical processes to a world class standard"*

The authors contend that Core Competence

(1) Provides customer benefits,

(2) It is hard for competitors to imitate,

(3) Can be leveraged widely to many products and markets.

The last factor (3) was not widely evident in Australian resource projects. Firms with good commercial results across a broad spectrum of process skills still had some notable failures, particularly with new process projects. The focus on specific skills, and evolved skills development in a narrow area of firm competence were more evident.

The concept of focused skills has ancient and enlightenment progenitors. Xenophon[75] writes of the division of labour possible in larger city states, like Athens, enabled a quality and quantity of specialised and luxury goods to be produced.

"Now it is impossible that a single man working at a dozen crafts can do them all well; but in the great cities, owing to the wide demand for each particular thing, a single craft will suffice for a means of livelihood, and often enough even a single department of that; there are shoe-makers who will only make sandals for men and others only for women. Or one artisan will get his living merely by stitching shoes, another by cutting them out, a third by shaping the upper leathers, and a fourth will do nothing but fit the parts together. Necessarily the man who spends all his time and trouble on the smallest task will do that task the best…--it is obvious, I think, that in this way a far higher standard of excellence will be attained in every branch of the work."[76]

Xenophon is describing a focused competence and that a team of collaborating specialists, repeating and refining their skills resulted in a more productive and value added product. Today firms that specialised in one type of transformational plant; probably in repeat collaboration with specialised suppliers, were able to use each new project to incrementally increase the performance or efficiency of the plant by 3-5%; and were successful in each new project.

Aristotle[77] is reputed to have taught *"We are what we repeatedly do. Excellence, therefore, is not an act, but a habit."* Implicit both of these observations from antiquity is that division of labour, with skill specialisation and the close association of upstream and downstream transforming skills produces much enhanced productivity, and hence wealth creation.

It is to be argued that the advantages gained from division of labour, and hence development of specialised skills in a firm is different to core competence.

Adam Smith[78] makes much the same point with the Pin Factory example, where the core competence at each operation enables a productivity increase of 2,400%.
"One man draws out the wire, another straights it, a third cuts it, a fourth points it, a fifth grinds it at the top for receiving the head; to make the head requires two or three distinct operations; to put it on, is a particular business, to whiten the pins is another; it is even a trade by itself to put them in the paper; and the important business of making a pin is, in this manner, divided into about eighteen distinct operations, which, in some manufactories, are all performed by distinct hands...Each person, therefore... might be considered as making four thousand eight hundred pins in a day. But if they had all wrought separately and independently, and without any of them having been educated to this peculiar business, they certainly could not each of them have made twenty...pins a day."

Smith continues: *It is the great multiplication of the productions of all the different arts, in consequence of the division of labour, which occasions, in a well-governed society, that universal opulence which extends itself to the lowest ranks of the people.*

Competence from repeated practice and incremental improvement leads to both productivity and diminution of risk. The US investor Warren Buffet[79] states "Risk comes from not knowing what you are doing." This might be extended to "Risk come from not knowing what the other parties are doing". Where the competent firm knows what they are doing, and what their supply partners are doing, they can provide the consumer what they want with minimal transaction costs and risk of failure.

The opposite possibility is cognitive ignorance of risks which would be obvious to experienced practitioners; being core incompetence. This incompetence is well noted in literature. *"Ignorance more frequently begets confidence than doe's knowledge"*[80] and *"One of the painful things about our time is that those who feel certainty are stupid, and those with any imagination and understanding are filled with doubt and indecision."*[81]

Dunning and Kruger[82] write that, for a given skill, incompetent people will:

1.) Tend to overestimate their level of skill;
2.) Fail to recognise genuine skill in others;
3.) Fail to recognise the extremity of their inadequacy;
4.) Recognise and acknowledge their own previous lack of skill, if they can be trained to substantially improve.

These studies[83] are focused on individuals, whereas we are interested in firms of many people. It is difficult to know whether a firm overestimates its competence and or underestimates the risks and difficulties. Failure was fast and devastating where competence was significantly over estimated and risks significantly underestimated; especially when this became evident to the shareholders and banks supporting the project.

Dunning and Kruger's work is a good model to modify from individuals to firms, with some changes. Companies with specialised core competencies, executing a project that they knew from habit, had the most successful projects; quick to reach nameplate capacity in this study; none failed.

Competency hereafter referred to as Firm competence in Australian resource processing takes the form of:

1.) Technical superiority embedded in the experienced production team.
2.) Practice in incremental innovation, where each successful project was incrementally

improved.

3.) Implementation know-how in production reduced risks and costs.

4.) Reliable processing and thus delivery to supply chain customers.

5.) Close relationships with customers, suppliers and stakeholders.

6.) New project or development pipeline, financed at preferred rates.

7.) A culture encouraging employee improvement and dedication.

8.) The outsourcing of activities that are not the company's core competency.

Where core competency yields a growing long term advantage to the company, it can be said to be a sustainable competitive advantage.[84]

There are three tests proposed for Core Competencies by Prahalad and Hamel:

1.) Potential access to a wide variety of resources and markets - the core competency must be capable of evolving low cost products and services in new markets.

2.) A core competency must make a significant contribution to the perceived benefits of the product.

3.) Core Competencies should be difficult for competitors to imitate. In many industries, such competencies are likely to be unique.

The two largest resource companies in the world, BHP Billiton and Rio Tinto, have unique core competences in both iron ore and coal supply. However that competence in moderately transformed resources, essentially managing governments to access resources and retain this ownership, logistic skills in moving large volumes of moderate value tonnages, maximising price and market share, and financing their business under favourable terms; do not translate to any unique competency in innovative or high technology projects. One of the firms has experienced significant difficulties with new and innovative mega projects, and admits so quite openly[85].

In a second paper[86] Prahalad and Hamel point out that core competency in a company "unlike physical assets, competencies do not deteriorate as they are applied and shared. They Grow!" Thus the people most practiced and perfect at a task build a competitive advantage, by utilising their skills frequently. ConocoPhillips[87]Darwin LNG plant is an example of a plant built by a firm who specialised in improving each new plant. They found that plant with risk minimised by core competence is much easier to finance in advance. It thus makes more sense to engage firms that are most practiced and competent. A competence rarely used, is rarely a competence, or a competence soon lost.

These three core competency tests apply equally well to the Firm Competence model to be described in Chapter 3.

2.6 New Process Innovation

The OECD published Oslo Manual [88] defines "*Innovation is the implementation of a new or significantly improved product (good or service), process, new marketing method or a new organisational method in business practices, workplace organisation or external relations.*"

Joseph Schumpeter[89] argued that economic development is driven by innovation through a dynamic process in which new technologies replace the old, a process he labelled "creative destruction". In Schumpeter's view, "radical" innovations create major disruptive changes, whereas "incremental" innovations continuously advance the process of change.

Successful mineral process innovation can be radical in initial concept and embodiment and then incrementally improved and expanded.

Schumpeter identified innovation as the critical dimension of economic change. He argued that technological innovation often creates temporary monopolies, allowing abnormal profits that would soon be competed away by rivals and imitators. He said that these temporary monopolies were necessary to provide the incentive necessary for firms to develop new products and processes.[90]

The Frascati Manual[91] defines:
Technological innovation activities are all of the scientific, technological, organisational, financial and commercial steps, including investments in new knowledge, which actually, or are intended to, lead to the implementation of technologically new or improved products and

processes.

Baumol[92] defines innovation as the *'recognition of opportunities for profitable change and the pursuit of those opportunities all the way through to their adoption in practice; in particular, as the activity of recognising economically viable inventions and doing whatever is necessary to bring them to market or to ensure their effective end use by some other means.'*

The "activity of recognising economically viable inventions" is a sharply focused idea, and an important consideration in this work, which will attempt to show that many of the "innovations" that failed; should have been recognised as failing this concept. The economic viability of the worked invention was below a threshold for successful implementation, and the project delays, cost over runs, and product underperformance brought forward the commercial failure to an earlier point.

The Australian Bureau of Statistics[93] definition: *business innovation as the process of introducing new or significantly improved goods or services and/or implementing new or significantly improved processes.*

Whilst Baumol's view is appreciated in the 2007 Productivity Commission Report[94] they favour a broader approach, including:

• *Governments, communities and their agencies are included, as well as businesses.*

• *Gradual catch-up to technological frontiers is included.*

• *It also incorporates preparedness — an enhanced capacity for dealing with future uncertainties.* By this definition, almost every enterprise is involved in multiple degrees of incremental innovation. Incremental innovation is encouraged, managed and often measured by almost all successful firms in this survey. But that is not the definition that is being applied to "new process" innovation.

The Productivity Commission Report also states:

There are widespread and important economic, social and environmental benefits generated by Australia's $6 billion public funding support of science and innovation.

– On the basis of multiple strands of evidence, the benefits of public spending are likely to exceed the costs.

– But, given a host of measurement and methodological issues, it is not possible to provide

anything other than broad estimates of the overall return to government contributions.
This might be seen as a rather equivocal measure for the benefit derived from expenditure of 2.78% of the Commonwealth Budget (2006-07).

Innovation and Science in Australia enjoy broadly bi partisan support at the Federal level, but with some nuances of emphasis. A more recent (2009) Innovation paper[95] leads with the credo from the Innovation minister:
This is a ten-year reform agenda to make Australia more productive and more competitive. Increasing our capacity to create new knowledge and find new ways of doing business is the key to building a modern economy based on advanced skills and technologies. It is the key to success in this, the global century.
Innovation is not an abstraction. Nor is it an end itself. It is how we make a better Australia, and contribute to making a better world — a prosperous, fair and decent world, in which everyone has the chance of a fulfilling life.

Innovation is here broadened to encompass building new industries, protecting the environment and advancing social justice. On building new industries:
Innovation has the power to transform existing industries — enabling them to operate more efficiently, to deliver improved products and services, and to win new markets. It can also give rise to entirely new industries, from carbon capture and storage to online retailing. A strong innovation system also gives us the capacity to match and adapt to the innovations of others. This is especially important given the pace of technological and organisational change in today's world.
The points of interest are that innovation is here an enabling process for government within a wider range of political objectives. This is a statement of "what should be."

Two themes developed in 2009 Innovation paper are publicly funded innovation for contribution to and consumption by public sector services implementing government policy, and a strong belief in the value of collaborative research.

In the 5 years from 2005 to 2010 no new innovative process plants were commenced. Four of the largest new process plants were closed down as failures. The Government rhetoric and models of action in innovation had a strong negative correlation with innovative process plant failure.

Voices of dissent are noted in 2007 Innovation report. Kealey[96] argues that:

- *Private companies would fund and undertake much of the valuable R&D currently supported by governments if public funding were not forthcoming. This displacement is sometimes referred to as 'crowding out' of private funding by public funding. Indeed, he makes the observation that frontier basic science is already done by private companies and openly published by them, undermining the conjecture that private firms have no incentives to participate in an open scientific system. Equally public sector research of commercial value is intensively protected by intellectual property units, seeking cost recovery.*

- *Much of publicly funded (basic) science is fun, but not valuable, or it may be pushed into commercial white elephants selected by bureaucrats, wasting valuable capabilities. Moreover, because public science has to be funded through taxes it has damaging incentive effects throughout the economy, so that the waste extends outside the activities of scientists and the organisations that employ them. As a consequence, he claims that public funding does not just displace private funding, but actually diminishes aggregate R&D spending, with adverse effects on economic growth and the innovativeness of a country.*

- *political forces behind the formation of the public science system in the United Kingdom and the United States (pp. 139ff), suggesting that while cloaked in the public interest, the leading advocates and bureaucrats were often motivated by personal and private interests that frustrated more sensible allocations of resources.*

- *Basic science does NOT necessarily lead to technological developments and economic growth — attributed to Francis Bacon originally and given fresh vigour by Vannevar Bush in post-world war two United States. He argues that this 'linear view' invariably places the cart before the horse. In many cases technology begets new technologies directly, and technology often raises interesting problems for basic science rather than the other way round. Project Hindsight by the US Department of Defence found that of the 700 research events that led to the development of weapons systems, only two had* *arisen from basic science (Kealey p. 163). Project TRACES (published the National Science Foundation) found the missing link to basic research, but ironically to research that was undertaken 50 years before, when it was mainly privately funded in the United States.*

The 2007 Productivity Commission concluded: *The key question about all of these potentially major deficits of publicly funded science is not whether there are vivid examples available — Kealey clearly provides many of them — but whether their presence is sufficiently systemic to matter when there are positive influences that go the other way. This is why consideration of the validity and interpretation of Kealey's more general empirical results is warranted.*

The clear outcome from the resource process plant case study is that radical innovation was strongly linked with negative outcome for the investors; and that this was less so in past eras when innovation was largely private. The examples mentioned in Section 1.3 from a century ago are quite the opposite.

A second dissenting voice on innovation was Davidson[97] questions wether: *the standard economic analysis supporting public expenditure on research is fundamentally and methodologically flawed?*

He argues: *Each of the stepping-stones in the case for publicly funded science is flawed:*

R&D is not a public good.

The cost of public funds is not lower than the cost of private funds.

The returns to public science are low.

Governments have a poor track record of picking 'winners'.

Publicly funded R&D has a negative impact on economic growth.

Economists are unable to explain how spill-overs occur, or how valuable these spill-overs are.

The notion that throwing an infinite amount of money at public research will somehow, at some time, automatically lead to some benefit is a myth. The government spends a substantial amount on public science and innovation. It is not clear that any substantial benefit is derived from that expenditure.

The returns from the largest public science innovation effort (Case 7) were strongly negative, and that Governments demonstrably had a poor investment track record (Cases 7 and 8) of picking 'winners'. The two dissenting voices question that innovation is always good or valuable. Davidson goes on to observe that many of the arguments proposed in reports prepared by consultants to support further public investment are self-serving.

Cutler[11] suggests that Innovations can be classified usefully along a variety of dimensions:

Process vs product: • Process innovations reduce the costs of producing and delivering a given good or service (a product), while product innovations improve the qualities of existing products or provide new products to be offered to consumers.

Radical vs incremental: • Radical innovations lead to fundamental changes in processes or products, while incremental innovations involve adaptations of a core innovation in particular applications.

technological vs organisational:• Technological innovations are generally embodied in equipment used by labour, while organisational innovations involve the organisation and reorganisation of groups of people into effective teams in the production and delivery of goods and services.

science-led vs customer-driven: • Science-led innovations are an outcome of scientific research both in the public and private sectors, while customer-driven innovation is built upon careful market research and user interaction.

Cutlers four points should be for resource processing projects.
The only project that sought to produce both a new process; and also produce an enhanced product produced neither. (Case7)
Radical innovation and incremental innovation are joined and follow one another to produce a desirable outcome.
All the projects were technological, in that they sought a new transformation step. However the organisational innovations introduced by BHP-Billiton and Rio Tinto into managing their logistics chains, finance management and marketing are largely unknown successes.
The only successful project (Case 40) was one that applied customer drive to the existing science lead.

The productivity Commission suggest: *From the perspective of this study, these improvements may be specific to the entity, to the industry, country or world, and could be incremental or novel. Innovation can be distinguished from knowledge generation per se, since to comprise innovation, any knowledge must be productively incorporated into an entity's activities and outcomes.*

Both concepts are worth adopting; the first as a means of grading the novelty or radical nature of the innovation. The second as a measure of innovation success or failure; where the innovation was unproductive it was a failure.

The measurement of innovation inputs and outcomes is not precisely defined. The OECD Oslo Manual (2005) Guidelines for collecting and interpreting innovation data"[61] spreads it discussion over 166 pages, but reaches the conclusion:

Both the measurement and analysis of the role of demand in innovation are problematic. It is very difficult to isolate demand effects from supply, and little is known about how to measure demand effects in surveys.

Demand for the productivity increase from innovation seems to be one of the most important success factors; though measuring this demand is not easy.

Rogers[98] recommends measuring inputs and outputs of the innovative activity. Looking at the capital invested into a project with many elements, and then examining the output as shown in the company annual reports; is a consistent measure applicable to all projects. This approach is taken.

Another measure proposed by Griliches[99] was using patents as an input indicator, but concluded *"inventions that are patented differ greatly in their quality"* and reflected only a firms willingness to spend the money to take a patent. This might be for political or strategic reasons, more than innovation. Basberg[100]asks:

- *To what extent do patents reflect the commercial use of technology?*
- *How does the usage of the patent system vary across firms and industries?*

The existence of a patent does not signal commercial activity, nor does lack of a patent

indicate that the firm is not about to spend billions of dollars on a process plant. Firms may choose to keep as trade secrets details of a novel plant, rather than reveal them in an open patent. An examination of patents held by a large multi-national firm showed well considered technology patents which they had not implemented, and huge technology plants that were not patented…and then failed. This is counter intuitive, and suggests that there might be more subtle motives in both patenting and innovative plant building.
Thus patent activity is of little obvious use in defining innovation in resource process plants, much the same result that Basberg finds across a broader spectrum.

2.6.1 Success and failure of innovation

Van der Panne, van Bers, and Kleinknecht[101] review 43 published papers on success and failure of Innovation, and found wide agreement existed on the positive impact of:

• *A firm's culture that is susceptible to innovation and recognizes the collective nature of innovation efforts;*
• *A firm's experience with innovation projects (learning-by-doing; learning-by-failing);*
• *The multidisciplinary character of the R&D team; in particular equilibrium between technological and marketing skills, and the attendance of a product champion;*
• *An articulated innovation strategy and a management style suited to that;*
• *Compatibility of the project with the firm's core competences;*
• *Product quality and price relative to those of substitutes;*
• *Adequate timing of market introduction.*

Some of these themes will be recognised in the models developed in Chapter 3.

Carr[102] shows that across a range of change projects the failure rate is between 70-80%, with those projects where the outcome is easily measured failing more often than those where there was some subjectivity. This finding is much more optimistic than Australian resource processing case outcomes, where failure rate was 99% of investment.

The linkage between a firms innovation experience is critical, whether they learned by failing, trying again and then succeeding or by doing and succeeding.[103] Bessant rhetorically questions: *if technological innovation is essentially a learning process, what capabilities need to be acquired in order to be able to deploy it as a strategic resource? And finally, how* *might such capabilities be developed within the firm?* The firms that found a pathway to innovation knew both routes.

Wind & Mahan[104] found that experience in similar projects allowed for substantial reduction in time and investment in following innovations. Larger firms who cut and ran earlier built no useful experience other than innovation avoidance. A firm's track record and focus is used to assess risk in innovation implementation in the models proposed in Chapter 3.

2.7 Government Involvement and Value Adding

There must be government involvement in every resource project as the States regulate and tax their land and coastal fringes; and the Federal Government owns offshore resources. They exercise this ownership for the benefit of the people; as they interpret this interest. They seek the optimum economic, political and social interest benefits from the lease terms under which they allows access to the non- renewable resources.

In Australia ownership of all mineral resources is vested in the State. As such, the Australian government is owner of the offshore petroleum resources seaward of the 3nm limit. It develops these resources as an agent of the Australian people, therefore assuming a stewardship role.[105]

Royalties average 4.7% for low and 7.8% for high resource value, and contribute an average of 9% of States revenues.[106] The details of the value of the resources on which royalties are collected are shown in Table 9.

Table 9 Resource value on which royalties are collected

Millions of $ Australian	NSW	VIC	QLD	WA	SA	TAS	NT	Total
High royalty minerals	$16,870	$1	$30,061	$16,660	$972	$0	$293	$64,857
Low royalty minerals	$4,818	$2,576	$7,734	$61,565	$5,060	$1,374	$1,898	$85,025
								$149,882

Table 10 shows the value of the royalty income flowing to the states. Western Australia is the largest recipient, and has involved itself more actively in value adding requirements.

Table 10 Value of royalties collected by states

Millions of $ Australian	NSW	VIC	QLD	WA	SA	TAS	NT	Total
High royalty minerals	$1,316	$0	$2,345	$1,299	$76	$0	$23	$5,059
Low royalty minerals	$226	$121	$363	$2,894	$238	$65	$89	$3,996
State revenue estimate	$1,542	$121	$2,708	$4,193	$314	$65	$112	$9,055

Value adding to resource processing within a state is believed by State Governments to enables further streams of taxable economic value, more widely spread wealth creation and higher wage and skill job, and professional services. Thus there are direct and indirect revenue implication, economic multiplier effects, and vested interest benefits from value adding.

As an example in the 2012-2013 financial year the output and approximate value of Olympic Dam (Case 48) was as shown in Table 11 [107]

Table 11 Olympic Dam production and values

Commodity	Mass	Value
Copper (t)	166,200	$1,227,719,400
Uranium (t)	4,066	$310,654,598
Gold (oz)	113,246	$141,557,500
Silver (oz)	880,000	$17,600,000
		$1,697,531,498

It was reported that BHP-B paid $ 90 million in royalties (or about 5.3%) but spent $ 664 million on wages for 4,000 staff and local supply contracts[108] the non-royalty cash flow may be many times more important to the state economy.

States also set the environmental conditions that must apply as part of the resource access agreement. These have become more comprehensive over time. Long established process plants with environmental regulations from decades past have a "right to pollute" advantage over a new project.

Government involvement in value adding has been long standing and is bi-partisan.
The emotion appeal of Government mandated value adding is captured in this 2001 example, but the practice of linking a licence to extract bauxite to secondary processing into alumina began in Western Australia in the 1960's.

Australia is the world's largest miner of bauxite, accounting for about 40 per cent of production. It is also the world's largest producer of alumina with about 30 per cent of production. However, it accounts for only about seven per cent of the world's aluminium production. About 70 per cent of Australia's bauxite is processed into alumina in Australia, but only 20 per cent of Australia's alumina is processed domestically into aluminium.
The total value of export earnings by the aluminium industry in 1998-99 was $6.3 billion—$2.9 billion from alumina and $2.8 billion from aluminium metal. Only $350 million was earned from the export of semi-fabricated products. There is a substantial amount of value-adding that already occurs in the aluminium industry—about $3.1 billion in 1997-98—but there is considerable potential for that to be increased.[109]

A "secondary processing obligation" is simply a "if you mine you must refine … in the way we tell you". "*The State's broad objectives are to:*

- *Facilitate the efficient and effective development of the State's natural resources;*
- *Manage the development by ensuring it is consistent with State policies on issues such as land use, conservation, competition, infrastructure sharing, secondary processing development and maximising local content; and*
- *Ensure that development provides economic and social benefits for the Western Australian community."*[110]

The obligation to transform $20-30 a tonne bauxite into $330 per tonne alumina has worked relatively well over the last 50 years. The process was mature; and well understood, the firms involved were large and reputable, and the economic outcome was favourable both for firms and the state.

The success of the bauxite to alumina obligations let to further planning for a more value adding from collaborative efforts directed by research agencies, funded by industry and for the advantage of government.[111]

The Light Metals Action Agenda produced a dynamic vision for 2020 that would see:

• *The aluminium industry to expand its combined domestic and export market by more than 30 per cent;*

• *Magnesium metal output tonnage of 800 000tpa, with exports capturing 50 per cent of the growth in world demand over the next 20 years;*

• *Titanium to develop a metal output tonnage of 25 000tpa, establishing a 25 per cent share of the global market, and;*

• *The downstream sector to continue in the establishment of a vibrant and sustainable export orientated industry using all three metals in new innovative products.*

The progression of the Vision will be through the collaborative efforts of industry, research agencies and Governments.

The $370 million[112] invested by the Federal, and Queensland Governments in the Stanwell Magnesium project was linked to this vision. CSIRO invested, and lost $75 million.[113] The vision has not been realised. The Aluminium industry is closing smelters, of the seven operating in 2001, Kurri Kurri, producing 160,000 tonnes a year closed in October 2012, and Point Henry, producing 190,000 tonnes per year will be closed in 2014. The Gove Alumina refinery is to be closed in July 2014. Australian production of magnesium and titanium is, as yet, non-existent. China now produces 640,000 tonnes of the total world production of 750,000 tonnes of magnesium.

A counterpoint, from the above report was provided by Minerals Council of Australia.[114]

The idea of adding more value to our minerals and agricultural products by further processing is often advanced. Value adding is seen as a way of increasing employment through jobs in processing; improving our net export performance - through exporting "higher value" products; reducing Australia's exposure to price fluctuations for raw materials; and improving regional or national income …"Value adding" is a subtle concept. Decisions to encourage and undertake further value adding must be taken in a manner that ensures they do not subtract value from the total economy by diverting resources from where they could be most efficiently and effectively used."

A second counterpoint, from the Australian Productivity Commission, stated:[115]

"The existence of a divergence of interests between public and private objectives is not

clearly established, and further, government agencies do not appear to have superior technical knowledge to that of the private sector, it is not clear that the benefits from government intervention outweigh the costs."

This quote points to a significant information asymmetry, and the possibility for strategic misrepresentation. The politicians and administrators making decisions; are at best, dealing with firms that have much better information and understanding of the processes and profits. At worst they may be seeking to implement political outcomes that are not economically rational for the firms.

Gravelle and Rees argue that market failure is often a problem of property rights.
Markets are institutions which organize the exchange of control of commodities, where the nature of the control is defined by the property rights attached to the commodities.[116] The rights to access and transform resource property owned by the state by firms can be less than optimal in information asymmetry and commercial understanding of market function. Both state and miners might utilise strategic misrepresentation to achieve an outcome favourable to them.

State Government rarely have mining engineers or successful commercial entrepreneurs amongst elected members, but often have a significant proportion of political staffers to previous ministers, lawyers and trade union officials. The difference in this example being both working knowledge and philosophical outlook; the entrepreneur or engineer has to work with "what is"; the lawyer or trade union official is much more focused on "what should be".
This leads to the next topic.

2.8 Asymmetric Information and Strategic Misrepresentation

The 2001 Prize in Economic Sciences in memory of Alfred Nobel was awarded to three academics for "for their analyses of markets with asymmetric information".[117]
"Many markets are characterized by asymmetric information: actors on one side of the market have much better information than those on the other. Borrowers know more than lenders about their repayment prospects, managers and boards know more than shareholders about the firm's profitability."
Akerlof[118]sought to establish *a structure … for determining economic costs of dishonesty.*

There are many markets in which buyers use some market statistic to judge the quality of prospective purchases. In this case there is incentive for sellers to market poor quality merchandise, since the returns for good quality accrue mainly to the entire group whose statistic is affected rather than the individual seller. As a result there tends to be a reduction in the average quality of goods and the size of the market. A market may even cease to exist where there is widespread uncertainty as to quality.

Akerlof continues with a model of new and used cars, which may be good or bad. The buyer does not know when he buys a new car, but after a period of time his knowledge of the cars quality is well informed. If it is good there is a desire to retain the vehicle, but if bad (a lemon) to on sell it to someone with less knowledge. Thus the used car market is perceived to have a higher proportion of bad cars and attracts lower prices. Even good used cars are driven down in value by the bad. *The "bad" cars tend to drive out the good (in much the same way that bad money drives out good).* From these examples he finds that the cost of dishonesty is born unequally by honest traders, and that this is a significant restriction to trade and development.

The Akerlof paper draws conclusions about the cost of dishonesty in markets in general:
The cost of dishonesty, therefore, lies not only in the amount by which the purchaser is cheated; the cost also must include the loss incurred from driving legitimate business out of existence.

If these concepts were applied to innovative resource process plant, the question could be asked as to the quality of the failed projects, and whether the many failures destroyed the market for local innovations in process plant.

Spence[119] proposed and developed the idea of signalling, using education as a positive example. A job applicant signals that they are skilled at learning, or at least will make the investment needed to graduate and to comply with authority. They thus signal that they are better prospects for a structured employment environment.

This type of positive example is recognised in resources plant projects by those firms with a track record of successful implementation. The signal is their past performance, which is a valued but somewhat subtle signal to the best informed. Those firms most active in signalling future suitability for investment, without this past performance, send a strong negative signal. Their signal is anything but subtle, and is usually directed at the least informed.

Stiglitz[120] established the theory of screening. *One of the most important kinds of information concerns the qualities of a factor or a commodity. We know that there are important differences among individuals, among bonds, among equities, among brands of automobiles. The identification of these qualities we call screening, and devices that sort our commodities (individuals) according to their qualities we call screening devices.*

Screening is the counterpoint to signalling, in that the buyer is seeking by a structured questioning procedure to differentiate between investments. As investors in a new process plant are usually under informed as to the risks and probabilities, a questioning and filtering process that used public domain information would encourage informed investment.

One the main factors Flyvbjerg draws from his work with reference class forecasting is “strategic misrepresentation” described in 1990 by Kain[121] and defined in 1991 by Jones and Euske.[122]

“Strategic misrepresentation is the planned, systematic distortion or misstatement of fact – lying – in response to incentives in the budget process.” They identify that this is most profitable in relation to government, a point that Merrow touches upon, through only in reference to cost over runs in military procurement of new weapons systems.

Flyvbjerg[123] expands on “strategic misrepresentation”, particularly in public transport projects, and finds that “costs are underestimated in 9 out of 10 projects”[124]

The inaccuracies in 111 projects, over an 80 year period, have progressively increased, though not as much as in the earlier synthetic fuel example. He points out that project promoters gain a financial advantage from under estimation, in that they win the project. Once the project is underway the cost and risk are often passed to the taxpayer. Governments seeking to win support for popular projects may not be rigorous in the costing as the benefit is immediate, and the actual cost many years, perhaps even a different government into the future.[125]

In addition to "strategic misrepresentation" and "optimism bias," there is a systematic tendency for people and organisations to overestimate their level of competence, and the likely outcome for an action. Long delay between action and the account; or lack of specific responsibility seem to be significant in all.[126] Flyvbjerg[127] suggests that the lack of accountability for strategic misrepresentation and the rewards that flow from the practice, lead to the selection of the unfit projects; and there is evidence of this in the worst examples in this study.

This is further explored in Chapter 3, with a model for information asymmetry and strategic misrepresentation.

The veteran journalist Trevor Sykes, has written; as "Pierpont"; for the Financial Review for almost 40 years, and has authored a series of detailed and incisive books on Australian Economic History.[128] His description of the problems with an innovative green-fields[129] plant has been quoted many times.

Pierpont routinely suggested that mining promoters were not always honest, and that the character, integrity and practical knowledge of the management team were the major considerations in success or failure. This seems probable with some projects, where the information asymmetry between the proponents and the investors was abused.

Case 7 a new technology process to produce light metal was the most spectacular failures in innovative plant. Pierpont's comment expresses disbelief in management actions. "*In all the statements about the Stanwell project, Pierpont has yet to see one which defines exactly why the project came up $200 million short. Didn't they know how much steel or concrete they needed? And if they didn't, what right did they have to put a prospectus before the public?* Worse, Pierpont questioned how one senior manager, could have collected $320,000 in consultancy fees for commercialisation of the project when it has never been commercial."[130]

In 1995-96 BHP had Australia's longest track record in conventional steel production; and their dominance of the market indicates that there were as competent at this endeavour as was possible in the local market. BHP was possibly better informed as to the economics of iron and steel production within the Australian market than any other firm. It was not a business they wanted to be in. The lack of growth or profits and decline in value of the steel making businesses since they divested indicates that the decision was well founded.

BHP did not have a demonstrated firm competence in converting research work to practical production. At the time they were investing in the HBI project, they were duplicating at large scale a process they believed would work. However the reason for this project, even as early as 1997[131] was political.

On 31 March 1994, the Western Australian State Government agreed to delete all secondary processing obligations in respect of these agreements in exchange for a new secondary processing obligation and limits on production from three mining areas: Mining Area C, Yandi and Jimblebar.

The new secondary processing obligation requires BHP Minerals Pty Ltd, alone or in association with others, to spend $400 million (in 1993 dollars) on the further processing of iron ore or on an alternative investment approved by the Minister for Resources Development. Further processing is defined to include the production of iron and steel, direct reduced iron, hot briquetted iron, iron carbide sinter or pellets. No time limit is given for this investment.

The Agreement provides for the consideration of alternative investments in lieu of further processing if further processing proves not to be technically or economically feasible. Until this obligation has been fully discharged, production from Mining Area C, Yandi and Jimblebar will be subject to tonnage limitations.

The Western Australian State Government has agreed that the obligation to invest a further $400 million (in 1993 dollars) will be treated as satisfied when the construction of the first train of the HBI Plant at Port Hedland has been completed and commissioning has commenced (i.e. when the first hot briquette of iron from that train is produced).

There is no mention of profit or market demand. This is a process to gain unrestricted access to an exceptionally profitable and desirable iron ore mining areas. BHP made the investment, built the plant, and produced HBI. They met the obligation and gained the access. There was no contractual obligation to make the process work, and after some reasonable time, and genuine efforts it did not.

The consideration that the project might not work, technically or economically; seems to have occurred relatively early on. The project finance structuring was exceptionally competent at recording and utilising the losses that eventually occurred. The quality of this aspect of project planning was only publicly realised in March 2010, when BHP comprehensively beat the Australian Tax Office (ATO) in the conclusion of a long running case.[132] The ATO had sought payment of $2.2 billion in tax.

The long-running case relates to two bad debts that were written off by BHP Finance after loans were made to two subsidiaries. One loan was for the ill-fated construction of a plant in Western Australia to produce briquettes from iron ore fines (particles) in a bid to turn them into a valuable product -- and to satisfy an obligation imposed by the WA government that BHP had to be involved in secondary processing of iron ore. The project suffered several setbacks from its inception in 1995 until 2000, when the financing company decided to write off $1.8bn of the $2.2bn owed. This development also ran into problems and BHP Finance wrote off $310.9 million in the 2000 financial year.

One of the issues in both the original case and the appeal was whether BHP Finance was actually in the business of lending money. The court heard the company had no employees and paid management fees to BHP. The tax office argued it was merely an "appendage" to BHP, and not in the business of lending money, but the court rejected this argument.

BHP met its state obligation, and gained access to iron ore resources, then passed the majority of the losses it incurred in implementing a value adding project that failed to the Commonwealth, and effectively the Australian taxpayer.

2.8.1 Moral Hazard in government involvement in value adding

Moral hazard arises where a person or institution can avoid much of the consequences and responsibilities of their actions. It applies as much to governments as firms, or institutions and individuals, who may act less carefully than they otherwise could. This leaves another party holding responsibility for the consequences of those actions. Some of the large resource plant failures may involve moral hazard. Government involvement and incentives have had mixed, and often negative outcomes, that is not well understood even after the events.

"In contract theory, moral hazard results from a situation in which a hidden action occurs.[133]" "It has long been recognized that a problem of moral hazard may arise when individuals engage in risk sharing under conditions such that their privately taken actions affect the probability distribution of the outcome.[134]"

The term Moral hazard has come from use in insurance industry, where one definition is: *Circumstance that increases the probability of occurrence of a loss, or a larger than normal loss, because of a change in an insurance policy applicant's behaviour after the issuance of policy. It may be due to the presence of incentives that induce the insured to act in ways that incur costs the insurer (but not the insured) has to bear. In common usage, moral hazard suggests a conscious malicious or even illegal motivation, as opposed to an unconscious change in behaviour[135].*

The concept was been mentioned by Adam Smith[38], *People of the same trade seldom meet together, even for merriment and diversion, but the conversation ends in a conspiracy against the public, or in some contrivance to raise prices…. But though the law cannot hinder people of the same trade from sometimes assembling together, it ought to do nothing to facilitate such assemblies, much less to render them necessary.* Arrow's 1963 paper[136] is widely cited. Whilst he makes a strong case for universal medical insurance, he points out that there is a moral hazard when the event insured against is within the control of the beneficiaries. Cars and homes are insured against accidental fires, with severe consequences for the beneficiary who initiates their own misfortune. However in provision of health services the insurer pays, and the doctor and patient both receive benefits…*in medical policies the cost of health care is not completely determined by the illness suffered by the individual but depends on the choice of doctor and his willingness to use medical services…the physician acts as the controlling agent on behalf of the insurance company …and it may be convenient to them to be pleasing to their patients.*

In an investment there is a risk that one party to a transaction or activity is not acting in good faith, or that one party has perverse incentives to act in a manner detrimental to the counter party. This is most probable when that party is insulated from a risk, borne more heavily by the other, and behaves differently than they would behave if it were fully exposed to the risk.

Hulsmann[137]argues that: *Moral hazard is present in "actions of economic agents to the detriment of others in situations where they do not bear the full consequences of their actions. It is the incentive of a person A to use more resources than he otherwise would have used, because he knows, or believes to know, that someone else B will provide some or all of these resources. The important point is that this occurs against B's will and that B is unable to sanction this expropriation immediately. Expropriation is using B's property against his will with impunity."*

Kotowitz[138] explains that moral hazard may *"be due to uncertainty and incomplete or restricted contracts which prevent the assignment of full damages to the agent responsible."*

Hulsman further argues that government effectively owns most property, or has the right to tax and regulate what is private, and government involvement has moral risk implications.

Moral hazard involves information asymmetry, a situation in which one party in a transaction has more information than another. Arrow[161] states: *Where there is uncertainty, information or knowledge becomes a commodity. Like other commodities it has a cost of production and a cost of transmission, and so it is naturally not spread out over the entire population but concentrated amongst those who can profit most from it.*

One example would be the promoters of a gold mine share float, who were far better informed as to the exact grade of the deposit, and the cost and complexity of extraction; that the purchasers who were impressed with the "forward looking statements" in the prospectus and presentations. In this case the party with more information is insulated from risk, in that they can sell their shares at the peak, and collect a salary for managing what unfolds, whereas the party with less information may take most of the negative consequences of the risk. Moral hazard can give the party with more information an incentive to behave inappropriately, and to the detriment of the party with less information.

Balakrishnan and Koza[139] explore joint venture, where information is shared by both sides to common benefit as a means of avoiding adverse selection. They found that such ventures between similar firms were beneficial and those between different firms more problematic. Adverse selection may have been a problem with some projects in the case study, where a larger asymmetry of information, or misrepresentation allowed flawed projects to proceed.

Akerlof and Romer [140] point out that where government implicitly guarantees a business there are "*severely distorted incentives*". *"Because of this disparity between what the owners can capture and the losses that they create, we refer to bankruptcy for profit as looting." "The introduction of even a relatively small number of looters can have a large effect on market prices."*

They also point out that *"Governments sometimes do things that optimizing agents would not do, and, because of their power to tax, can persist long after any other person or firm would have been forced to stop because of a lack of resources."*

They propose a simple model:

First, limited liability gives the owners of a corporation the potential to exploit lenders.

Second, if debt contracts let this happen, owners will intentionally drive a solvent firm bankrupt.

Third, when the owners of a firm drive it bankrupt, they can cause great social harm, just as looters in a riot cause total losses that are far greater than the private gains they capture.

To modify this 1993 model focused on US "thrifts" to Australian resource projects the model changes only slightly.

First, limited liability gives managers of a project the potential to exploit the investors.

Second, if circumstances indicate that failure is unavoidable, managers have an incentive to intentionally drive a project to an outcome that maximises insider benefit in failure.

Third, when projects are managed to fail, they can cause great social harm. The total of the losses, in the present project, and future projects foredoomed, are far greater than the private gains that were captured.

They propose*: Once owners have decided that they can extract more from a firm by maximizing their present take, any action that allows them to extract more currently will be attractive-even if it causes a large reduction in the true economic net worth of the firm.*

A dollar in increased dividends today is worth a dollar to owners, but a dollar in increased future earnings of the firm is worth nothing because future payments accrue to the creditors who will be left holding the bag.

As a result, bankruptcy for profit can cause social losses that dwarf the transfers from creditors that the shareholders can induce. Because of this disparity between what the owners can capture and the losses that they create, we refer to bankruptcy for profit as looting.

Businesses are run by economical rational agents; Governments are run by politically rational agents. Business managers and politicians are professional insiders, often with significant skills and intuition. Shareholders and the electors are outsiders, often with limited interest or understanding of the complex processes involved.

In theory business rewards managers for increasing shareholder value, but the two are not always directly related. When a business goes bad it is often necessary to pay management more for “staying on as Captain of the Titanic” rather than exiting.

Managers as economically rational group; might be expected to put their own outcomes as a priority. When a receiver is appointed to a failed firm, they prioritise their costs and expenses as a priority over all others. The logic is the same.

The largest worked example of this type of looting of a financial institution in Australia was the collapse of HIH Insurance on 15th March 2001, with losses of $5.3 billion. In sentencing Rodney Adler, the Director of HIH to 30 month jail, Justice Dunford said: [141]

The offences are serious and display an appalling lack of commercial morality…Directors are not appointed to advance their own interests but to manage the company for the benefit of its shareholders to whom they owe fiduciary duties…They were not stupid errors of judgement but deliberate lies, criminal and in breach of his fiduciary duties to HIH as a *director*.

This is very much what Akerlof and Romer are documenting, and may be option to consider when looking at failed resources plants at much the same time.

2.9 Conclusion: The need for such a new model and methodology

In this study the failure of fifteen projects lost $12.5 billion dollars; 29.68% of capital invested. All had mathematically based “bankable feasibility” studies using existing insider methods. The majority of this loss was to shareholders and taxpayers. The failure of every “new process plant” made firms risk averse; yet a number of “improved process plants” gave great results.

A new public domain model of resource project evaluation is needed. This model should:

1.) Be simple in concept and application
2.) Not require exceptional skill or knowledge
3.) Use publicly available sources of information
4.) Have robust predictive power
5.) Gives prediction at the earliest stage of project conception
6.) Uses an open model that may be tested, adapted and developed

The retrospective models developed from the case study data assist in understanding why there was failure. These might be used as forward looking models to predict failure, without stopping successful projects. These models use data that is known before the project started.

Project evaluation from the insider (expert or proponents) view:

- builds in bias
- is by proponents seeking to proceed;
- is by contractors seeking further work;
- is focused on inputs from insiders; and political goals;
- is about control, and access to reward;
- is defensive against later responsibility;

- is based on private and proprietary data;
- looks at “what ought to be”;
- is based on explicit value judgements;
- is related to ideal models;
- assumes fully informed rationality;
- is more about system design and specification;
- is rewarded by participation not outcome;
- is open to optimism bias or strategic misrepresentation;
- and it was wrong with nearly 30% of investments.

Project evaluation from the outsider (investor) view is:

- a control for bias
- for consumers or investors who are seeking positive outcome;
- focused on measured outputs
- based on publicly available data
- looks at “what actually happens”
- free of explicit value judgements
- encompass human flaws with models based on history of prior actions
- more about system cost and performance

Chapter 3
Indicators and estimation model for success and failure

“No problem can be solved from the same level of consciousness that created it.”
- Albert Einstein

3. INDICATORS AND ESTIMATION MODEL FOR SUCCESS AND FAILURE

3.1 Introduction

Five models are proposed to deal with managing and considering the complexity of the data. These are shown on Sheet 8 of Appendix and through this chapter in tables. The first is a model for estimating the spectrum from failure to success. This is then applied to the other four models to examine the contrasts between the best and worst, and explain why this happened. The second model is an evolved model of firm competence, with the assumption that competent firms will be successful. The third model of New Process Innovation, contrasts the 99% of investment that failed with the 1% that succeeded. This raises the anomaly of why otherwise highly profitable firms could invest and lose billions in these endeavours. This leads to the last two models, the fourth examines the positive and negative roles of government involvement in value adding, and the fifth the model of information asymmetry and strategic misrepresentation in project failure.

3.2 Success and failure estimation model

The criteria for measuring success and failure are related to the viewpoint of the observer and the context of use, and may undesirably reflect a collective interest, ideology or belief system. This simple objective model of success and failure to large capital resource processing plants, based on post project evidence and comparative numerical data is developed, and applied equally to every case; using public domain data.

Success is from the Latin “successus” an outcome. Thus success and its opposite failure are post event outcomes, capable of being judged from different angles. An outcome considered to be a failure by one party might be considered a success by another party, applying different criteria. . There is even more opportunity for variability in assessing the degree of success or failure in a project with a valued social change component, such as innovation.

Success is defined by Collins English Dictionary 2003 as “the favourable outcome of

something attempted” and “the attainment of wealth.” Failure is defined by the same source as “non-performance of something required” “cessation of normal operation” “an insufficiency or shortage” “a decline or loss” and “not reaching the required standard”.
The model for failure and success is shown in Table 12.

Table 12 Failure to success model

Failure outcome model	Success estimation model
The project and the firm made a loss	The project and the firm made a profit
Production less than 70% nameplate capacity in 36 months	Production better than 90% of planned output
CRoI more than double industry average < 106 months	Calculated Return on Investment > 105 months
Firm has ceased, been taken over, been deregistered	Firm is alive, grows and evolves
Process is no longer worked, or only worked sub optimally	Transforming process is worked and duplicated

A resource processing or transformation plant might be viewed as a black box with inputs and outputs. Inputs, usually investments of capital and skills are supplied to meet quite specifically defined output objectives. A proposed investment of $100 million in a plant for gold extraction will have a “nameplate capacity” at which it will transform predicted volume of ore into a stated mass of gold. The reason to make such an investment is that the investor believes that the outcome of gold produced, less cost of production will be significantly more profitable than having the same funds being held in bank term deposits. The successful attainment of this objective give further life and growth to the company, and if it involves a new or innovative process, results in the adoption of this better process in other similar projects that follow.

These criteria can be shown as outcomes. The first criterion is **profit**, which is related to production, commodity price, and return on investment. In the short term this is not always clear, as the profits of a firm may be across many projects, and only the agglomerated results show a firm profit. Firms with only one project that show a significant loss are easy to allocate. Firms with many projects of variable outcome, and modest profits can fail, and be taken over; even though the projects go on to be successful. Successful firms with solid profits can have anomalous project failures. In the long term this becomes clearer as successful firms decline to fund failed projects, and troubled but ultimately successful projects work by all the other criteria for their new management.

The second criterion is **production** of transformed commodity as a percentage of the "nameplate capacity" where percentage below 90% indicated trouble, and a percentage below 60% was fatal. The average the most successful 50 projects was 99%. The average for the 17 projects least successful projects was 33%. Case 46 which failed with a production of 88.5% was wiped out by low commodity price, and freak weather occurrence, a pollution disaster and failure of its US parent. Case 44 which succeeded with a production of 65.3% has subsequently been closed as the most uneconomic alumina refinery in Australia. Case 63 which succeeded with 63.9% was a large deposit with unusual ore, but may have contributed to the economic failure of the firm who developed the mine.

The third criterion is **return** of investment, as calculated by methods shown in Chapter 4. The point of differentiation between failure and success is captured in the quote from the 1930's depression era American commentator Will Rogers: "People should be more concerned with the return of their principal than the return on their principal." Successful projects give the investors a variable but largely private return. Failed projects consume, rather publicly, the invested capital. Successful plants pay back their investments quickly and go onto profits. Failed plants have the potential to repay their investment so slowly, that they have difficulty attracting further investment to sort out their myriad problems. They eat the investors' capital till it is almost gone, or worse, if they use complex financial structures; leave the investor with nothing. The average for successful projects was 53 months. Projects over 106 months were failures or in 4 cases projects done for an environmental outcome, not a production increase.

The fourth criterion is the **"life" of the firm**. Success allows firm growth, and evolution. Failure leads to firm extinction via bankruptcy and de-listing or incorporation into a more successful firm. Better managed failure, enabled the selection of the new owner. Employees were able to continue with careers, plants continued to transform and investors moderated their loss. Badly managed failures spend much time having their troubles examined by lawyers and regulators. Employees had to find new roles, and investors largely lost their finds.

The fifth criterion is the **life of a transforming process**. Successful process innovations are reasonably widely and quickly adopted, in that they are notably more efficient at the desired transformation than previous technology. Unsuccessful process innovations may offer some advantages, but with risks and difficulties that make them unattractive in the Australian economic context. Failed process innovations are not duplicated, as whatever advantage they might have offered was counterbalanced by more powerful risks or unforseen outcomes.

These five criteria together differentiate a continuum from most emulated success, to “never to be repeated” failure. Around 72% of these private sector projects were successful enough to still be operating. 6% are still operating, but only as the initial failure and losses reduced their value to such a low level that they can “limp along”. 22% are dead; with their tombstones as stark reminder “not to do this”.

The estimation used in the Appendix 3 is the addition of **production** (which is variable between 0 and 2.06 but averages .82 over all the 67 projects) plus **life of firm** and **life of process**, (which are 0.1 to 0.5 variables). The sum is multiplied by five to balance the weighting against the much larger numbers of **returns** (which is divided by 53 which is the average for successful projects).

Of the 67 projects considered, fifteen failed, but 3 were purchased for around 10 cents in the dollar invested and returned to work, though under different production routines. 15 projects encountered difficulties that saw their firms seek takeover, or were in the takeover due to other firm difficulties; all went on to satisfactory performance. Thirty seven projects were successful. Two have subsequently been closed after operational conditions changed, and four were environmental upgrades. These are show as coloured bars in Appendices.

3.3 Firm competence model for resource transformation

Firm competence is a predictive model, for resource processing plant, of the ability and probability of a business entity to successfully complete the task they have proposed, with a better than average outcome for the investor. The plant operator obtains the wealth proposed by effecting the resource transformation in a superior manner, with favourable reliability and economy of production.

Warren Buffett says “Risk comes from not knowing what you are doing.” This is applicable to individuals or groups. A person learning to be an airline pilot, a brain surgeon, or a concert pianist; and a firm seeking to produce exceptional returns from transforming resources, follow very similar paths. Firm competence comes from knowing, exceptionally well they are doing, whilst and practicing and improving.

Experience and practice in the field, focus on refining the particular special skills, scaling up of both to build competence and avoid risk, and the confidence of experts in all these abilities; are the four common factors of the Firm Competence model. The selection of a pilot for a Boeing 747, or a brain surgeon who one would choose to operate on a loved one, or selecting a famous musician to hear at the Opera House follow this model.

The pilot, for example, may start learning to fly on a glider or small single engine Cessna, work up over time to larger and more powerful and complex aircraft, spend some time in military or freight transport, before becoming responsible, after rigorous training and certification; for the safety of hundreds of passengers as part of an organised team.

Few airline passengers would want to trust their lives to a pilot or team without the knowledge, skills and practice to safely get them to their destination. Yet investors have entrusted their capital to teams lacking all four factors; who were attempting a new process for transforming resources into high value commodities. These investors lost their money.

Where a resource processing firm had a track record of successful project implementation; a focus on a limited field of skill and technical competence; allied with a program of incremental improvements; who then scaled up existing successful plants to new and better plants by a moderate ratio; experienced the least risk, achieved the best project outcomes, and received a better return on investment.

There is an apparent exception or anomaly with large and diversified firms, like BHP-Billiton and Rio Tinto. These firms have a broad range of largely successful activities, and have developed their firm competence in high profit areas, rather than technically challenging areas. Both are predominant in iron ore and coal, which are harvested more than processed. This firm competence, which involves minimal resource transformation, is outside the focus of this study.

The firm competence model and the core competence models are shown in Table 13. There are five key components to “firm competence” in resource processing plants.

Table 13 Firm Competence model

Firm Competence failure model	Firm Competence success model
Limited or no relevant track record of success	Track record of successful implementation
Limited or no prior firm focus in area endeavour	Firm focus in particular area of endeavour
Large scale up from previous similar project success	Modest scale up from previous similar project success
Firm financed at high interest from least informed	Firm engenders financial confidence from best informed
The firm and the project made a loss	The firm and its projects regularly made a profit

Firm competence is the demonstrable skills, resources and will to complete the task. It is most easily assessed as the historical **track record** of project implementation, production performance, and commercial outcome. They get the job done.

Firm focus is specific dedication to excellence within a particular well-practised process expertise to achieve a superior outcome. This is rarely general over a broad range of complex resource transformations. As such a focus is exceptional; it will be difficult to copy. The productivity increase from focused specialisation has been noted from Greek Antiquity with Aristotle's quote of *"We are what we repeatedly do. Excellence, therefore, is not an act, but a habit."* A specific focus on a particular resource, with a practiced and evolved technology, leads to superior reliability of commodity delivery at enhanced profit margins. The focus on a particular resource, processing technology, and supply chain to customer; leads to planned and constant incremental improvements that reduce risk. The focus on a specific resource and technology means that the new plant to be built will incorporate much of the skills and design of the last. The "DNA" from previous plant design and implementation "evolves" by selecting what works best and avoid that which was troublesome.

Scale up ratio on previous similar plant a simple metric. Skills and knowledge are more economically developed through small scale trial and error, scaled up in progressive steps. Radical innovation at bench scale has a low cost of failure, and full opportunity to learn from failure. Trial and error with a full scale plant is a recipe for waste, and delay at exceptional cost. Cutting and changing pipework on a 50 kg per hour pilot plant has a moderate cost, in that few people are idle whilst it happens, and it is expected in the budget. Cutting and changing pipework on a 5 tonne per hour production plant (~ 45,000 tonnes per annum) usually sees the whole plant stopped, and hundreds of employees idle on full pay. The loss of a week's production of nickel and cobalt from a HPAL plant can be around $4 million of production. If the budget is tight and financial confidence short, the plant is probably doomed by a few such weeks. Building a copy of existing working plant with improvements, or a copy that is 50% to 100% larger is largely risk free. Building a new process plant at mega scale, without these steps involves almost certain risk of failure.

Financial confidence comes from investors, customers, and stakeholders. If they believe, based on past performance, that the firm will get the job done, reliably and with minimal risk then they will invest, and enter into favourable contracts. Once a firm is widely perceived as competent, reliable and low risk they can raise patient capital at favourable rates and terms. Their shares are often sought after and rise significantly in value, which is highly desired by the initial investors. They can win long term supply contracts from customers who are adverse to delivery uncertainty. An example would be LNG supply to a Tokyo gas company with 25 million customers who will be irate if the gas or electric supply is interrupted. Failure and risk are not financeable options. This firm competence is difficult to imitate, and is a barrier to new entry that gives advantage to existing competent operators. Firms with limited financial confidence, have higher cost of capital, often at twice the interest rate applicable to competent firms. In retrospect this is not high enough to compensate the investor for the losses that are shown in this study, linked to lack of firm competence.

Regular profits are both an outcome of the other criterion, and one that contributes to financial confidence. Investors seek returns from a share of profits paid as dividends, and the payment of good dividends also leads to a sustained appreciation in share price, again rewarding the investor. No profits, no dividends and declining share price destroy the original investment.

These five points have parallels and differences from the original work by Hamel and Prahalad who proposed three key criterions for “Core Competence”.

- It is not easy for competitors to imitate.
- It can be re-used widely for many products and markets.
- It must contribute to the end consumer's experienced benefits.

This new model is proposed as, based on the study of sixty seven resource processing projects, the first and third of Hamel and Prahalad’s criteria are demonstrated, but the second;

that core competence could be used widely over many projects is not evident. In fact the opposite is shown in the case studies. Large firms with exceptional competence, and long term profitability in some areas of resource businesses; had significant problems in successful implementation and operation of process projects that were outside their "firm competence". BHP and after 2001 BHP-Billiton is the world's largest mining company, with 125,000 staff at more than 100 locations, generated revenue of $72.2 billion US, and profits from operations of $23.752 billion US[142]. In the 67 Australian resource processing projects over 18 years, 13 are associated with BHP or BHP-Billiton.

Five processing plants (12) Kalgoorlie Acid Plant, (13) Phosphate Hill, (41) Kambalda Nickel Concentrator, (42) Mt Keith mine and concentrator, (48) Olympic Dam expansion; were all purchased from WMC Resources Limited on 29th June 2005. Phosphate Hill was in financial difficulties due to low commodity prices and was sold to Incitec Pivot Ltd. The other four plants were retained as profitable operations. In retrospect the purchase price of $9.2 billion Australian seems to have been an exceptionally good investment.[143]

Four resource processing plants, all utilising new process technology; (1) Boodarie Crude Steel plant, (9) Ravensthorpe Nickel/Cobalt from Laterite plant, (10) Yabulu Nickel refinery, and (11) Beenup Mineral sands operation all failed.

Two resource processing plants owned and operated by BHP-B (64) the Cannington silver and lead plant, and (25) the Worsley Alumina Refinery (86% BHP-B Owned) have been completed and operate successfully. Two plants on which BHP-B has a 16.67% interest were managed and operated by Woodside Petroleum Limited.

BHP-Billiton has demonstrated firm competence in gaining control of iron ore and coal resources, that are not elaborately transformed or processed; and this is the core of their profitability. They also show firm competence at high level in the harvesting of these resources, then transport and shipping to customers, and maintaining margins and sales volume with their customer base.

However this exceptional and profitable firm competence did not extend beyond the mature technologies employed at Worsley and Cannington. WMC, which effectively ran out of capital in 2005, was far more competent at implementing complex new process plant projects.

The role of financial confidence is crucial in resource transformation, and will be illustrated with a number of case studies. Firm and team competency engenders respect and trust from groups who study and finance resource projects. They back teams with a track record in a particular type of endeavour, because risk is low and probability of repayment high. Firms with adequate capital usually succeed; firms without adequate capital usually fail.

Dunning and Kruger proposed that, for a given skill, incompetent people will:

1. Tend to overestimate their own level of skill;
2. Fail to recognize genuine skill in others;
3. Fail to recognize the extremity of their inadequacy;
4. Recognise and acknowledge their own previous lack of skill, *if* they are exposed to training for that skill.

Competent firms:

1. Tend to rationally estimate their own level of skills in specific areas
2. Tend to recognize genuine skills in other firms, that they engage with;
3. Accurately recognize the limits of their adequacy;
4. Organise projects to match critical needs to recognized skills.
5. Operate to the advantage of their investors.

Firm competence is shown by:

1. A track record of successful implementation within
2. An area of firm focus, in which they are known to be exceptional
3. At modest plant scale up ratio, or using small steps up for innovation
4. And is recognised and rewarded by astute business and financial partners.
5. Investors being rewarded with above average returns.

3.4 New process innovation model

The model is related to the previous hypothesis, and focuses on the projects with more radical innovation processes, and focuses on the scale up steps in the development. A new process is one where few if any working process plants have been build. Firm competence and practical

experience come from their existing projects and the stage of knowledge building in pilot plants. A firm that develops a process to solve a problem they face every day has an advantage over the firm that adopts a process to meet a need they believe is important.
When the process is new, so the interactions with the specific ores can be a painful process of discovery, and the knowledge, based on prior experience, to manage both is valuable. Trying "something new" at a small scale where inevitable troubles and learning can be low in cost; is logical and desirable. A staged scaling up of plant size allows a new process to be evolved to match the resource, test the market, and for the operators skill to increase.

This only happened in one new process plant, the least expensive and the only success.
The reasons for a firm to invest in a new process plant project are often, but not exclusively found in the following six concepts.

- A new method is proposed to affect a much improved or unique value adding transformation. Such radical innovations as MacArthur Forrest Process (Gold), Bayer Process (Alumina), Hall Herault Process (Aluminium) and Flotation process (Ore concentration) transformed the respective industries, brought wealth to practitioners, and rendered the prior processes obsolete and uneconomical.
- The existing processes are progressively less productive, often due to exhaustion of a preferred type of resource. An alternate, less desirable, more available and or more complex resource requires a new process. The HPAL Process for nickel and cobalt from Laterite ores is an example.
- The potential resource body is large, under-utilised, and low in cost, compared to the declining availability of traditional resources. Large reserves of laterite ores are an example, with nickel sulphide ores increasingly exhausted.
- The desired commodity is seen to be likely to be, or projected to be; subject to increasing demand and hence increasing commodity price rise; and thus profitability.
- The new process is often promoted, with a positive or promotional bias, as relatively trouble free, and giving an exceptional commodity with superior quality and hence price. If the new process can deliver productivity benefits the profit potential can be more attractive than traditional ventures. Enthusiastic "new process" promoters had found investors more than willing to be optimistic in the time frame when these projects were built. Due to failures this is much less so now.

- New processes have been in the more distant past, exceptionally profitable investments. The MacArthur-Forrest process transformed the Gold recovery and the Bayer and Hall–Héroult process created the Aluminium industry. These rapid advances in many types of technology have made the successful firms wealthy and rewarded the astute investor. As an example, in 1888 Charles Hall started the Pittsburgh Reduction Company to implement his invention. In 1907 this became the Aluminum Company of America, and today is the $25 billion a year turnover Alcoa.

New processes, to resolve technical difficulties in processing a resource, are often radical innovations, and have high risk. Those new processes when scaled up rapidly and without extensive testing, and without a capital reserve to resolve implementation difficulties failed. Two new processes that followed a long path of progressive scale up, incremental innovation, and adequate capital; one succeeded and one did not as yet.
There are twelve projects that are radical innovation new process plants, which hoped to transform their industry segment. One project (Case 40) succeeded brilliantly and has been duplicated many times and the technology exported around the world. The eleven other projects failed rather disastrously, largely destroying the investment. The input steps are subtlety different, the outcomes diametrically opposed. There are two outcomes, each with dramatic and subtle differences in development and implementation models.

The 12 new process plants represented a total investment of $12,098 million with an average project value of $1,008 million. The 55 plants that were “old or incremental innovation process” had an average project value of $616 million. The new process plants were almost 64 % more costly than the average mineral processing project. Had the plants been built for the original estimated cost, as first shown in ABARE data their total cost would have been $5,050 million or an average cost each of 421 million. This is well below the average for the complete set of 67 projects, and still below the average for 55 mature process plants. The time management or completion delays for the new process plants was estimated at 97% over estimates leading to a cost over-run estimated at 2 .4 times the original budget.

The successful project Case 40 was the exception. It experienced no completion delay and only a 10% cost growth.

All new process plants, except Case 40 failed. One failed plant, under new management

(Case 10) reverted to an earlier old process technology and went back to full production. Another one (Case 3) was able to produce a reduced product stream, after more investment beyond the initial failure. One plant (Case 7) was only 5% complete, when stopped. The others all reached variable, but below nameplate, levels of production, before being closed. Seven have been scrapped, or are in the process of being "de-constructed"[144] (Cases 1, 2, 4, 5, 6, 7, & 8). Three sold to new owners, one (Case 10) returned to its original and profitable pyro-metallurgical use, another (Case 3) returned to partial nameplate production, and the third (Case 9) has not yet reached moderate success.

Case 40 has transformed 210,000 tonnes of ore per year into copper for the last 20 years. This 4.2 million tonnes of production, at the March 2013 value of $7,700 per tonne could be valued at $32.3 billion. The new process, ISASMELT, has been installed and is operating at 11 other locations since Case 40 was completed, and is in the process of installation at 6 more sites.[145]

The remarkable contrast between the successful ISASMELT Case 40 and the other 11 failures is that the successful project, at $110 million was the lowest in cost by a wide margin, the fastest to build, and lowest in cost over-run.

ISASMELT cost $110 million; the average for the 11 failed projects was over a billion dollars. It was built in seven months; the average for the other 11 projects was 31 months, with an average of 59% delay over projected completion. ISASMELT was 10% over budget, versus an average 2.4 x original budget for the others.

Every one of the 11 new process projects that failed destroyed the vast majority of investor value, or transferred losses to the taxpayer via complex accounting. Sadly the firm that developed the new process that worked so well, Mount Isa Mines, fell into financial difficulties and was taken over by Xstrata in 2003 for $2.9 billion. Xstrata has continued to develop and promote a suit of process technologies.[146]

Some of the evolutionary concepts of how "scale up ratio" interacts with "new process projects" were put forward 85 years ago by Russian engineer Peter Palchinsky. [147]
The three concepts are:

1.) Seek out new ideas and try new things. This is like the evolutionary concept of "random variation".

2.) When trying something new, do it on a scale where failure is survivable. Building a "mega-project" without a trial and learning mini-project can be costly.
3.) Seek out feedback and learn from your mistakes as you go along. This is like the evolutionary concept of 'natural selection.'

These concepts model natural evolution, and successful incremental improvement in resource transformation plants. The one successful new process project, ISASMELT, was the one project that largely followed these concepts. Eight others launched from limited prior application into mega-projects, in one over reaching step and failed.

Peter Palchinsky was executed in 1929 for his opposition to gigantic projects. After his death the three major projects he had opposed, the Dnieper Dam, Magnitogorsk, and White Sea Canal had human and economic costs that that could only be tolerated in a dictatorship, and benefits that were delayed, subject to extensive and repeated rebuilds, and well below expectation.

Two key factors are highlighted by the conflicting views of Palchinsky and Stalin. The first is that the state driving innovator is top down, a decision is made and implemented, and questioning is unwise. The collective structure of the state is engaged, people and organisation are joined in. The second part is that collective projects are often big. The building of the pyramids can only happen in an organised state focused on a common goal over decades. Such a project, a large dam, canal, pyramid or process plant is hierarchical, and difficult to modify once committed. This has many similarities with mega project construction.

The alternative is the individual or small team, trying and testing small ideas that can grow. Most, like random genetic mutation, will fail, cheaply and quickly. Some that have technical advantage will grow and prosper in small steps and stages. Each step and stage has a low cost self-correction potential. In time as the scale of the projects grow, the level of investment and organisational control must increase, but they are then duplicating and scaling up a concept grow by multiple iterations. Failure has already happened many times early, cheaply and quickly, and has been corrected when small.

The model for new process innovation is shown in Table 14.

Table 14 New process innovation model

New process innovation failure model	New process innovation success model
Management with limited responsibility or ownership	Individual Ownership and responsibility
Initially complex process that became more complex	Initial process simplicity that evolved
Rapid scale up to mega scale without evolution	Multistage incremental scale up with evolution
Many firms chasing same perceived opportunity	Niche demand for innovation
The process made a losses from start to finish	The process made profits quickly and repeatedly

The first criterion is **ownership and responsibility**. Innovation is more efficiently "championed" by an individuals or small teams of innovators with direct ownership and responsibility. Their greatest reward comes from the successful implementation and adoption of the process. They have made a personal and public investment in success, and failure brings pain, shame and fiscal disadvantage.

The second criterion is **Complexity and performance.** The innovative process is initially simple, and with evolutionary development becomes incrementally more complex. The process works at the micro scale, and shows utility at every stage of the scale up. The initial process system is simple, low cost at small scale, and incremental improvements are economical. Thus it is relatively easy and quick to implement with modest resources and early trial and measurement of outcome is practical. Rapid modification at small scale is practical and economical, there is little ego invested, and a billion dollar plant construction is not delayed. Process complexity evolves with process incremental improvements over a longer time

The third criterion is **Step up stages and benefits.** Multi stage scale up steps, incremental improvements, and "bug fixes" before a commercial plant. Many moderate iterative scale-up steps in process development enhance efficiency and potential utility. Incremental improvements in process, associated knowledge base, and tacit knowledge of operators is built with low cost and risk

There is a great advantage in being able to fail fast, change cheap, learn quickly at smaller scale. Failure is able to be admitted and resolved without endangering the project. Complexity evolves with process incremental improvement steps over time, leading to a new process that delivers significantly more product for lower cost than existing processes.

The fourth criterion is **Niche demand and uptake.** The small focus a "micro climate" of small scale innovation is not visible to larger predators. There is a strong unmet demand for product and process visible to practitioners, who are often closely connected to the firms who will benefit.

They can see that existing processes are inadequate for transforming new of existing resources. A new type of cheap and abundant resources may be available but requires new process to implement. This unique transformation advantage is relatively easy to establish at small scale. In some cases due to the small scale of innovation there are few competitive players in early stages of development. Firms that have unique need for the new process, for their resources, often have a good expertise base to do implement it.

Once implemented successfully and profitably other firms with similar unique needs adopt process world-wide relatively quickly. The new process transforms the market and makes others processes economically and technically obsolete within the life span of existing plant.

The only successful innovation project was built on brown-fields site, by a firm who wanted a solution to a problem costing them dearly. The development and practical of the submerged lance smelting process by John Floyd, inside, then outside CSIRO enabled smelting of sulphide ores and waste slag recovery of lead.

The fifth criterion is that the **process made a profit.** The one successful innovation project (Case 40) first enabled its developing firm to process ores more productively, and make better profits. The productivity and profitability are shown by other firms with similar needs buying licences to duplicate the process over the next two decades.

3.5 Government involvement in value adding process model

Ownership and taxation of resources has become more complex, with competing and overlapping interests. State governments own the resources under their boundaries, and three nautical miles to sea. Oil and gas outside three nautical miles is Commonwealth owned. The

Commonwealth collects income taxes, and a range of other taxes, charges and levies. States collect royalties and a range of taxes, and indirect benefits from resource extraction and processing.

For states the value that may be extracted from local supply contracts feeding the state taxable economy, as well transport and infrastructure charges, can be larger than the royalties. An example would be the investment in building the narrow gauge rail line that linked Mt Isa to Townsville in the late 1920's enabled the development of the rich mines, but at a price that has since taken a large share of profits, and largely funded the Queensland rail network for the last 90 years.[148]

Governments seek both economic and political return from resource access. These can be contradictory, in that maximising economic return can be based on best past practice for the type of resource. Political advantage may be more urgent and effectively trade off economic return for a concession to an interest group.

Uranium mining has been intensely political, especially in South Australia. The S.A. Government has urgently wanted the royalties and economic activity, from Olympic Dam. But they have sought to manage the uranium issue, with local processing and value adding. That this has led to an outcome that may be less than optimum for the state and the operator is explored in the Case 48 study.

Gold mining is only moderately political, with State Governments largely content to collect a share of revenue. The modern exception is in the growing opposition to the use of cyanide in extraction. This is most notable in NSW, where two of three operations ship concentrate, and do not refine.

In New South Wales the problems with poisonous cyanide tailings water required a more expensive modified process in Case 58. The gold and copper mine in Case 47 is the state's largest investment at nearly $2 billion. Yet it has chosen to not refine the gold or the copper, avoiding the use of cyanide; and ships the metals as concentrate. This reduces risk and capital investment for the operator, and increases rail freight and port charges. The concentrate shipped in containers is between 25 and 26% copper by mass and 75 to 80 grams per tonne of gold[149]. The other 74-75% if fine crushed rock. The value of the concentrate is around $2,000 per tonne.

Value adding is the processing of a resource to the most refined and highest value commodity, which is hopefully integrated into a local manufacturing value chain. To give a simplistic example, bauxite is valued at around $30 a tonne, alumina at around $300 a tonne; and aluminium until recently was around $3,000 a tonne. Transforming the aluminium into a motor vehicle could theoretically increase the value, the input of skilled human labour, by between $30,000 and $60,000 more per tonne.

The opposite to value adding is concentrate shipping. In this process an ore is concentrated to a balance between transport costs and the value to the refiner for their needs and processes. The metal content might be between 20% and 30%, and poly-metallic ores are common. As local refining costs in Australia have risen over time, and transport costs have generally fallen, shipping concentrate is often more economical, involves less capital, and less risk.

The purchaser in China, Japan or Korea feeds an existing refinery that may be closely linked to the next steps in the value chain.

State and Federal Governments, and their public sector research organisations favour value adding, to the point where they invest in projects that are seen as strategic. Case 7 received $370 million and Case 8 received $155 million. Both failed are now scrapped. The governments received no value or return for their investment.

For the operator the lower levels of transformation, such as concentration involve little risk. In this study of 67 projects over 18 years no project that concentrated ores failed. All failed projects were value adding refineries.

Australia is the world’s largest exporter of low valued bauxite, with 73 million tonnes shipped in 2012. Bauxite has traded as low as $19 per tonne (in 2003)[150] and as high as $39 (in 2011).[151] Through government value adding requirements, Australia is also produces 20.4 million tonnes of alumina in 2011-12. Approximately 17.1 million tonnes of alumina was exported in 2011-12, with estimated revenue of $6.03 billion for the year; or about $352 per tonne.

Starting in the 1960's The Western Australian Government tied access to Bauxite to establishment of an alumina refinery. Other states followed, and this has become an accepted practice. Whilst there are some financial stresses on a number of Alumina refineries in 2013, over nearly 50 years the linking of profitable value adding in return for access to bauxite deposits has been successful. This is explored in the alumina case studies.

Australia has the second largest reserves of bauxite in the world, about 22% of total. Far more precious is nickel, valued at between $22,890 (2011) and $17,600 (2010).[152] Australia is the leading resource holder, with 28.4% of world total.[153] This is larger than the next two resource holders, Brazil on 11.9% and New Caledonia on 9.7%.

Australia is the largest exporter of iron ore in the world, with 525 million tonnes in 2012[154] contributing $62.7 billion of export revenue[155].

In contrast to the successful government intervention the mature technology of alumina production, there was little Government interest in the five innovative laterite nickel cobalt process plants that failed in the 18 year period. There was strong Western Australian government intervention, to develop new and innovative steel making technologies; along similar lines to what had been achieved with bauxite and alumina. These achieved quite an opposite result; both projects failed and no secondary processing to crude steel now takes place.

Thus the comparison in government intervention is; why did it work so well for bauxite to alumina and so poorly for iron ore to crude steel?

A secondary consideration is why the South Australian government has received so little benefit from so much involvement in Case 48?.

The government involvement in value adding model has five parameters shown in Table 15.

Table 15 Government involvement in value adding model

Government Involvement failure model	**Government Involvement success model**
New process, not well understood	Mature and well understood processes evolved
New firms with less established value chains	Mature firms with complete value chain
One sided benefits sought upfront	Mutual benefit from decades on agreed collaboration
High level of reward for information asymmetry	Low level of reward for information asymmetry
The project made a loss despite government investment	The project made a profit after government involvement

The first criterion is a **maturity and well understood process that has evolved over time**. Alumina refining is the best example. This is closely related to the Asymmetric information model, in that where all parties have a good understanding of the inputs, the process and the probable outcomes, government involvement is likely to achieve the desired outcome. Conversely where the Government party has an information poor understanding or the inputs, process and probable outcomes government involvement is unlikely to result in the outcome desired by government. This can be related back to the first model of firm competence. Risk comes from not knowing what is being done.

The second criterion is that the firm involved in government involved value adding is that it works best when the counterparty is **mature firm with a complete value chain** built around the commodity. The maturity of the firm means that its preferred business activities are well known, and how it deals with other parties, especially government are also well known. Examples would be Alcoa, which has been operating a value adding chain of bauxite to alumina to aluminium to processed aluminium products for more than a century, and has been involved with multiple governments in its international engagements. Where the firm is new, or only wishes to work in a single transformation stage of a larger value chain, often with good reason; then the outcome will more likely be disappointing. The reason being that the extra transformation stage required is not one that is economic for the firm to undertake.

The third criterion is related to the first and second. Where the value adding results in **mutual benefit** to the government and firm over many decades, and they openly agree to such a venture, then success is likely. Where the economic feasibility of carrying out the government desire marginal or where a Government commands an outcome that is contrary to economic reality, they can expect disappointment. The story is told of King Cnut (Ruler of England 1016-1035) commanding the tide not to rise, and getting his feet wet.[156] Where a lease requirement is at odds with economic reality the cost of compliance is uneconomic. Either the firm must absorb the loss, and potentially fail, or the firm must manage the compliance to avoid the desired government outcome. Many Governments have a political desire for high technology projects that elaborately transform low value resources into high valued added commodities. This is more apparent in marginal electorates, before elections, and when good news is required. The investment in new plant often benefits the broader state manufacturing economy. The potential for more highly skilled and paid jobs is played out in media releases.

An environmental counterpoint is that final value adding can be the part of the process with the greatest potential for environmental emissions. Government and operators have increasing social pressure to reduce any potential for pollution. This is a growing factor in decline of government enthusiasm for value adding projects.

Where the process is not mature; and poorly understood by the government party, the risk of adverse outcome is unacceptably high. Risk comes from not knowing what is being done.

Where the cost of meeting lease conditions is uneconomic, or unrealistic, then selective avoidance or decreased operation viability are likely to follow. The failure of the crude steel projects (Cases 1 and 8) are an example of the former, and the failure of WMC, who accepted value adding conditions for Case 48 project a part of the second.

The fourth criterion points to the next model, of **information asymmetry and strategic misrepresentation** when related to government mandated value adding. Where there is a high level of potential reward for abusing information asymmetry, or engaging in strategic misrepresentation and the responsibility or liability for this action is limited; then it may be expected.

The fifth criterion is that the project **made a profit** for the firm operating it, and indirectly delivered the benefits that the government hoped to achieve from the intervention. Where the project made a loss the firm operating it must eventually close or the government make good the shortfall. Case 30 was closed down when an offer of low cost natural gas supply was curtailed Territory government. The project was uneconomic and will be closed.

3.6 Asymmetric information model.

The asymmetric information model draws from a body of related academic research in economics and contract theory. Where one side has better information than another, the unbalance of power, may be used by the more powerful to their advantage. Contracts between two or more unequally informed parties do not give the outcome the less informed party expected.

Information asymmetry is a situation where the "insider" party in a contract has superior information or the process and probable outcomes compared to the others. The informed party, usually a proponent or project implementer can take advantage of the other party's lack of knowledge for commercial advantage, and or avoidance of responsibility for their managing actions. This creates an unbalance of power in contract negotiation, and implementation.

Information Asymmetry can lead to two morally questionable outcomes:

Adverse selection is where the insider knowledge leads to behaviour that takes advantage of asymmetric information **before** a transaction. As an example, insisting on a cost plus contract; where a project can be projected by the informed insider, to have many complexities likely to drive up price; not understood to the outsider; usually investors. An alternative adverse selection would be where an informed party structured and managed a process to an outcome that failed to deliver the benefit sought by a Government that granted a valuable licence.

Moral Hazard is where the insider knowledge leads to behaviour that takes advantage of asymmetric information **after** a contract. As an example, a manager in a cost plus contract is rewarded with greater margins if project costs escalate unsustainably. They are further rewarded if the project fails as they are fully remunerated up to failure point. They avoid responsibility for project performance as in failure the project does not perform. A project disaster hides a multitude of sins and mistakes that would be visible in a working embodiment.

.

The adverse selection example with Government may be extended into a moral hazard situation after contract. If the informed party felt that the benefit demanded was unrealistic and/or undeliverable, it might encourage the informed party to behave strictly within the law, but in a manner that avoided responsibility for a negative outcome, that still met the contract conditions.

Adverse selection is also a negative outcome selection for the less informed, in that they invest in a "bad" project that they would not have selected if they were better informed.

Two options for managing adverse selection are signalling and screening methods.

Signalling is modelling of the information publicly available on the proponents. Signalling is what a client tells the bank manager to elicit a loan. It may be self-serving, but can contain a pattern of useful information. A loan applicant displaying a noticeable lack of veracity in their signalling might well be politely declined. A skilled contracting firm declining a project or insisting on a cost plus contract is signalling that they see the project as troubled. Project managers who seek to limit legal responsibilities by avoiding liability for the outcome send an even stronger signal, indicating trouble is almost unavoidable.

Screening is a proactive process of gathering and modelling information. Screening is the questioning and checking done by the bank manager after the application in assessing the risk in the loan. The data gathering and methods of this thesis are a template for project screening. Moral hazard can be confirmed post project if the well informed insiders received almost all the benefits, but sustained little if any of the loss. The less informed outsider finds they have taken all the risks, taken almost all the losses, and received few if any of the benefits. The people paid to manage the project have taken the benefits but not been able to deliver any outcome promoted to the investor.

"Strategic misrepresentation is the planned, systematic distortion or misstatement of fact—lying—in response to incentives in the budget process."[157] As such it is difficult to prove outside a court of law, but may be modelled and patterned from the examples in case studies. The contrasts between exceptionally optimistic projections and subsequent lacklustre performance; where there is no other obvious reason; might reasonably lead to a well-founded suspicion of strategic misrepresentation.

Strategic misrepresentation should be differentiated from optimism bias. In optimism bias the proponent genuinely believes the projection and often shares in the risk. Where a management team, accurately report events and these insiders suffer loss, then optimism bias is most likely. Where firms like WMC have in optimism bias taken on too many challenging projects and suffered a reverse, the WMC management chose the path that gave the investors the greatest reward even at the cost of their own positions. The acceptance of responsibility for managerial actions is an indication of honest optimism bias being realised.

But here the management team report events in an evasive and /or repeatedly unrealistic manner, transfers losses to less informed parties, shows unusual diligence in avoiding legal responsibility, whilst maintaining their own significant rewards, then strategic misrepresentation is more likely. A confirmation would be that the finally revealed losses are dramatic, unexpected to outsiders, and involve the insiders in no losses. The planned, systemic and effective transfer of risk and loss from the managing insiders to the investing outsider is a strong indicator of strategic misrepresentation.

Strategic misrepresentation might be active or responsive. In active strategic misrepresentation, the insider is the architect of risk transfer to the outsider. In responsive strategic misrepresentation the insider is not the architect of the disaster, but the manager who can see an inevitable disaster coming and takes every careful step to ensure minimal losses for their own party.

A firm that has a poorly considered commercial undertaking forced upon them, by superior force, might gain a better outcome by going through the required actions. By managing and planning for the almost unavoidable negative outcomes they aim to meet statutory requirements, avoid the superior force penalties, and minimise or transfer the losses that will inevitably occur.

Whilst strategic misrepresentation may have a limited financial sacrifice involved for the insider proponent, the bulk of the loss is borne by the investing or contractually participating outside parties, and the bulk of the benefit is won by the strategic misinforming inside party.

The problem in assessing where optimism biases (a genuinely held belief) ends and where strategic misrepresentation (a systematic plan to deceive) starts is not new.

The maxim attributed to Lucius Cassius Longinus Ravilla, a Roman Consul of 127 B.C. who asked “Cui Bono” translated from Latin as “who benefits”, or” to whose benefit”; could well be applied. The logic behind the question is the assumption that the person or people responsible for misfeasance may be found among those who have something to gain, or have retained financial gain as a result of their actions. In modern U.S. terminology “follow the money trail” says much the same.

Proponents with optimism bias often invest their own capital in the venture, and suffer loss. Having optimism bias they may fail to foresee the responsibility they will bear if the project fails, and do not plan carefully to avoid legal liability.

Proponents with strategic misrepresentation in mind have two well-formed models of reality. The first optimised one, of great benefits, is loudly proclaimed, and lavishly illustrated. The second pessimistic one is where they want to be sure they are not found responsible; usually has very few words or small print. Where both can be seen in a prospectus or a series of presentations there is a higher probability of failure.

With Asymmetric information “Risk comes from not knowing what is being done or why the insider proponents are doing it.”

The concept of information asymmetry being abused, to the benefit of the insider, at the expense of the outsider, is long standing. American author Samuel Clemens, writing as Mark Twain (1835-1910) was quoted as saying "A mine is a hole in the ground with a fool at the bottom and a crook at the top." This encapsulates the idea of abuse of information by strategic misrepresentation elegantly.

The model, based on this rather complex preamble is as follows.

- The level of information asymmetry between the parties is potentially the level of power unbalance in contract and or management responsibility; should the better informed party have wish for avarice or need to exercise this power in self-defence. The extension to existing theory is the concept of “active strategic misrepresentation” or self-benefit and “reactive strategic misrepresentation” or self-defence. This is the same sort of question asked for in a violent homicide … did the survivor seek the outcome, or find they had to defend their interests with whatever force was required.
- The level of information asymmetry is all important. Where the parties are both well

informed of the opportunities and risks of a venture, based on a long history of implementing previous similar agreements, then there is little power disparity or risk. Where the less informed party is uninformed to the point where they are incapable of adequately understanding the process, the market, and the probabilities of risk, then an adverse outcome is more certain.

- Government by control of resources and the apparatus to make and enforce laws is usually in possession of superior force. Operators and project proponents by experience and knowledge of the project details are usually in possession of superior information. Government uses the power to tax to implement social policies; business uses their knowledge of transforming operations and markets to make profits. They are fundamentally different in outlook. There is an asymmetry of power on one side against knowledge on the other. Both sides can easily lose, if the group with power dictate non-commercial outcomes.
- Adverse selection and moral hazard are divided by the contract, but otherwise closely linked. The adverse selection chosen by one party largely leads to the morally hazardous practice that follows.
- Structuring a project to avoid responsibility for an outcome that the information rich can foresee as probable, whilst advising or signalling to the information poor almost diametrically the opposite; is common to self-benefit and self-defence strategic misrepresentation. Optimism bias firms send similar signals, but do not focus on responsibility avoidance, as they believe the signals they send.
- In strategic misrepresentation the risk and cost of failure is disproportionately carried by the information poor, the least informed, and the benefits flow by the same tilted margins to the best informed regardless of, even in spite of, actual outcome or performance.
- The outcome of information asymmetry, when driven by greed or need, leading to strategic misrepresentation, in this study, is predictable. The under informed investors, stakeholders, government achieved a much worse outcome than proposed, but the informed proponents suffered limited losses and are well rewarded beyond actual performance. The preferred alternative model of competent firms using their information advantage to provide reasonable outcomes for investors and customers is the common model with most successful firms following this path.
- The unwelcome outcome is market failure, when the allocation of “desirable

activities" is not efficient, or there is a failure to halt "undesirable activities" that lead to economic waste[158]. Economic waste is a situation where the loss to one side was not balanced by gain to the other.

The model for asymmetric information has five parameters, which may be indicative of success or failure outcomes. These are shown in Table 16.

Table 16 Asymmetric information and strategic misrepresentation model

Asymmetric Information failure model	**Asymmetric Information success model**
High of information asymmetry and power imbalance	Low of information asymmetry and power balance
Driving force exists for strategic misrepresentation	Limited motivation for strategic misrepresentation
Asymmetrical information used to manage ignorant power	Open and commercial access to resources
Loud strategic misinformation to promote investment	Little information noise on good projects
The project made a loss that was unexpected	The project made a profit that was expected

The first criterion is where the there is a high level of information asymmetry, such as where proponents of a new process plant had detailed information of technical difficulties in the pilot plant, but were seeking to use the power imbalance implicit in that to present a quite different outlook to uninformed investors in the project.

The second criterion is where a party possessed of crucial information is subject to a strong driving force that leads them to strategic misrepresentation. This could be opportunity for enrichment, or self-preservation or a little of both. The informed party may have valid reason to feel that they face irrational force majeure that is beyond their reasonable control. Dealing with government bent on uneconomic and unavoidable requirement could cause a party to take actions they would not normally choose.

The third criterion, and this is related to the second, is that the access to resources is open and on a commercial basis. Where the exercise of sovereign power is seen as ignorant of reality or capricious in allocating valuable resources, the choice is either to loose or play a game as adverse in outcome as the exercise of power.

The fourth criterion is where selective and strategic misrepresentation is loudly given to promote investment in projects with high risk, by firms with little competence. The louder the promotion, the longer the promotion goes on, the less informed the targeted investors are all signs of a campaign of commercial strategic misrepresentation. Good projects from competent firms have often raised all the capital they needed, quietly from well informed investors.

The fifth criterion is the return of a profit that was expected, or a loss that was to some unexpected. Where there was a high level of asymmetric information, leading to strategic misrepresentation the loss was unexpected to the uninformed outsiders.

From examining hundreds of annual reports over the 18 years of the study, the firms that are competent have concise reports where one can find the production statistics in less than 15 seconds, and can see that they are transparent. The reports are prepared for professional investors who want hard numbers. Firms that failed, with evidence of strategic misrepresentation involved in attracting capital, have the glossiest reports, often with many unrelated pictures of attractive and blissfully happy indigenous children on many pages. Production reports may be difficult to find or are simply projections that cover a range of figures from unbelievable to outlandish. The report that tells of 87,635 tonnes of copper produced in third quarter, down 3% due to a failure in crusher control gear that took 4 days to fix is believable. A report that states that 100,000 to 600,000 ounces of gold will be produced, just as soon as the latest share placement is complete, is an invitation to fantasyland.

Unsuccessful resource transformation firms use information asymmetry routinely, and egregiously; and thus fail. Successful firms have no need to do so.

3.7 Conclusions

The models are derived from what was seen in the case studies. They reflect the patterns in the data.

Each of the five models has been reduced to five key indicators with a distribution with success and failure extremes. In the case studies the best outcome examples show the success indicators, and the worst outcomes show the failure indicators.

Chapter 4
Observational outsider data

"Research is to see what everybody else has seen, and to think what nobody else has thought." - Albert Szent-Gyorgyi

4. OBSERVATIONAL OUTSIDER DATA

4.1 Introduction to methodology

The methodology to be used is mix of qualitative and quantitative data available to an outsider. Sixteen measures are used in this analysis, ten are qualitative and six are quantitative. The qualitative relate to inputs that influence the outcomes, and description of the outcomes. The quantitative data are indicative calculations based published numbers relating to the performance of the project in its life.

Qualitative research is word based, and includes stories and evidence. The aim is to understand human behaviour and the reasons that govern such behaviour. Quantitative research is number based, and includes statistical, mathematical or computed data techniques.

The qualitative and quantitative data is derived from a longitudinal series of 67 case studies over 18 years, from January 1993 to December 2010. The case studies were those projects shown by ABARE as resource processing projects with a planned investment of over $100 million. Projects that extracted coal, or iron ore, or gas that was then reticulated by pipeline; have only minimal processing stages that modestly transform, and add limited value. The majority of investment is in the extraction and transport, not in elaborate transformation.

The cost of the process plants; and the cost of the extraction process are difficult to determine separately, and vary with the location and geology of the resource, as well as the type of process plant. The total cost figure is the only one shown in ABARE and press publications.

The ABARE data provided the complete set of case studies. Data from Company Annual Reports, articles from newspapers, trade journals, and professional institute publications provide greater detail of what is in the public domain.

Practical and empirical data collection for this thesis took place during plant visits, involved operators, process experts, and financial analysts. They often highlighted facts that the firm did not want public. Where the public statements and the expert analysis were in sharp variance, more research was required; and more detailed case studies will follow. It will be no surprise that failed projects had a much greater variance between what was presented, and what apparently happened.

4.1.1 Limitations of the data, and advantages

The case studies use best available information in the public domain; which may be somewhat at variance with proprietary data. Firms have many incentives to put the best public face on adversity, and may release favourable views of data selectively, or “massage the numbers”. Enron famously hid the true state of their financial affairs with a range of morally hazardous reporting and accounting practices; over many years. Table 17 shows the sources of the data.

Table 17 Sources of data

1	ABARE	Minerals and Energy Major Developments Projects
2	ASX	Company Annual Reports
3	Government	Specialist publications and webs sites
4	Trade press	Technical and project articles
5	Online references	of variable veracity
6	Newspapers	Business articles
7	AusIMM	Papers and confrence proceedings
8	USGS	United States Geological Service
9	Company websites	Project descriptions and statistics
10	Site visits	to a number of projects
11	Personal contact	with project participants
12	Court actions	with damages awarded

The initial selection of sixty seven mega projects with initial cost of greater than $100 million was taken from published Australian Bureau of Agricultural and Resource Economics ABARE data. This organisation is now named Australian Bureau of Agricultural and Resource Economics and Sciences ABARES. This date is independent, but represents what firms have told them. ABARE also published data on commodity values at monthly intervals, which were used to calculate Commodity values, Pay-back plan measure, Return (actual pay back).

These Commodity values are matched with data taken from United States Geological Survey (USGS) published data, and also with data from London Metal Exchange (LME).

State and Federal Government departments, such as Geoscience Australia, CSIRO or Western Australian Department of Industry and Resources are examples of Government data resources.

Where possible data is taken from published Annual Reports, where the data has a legal requirement to accurately represent a true state of affairs, and these figures are used in preference to any alternatives. Company annual reports are retrospective; and by their nature seek to reassure the shareholder, and explain in the best light what has happened.

Trade press are technical in focus, and promotional in outlook, but they can provide an “insider insight” into a project. An example would be the details provided on the use of Pre-Assembled Modules (PAM’s) in the Gove G3 project.
Online reference to projects are low in cost to access, and at best cause one to think about an issue and seek verification on an insight or viewpoint otherwise not considered.

Australasian Institute of Mining and Metallurgy (AusIMM) papers, monographs, conference proceedings and site visits are part of the data gathering in this thesis. What is publicly presented in print and at conferences is almost invariably positive, not untruthful, but carefully selective. Professional organisations do not seek to invite criticism or scrutiny of their less successful activities. However in private conversations a different accounting can be heard.

Newspaper articles and internet sources are also used to try to fill in gaps in knowledge, of what must be an incomplete data set. All were freely available and open to the public. Many are written by journalists who have been following the industry for some time, and are keen to reveal as much as they can.

Where a figure is shown; in the next section; such as project cost, this is the figure from the most trusted source; or the most frequently mentioned figure. The numbers are comparative rather than absolute.

Some firms are more transparent than others in their public data, others more opaque. The more imaginative and visionary statements made by entrepreneurial promoters contrast later releases that ameliorate the different outcome.

Large and difficult projects are found to be better documented, and more extensively studied than upgrades in capacity at existing plants that appear to have been accomplished. This is because there is little data available, and because of the usually low risk and successful nature of the projects. Their existence, size and value are counted to balance out the more well known cases. Data for construction time of alumina and aluminium smelters is largely estimates, as the exact start and finish date for extra capacity is not widely publicised.

Project start and completion dates are more often estimates from ASX and ABARE data, and are indicative only. The exact start and finish of a project is very much whatever the operator says it is. A resource processing site being private property, and secured for safety; so is a black box. Project cost from the outsider view is also, what the company chooses to report.

Every project described in this study was designed to elaborately transform a resource into a higher value and more compact form. The planned performance of the plant is "nameplate capacity" or the mass of output meeting a commercial specification. But for hard rock mining the limitation is the capacity constraint is the volume of ore it can process. The feed in of a carefully selected ore with many times the planned grade of gold per tonne, can allow greater than nameplate capacity, and hence profitability, early in the operational ramp up. In small to medium gold process plant the mining and stock pile of the richest grade ore is an indication of an exceptionally competent and experienced team.

The data that is available for outsider modelling is not as accurate or immediate as proprietary data available to insiders. However it is more difficult to massage, and over many projects and many years presents a different view point to insider data. This outsider data can be modelled for understanding of the mechanisms in the black box, especially the efficiency at converting investment into desired outcome.

Outsider modelling examines inputs, specifically investments, and firm capabilities against outputs and outcomes. An output is the plant production; the outcome is its value when multiplied by the commodity price. This study focuses most on the relationships between investment, and the ability to repay the investment; a risk factor. It also examines a range of factors and measures that are evident to investors before a project has started, and investment has been made.

Investment in firms and projects often comes from the public. The public can only utilise public information to make their choices. Thus they invest with limited and asymmetrical information, in the hope of increasing the value of their investment.

The general model of collection of inputs and outputs may be used to model almost any black box activity. A black box activity is one where the internal workings are not transparent, or are deliberately obscured. The internal functions of a private firm are proprietary. But their inputs, outputs and outcomes can be modelled over time. Where the public pronouncements about the firm's success or value are not matched by the model, moral hazard is suggested, and the risk to investment increased. The wonderful business success claimed by Enron, and the quarterly profits regularly reported, was in conflict with the increasing size of borrowings from a host of financial institutions. Once this was realised by investors and lenders the firm quickly collapsed in debt spiral.[159]

In the public domain, the comparison of the benefits that will flow from public investment, with the actual benefits finally delivered; in a range of government programs, invites modelling of black boxes. The funding inputs for rail infrastructure or indigenous housing, or defence procurement are consumed within the black box, but the proposed benefits are often delayed, and or well below that originally proposed.

The provision of housing to indigenous people in the Northern Territory would be an example. The Australian Broadcasting Commission reported[160] on 31st August 2009 that after investment of $672 million, and a time of 18 months, not a single house had been built. This can be compared to an earlier news article[161] from 2006 where the then indigenous Affairs Minister Mal Brough revealed "the federal Government cannot account for what happened to $2 billion given to the states in the past decade to provide houses for Aboriginal communities. The states and territories have been unable to answer a request from his department asking how the taxpayer funds were distributed and where or how many homes had been built with the money."

Thus an outsider model of inputs, specific to a worthy cause, and outputs for which the money is directed, might reveal a high level of inefficiency within the black box.

By comparison with public sector black boxes, the majority (more than 70%) of resource transformation projects had outcomes that reasonably matched, and in many cases exceeded their investment objectives.

4.2 Data collection steps for an outsider model

The first stage of data gathering was to select the 67 projects over $100 million, where there was elaborate transformation. The Australian Bureau of Agricultural and Resource Economics (ABARE) first started collecting data on new resource projects in 1993. This data was published annually and then biannually till April 2011 when it halted. It is an independent source of public information, prepared by an Authority with an interest factual statistics. Recent data is available from their website [162] and early data is held (in booklet form) at the National Library of Australia.[163]

By taking data on the 67 projects over 18 years a longitudinal study is also possible. The proportion of harvested to transformed resources has changed between 1993 and 2010, with iron ore and coal becoming more important and valuable. Also the cost of plants to produce a given volume of a commodity has risen over time.

From this ABARE data every (elaborately transforming) project with an initial project value over $100 million was selected. Projects that only harvested resources, with minimal transformation were not included. Iron ore and coal are only moderately beneficiated. The extracted product and shipped product are only minimally transformed to meet specification. Natural gas fed into a pipeline after stripping of water, inert gases, and sulphur compounds, is equally only moderately transformed. When it is compressed by 614 to 1 in volume, and reduced in temperature to -162° C, it has been elaborately transformed.

The second stage of data gathering was to seek news articles and commentary from media and trade press to understand what was relatively common knowledge.

The third stage of data gathering was to seek informal insider comment from those participants willing to discuss projects they were involved in at conferences, social function and mine visits. In the Toyota Production System[164] one of the ways to understand and solve root problems within an organisation is to "Go and see for yourself to thoroughly understand the situation" (Genchi Genbutsu). By visiting many of the plants and talking with participants informally and off the record, it is possible to find "where to look for the bodies."

These insights led to the introduction of some new factors related to isolation and competence levels. An example would be the case of the then largest, and most complex chemical engineering plant in Australia. An operator from the plant[165] advised: "The reason that the project will fail is that it is run by a bunch of fly-in fly-out miners, who don't want to be there." Another would be for different case: "The contractors soon realised that the project was doomed, and put their B Team on the job." This sort of comment can neither be used as evidence, nor presented as attributed data. But they do enable a data structure to be structured to look for more solid evidence or numerical data that either confirms or denies the idea.

The fourth stage is to read through annual reports from local firms in the years before and after the project was built and operated. The second and third stages have built up a list of suspicions that the reports can confirm, or provide numerical measures on which to evaluate the gossip.

Connect4 is a Thompson Reuters service of Australian Company Information provides a valuable resource for much of the hard data.[166] This is accessed through the Sydney University Library online.

Australian Company Reports are legal documents, and should be accurate and truthful. Some are models of transparency, closely associated with competent firms, and ethical management. Production statistics are easy to find, and are shown in comparison to past performance and expected nameplate capacity. The firms are proud of how well they are transforming resources with the investors' capital.

Other Annual reports are evasive and misleading, usually associated with firms with less obvious competence and ethics. This is difficult to quantify, but is a recognised phenomenon.

Annual reports provide both the stories and the numbers. The story of how good the ore body is and the riches that will follow can be contrasted with the actual production performance data. A simple metric would be to equate the competence of the firm with the timely delivery of the proposed outcome, with minimal cost overrun. This is shown in with the measures that look production performance proposed before the project and actual delivery in the 36 months after, with the commodity price included.

The fifth stage is in compiling data on supply, demand and commodity process. Australian commodity prices for most commodities are from ABARE, and are shown as ABARE Commodity Price Appendix. Data on supply and on US costs on a wider range of commodities comes from the United States Geological Survey (USGS) website[167]

The sixth stage is in compiling the data into large Excel spread sheets that encompass all 67 cases, and the range of factor and measures later discussed. These spread sheets are shown in the Appendix section.

Once this was accomplished the data was structured along the lines of the five step model of Dan Lovallo and Daniel Kahneman model described in Chapter 2 where he identifies that a new process may be more important class that the type of transformation. So the iterative process followed was as described in these five steps.

(1) Select a relevant reference class of past, similar projects. The class must be as broad as possible to visualise meaningful distributional but narrow enough by key parameters to show patterns and variations within a project class.

(2) Establishing an input and outcome distribution for the selected reference class. This requires building a census-like database of credible, empirical data for all similar projects within a project reference class, in a location with similar customs and law, and sufficient time to watch evolution of inputs and outcomes. Sheets 1 and 2 in Appendix do this.
(3) Compare similar projects, by distribution according to risk factors, to observe patterns and variations. These patterns and variations may be modelled to give increased understanding, which may be used to manage future projects, or avoid obvious risks. Sheet 3 in appendix covers risks, sheets 4, 5, 6 and 7 show outcomes related to risk for the four hypotheses.

(4) Examine how well the modelling explains in the simplest possible manner the more numerically significant patterns of most common outcomes and the less common anomalies.

(5) In the light of case studies, adjust the models till they match all the data. The evolved models are shown in Chapter 3.

4.3 Project classes

The 67 projects are broken down into 6 classes. New process plants, Gases transformed, Light metals, Mineral sands, Nobler metals, and Baser metals. This differentiation is a fundamental element of reference class forecasting. New process plant investment was unusually risky, 99% of investment failed, and this class of investment is now not well considered. Gases transformed, especially LNG was remarkably rewarding and now represents a large share of new investment. The classes and data are shown in Sheets 1 and 2 of the appendix, and briefly described below.

4.3.1 New Process Plants

Twelve "New Process" projects were new technologies to transform resources by innovative processes. All plants were the implementation of a new or significantly improved process, which aimed to transform a difficult resource into a higher value added commodity.

Some were more radical innovations, of first in the world or first in country processes. Three projects were based on extensive local research and development. (Cases 7, 8 and 40) Six were first in country plants for processes that were not well proven overseas, (Cases 1, 2, 6, 7, 8, 40) and two (Cases 9 and 10 process inter-connected plants) were the effort of a firm without specific focus to use modified processes based on an earlier least-worst failure.

All but one (Case 40) destroyed the majority (between 90 and 95%) of the original investments. Eight plants are closed and/or demolished, 2 are under new management, with one producing a fraction of nameplate capacity, and the other abandoning the new processes and operating an older (and pre-existing) 30 year old pyro-metallurgical plant with apparent success.

4.3.2 Gases Transformed Plants

Eight “Gases Transformed” projects included Liquefied Natural Gas (LNG), Fertilizers and Explosives from natural gas, and Acid plant projects. All eventually succeeded with the majority of investments yielding good returns. One plant (Case 13) was a struggle for the original owner; then a windfall for the new owner as commodity prices changed. The others returned handsome yields to competent owners.

4.3.3 Light metals plants

Eleven “Light Metals” projects transforming Bauxite to Alumina and Alumina to Aluminium. The technologies are exceptionally well known and developed. Commodity price fluctuations were the major risk. Over production may have influenced negative commodity price trends. At time of writing (February 2014) one older Aluminium Refinery at Kurri Kuri had closed, and the Alcoa Point Henry Aluminium Smelter and the Alcan Gove Alumina plant had closure announced due to low world prices for Aluminium.

4.3.4 Mineral sands plants

Eight “Mineral Sands” projects returned seven good outcomes to experienced operators and one poor outcome to inexperienced investors. In case 33 only 1.2% of the proposed 175,000 tonnes per annum was ever produced and when the firm folded investors lost their capital.

4.3.5 Noble metals plants

Twenty seven “Nobler metals” projects covered the extraction of higher value metals like Gold, Copper, Nickel Sulphide, and Vanadium, usually from hard rocks in relatively low grades. A few parts per million of gold to 1-2% or less for copper or nickel, is indicative of the low grades. These grades declined over time. Three firms failed, destroying much of the investment, but this is a sector dominated by experienced firms with moderate risk.

The three cases of failure were Case 46 where production reached 88% of that proposed, but at a higher cost of production, at a time of low gold price, and with a flood thrown in. Case

52 only produced 50% of nameplate capacity, and experienced difficult market conditions, possibly aimed at assisting the firm to fail, and maintaining market demand and price of vanadium. Case 60 only reached 26.8% of projected output, largely due to the lack of gold in the ground in anywhere like the volume the investors had been advised.

4.3.6 Baser metals projects

Five “Baser metals” projects covered Zinc and lead, with traces of silver. The lead and or zinc is often at higher grades ~ 10% metals, but the zinc and lead have had limited demand and flatter commodity prices than most other commodities. All projects succeeded, some better than others.

4.4 Factors and measures

There are sixteen factors and measures. The first ten explain and potentially predict the outcomes shown in the last six. These are shown in detail in sheet 3 of the Appendix spreadsheet, and are selectively used in Sheets 4 to 7 to show 804 data points over the 67 projects in a semi visual manner. Patterns and anomalies may be more easily seen, which has led to more hypotheses and models to explain.

The pattern shown in charts 4, 5, 6, and 7, is that the chart is a progression in time from initial planning, from the top down to the conclusion of a project when it has either failed or worked well for many years. The risk indicated in positional location in these four “hypotheses charts” are from the theoretical highest risk of failure at the left to theoretically least risk at the right over the sixty seven projects.

The first ten are in the planning and estimating time zone, and might be used as a predictive measure for a considered project investment. Anomalies are easy to see in this form, as a red flagged failure from an otherwise successful firm invites closer scrutiny.
Shown in Table 18 are the factors in a time sequence from before to after project.

Table 18 Sixteen factors in time sequence

Time	Parameters	Greatest risk	to	Least risk
	Visible before project start			
Planing	**Past record of firm**		**>**	
	Process focus of firm		**>**	
|	**Scale-up ratio**		**>**	
v	**Financial confidence**		**>**	
|	**Innovation type**		**>**	
v	**Government involvement**		**>**	
|	**Value-adding level**		**>**	
v	**Information Asymmetry**		**>**	
Estimating	***Visible after project build***			
|	**Commodity value**		**>**	
v	**Pay-back plan measure**		**>**	
Building	***Project build factors***			
|	**Time management**		**>**	
v	**Cost management**		**>**	
Working	***Visible after project operation***			
|	**Production performance**	*typically*	**>**	*typically*
v	**Return (actual pay back)**	*poor outcomes*	**>**	*good outcomes*
Outcome	**Life of Firm**		**>**	
	Life of Process		**>**	

The first eight are input factors that differentiate projects by characteristics that are visible before a project has commenced. These factors are elements of understanding and explanatory models. All are Qualitative, and are derived from the gradation of the factor, by Improper Linear Models, as with an APGAR score.

These first eight factors, shown in Sheet 3 of Appendix are qualitative with classes ranked from most risk (and or least competent) at 0.1 to least risk (and most competent) at 0.5. The qualitative data can thus be entered into a mathematical model easily. The full table, with descriptions of each level of risk is shown as Appendix 16 Project Factors in the Appendices.

The next two factors are based on numerical data, worked into simple models. Commodity value is the average price for the commodity or commodities to be produced by the project over the 36 months prior to commissioning. They are thus indicative of the value per tonne of production produced. Pay-back plan measure is calculation of how long it would take to pay back the investment if the plant is built for the investment proposed, and works at nameplate capacity, and the commodity sells for the prices that have previously existed. These are explained in greater detail in the next section.

As a project is built two factors attract attention, the time taken to reach commissioning, compared with the time proposed in the plan, and the cost of doing so, as compared to the initial budget. Projects that take more time to complete, and require a greater budget than planned are at greater risk of failure than those that are close to time and budget.

Once a project is operational the actual production performance compared to that proposed becomes evident. A significant shortfall is a risk indicator, and is related to project failure.
The calculated actual payback time is similar to pay back plan, except that it uses actual cost of completion rather than proposed, and adjusts for actual production performance at the commodity price that existed in the 36 months after the plant began operation.

The 10 factors that are visible to the outsider whilst a project is in a virtual or planning stage, can, given reference class forecasting models give a probable outcome, when only a small percentage of project cost has been invested. This is before the first steel is cut or joined, before the first concrete has been poured. The predictive indications are valuable to a potential investor, as well as an operator.

4.4.1 Detailed description and working of project factors

For the ten factors that are visible before the projects starts

Factor 1: Past record of firm

The past record of the firm, with a record of similar project outcomes is a good indicator of future outcomes. A firm develops an organisational culture, which changes relatively slowly. People comfortable in the culture adapt to it and pass the culture on. Competence in a firm can grow gradually or decline gradually, but in the 18 year study, tended to be relatively stable. Firms with exceptional competence largely built upon their skills; and firms with more generalised competence either selected less challenging projects, or came to commercial grief. New firms were far more risky that established firms. A few new firms were built by astute amalgamations of exceptionally competent management from previous successful teams, and prospered, but these were the exception. Many other firms with less skilled management, without a successful past record, suffered very poor outcomes. The difficulty in assessing the competence of new firm is that it must be done by very careful examination of the new team's skills, motivation and culture. A firm with long and mostly successful record would be "mature" in Halbe & McNulty model terms.

The scale runs from greatest risk at .1 to greatest competence at .5 by relatively simple classing. The observation by Warren Buffett that *"risk comes from not knowing what you are doing"* explains the concept well.

.1 Is a new firm, only traded on the Australian Stock Exchange (ASX) in the previous 3-5 years, without any record of major project success. No dividends have ever been paid to investors or shareholders. The assessment of their risk thus depends on evaluation of the skills brought together by the new management team, and how well they work together, which is a more complex study, outside this work.

.2 Is a firm with a short history, traded on the ASX, with only short history of dividend payment over a short history (less than 5 years) of trading. Where a firm has had a complete change of directors and management; the old culture; and hence indicators to predict their actions is lost. (They would go back to being a .1) A firm that has changed its name, and risen like a Phoenix from the ashes, with the same directors would remain a .2, but would attract a more careful and critical review in the asymmetric information measure.

.3 Is a firm with an established history overseas, but in the particular project new to Australia. Firms with a long record of Australian investment and operations over multiple projects are not included. Firms with specialised focus in a particular transformation can bring exceptional competence to a new project, where as a firm with a questionable record in their home country can be at high risk; hence there is a strong interdependence with other measures.

.4 A firm with a long track record over many years (more than 10), and where the firms good results were much greater than the occasional poor result. A diversified resources firm has strength in terms of balancing the economic and commodity price risk, but a weakness in that they cannot be focused in all the areas where they operate. The largest resource firms must be in this class as they are so widely diversified, but over time have made a few bad calls.

.5 Firms with a long record of successful project outcomes have over a long time returned superior outcomes to the industry and market in general. This is associated with exceptional competence in a relatively specific area of resource transformation, and thus is linked to the next measure. A measure of these superior outcomes is in the control over cost growth and project delay, and in meeting and exceeding nameplate capacity quickly after commissioning.

Factor 2: Process focus of firm

The development of a narrowly based core competence, refined by continual incremental improvement, is at the heart of any productive specialisation. Firms that specialise in a single process may build up a knowledge base and practical expertise that enables them to produce exceptional results with low risk.

Firms that had a broad spread of business activities, often performed better in areas where they had their key skills, such as securing, transporting and shipping moderately transformed resources. When they tried transforming difficult ores; that required particular competence, their performance was often disappointing.

.1 Is for a firm with no track record in the specific transformation process. This is closely tied to the degree of process innovation. Processes that are have severe conditions of temperature, pressure, acidity, or potential for dangerous outcomes, like fire or explosion present a higher combined risk the new entrant. Processes that are not well developed or fully understood equally increase risk for inexperienced firms.

.2 Is for a firm with limited experience in all key skill areas. The key skills are those required to master the most challenging risks. The skills gained in operation of one type of concentration plant, are reasonably similar to another type of concentration plant, and or a different resource.

.3 Is for a successful firm, with a diversity of processing plants, and thus a broad skill set in mineral processing. However they do not have specific skill and well demonstrated sets for unusual or challenging projects that involve unusual and specific skills. Again this is strongly tied to the level of innovation.

.4 Is for a successful firm, which has a demonstrated skill set closer to the challenges that are presented in the specific project. A transformation project innovation in a field of expertise that was related to the new project presents less risk.

.5 Is for a successful firm, with close focus on specific resource transformation process. They are often solely focused on just one specific resource transformation, and have an internal culture of continuous improvement and cautious innovation. Their expertise in the transformation is their core business value. They cannot afford to get it wrong, and thus devote considerable investment and energy to prompt and successful outcomes. These firms are core competent in their specialised area, and are often associated with better than average outcomes in their class of projects.

Factor 3: Scale-up ratio

A firm building a moderately larger scale of an existing plant faces low risk. They would not be duplicating if the process had not worked well and made satisfying profits. Conversely, a firm who have never built a $100 million plus plant before, and / or have no prior experience with the type of plant and process, have significantly greater risk. Past record, process focus, and scale up ratio are combined into a risk profile. A firm with 5 in all has very limited risk; a firm with 1 or 2 in all is managing high probability of failure.

The same may be illustrated with commercial aircraft pilots or brain surgeons. Their expertise is built up over a long time with progressively greater challenges and successes. The pilot of a 400 tonne Boeing 747-400 probably starts learning in a 1 tonne single engine Cessna; and worked up; over many years in aircraft size, length of experience and professional responsibility.

.1 Is for a new project that has no predecessor, thus is an infinite scale up. Logically this entails high risk. If the team have exceptional skills it might work, but a $100 million plus resource process project is a bit like taking the first flying lesson in the 747. Not for the faint hearted investor.

.2 Is for a new project that is a massive scale up, more than 5 times from an earlier working example. If the scale up is a new technology, and the previous plant was the pilot plant used to “prove” the process, there is high risk level. Pilot plants are for questioning and learning, not showing and demonstrating.

.3 Is for a scale up of an existing, successful, commercial process plant by 2 to 5 times. The fact that the earlier plant has been a commercial success, (the only rational reason to up-scale it), reduces risks significantly.

.4 Is for the duplication of an existing plant, with all incremental improvements available, of similar size to double size. The risk, apart from commodity price loss, is quite moderate.

.5 Is for duplication of an existing plant, with any incremental improvements available, of generally similar size, as the previous plant was notably successful, and well adapted to the new resources. This has the lowest risk.

Factor 4: Financial Confidence

The type of investment sought for a project is also an indicator of potential outcome. At the highest risk end of the spectrum the least well informed investors are targeted, with selective and strategic misrepresentation and attractively high interest rates. At the other end of the risk scale are firms whose project success is so trusted that they can finance a new project at the most favourable rates, from investors who are well informed, such as the existing consumer of transformed resources.

.1 Is for raising capital in high risk projects, with unusually high finance cost. Marketing to investors with limited knowledge of the local risks, via overseas bonds, or shares promoted with unusual methods and enthusiasm; is an indicator that the investors who are better informed have decided that risks are too apparent. Wording in the prospectus documentation, that absolves the promoters and or managers of responsibility for adverse outcomes is a third high risk indicator. No firm at this risk level was succeeded. There was actually little uncertainty, failure was assured.

.2 Is for shares floated on the ASX, where the risks were seen by the market, at the time, as reasonable. The difficulties the underwriters had in achieving share placement been an indicator of the perceived risk level. The nature of the venture, the experience of the management, and how this relates to risk; is covered in other factors.

.3 Is for established firms, with sufficient track record, and assets, who can borrow on commercial markets as various degrees as a trusted firm. The smaller firms are borrowing at business interest rates determined by the banks estimate of risk, and the enthusiasm for lending at that time. Larger firms can issue "commercial paper", secure attractive loans in financial centres, or issue bonds at close to AAA rate. Smaller firms, with perceived higher risk pay more for their capital and proportionally with fees.

.4 Is for larger firms, who are able to finance new projects from their cash flow streams and forms of lower cost capital. The integration of the revenue flow from substantial sales, and capital needs, within their financial departments is one of the major advantages of the largest resource processors. With well managed finances, and control over a significant share of a traded commodity a firm has the opportunity to manage the market to a degree, lowering risk.

.5 Is where a firm with a track record of successful projects, can seek the majority of its new project finance, from the purchaser of the transformed commodity. This only works where the firm is trusted by the consumer and the contract is a long term supply. Liquefied Natural Gas is one such commodity, where the contracted price can be adjusted to cover the finance costs. This is very attractive capital, and indicates that the risk of failure is negligible. No project financed at this level failed.

Factor 5: Innovation type

The more radical types of innovation in a new process plant are strongly associated with risk. Only one firm in either of the highest risk level succeeded. The eleven others failed.

.1 In projects with new technologies, and or processes with radical innovation had the greatest risk. All six projects in this class failed.

.2 For New and radical technologies, with long and systematic pilot testing to work out the problems, and stage scale up of facilities is model proposed by Halbe & McNulty, to reduce risk. Of six projects in this class, five failed. The one project to succeed had the most extensive scale up pattern.

.3 For projects that had tested processes established and worked in commercial plants at scale, but with significant innovations. The significant innovations were often combinations of existing proven processes in a novel manner to solve a unique processing problem.

.4 Is for projects that used mature technology with some novel elements.

.5 is for projects that used mature and well tested technologies, with only incremental improvements usually introduced by the plant supplier. This is the lowest risk, and was often chosen by competent firms.

Factor 6: Government involvement

Government involvement was detrimental to some projects where it sought or backed a non-commercial outcome from the firm. Government involvement where they offered a valuable input to transformation, such as electricity or energy, at below commercial rates, for a long term, led to successful projects to produce Alumina and Aluminium.

Thus .3 is the median point of minimal government involvement, which is the basic licence to mine and royalty payment agreement relevant to the commodity. Lower numbers are for more negative involvements which increase risk, and higher numbers are for positive involvements that reduce risk.

.1 Is where the contract with the State Government includes non-commercial activities that the resource project firm accepts to gain another more valuable concession; and / or where government desire is a political outcome that challenges commercial reality.

.2 Is where commercially unfavourable terms were so onerous that the firm experienced difficulties; that might stop future investment or send the firm into financial hardship.

.3 Is the normal lease conditions for the type of resource, without any further involvement. Between 1993 and 2010 the number environmental conditions have increased significantly. In parallel the capital cost of transformation projects has increased at a similar rate for a number of reasons.

.4 Is where favourable infrastructure and concession are made by a State Government to attract a desired industry. Case 16 had such conditions.

.5 Is where State Government made the longest term and most beneficial concessions to attract an industry to their state. Selling electricity to an Aluminium smelter at below production cost is an example. Supply of natural gas at below export price to an Alumina smelter is another. The government buys a desired political outcome with an ongoing reduction of the major operational expense of the plant, at the expense of state taxpayers.

Factor 7: Value-adding level

There are strong beliefs and arguments to add as much value as possible within a state or national economy. Transforming $30 a tonne bauxite into $300 a tonne alumina, into $3,000 a tonne Aluminium, and then perhaps a $30,000 a tonne car seems like a good idea, with significant creation of wealth. Adding value increases technical complexity and risk. All failures were value adding projects. Projects that added minimal value were low risk.

.1 Is where value adding was a condition of the lease to access resources. The level of risk will vary with the commodity, and its price, and the costs involved in meeting the lease conditions.

.2 Is where a process plant is built to produce a fully refined commodity. In general this would be to produce a metal that could be sold via the London Metals Exchange (LME) standards of purity. Refineries require reasonably specialised staff, and present difficulties when located away from attractive centres of population.

.3 Is where the value adding process is a mature process, such as smelting gold Dore at a mine site. The gold may contain silver and or copper in variable proportions that are later refined out. Alumina and Aluminium production are also in the class, as the processes for gold, alumina and aluminium production are 1880's technologies that are well understood.

.4 Is where an intermediate or transitional level of processing is taking place. Case 16 is the only example, where low cost natural gas was transformed to Ammonia, by a mature and trouble free process.

.5 Is where the firm has chosen to concentrate the ore only sufficiently to economically ship the material to a consuming refinery. Concentration is a process stage where the metal content in ore is selectively increased from parts per million to a concentrate with 20-50% metal content. Concentration is a low risk.

Factor 8: Information Asymmetry

Abuse of Information asymmetry, leading to strategic misrepresentation with a perceptible avoidance of responsibility for outcomes is a danger signal for investors. Information asymmetry exists in the most competent, skilled and successful firms. They know how to conduct their transformation business better than almost anyone else. But they have a record of performance that engenders trust, and for which they are responsible.

.1 Is where high level information asymmetry, usually associated with strategic misrepresentation is used to allocate almost certain risk and loss to one outsider party and maximise potential for reward and avoidance of responsibility to the other insider party.

.2 Is where there is a limited responsibility for risky actions is accepted by those directing them. Management who invested their own funds into a high risk venture and held onto them in optimism bias would be an example. Management with some investment have a vested interest in the gentlest crash of a failed project.

.3 Is where average risks are balanced by average responsibility. A large corporation undertaking a risk venture can ask a board member to take responsibility for the project. Should the project fail the board member loses their seat on the board, and the respect and reward that goes with the position. The firm accepts the responsibility for payments to suppliers, entitlements to workers, and doesn’t take on larger risk than it can manage.

.4 Is where the risk level is lower than above, due less enthusiasm for risk and higher level of responsibility. They may make less profit than their more enthusiastic competitors, but they have fewer surprise losses.

.5 Is where the risks are lowest, due to the skills and accountability of the firm. Firms that are competent, have transparent accounts, and regularly make profits and pay dividends can be held accountable with little risk to management.

Factor 9: Commodity value

The value of the commodity can be the single most influential factor in project economic outcome, once the project is producing close to nameplate capacity, and with moderate operational costs.

The commodity prices used for this numerical indicator are the average prices over the previous 36 months or 3 years based on ABARE or USGS data.

Whilst the previous 3 years commodity prices are not a guarantee of the prices in the future first 36 months of operation, they are a simple indicator.

Factor 10: Pay-back plan measure

The data available to an outside viewer is far less complex that that presented for proprietary review. It is less subject to “massaging the numbers” and can be used to provide a single simple metric of investment to potential repayment. This metric is like the “Baltic Dry Index” (BDI).[168] The BDI is an assessment of the cost of moving bulk commodities by sea. As the available shipping fleet only changes slowly, then the premium or discount freight price for iron ore, coal, grain, even cement, is an indicator of expected economic activity about 90 days into the future.

If buyers of raw materials for production and construction believe that demand will rise, then the price for shipping rises. Alternately if the same buyers feel that economic activity will fall or be less rewarded, they consume local resources and/ or stocks on hand, and the price for shipping falls. Ships can only earn income whilst moving, so they have to accept whatever price supply and demand allows. The BDI is a simple indicator, not a perfect indicator. It dropped sharply in February 2011 as new ships were delivered, and flood in Queensland closed coal ports.

In the same way the index of proposed project cost to reasonably expected income is a very simple metric that is indicative of what should happen if all expectations are met.

A project has a capital cost that is stated and expected. The plant has a nameplate capacity, which in this example is expected to be 100%. The commodity price is an average of the previous 36 months, and so represents a reasonable expectation of what might be in the future. The operational cost of a process plant is variable, and hence the profit on each tonne transformed. However across diverse resource plants an average of about 50% is common. This is an expected cost to expected benefit measure.

So this simplistic indicator is “how long it will take to pay off the project if half the expected income is profit, and everything else works the way we said.” This will indicate projects with high costs and low potential profits, or vice versa, and how they rank against the median. This is a theoretical figure that can be used when project is being considered conceptually. If the “expected payback” time in months is unattractive, and the class of project has high risk, then it might be re-examined.

Also if the project was in a class where there was a higher probability of cost over runs, construction delays, and performance under-delivery, then the risk is elevated.

Project cost and time management statistics are insider data. The data publicly available to an outsider is fragmentary, and sometime contradictory. Firms that can quietly bring their projects in close to time and budget often reveal limited information that would allow fine statistical analysis.

Thus some results are recorded as 100% there is no data to show the exact figures; and no indication that the result was too far away. The real disasters are somewhat more transparent, in that the delays are so large they cannot be hidden, and the cost escalations so large they are frequently discussed in the media.

4.4.2 For the two factors that are visible after the project is built

Factor 11: Time management

Time management is the factor of the estimated actual build time over the projected build time listed in ABARE data. The start and completion dates are as far as is available data from annual reports, or from ABARE data. The ABARE data is from 6 monthly publications, and noting that a project was no longer under construction, so some error is possible. Firms are often a little vague as to when a project has been started; and equally unspecific as to completion and operational status. This may be partly to make exact estimation of project delays difficult to calculate, as it can lead to difficult questions from media, investors and shareholders. Time management can be expected to be related cost management, in that extra time usually indicates extra costs. Whilst the evolved data is imperfect, it is equally imperfect over a long period of time, and collected by the same methods. Thus it is useful for a range of comparisons in later chapters.

Factor 12: Cost management

Cost management is a little more publicly transparent than time management. I have taken as the base point the original cost estimate first shown in the ABARE tables compared to the best estimate available of the actual project cost at completion. The estimated project cost is divided by the original ABARE cost to give a percentage. This results in a usually larger cost over-run than time over- run. This is an imperfect measure in that it compares only what firms told ABARE, rather than actual figures. However it is applied equally to all projects, and indicates projects whose costs grew in planning stages.

A poorly considered project may suffer a significant increase in cost before it even started. This is often related to continuing cost growth in construction. A project with a 300% cost increase is obviously at a severe disadvantage in a cost to benefit analysis, and would be expected to be at much higher risk of failure.

Firms can deal with cost over-run in two ways. Where the cost over-run is for project that could send the firm broke, there is a temptation to move cost over-run from capital expenditure to operational expenditure. This can result in a modest cost over-run, but a build-up of operational expense that can be fatal to investors. This will be explored in later chapters.

Alternatively where a firm is very large and profitable, and the cost of the write off will be partly balanced by reduced tax payments there is a temptation to show every dollar invested in capital on a bad project to maximise the write off. This is not to say every firm did so, but there are financial temptations to do so.

4.4.3 For the four factors that are visible after the projects is operational

What actually happened after the project was complete is relatively public. By incorporating production volumes and commodity prices, a relatively impartial measure of economic outcome can be shown.

Factor 13: Production performance

Resource processing plants are designed with an expected capacity to transform raw resources into a concentrated and value added product able to be economically shipped to market. The nameplate capacity is stated output of product to a given standard.

Production performance is the reported actual output of the plant in the first 36 months of operation as a percentage of the stated nameplate capacity.

Factor 14: Return (actual pay back)

The time to pay back the completed project with the calculated income is also a very simple metric that is indicative of project success or failure. A project has a capital cost that is reported in annual reports and press reports. Annual report figures are preferred as there are penalties for miss-statement. However the cost can be variable depending on whether the cost of fixing a sub- functional plant is allocated to capital works or operational expense. Capital cost is usually kept to the minimum figure practical, as the gap between projected costs and actual completed cost is a very easily understood metric of poor performance. Directors seeking to raise new funds for a troubled project have to put the most attractive presentation on results, if they are to succeed.

Thus capital cost is more likely to be the actual amount paid to the contractors at the time they stopped work or completed the project. The gap between completion and operation at close to nameplate capacity can be moderately short, or agonisingly long. Moderate ramp up time is an indication of the competence of the management in fully understanding the ore and process.

Agonisingly long ramp up times have a compounded financial pain. The first is that the expected profitability to pay back in investment is not available. Seeking extra finance to cover the gap is not easy, and the project is known to be in trouble, and more risk adverse financiers, at lower interest rates are unlikely to invest. Finance is more likely to come from investors who have their earlier equity at risk, who are being asked to put more good money after that at risk to save it.

The second financial pain is that long ramp up times usually involve discovery of significant design faults. These must be rectified in haste, and at much higher cost that doing the job right the first time. The contractors engaged in such work, realising the project risk will want to assured of prompt payment, and may be in a position to charge high prices for what is an emergency rescue.

The plant actual production, as far as can be calculated from public domain information is shown as a percentage of stated nameplate capacity, which can be from zero where the plant never completed or operated to over 100%. The commodity price is an average of the 36 months in the years after the plant commended operation, (or construction was completed or terminated for the non-operational plant). This represents a reasonable expectation of what could have been achieved in the vital first three years of operation.

Where the plant reasonably quickly (90-180 days) reaches close to nameplate capacity, and the commodity price has risen, will likely succeed. Where it has only reached a fraction of nameplate capacity and the commodity price has fallen, the investors are at great risk.

The operational cost of a process plant is variable, and hence the profit on each tonne transformed. However across diverse resource plants an average of about 50% is common. This is an expected cost to expected benefit measure.

So this simple indicator is "how long did it take to pay off the project" if half the estimated income is profit. This will show projects with high costs and low profit delivery, or vice versa, and how they rank against the median. This figure that can be compared to the estimated project payback plan; as one is a projection, the other the outcome. If the "actual payback" time in months is well beyond the median for a class of projects; then it will probably be a failure.

Factor 15: Life of firm

A firm is a legal business entity with a name and often an Australian Securities Exchange (ASX) listing. It can "live" and grow for centuries. The largest mining firm in the world is reputedly BHP-Billiton, BHP on the ASX. This firm grew from the Broken Hill Proprietary Company Limited, which was incorporated in 1885. Their first operation was a silver and lead mine at Broken Hill in far western New South Wales. Their first 48,256 kg consignment of high grade ore yielded 35,605 ounces of silver. This was influential in the success of the 10th August 1885 initial share offer. The firm has evolved and grown. Unsuccessful firms descend into bankruptcy and de-registration. These firms have died, their liabilities extinguished. Some firms, having consumed the investor's capital can arise like the phoenix from the ashes, with new names and new prospectuses.

.1 Is where the firm who commissioned and managed the project has gone into receivership, gone bankrupt, been de-listed on the ASX, been taken over for a residual or otherwise extinguished its public liabilities. Investors have lost almost all their capital.

.2 Is where the firm exists, but in a state where low production and limited capital make it like a corporate zombie; not really alive and not quite dead. The investors have effectively lost almost all their capital, but the loss has not crystallised.

.3 Is where the firm with valuable assets, in plant, licence to resources and human capital, but limited cash flow, is taken over to acquire new capital and management. The investors loose a share of their firm, but usually retain the majority of their capital, sometimes see it appreciate.

.4 Is where the firm has variable results depending on new project outcomes and the prices for its commodities. The firm is alive and fighting trying to meet changes in market demand.

.5 Is where the firm has a history of superior to average returns, and hence enjoys a good share price. The firm is alive and growing, often evolving to meet new market demand and conditions.

Factor 16: Life of Process

Processes, like firms have a life and evolve and grow in the successful embodiments.

The quote "Nothing is as powerful as an idea whose time has come" attributed to Victor Hugo, has applied to past innovations that have transformed resource processing. The use of cyanide in gold extraction, the Bayer process for alumina, the Hall-Herault process for aluminium, the Flotation process for mineral concentration have all been new ideas that over time have displaced the prior art. These processes had dynamic life and transformed the industry. Recently hydraulic fracturing has transformed the oil and gas industry in the United States, and now world-wide. In 2010, it was estimated that 60% of all new oil and gas wells in the world were using hydraulic fracture processes.[169] Conversely five projects have invested a total of $4,588,000,000 in pressure acid leaching of laterite nickel ores, with very poor outcomes.

.1 Is where there are no more similar process projects in Australia since this project or series of projects in the time since failure was widely appreciated.

.2 Is where there are no more similar process projects by this firm since this project or series of projects in the time, since failure was widely anticipated.

.3 Is where other firms have successfully duplicated this process outside Australia.

.4 Is where the firm has built a second similar plant and or expanded an existing plant.

.5 Is where there is a project pipeline of similar plants in Australia and worldwide.

4.5 Methodology for resolving four hypothesises

The methodology for resolving the four hypotheses is that the appropriate non-linear model factors are selected from the eight indicating factors that are visible before a project has begun, for the hypotheses being examined. These factors are arranged from those that it is hypothesised pose the greatest risk on the left, to those with least risk at the right. Four distributional spreadsheets (Sheets 4 to 7 in Appendix) show the indicators and outcome, so that a visual comparison across all 67 projects can be reviewed. Comparisons between the successful and failed projects are made. Case studies are then detailed to contrast and compare success and failure. These case studies examine as many of the sixteen parameters of the four models proposed in Chapter 3 as are relevant and conclusions are drawn.

Chapter 5
Competence and innovation

"Innovation distinguishes between a leader and a follower." - Steve Jobs

5. COMPETENCE AND INNOVATION

5.1 Introduction

Chapter 5 deals with the two core concepts of competence and innovation in relation to success and failure. Competence was unsurprisingly associated with success, and innovation sadly associated with failure. Chapter 6 deals with two concepts which explain anomalies that arise from Chapter 5, such as why otherwise successful firms failed at innovation; or how Government involvement in value adding gave best and worst outcomes. One example, Case 7 was the outstanding worst performed in every category, and probably represents the most egregious example of what to avoid. This is shown in Table 19.

Table 19 Case studies and linkage to Hypotheses and Models

No.	Case Study	Firm Competence	New process Innovation	Govt Involve Value Add	Asymmetric Info
17	NWS T5	Best	Incremental	Limited	Limited
15	CoP Darwin	Strong	Incremental	Limited	Limited
64	Cannington	Strong	Limited	Limited	Limited
40	ISASMELT	Strong	Best	Little	Little
7	AMC	Worst	Worst	Worst	Worst
8	HIsmelt	Puzzling	High	Adverse	Adverse
24	Wagerup 2	Strong	Limited	Positive	Limited
1	BHP HBI	Puzzling	High	Adverse	Adverse
48	Olympic Dam	Troubled	Incremental	Negative	Adverse
45	Sunrise Dam	Strong	Limited	Limited	Limited
4	Bulong	Weak	High	Limited	Adverse
60	Bendigo	Weak	Some	Limited	Adverse

5.1.8 Hypotheses and expectation:

In this chapter the 2 hypotheses proposed will be tested by the methodology shown in Chapter 4, and the data listed in the Appendices.

1.) **That project success was associated with <u>firm competence</u>.** Four factors are considered; the past track record of the firm, the focus or specialisation of the firms' activities, the difference in scale between past successful plant and new plant, and the confidence the firm enjoys when seeking project finance. It is expected that firm competence will be strongly linked with successful project outcome. The resolution sought would be to see if any firm with a high firm competence had failed projects and to look for other hypotheses factors that might explain this unexpected outcome.

2.) **That new process innovation was associated with project failure.** Two factors are considered in defining the newness of the innovation and the risk involved. First the innovation type, from new and radical to incremental on mature, only the two most radical rankings of innovation are considered. Secondly the scale up ratio where incremental steps reduce risk and large plant as first off accentuates risk. It is expected that new process projects with higher risk will be strongly linked with unsuccessful project outcome. As all but one of twelve most innovative projects failed four differentiating factor are considered that seem to explain why one succeeded and why at least nine of eleven failed. The differentiating factors are Individual ownership and responsibility, initial process simplicity, multistage scale up, and niche demand for the innovation.

There is still the anomaly of otherwise successful firms who have taken some of the steps associated with reduced risk and failed, which leads to the 2 explanatory hypothesis in Chapter 6.

3.) **That successful government involvement in value adding processes was related to process maturity.** It was strongly negative for more innovative processes, and moderately successful for mature processes. Mature processes, such as the 130 year old Bayer process for Alumina production are well understood, and are low risk due to low information asymmetry. With new processes, or those where there was limited economic and process understanding the role of government involvement was associated with some of the largest failures, including those involving otherwise successful firms.

4.) **That information asymmetry leading to strategic misrepresentation was associated with project failure.**

Where there is a significant asymmetric information differential between the resource owner and regulator, (Government) the investor, and the process operator or proponent, risk is elevated. This can lead, through greed or need, to a strategic misrepresentation and project failure.

5.2 Hypothesis 1: "That project failure was associated with lack of firm competence"

The management theory concept of Core Competency was developed by C. K. Prahalad and Gary Hamel. It is a way the firm and its employees work. It is defined by three key criteria:

1) It is not easy for competitors to imitate.
2) It can be reused widely for many products and markets.
3) It must contribute to the end consumer's experienced benefits and the value of the product or service to its customers.

The application of this theory to resource processing invites some critical review and evolution of theory. Firm competence comes from firm and employees knowing exceptionally well what you are doing, based on similar recent and successful experience, refined by practice and incremental improvements; and therefore minimising's risk.

The firm competence theory has five key criteria:

1) That the firm has a track record of notably successful, even exceptional, project implementation in a particular field. This is, by definition exclusive, and hence few competitors will be able to imitate.

2) That the firm has a focus on a limited field of established skill and demonstrated technical competence; allied with a program of focused technical and skills developments. Whilst this concept may be applicable in many products and markets, it is in practical application a specific linkage between a firm's focus and a specific transformation process, at which they endeavour to be world's best. This draws upon a long history of noticing the productivity benefits of the specialisation of labour.

3) That these firms scale up existing successful plants and processes to new and better plants by a moderate ratio and incremental improvements. In doing so, they minimise risk and build knowledge in the process. Scale up in chemical engineering from lab scale to fully operational plant requires an evolving multi step process. Scale up ratio is perhaps an under-appreciated factor and metric.

4) That superior past performance of competent firms is recognised by well-informed commodity buyers and professional capital managers for their superior outcomes. Firms perceived as firm competent can finance new projects from customers and financiers under preferential terms due to the low perceived risk.

The counterpoint is that firms perceived as “not knowing what they are doing” pay high margins for the risk. As an indication this was between 8 and 13% in the 1995 to 2005 period. In hindsight this was not enough as the most risky projects defaulted and paid back little.

Governments have a poor track record at “picking winners”. In this study the only projects backed by State and Federal Government were the worst failures.

5) That the firm and its projects regularly made profits. This applied to medium sized competent firms with a specific process focus. The counterpoint was that firms that had never made regular profits were very poor risks for mega projects. But there was an anomaly with the largest and most diversified firms. BHP-Billiton and Rio Tinto have a broad range of largely profitable activities. They seem to have developed their firm competence in high profit areas; specifically winning rights to access easily harvested resources, transportation and marketing; rather than technically challenging processing areas. Both are predominant in iron ore and coal, which in Australia are more logistics than processing. BHP-Billiton experienced failure in four of four new process projects yet succeeded in two other traditional process projects. Most of their profitable activities, investments and returns were in iron ore and coal, outside this study. Rio Tinto failed with one new process project yet succeeded in seven other traditional process projects. This anomaly will be examined in the next three hypotheses.

5.2.1 Distributional data of factors that make up inputs for prediction

Firm competence is a significant factor in all resource processing projects, so the reference class is the full set of all 67 projects. Firm competence is shown in sheet 4 of the Appendix.

Distributional data is displayed as positional format, with worst indicators (with most obvious risk) to the left of the sheet and best indicators (with least obvious risk) to the right of the sheet. This inputs data is derived from published public domain reports, and case studies, and based on the predictive “firm competence” model, where the indicating factors are show in items 1 to 4 with a sum of these shown as “Least to most competence” in line 13.

This may be compared with the financial calculations, items 9 and 10, with project build measures, items 11 and 12, and with project performance measures, items 13 and 14, and finally with project outcomes in lines 28 and 29.

Whilst there are acknowledged anomalies, which will be explored in following hypotheses, the general correlation between the predictive indicators and measured outcomes is robust. The greatest risk from low firm competence is loaded strongly to the right of the spreadsheet with the worst outcomes. Averages across all 67 projects are shown at the right of the d sheet.

The fifty more competent firms achieved 99% average of production against nameplate capacity, the seventeen least competent only 33.3%. This factor is the major difference between success and failure. When other factors that contribute to how long, using the simplistic model explained in Chapter 4; it would take to pay back the investment the differential is more dramatic. The average competent firm project by the prediction method; paid off the investment in 52.6 months, a little over 4 years. The average unsuccessful less competent firm by the prediction method, theoretically, would have taken 98 years.

The break point shown at 1.4 is shows failure and success. 1.2 would be a better failure prediction point, with the other 3 hypotheses explaining why projects with 1.2 to 1.4 rating failed. To a lesser extent commodity price fluctuations and unexpected process problems are the extra factors, but they are covered in the commodity value data shown, or mentioned in the case studies.

Some of the firms that had difficulties were competent at project implementation, but less so at making profits. WMC Resources and Mount Isa Mines (MIM) were firms that succeeded with complex projects yet were taken over by firms with better profit competence. Conversely the two largest firms were exceptionally competent at profits but were challenged by new process projects.

An investor who chose projects with a firm competence over 1.5 would have taken minimal risk and made a profit. These forty six” safe” projects were 68.5% of the total. Any investments below 1.3 were high risk. Only Case 56 did not destroy almost all the investment.

5.2.2 Distributional data on execution, performance and outcome

This is quantitative analysis, based on numbers taken from trusted public sources, (such company as annual reports) and is similar to reference class forecasting.

Of the seventeen least competent, (by predictive model) all but one (Case 56) failed. Eleven reduced the investment made to almost zero; six were sold for between 5 and 10% of original investment. Ten sent the owners broke, and in two more (56 & 13) the firm is no longer in business. All six plants that were sold required significant new investment, by new owners. Only two (56 & 13) produced at close to nameplate capacity, with new management and investment. Another (10) reverted to an old process that had worked before the failed innovation. The other three (3, 9 and 60) produced at a fraction of nameplate capacity. This is shown below in Table 20.

Table 20 Least Competent outcomes

Case	Project	Project Terminated	Firm Broke	Plant Scrapped	Plant Sold
1	HBI Bondarie Crude Steel	1		1	
2	Southern Pacific Copper Refinery	1		1	
3	Murrin Murrin Nickel Cobalt		1		1
4	Bulong Nickel Cobalt	1	1	1	
5	Cawse Nickel Cobalt	1	1	1	
6	Stuart Shale Oil	1	1	1	
7	Australian Magnesium Stanwell	1	1	1	
8	Hismelt Crude Steel	1		1	
9	Ravensthorpe Nickel Cobalt	1			1
10	Yabulu Nicel Cobalt Refinery	1			1
11	Beenup Mineral Sands	1		1	
13	Phosphate Hill Fertiliser Plant		1		1
33	Skardon River Kaolin	1	1	1	
46	Mt Todd Gold Mine	1	1	1	
52	Windamurra Vanadium	1	1	1	
56	Fosterville Gold Mine				1
60	Bendigo Gold Mine	1	1		1
		14	10	11	6

The original investors lost almost all their capital in fifteen of seventeen least competent projects, with (56 & 13) being the exceptions. Here, and in most cases where an orange block indicates a firm that fell into financial trouble, good management negotiated a transfer of ownership to firms with the capital to take over the operations.

The differences between 50 successful projects and 17 unsuccessful projects are significant. The average figures are skewed by the spectacularly bad numbers of Case 7, but construction delay of 89% rather than 8.9%, and cost over-run of 315% rather than 22.6% show the marked difference between failure and success.

According to the simplistic metric for time to payback the project investment before profit can be generated, the more competent 50 cases averaged 52.6 months to payback. The less competent on average would have taken 1,178 months or 98 years to get to break even.

The metrics on project execution, or building the plant, are shown as time management and cost management, as items 11 and 12 in Sheet 4 of Appendix. Time management of 100% indicates that the actual time taken to build the plant was the same as the prediction given at project initiation. Cost management of 100% indicates that the capital apparently invested to build the plant was the same as the prediction given at project initiation. This does not perfectly account for projects that saw the cost estimate grow during planning. Projects that rose in price whilst still on paper, were those with lower competence, and unsurprisingly performed poorly, and usually had cost escalation and delay during the execution. In the only project not to complete (7) an estimate is made based on percentage complete at the termination. Half the build time had been used and almost all the capital to achieve 5% completion, so the outcome was negative by a degree approached by no other project.

The metrics on project performance, or production output in the initial 36 month period, are shown as item 13, production performance. Here the percentage of production, compared to the stated nameplate capacity is shown. This is calculated over the first 36 months of operation taken from commissioning. An exception is in Case 45, where the immediate start up performance was so exceptional in the first 12 months that this figure is used. A ramping up of production, where output rises over time to meet nameplate capacity, is expected. This allows for teething troubles and integration of the multiplicity of systems in a complex process. Firm competence is at the highest level enabled nameplate capacity to be exceeded in the first 90 days. Cases 45 and Case 15 were able to do so. Cases 65, 49, 64, 66, 43, 42, and 53 exceeded nameplate capacity in the first 36 months and went on to be trouble free and profitable for their competent firms.

Production performance is one factor; the variable commodity price is second factor, shown as change in the first 36 months in item 9. Production and price, leads to income, which can be used in a simplistic metric to measure the time taken to pay back the actual investment. The details are in covered in Chapter 4. This does not cover the variable and largely non-publicly visible costs of plant operation. Plants that run exceptionally well from start-up usually have moderate operating costs, sometimes below that estimated. Plants that have significant problems in reaching a fraction of predicted production usually have crippling operational costs. Desperate and expensive actions are taken to try and get them working. The "fix it" cost is a major contributor to financial failure in the first 36 months. Item 10 is the estimate of how long the project would have taken, by the simplistic formula described in Chapter 4, to pay back investment if the plant performed at nameplate capacity. This compares with item 14 of estimated actual payback, given the actual production performance and commodity prices.

Logically those projects with shorter payback plans and shorter actual payback performances are to the right of the spread-sheet, where firm competence is highest and risk is lowest.

The metrics on longer term project outcomes are shown as items 13 and 14 and discussed further in case studies and conclusions.

It may be argued that firm competence is less critical in simpler operations, utilising mature and well understood processes, or those projects that have especially rich ores. Alternatively competent firms might wisely choose these lower risk options. Warren Buffet's quote *"I don't look to jump over 7-foot bars: I look around for 1-foot bars that I can step over"* captures this idea.

On average with the 50 successful projects the commodity price rose by 16.4%, for the 17 troubled projects it only increased by 6.7%. Whilst for a few troubled projects the commodity price was critically negative (52 and 13), it was a saviour for others (56 and 3).

Of sixty seven projects, fifteen failed; these are shown with red or yellow marker on spread sheet. The three with yellow were restarted under new management. Fifteen projects were owned, and built by firms that ran into financial difficulties. These are shown with orange marker and were taken over, and continue operating. Four projects were built, not to increase production, but to reduce environmental emissions and or increase plant efficiency. These are shown with the green marker. Two projects with dark blue marker have closed recently. Case 43 reached the end of viable ore as expected. Case 30 was a casualty of the sustained drop in Aluminium prices after 2009.

In a wide view of the data all the red projects are tightly grouped at the far left of the distributional spread sheets. Failure is graphically co-related with lack of firm competence. Yet the orange projects are grouped more broadly across the left 60% of the distribution.

The green projects are distributed more to the right of the table, and are show as the motivation for the investment was to make significant environmental improvements, rather than increase productive capacity. Making an efficiency improvement in an alumina or aluminium refinery increases profit over time, even if capacity is unchanged. Building a sulphuric acid plant (Case 12) enables a pyro-metallurgical smelter to continue to process sulphide ores and meet air quality standards.

More competent firms, by virtue of their reliable production and favoured credit terms, have the cash available to invest in long term efficiency. Firms with less competence will often have a critically leveraged cash flow, due to production difficulties and unwilling creditors. This gives an added advantage to the competent firm unavailable to the less competent firm fighting to survive for a few more months.

5.2.3 North West Shelf Train 5 (Case 17). $2,600,000,000 invested. 8.3% over budget, 2.8% delayed delivery. 100% of 4,400,000 tonnes of LNG produced. Built 2005 – 2008.

To build the most firm competent project in this study took a lot of time and investment.

Woodside had started in 1989 with LNG Train 1 (2.5 million tonnes a year), in 1989 another almost identical LNG Train 2 (2.5 million tonnes a year), followed by LNG Train 3 (2.5 million tonnes a year) in 1992. The 2004 LNG Train 4 (Case 14) built between June 2001 and October 2004 to transform 4.4 million tonnes per year of natural gas into LNG for export, had been a disappointment. This project was originally projected to cost $2.3 billion, but ended up costing $2.7 billion. This was a 17.4% cost over-run, and took 39 months to complete. The cost and availability of labour was and is a constraint. Technical problems took the plant out of service on three occasions in the first 24 months. Woodside, a firm noted for its competence, sound management and shareholder value; took action to ensure that the difficulties were not repeated in NW Shelf Train 5.

All these plants processed, compressed and cooled millions of tonnes of Natural Gas, largely methane, to a -162° liquid with 1/614th the volume. This was shipped from the Burrup Peninsula about 13 km NNE of Dampier in Western Australia to customers in Japan, Korea and China.

Train 5 was a replication of Train 4, but to manage the local labour shortage Woodside used offshore manufacture of "pre-assembled modules" (PAM's). These 75 pre-assembled modules, weighing 24,000 tonnes in total, were floated to the site, landed, moved into position and installed. The heaviest single module weighed 1,835 tonnes.[170]

PAM's are effectively the taking offshore of chemical engineering plant construction. The local input may be design, and bolt together assembly of the modules. The 75 modules in this case were manufactured on the Indonesian island of Batam located 20km from Singapore. The 415 square km island enjoys free trade zone status, and has developed into a strong industrial centre, housing hundreds of factories. [171]

These PAM's have pressure tested pipe work, insulation, electrical and instrumentation requirements installed. The modules were delivered in sixteen separate shipments on heavy-lift and roll on, roll off ships. The break-downs that had troubled Train 4 were not duplicated. Woodside completed the plant in 37 months, for $100 million less.

This project fits the firm competence model well.

Track record: Woodside has a 23 year track record of building and operating LNG plants of between 2.5 and 4.4 million tonnes per annum. With few exceptions they have performed well. The exceptions are fixed and do not happen in the next plant.

Firm focus: Woodside has a firm focus in offshore sourced gas, with some condensate and oil inclusions. Their “principal activities” are listed on the ASX web site as “Management and operation of hydrocarbon exploration, development, production, transportation and marketing; implementation and operation of the North West Shelf Gas Project; exploration and development of gas, oil and condensate reserves.” The market is competitive, failures and delays are unacceptable, and performance brings great financial rewards. They are a focused firm.

Scale up: The process plants have been the same size for the last 12 years. Costs have been held down and efficiency and reliability increased. It is hard to find a better example of avoiding scale up risk, or that when it occurred it was at scale up point between train 3 and 4.

Financial: Woodside is able to finance new projects from funds secured against long term contracts. The approximately $32 billion invested in the Pluto LNG “is underpinned by 15-year sales agreements with Kansai Electric and Tokyo Gas. Both companies became project participants in January 2008, each acquiring a 5% interest in the foundation project.” [172]

Profit: Woodside is the lead of six partners in these LNG projects. The other five partners are BHP-Billiton, BP, Chevron, Shell, and MIMI. MIMI is a joint venture between Mitsubishi and Mitsui, two of Japans leading trading houses. All routinely record profits from these NW Shelf LNG ventures.

5.2.4 Darwin LNG Plant (Case 15) $1,750,000,000 invested. 8.7% over budget, 50% delayed delivery. 100% of 3,500,000 tonnes of LNG produced. Built 2003 – 2006.

The US based Conoco Philips Darwin LNG facility (Case 15), with the benefit of hindsight be an even more firm competent project than Case 17. It was built between June 2003 and February 2006 to process 3.5 million tonnes per year of LNG. It is said to have cost $1.75 billion, and was delivered on time in 32 months with a 16.7% cost increase. The plant uses aero derivative gas turbines for the compression and refrigeration services. The plant was able to exceed nameplate capacity shortly after commissioning, and is claimed to have shipped LNG two months ahead of schedule. For a green-fields project, by a foreign firm, in a new location, with a resource of different character than previously processed, the project performed beyond projection.

The investment by Woodside in Case 17 was $591 per tonne of LNG, by Conoco Philips in Case 15 it was $500, a saving of almost 20%. Three LNG projects under construction at present for processing coal seam gas, Queensland Curtis LNG, Gladstone LNG and Australia Pacific LNG have chosen the same "Optimised Cascade" process.

The Conoco Philips Darwin LNG plant also fits the firm competence model well.

Track record: ConocoPhillips have a 44 year track record of building and operating LNG plants with their first in Kanai Alaska in 1969. They have long used their aero derivative turbine technology.

Firm focus: ConocoPhillips is an oil company, with specific developments in LNG plants and technology. They are more diverse than Woodside, in that they have legacy oil fields, and oil sands in North America. Internationally they are known for LNG technology and projects.

Scale up: The Kenai facility is a million tonne per year plant, so the scale up to Darwin is 3.5 times.

Financial: ConocoPhillips as a reliable supplier is able to negotiate long term contracts with firms like Tokyo Electric and Tokyo Gas for LNG supply into favourable finance for new projects. As LNG plants are relatively dependable shippers of a commodity with a fixed price over a long term, the financing of projects has been seen as low risk.

Profit: ConocoPhillips may be the most profitable LNG plant operator in Australia. The Darwin plant had the lowest capital cost, per tonne of LNG produced annually. The cost of $500 invested per tonne transformed was 84.6% of Woodside's NWS 5 project and 78% of the NWS 4 project. The rapid ramp-up to more than name plate capacity in the first 90 days is another indicator of a low cost plant.

ConocoPhillips utilise their unique Optimized Cascade technology for their Darwin LNG production. The budget includes the 26" diameter, 500 kilometre long undersea pipeline and a 3.7 million tonne per annum LNG plant. LNG is sold to Tokyo Gas and Tokyo Electric, who are also partners in the development.

The plant at Darwin cost $1,750,000,000, of which $355 million was Australian contracted.[173] ConocoPhillips claimed considerable innovation, and technical advance with the use of aero-derivative turbines for refrigeration service.

The plant operators claim to have built the project, and shipped LNG 2 months earlier than projected. In the first year the plant was available 95% of the year, and was able to exceed nameplate capacity shortly after start up.[174] ConocoPhillips built their first Optimized Cascade process LNG plant in Alaska in 1967 to supply Tokyo Gas Co Ltd and Tokyo Electric Power Company Inc. At the time it was the largest plant in the world. It is still operational, and the two Tokyo power and gas companies are still the customers and financial underwriters of the new projects.

ConocoPhillips focused on one task, and one technology to satisfy their customer. Incremental innovation with each new plant increased the thermal efficiency, and decreased the risk.[175]

5.2.5 Cannington Silver, Lead, and Zinc plant (Case 64). $460,000,000 Invested. 2.2% over budget. Completion on time. Built 1995 – 1997

The Cannington mine and process plant built by BHP, 200km South East of Mt Isa is an example of firm competence built up over 110 years. The outcome was better than the projection, and the investment grew more rewarding as production surpassed the plan, costs of production fell, and annual output value became a multiple of the original investment.

The project aimed to produce 175,000 tonnes of lead, 50,000 tonnes of zinc and 750 tonnes of silver per year. This initially required a plant that could process 1,500,000 tonnes of ore. In time as the best grades were consumed the ore processed rose to 1,800,000 tonnes in 2001, 2,100,000 tonnes in 2002, 2,700,000 in 2004[176] and 3,100,000 in 2006.

Production increased to 213,425 tonnes of lead, 56,281 tonnes of zinc, and 966 tonnes of silver, in 2012-13 financial year.[177] This production had a sale price of $1.3 billion dollars, at a time when this project was reputed to be the largest single silver mine in the world, producing 6% of all silver, and 7% of all lead,[178] with the lowest cost of production per tonne.

BHP has long had a long track record and firm focus on rich lead silver and zinc mines. The firm was founded and traded on the Adelaide stock exchange in 1885. There first consignment of 48.25 tons of ore produced more than a tonne of silver (35,605 ounces at a Melbourne smelter). This Case 64 project is matched against the five firm competence criteria.

Track record: BHP grew from the original silver, lead and zinc mine to become a steel maker, and a diversified firm in energy and minerals. They have divested assets that were sub optimal, such as the Broken Hill mine, and were only interested in re-entering this base metals sector when they had an unusually profitable opportunity. The Cannington project had to compete for resources as a business case, against a wide range of alternate investment opportunities. The selection of the resource and the skill at expanding the processing indicate this process worked well in this case.

Firm focus: BHP was in 1995 and is today a diversified firm. They were not focused on base metals, as were Pasminco, who were the operators of the Broken Hill mine at this time. BHP was focused on a profitable supply chain for all their commodities. Pasminco became insolvent in 2001.Their successor Zinefex had difficulties and merged to become Oz Minerals in 2008, which was then taken over in deep financial distress by China Minmetals in 2009. BHP's focus on profitable operation of base metals operations was an important firm focus difference. The separation of silver lead and zinc from ores is a mature process evolved and improved for nearly one hundred years.

Scale up ratio: The operation of an underground mine and a concentration plant are essentially similar for a range of metals recovered from ores. BHP had experience in both from comparable operations in copper processing at this time.

Financial confidence: BHP was one of the largest resource firms in the world in 1995, with a record of profits over many years. If the needed to have raised capital for the project, it would have been on the strength of their balance sheet, as well as the quality of the resource

The 1997 Annual Report predicted that *"The mine is expected to reach its full capacity of 1.5 million tpa by mid-calendar year 1998 following completion of the main hoisting shaft."* In the 1999 Annual Report they revealed that *"The mine's nameplate capacity of 1.5 million tpa was reached in January 1999. The processing plant has exceeded its nameplate capacity on* *a number of occasions and continues to be fine-tuned to maximise recovery to concentrate over the full range of ore blends."* They had taken the time to understand the multiplicity of ore types, and that with that achieved the capacity of the plant to process more ore than was proposed. Later increases on ore throughput showed that with further upgrading the plant would, over the next 9 years, process more than twice the ore throughput originally planned, though at lower grades.

Profit: Few plants annually produce concentrate with more than 2.8 times the value of the initial plant investment; and BHP is proud of this project. A mine that has 110 kg of lead, 40 kg of zinc and ½ a kg of silver in each tonne of ore is likely to be profitable, and it was. Carrington ore with this metal value in each tonne was worth $1,065 at January 2014 values. BHP-Billiton is the largest mining firm in the world and one of the most consistently profitable.

5.2.6 Conclusions

Firm competence is the ability of a business entity to successfully complete the task they have proposed; meeting or exceeding the aim, to achieve a favourable outcome … one better than the investors might reasonably have expected, compared to the median outcomes. This is based on their past practice in the field of endeavour.

That there should be a strong correlation between the past demonstrated competence of a firm and successful project outcome may be obvious. However a lack of firm competence was not given due consideration in fifteen of sixty seven private sector resource processing plants, and all failed.

The firm competence model was evolved to match what was observed in the positional representation shown in sheet 4 of appendix. Projects which displayed the least competent outcomes were to the left, and most competent to the right.

Firm competence in mature and well understood processes is common. Alumina plants are an example. Firm competence in new process innovation is amazingly rare. Only 1% of investment returned a profit. As firm competence in implementing the new and unknown is so rare and so valuable it is core of this work.

The lack of firm competence in achieving the agreed outcome, on budget and in time, in public sector projects appears much worse. Government investment was made only in projects that failed.

Firm competence is measured and rewarded by the best informed investors and customers. That the competent firm has a positive disparity in knowledge of how to achieve a desired outcome is obvious. There must be information asymmetry between the most competent firms and the rest of the market. This information asymmetry, in intellectual property, skills, and organisation must grow to stay ahead. However the competent firm derives no value from strategic misrepresentation. They have no need; it is the tool of the incompetent.

Firm competence is variable across a broad range of performance and outcomes. Firms may be exceptionally competent in some areas and much less so in others. The most competent firm at new process innovation (MIM) lacked financial competence and was taken over. The most competent firm at implementing difficult and complex chemical engineering processes (WMC) also was taken over. The firm with the most project failures is the largest and most profitable mining firm in the world.

Even the most profitable firms will be competent only in a few areas. If this is their core business and they avoid or manage their weaknesses, they may prosper. The hero Achilles in the Trojan War was vulnerable only on one heel. Yet the arrow there killed him. Sadly Australia's leading mining firms seem to have an "Achilles heel" with new process innovation and now avoid it.

The difference between the fifteen least competent projects, as measured by the indicating criteria and the more competent 52 projects is stark. The fifteen least competent all failed. The fifty two more competent all succeeded. The average performance indicators for contrasting least and more competent are shown in Sheet 4 of the appendix. Table 21 summaries these outcomes. Case 7 has not been included in these averages as it was only 5% complete when the firm ran out of capital and was the only project never completed. It is the worst example in every hypothesis, and is the most negative example in all.

Table 21 shows the comparison between the fifteen least competent firms and the other 52 more competent firms.

Table 21 shows a comparison of outcomes of least to more firm competent projects.

Firm Competence	15 least	52 more	Ratio
Time management over	144.0%	108.0%	5.5 x worse
Cost management over	225.0%	122.0%	5.7 times worse
Production performance	28.5%	99.8%	less than 1/3rd
Pay back time months	1,413	54	26 times worse

The average of 28.5 % of production meant that the projects could never pay off their investment.

5.3 Hypothesis 2: "That new process innovation was associated with project failure".

5.3.1 Distributional data of factors that make up inputs for prediction

New process innovation applied to twelve projects of sixty seven. Eleven failed and one succeeded remarkably well. Whilst there were many reasons for failure, eleven of fifteen failures were in new process innovation. If new process innovation were a disease, one would go to some lengths to avoid it, as it was fatal more than 92% of the time. New process innovation is shown in sheet 5 of Appendix. The distributional display view shows distribution ordered by predicted outcome value, according to the model.

Distributional data is displayed as positional format, with worst indicators (with most obvious risk) to the left of the sheet and best indicators (with least obvious risk) to the right of the sheet. It should be noted that the two high risk factors of innovation type (identifying those with greatest or most radical innovation) was matched with scale up ratio, which multiplies the risk for innovation, but also brings into the high risk group other projects with less innovation, but very large or infinite scale up. Thus the innovative projects are identified with a mauve colour in line 3.

This inputs data is derived from published public domain reports, and case studies, and based on the predictive "New process innovation" model, where the indicating factors are show in items 3 and 5 with a sum of these shown as "Simple risk number" in line 10.

This may be compared with the financial calculations, items 9 and 10, with project build measures, items 11 and 12, and with project performance measures, items 13 and 14, and finally with project outcomes in line 25 and 26.

There are still significant anomalies, which will be explored in following hypotheses the general correlation between the predictive indicators and measured outcomes is robust. The greatest risk prediction is loaded strongly to the right of the spreadsheet with the worst outcomes.

Innovation is a strong indicator of risk, but lack of innovation is not as good a predictor of success as firm competence. The one innovative project that succeeded invites further detailed examination in the case studies as to find what the difference were. New process innovation failures have left a negative model in investor's and plant operators' minds.

The break point in prediction between .4 and .6 is simply a break between obvious failure and success. As will be revealed in the case studies, the difference between Case Study 8, HIsmelt and Case Study 40 ISASMELT, for the two indicators, were relatively small. They might have been ranked the same by another party reviewing the case studies, as they have much in common in time, and technology, but not outcome. They are like non identical twins in a longitudinal medical study, where one lives and the other dies. They are thus much contrasted in the case studies, and were significant in formulating the models for the last three hypotheses.

The firms that had difficulties with more complex project implementations and project finance, WMC Resources, Mount Isa Mines and Zinefex all show up with projects that caused them difficulties in this risk ranking. All three were taken over by firms with better financial backing, and the projects operated profitably. Equally two large firms that were exceptionally competent at project finance, and management of income from commodity sales, were challenged by new process projects; BHP-Billiton has four new process innovation failures and Rio Tinto one important example. Why this was so is explored in the following hypotheses.

An investor who only chose projects with an innovation risk number over 1.5 would have taken minimal risk and made a profit. But they would have missed the only successful innovative project. To a large extent this is what the operators and market have concluded, innovation is too risky. They would like to be second or third to try something new; after it has been proven to work. New process innovation had a failure rate of 99.1% of the total of capital invested in innovative new projects ($12,278 million). Only 0.89% ($110 million) led to success.

This is an appalling outcome in the industry that drove the local economy in the last two decades. No new process innovation project was started in Australia after 2005, and there are no new process plants to transform resources planned as of 2014. All plants being built are duplicates of prior existing plants, using proven technology at similar scale.

5.3.2 Distributional data on execution, performance and outcome

This is quantitative analysis, based on numbers taken from trusted public sources, (such company as annual reports) and is similar to reference class forecasting.

Of the nineteen at highest risk by type of innovation and ratio of scale up included all twelve new process innovation projects (by predictive model) and seven other projects, including all failed projects. The four projects that succeeded were all by firms that later encountered financial difficulties, but then went on to be productive and valuable assets. None of the nineteen are now producing profits for the original firms. Yet the twentieth is one of the most consistently profitable operations in Australia, possibly the world, and the fourteenth is the one project most duplicated and repeated of any of the sixty seven.

The thirteen at most risk all failed. The subtlety in this distribution is not why the 13 most risky failed. It is why four projects (Cases 40, 13, 56 and 65) out of the six in the group 14-19 were quite good investments.

The simplest explanation is that it was in how innovation and scale up ratio were managed. Of the nineteen highest risk projects one, Case 40 produced great value. Fifteen produced significant loss. Of these fifteen, three projects went on to produce moderate returns after firm failure. These three Cases, 13, 56 and 65 were difficult for the original firm, but now produce close to nameplate capacity for new owners. The value of the distribution table is seeing so clearly where the contrasts lay. The contrast between Case 8 and Case 40 is explored in the case studies that follow and in the models for innovation evolved.

The group of thirteen most risk projects (1-13) show poor production output, 50% or less; and long theoretical times to pay back investments; an average of 130 years, compared to a little over 4 years for low risk projects.

The original investments for the thirteen greatest risk projects were largely destroyed. For investors in the next greatest risk group (14 to 19), four of six lost little but failed to gain the benefits of the growth the projects generated once under new management. So they were less desirable investments from the view of a superannuation fund, which simply seeks a solid and largely risk free return on capital over a longer time. This is an unwelcome outcome, as it would be known to superannuation fund managers. Based on these outcomes it would be imprudent for such funds to invest in any innovation or large scale up project.

5.3.3 ISASMELT (40) $110,000,000 invested. 210,000 tonnes of copper produced. Built 1992 - 1993

ISASMELT is the only successful outcomes of initial publicly funded research. In 1973 CSIRO began developing a more energy efficient and environmentally safer smelting technology to separate metal from ore.

They teamed up with Mt Isa Mines in 1976 to build new smelting reactors that use special combustion tubes or lances to force superheated air and fuel below the surface of the ore mixture. This mixes the ore around and melts it evenly.

Mt Isa Mines and Ausmelt have been licensed by the CSIRO to market this innovation in Australia and around the world. It is used to separate copper, lead, nickel, zinc and tin from mineral ores.[179]

The first full scale plant was built in Mt Isa in 1991 to smelt 60,000 tonnes of lead per year.

The second plant, also in 1991, was built for Britannia Refined Metals, of Northfleet, United Kingdom, and was a secondary Lead Smelter, with a 30,000 tonnes per annum capacity. The third was built in 1992 for Phelps Dodge, located in Arizona, USA and was a copper smelter with a capacity to transform 700,000 tonnes per annum of copper concentrate.

The fourth plant, and the subject of this case study was built in 1992-3 and was to transform approximately 1,000,000 tonnes per annum of concentrated ores into 210,000 tonnes of copper. As far as can be seen from this distant point in time, and of a completely in-house development, the project was built on time, on budget, then proceeded to deliver the nameplate capacity.

This process plant was a slight scale up of the Arizona plant, and as such involved little risk. The UK plant was a half scale plant of the first plant, and was thus also low in risk.

The fact that Mount Isa Mines (MIM) proceeded to sell another seven similar plants to customers around the world over the next 18 years, as well as further variants for secondary copper and lead smelting indicates that their close focus on perfecting the process was successful.

ISASMELTs' resolution of technical and operational problems, as shown in the 1993 plant, was as a direct result of 12 years research and systematic moderate scale up.

The first small scale pilot plant was built in 1980 to test the operation of a two stage process for lead concentrates. Five major findings came from the research between CSIRO and MIM. These were:

1.) Lead fuming could be controlled over a wide range of slag compositions and temperatures.
2.) Increased oxygen content of lance air, decreased the fuel requirements, decreased the fume production, and lead to no significant increase in lance wear.
3.) Refractory wear was less than expected; and higher during reduction than oxidation.
4.) Slag reduction was demonstrated in batch operation, and proceeded quickly using lump coal addition.
5.) Zinc fuming was very temperature dependant.

A United States Patent 4,514,222 for "High Intensity lead smelting process" was awarded on 30th April 1985, with Mount Isa Mines as the assignee.

The successful ISASMELT case study was from a "competent enough firm" that later was taken over. There was no government involvement, and little information asymmetry. Thus only the new process innovation parameters are considered.

Individual Ownership and responsibility: ISASMELT is an evolution of the 1973 SiroSmelt pyro-metallurgical furnace, developed from earlier bench work in half kilogram sized crucibles by Dr John Floyd.[180] A 50 kg pilot plant followed.

In 1981 Dr Floyd decided to leave CSIRO, who allowed him to licence and utilise the intellectual property, in which they had limited interest, and further develop it for non-ferrous applications. In 1983 Dr Floyd was joined at Ausmelt by his CSIRO colleague Brian Lightfoot.

At the same time, and in parallel, MIM were interested in the process for lead smelting, and obtained CSIRO licence and permission to adopt the name 'Isasmelt' for any processes developed on their sites. Mount Isa Mines also needed to replace their obsolete Reverberatory Copper Smelter, and had initiated collaborative investigation of SiroSmelt as an alternative route for copper smelting.

Thus there were two groups competing for similar markets with the same seed technology, till 2010 when Finish firm Outotec purchased the majority of shares in Ausmelt. Both Ausmelt and ISASMELT were successful in marketing and licencing their similar technologies around the world.

Initial process simplicity: The ISASMELT process was initially simple, being built by John Floyd at CSIRO in 1970 at *500-gram scale in ceramic crucibles, which confirmed that rapid reduction rates could be achieved with gas injection. Realising that efficient mixing required a reactor with similar cylindrical geometry to the crucible-scale tests Floyd commenced the development of a 50-kg scale pilot plant comprising essentially a refractory-brick lined cylindrical drum with a cast ceramic lid, housing a slag bath 300 mm diameter and 250-350 mm deep, a water-cooled vertical top-entry lance initially fired with natural gas and technical-grade oxygen to provide both mixing and submerged-combustion heating. Early test results proved so promising that in 1973 CSIRO provided Development Pool Funds to promote commercial development.* [181]

Different applications of the process were worked by John Floyd at Ausmelt and by Bill Denholm at CSIRO for MIM in 500 gram bench scale prototypes, with practical results. The process was simple and could be implemented at low cost with representative outcomes. The process was promising at ½ a kg, and more so at each scale up and incremental improvement.

Multistage scale up: ISASMELT had seven stages of pilot plants, between 1970 and 1993. ISASMELT grew from a simple, successful ½ kg bench scale model to a 50 kg trial, and by 1983 a small trial and demonstration plant, this was expanded in 1985 and commercial in 1993, and from then twenty more plants around the world. The scale up stages over the years is shown in Table 22.

Table 22 Scale up of smelting prototypes.

Date	Stage	Tons p.a.
1970	SiroSmelt 500 g	
1973	SiroSmelt 50 kg	
1973	Aircooled lance	
1980	4 tonne per hour sulfide plant	
1981	John Floyd leaves CSIRO	
1983	Lead Smelting demo plant	12,000
1985	Lead Slag Reduction plant	30,000
1991	Primary Lead Smelter	60,000
1993	ISASMELT Copper Smelter	210,000

Niche demand for innovation: The demand for ISASMELT is strong for lead and copper concentration. 5 plants are under construction, four with 3,340,000 tonnes of copper smelting, and one of 160,000 tonnes of lead smelting capacity being built. Over the last 21 years twenty two process plants have been built or are in the process of being built.[182]

Profit from the process: The process made profits for all the plant operators, and for the firm holding the licence.

5.3.4 Australian Magnesium Corporation Limited (Case 7) $1,000,000,000 invested. 94.4% over initial budget never completed delivery. 0% of 97,000 t Magnesium produced. Built February 2002 – June 2003

This case shows the most extreme lack of firm competence in the unusually negative project outcome. It is also the worst example of failure in radical innovation. It received the greatest level of Government investment, 32% of its budget. There was significant information asymmetry, and evidence of strategic misrepresentation. This it is a case study to be used in all four hypotheses, and all twenty model parameters will be considered. Australian Magnesium Corporation (AMC) failed to complete the project and never delivered any production. The demonstration plant produced 240 tonnes of Magnesium over 26 months. It is the only case in sixty seven projects over 18 years to fail so completely.

The project work started in February 2002, with a projected 35 months to plant operation.[183] The figure of $1.0 billion is an estimate of what was actually lost. The Melbourne Age of 19th April 2003[184] reported "originally planned $1.8 billion raising for the Stanwell project, including nearly $400 million in federal and state funding commitments" and "last August, the cost of the engineering, procurement and construction was $987 million". The Auditor General of Queensland[185] estimated the project cost as $1,847,000,000, and the data shown in Table 23.

Table 23 Source of capital for AMC

Source of funds	$ Millions
Bank Finance Facility	902
Normandy Mining Equity	100
State and Commonwealth Government	320
Investors buying AMC Securities	525
Total for project	1847

It ended with only 5% of the project complete and the money, just under a billion dollars, almost all gone. As much of the investment, $320 million, came from State and Federal Governments, it will be referred to in all hypotheses. This project was the only project built with direct involvement of and $75 million in funding[186] from CSIRO. The four year alliance[187] with Australia's largest publicly funded research body, demonstrated the highest level of Government involvement.

Track record: Australian Magnesium Corporation grew from a previous magnesia operation. The magnesia resource was rich, pure and easy to harvest, 437,223 tonnes was extracted at Kunwarara in 2001. The 2001 ANM Annual Report indicated sales revenue $72.7 million; that resulted in a consolidated loss $16.9 million. The firm had a cash balance of $11.5 million; and a proposed project for 1.85 billion plus. This is less than the ideal track record of management financial performance to reassure investors, in what turned out to be Australia's most complex chemical engineering project. There was limited firm background of plant operations or experienced chemical plant operators or engineers, within the firm; who had resolved difficulties with similar complex new process plants in the past.

Firm focus: Whilst the firm was focused on their unique enterprise, they had no prior team experience beyond calcined or dead-burned magnesia process, to build technical or managerial expertise needed to operate a new process refinery before being starting. The skills displayed in raising capital by misplaced optimism, strategic misrepresentation, and information asymmetry seemed to have been better developed than skills in project management or process plant cost estimation. CSIRO had not previously been involved in what was effectively a joint venture to implement the process they had developed.

Scale up: The 97,000 t.p.a plant was theoretically a 65 x scale up of the 1,500 t.p.a "demonstration plant". This would only be valid if the "demonstration plant" in fact produced the nameplate capacity or close to it, reliably. Whilst the AMC project had a body of laboratory bench work by CSIRO, this was followed by a $73 million to $135 million in cost demonstration plant that produced less than 10% of nameplate capacity and never ran for more than 6 days before breakdown in the 26 months it was operated. Thus the investment in the Magnesium project was a bold leap forward at best. At worst it was negligent business strategy to build a large scale plant when the "demonstration plant" was performing so poorly. To scale up a process that works well in pilot scale has risk. To scale up a process that doesn't work reliably is risk taken to a point of almost certainty of failure.

At the time of project start, the plant would have represented more than 22% of world demand, (432,000 t p.a. according to USGS) and so was a very large scale plant. There were significant problems, under performance and fragility of operations in the smaller scale demonstration plant. To progress to a full scale plant without these problems being fully resolved, seems in retrospect, unconscionable. The CSIRO process was unique, apparently innovative, and unusually complex. A number of interdependent steps and recycling processes, not typically used in resource processing; each had potential to frustrate the operational process flow.

The problems experienced with early Alumina process plants in Australia when processing a new resource, were experienced by AMC.

Financial: AMC sold remarkably optimistic projections, to unsophisticated investors, which seemed unrepresentative of what was in fact happening in the “demonstration plant”. This was appreciated by informed investors. The first equity raising for $680 million, organised by Merrill Lynch failed. A second only raised $525 million and that largely due to guaranteed capital return, care of a government loan. For this AMC was to pay an 8 per cent yield. Institutional investors, who might have formed more accurate assessments; chose not to participate in either of the equity issues, wisely as it turned out. The Queensland stockbroking arm of Dutch bank ABN Amro, offered its retail clients even more of an incentive. They would get bonus shares if they subscribed to the issue. Race car champion Dick Johnson led an extraordinary advertising campaign, unusual in a share market practice, largely to “first time investors” through Northern Queensland and the Northern Territory.[188] Four thousand individuals in Central Queensland, who had never purchased securities before believed the representations and lost their money. The most informed investors, and construction firms, chose to take a prudent step backwards, the least informed were aggressively targeted, and funding only fell across the line, short of the capital required to actually build the plant, with a government investment and guarantees.

Profit in any of the measures: There was never more than a 5% complete plant, no production, and no income. There was no profit from the business of producing magnesium. In contrast the business of separating investors and government from their funds was almost perfect.

Individual ownership and responsibility: The Magnesium research was contracted by AMC to CSIRO. CSIRO’s Light Metals Flagship invested their funds and reputation into trying to reach a successful outcome. As an organisation promoting research and new processes of value to the nation, this was a trial by fire, and the notable failure of has been keenly felt. There are no individuals identified who owned the research, or were named in presently available press releases in association with it. There was no apparent responsibility with AMC or CSIRO for the outcome. The CSIRO Flagships budget was cut $24 million after 2003. The Light Metals Flagship ceased operation in July 2011.

Initial Process simplicity: The MG Process to transform Magnasite to magnesium metal was complex 5 stage operation that required: A hydrogen plant, a hydrochloric acid plant, a water treatment plant, a methanol recovery plant, chlorine recycling plant and a glycol/ammonia recovery plant. It had leaching, purification, filtration, dehydration, crystallisation, centrifuging, calcination, electrolytic cell and foundry stages.[189] Whilst this may have been elegant chemistry on a well- equipped capital city research laboratory, it turned out an impractical option on a green-fields site in rural Queensland. The pilot plant lacked buffers for many of the processes, and only ran for a few days before shutdown or failure. The initial process was complex beyond the capability and financial resources of the proponents.

By comparison to the simple Pidgeon process, used in China to produce most of the world's magnesium metal, the AM process was complex, and has not been implemented by any other firm since. The Pidgeon process was developed in 1940 in Canada based on a 1938 thesis from Padua in Italy. The first plant was built in 1941 and operated successfully for 63 years. In 2012 China produced 640,000 tonnes of the total 750,000 tonnes by the simple process.[190]

Multistage scale up: The MG process seems to have had 3 steps up scales. The first prototype was in the CSIRO probably at Clayton laboratories, at bench or similar scale. The second was the $72 million demonstration plant. This had the aim of *"provided AMC with a facility to showcase and verify to financiers, customers and stakeholders the AM Process technology and the operability of that process."*[191]

Designed to produce 1,500 tonnes of magnesium metal annually, in the entire 26 months it operated the plant produced only about 240 tonnes of metal, or less than 10 per cent of its planned annual output. Its longest continual period of operation was just six days.[192] The third stage was the 97,000 tonnes per year plant never completed. The scale up from a 125 tonnes a month plant to an 8,083 tonnes a month plant is 1 to 64. But the scale up from a 9.23 tonnes a month plant (which was the average production over operation) is 1 to 876. The outcomes indicate that this is not a good model.

Niche demand for the innovation: The demand for high value magnesium metal for light weight automotive use has not eventuated as CSIRO and AMG had hoped. 85% of the world's magnesium is now produced in China, mostly to alloy in small quantities with aluminium. The use of magnesium in automotive castings in America is 2012 is about 47,000 tonnes, spread over 16.4 million light vehicles; on average 2.8 kg per vehicle. The peak use of magnesium in automobiles was in 1971, when 42,000 tonnes was consumed, almost all by Volkswagen who had been using about 20 kg of magnesium in their engine blocks since

1936.[193] At the time AMC was building the Stanwell plant nine other firms (Anaconda, Crest, Pilbara, South Australia, Tasmania, Mount Grace, Hazelwood, Woodsreef and TasMag) had registered plans for similar projects with ABARE, and were attempting to raise funding.

Mature and well understood process that has evolved: The MG process was new, unique and patented.[194] It had not evolved in a commercial sense, in that there was only 240 tonnes of demonstration metal made, and the process has not since been copied, licenced or duplicated. The low level of production and short campaign intervals with the demonstration plant, indicate a process that like Macduff in Shakespeare's Macbeth, "was from his mother's womb Untimely ripped."

Mature firm with complete value chain: AMC was not a mature firm, and the value chain, symbolised by the $50 million investment by Ford, did not materialise, nor was it taken by any competitor. Magnesium use in light automobiles has declined over the last forty three years.

Mutual benefits from decades of agreed collaboration: As there was no production, there were no benefits and no time scale to share them over. No similar magnesium metal product has taken this unique market share, so it is doubtful if it actually existed.

High level of reward for information asymmetry: The gap between what was projected, and what actually happened was large, but perhaps not a complete surprise to the proponents.

CSIRO projected that the 96,000 tonne production *would "generate more than $400 million (Australian) annually in export income."*[195] This would require a selling price of $4,167 (Aust) per tonne, which was based on the historically low Australian dollar, then trading at 53 US cents, and unusual optimism as to market demand. The Australian dollar increased in value (to 79.4 U.S. Cents by 2004), demand for extra magnesium production did not occur, and the price of magnesium metal fell from $2,500 U.S. per tonne in 1999 to $1,900 a tonne in 2003[196]

It is anticipated to produce at US$0.64 per pound and at project prices, projected to provide an ROI of around 16 per cent[197]. There was never more than 5% of the plant, no production and no return on investment.

In the 2000 Annual Report it was stated: *The magnesium metal activities culminated in the completion of the Feasibility Study confirming the economic and technical attributes of AMC's proposed 97,000 tonnes per annum Stanwell magnesium metal plant and its potential as one of the lowest cost producers of magnesium metal in the world.* No firm has sought to produce Magnesium by the MG process, which indicates that low cost is not widely perceived as credible.

Yet the outcome was not a complete surprise. The italic text is from the risk section of the October 2001 prospectus, AMC stated that *"there can be no assurance that construction will be completed and the Stanwell plant commissioned on time and within the capital cost estimate."* These twenty three words protected the proponents from liability.

On 25th June 2003 the Australian Securities and Investments Commission (ASIC) today announced that it has commenced an investigation into disclosure by Australian Magnesium Corporation (AMC). They revealed what "insiders" had known for some time, that *"since the outset, it has been clear that the AMC venture carried significant risk. The existence and extent of this risk was the subject of substantial disclosure in the company's prospectus."* [198]

High level of information asymmetry and power imbalance: Almost a billion dollars had been spend, the proponents retained the remuneration for their skills, the investors lost almost all their capital, no one went to jail, and very little money was recovered.

The question might be asked: "Who benefited?" To follow the money trail "what was claimed to have been achieved" and "what was listed as spent" are taken verbatim from page 3 of the 2003 Annual report.

"When project work ceased in June 2003, approximately 70% of the project had been engineered, 80% of the equipment items had been ordered or priced (most of which were in line with estimates) and less than 5% of site construction had been completed.

Major costs and expenses on the project included $194 million spent on equipment, $86 million on engineering, $60 million on bulk materials, installation and temporary assets, and $272 million spent on project operations and commissioning management, fees, charges, *insurance and other project expenses."*

The largest single expense, at $272 million, on a project stated as having a high risk of failure and non-completion, was administrative. The (insider) management group who were best informed as to the risks and probabilities, but were protected from liability for the outcome; seem to have directed the majority of funds to managerial expenditure.

A small example relates to the chairman of Australian Magnesium. In addition to his remuneration of $170,385 for managerial skills in 2003 year he also collected $182,500 for advisory services. His advice was in relation to: Capital-raising programs, Government liaison, Bank relations, Investor relations and Market development.

As a disgruntled investor, Pierpont[199] noted that: *Australian Magnesium had to mothball its $900 million project at Stanwell because it couldn't raise any more capital. The Queensland government refused to invest any further in the project. The banks scooped out $50 million in commitment fees and then walked away. The disaster left investors quite hostile. There wasn't much point developing markets if the project couldn't produce.* These comments, published in "The Australian Financial Review" were not challenged.

The $340 million spent on equipment, engineering, materials and assets was exchanged in 2004 for a Deed of Transfer and Release (from financial obligations) valued at $11.6 million, or 3.4 cents in the dollar.

Driving force exists for strategic misrepresentation: Almost a billion dollars of investment, left project assets valued at just $11.6 million. A curious soul might ask "where did the other 99% go?" No other project in the sixty seven projects over eighteen years failed to complete. No other project had a firm so incompetent at converting investment into proposed outcome, who chose so radical and unworkable an innovation, and received so much government investment.

In August 2001 an initial bid to raise $680 million in equity funding, on top of a $930 million debt package, failed. A second raised $525 million, $155 million short of the initial target. The Federal government provided a $100 million loan guarantee while the Queensland government offering a further $100 million of subordinated debt.

The proponents were rejected in their fundraising by professional investors and service providers. They then sought funds from the least informed investors, with projections remote from outcomes.

The four tonnes per day pilot plant produced just 240 tonnes in 26 months, and never ran for more than 6 days, so it is unsurprising that the emphasis was on management fees, and not on construction of a 265 tonne a day that might well have been even more problematic. Every other $100 million plus investment process plant was completed, a 5% completed plant, at financial exhaustion, is the exception.

The Case study in chronological order:

Queensland Metals Corporation Limited (QMC) had mining and exploration licenses covering 1.2 billion tonnes of magnesite ore from the Kunwarara deposit, 60 km north-west of Rockhampton. QMC had entered into a collaborative research project with the Australian government owned research group, CSIRO. A $73 to $135 million pilot plant at Gladstone worked on the patented process which involves leaching magnesite in hydrochloric acid to produce magnesium chloride. After purification and drying, it was to be smelted in an off-the-shelf Alcan electrolytic cell that required 99.9 per cent pure magnesium chloride.

CSIRO estimated that the 96,000 tonne production would “generate more than $400 million (Australian) annually in export income.”[200] This would require a selling price of $4,167 (Aust) per tonne, which was based on the historically low Australian dollar, then trading at 53 US cents, and level of market optimism.

In December 1998 and June 1999 ABARE reports a “Magmetal Project” was listed as a new project to cost $720 million, and to commence operation in 2002. By June 2000 the projected cost had risen to $1.13 billion dollars and commencement was to be in 2003. A cost increase of 57% and delivery slip of a year … in a year does not indicate a high level of competence in the early stages of planning.

In May 2003, the project had stalled with cost overruns of $200m and, according to the CEO, “the future of the project was under review". At this point it had received $320 million in loan and grants from the Federal and Queensland governments and Ford provided $50 million. The bank debt package of $902 million could only able to be accessed "following completion of substantial engineering work and equipment procurement.” The banks were paid $50 million in fees for this unused option.

By 5th June 2003 the firm had then run out of capital and any faith by the investors that an outcome could be reached; and requested the suspension of its securities”. The project was placed on care and maintenance. The $74 million left in the bank by the end of June was utilised in ongoing management expenses and restructure. When project work ceased in June 2003, less than 5% of site construction had been completed.[201]

The loss for 2003 financial year was $812,600,000. “Debt forgiveness” in 2004 was recorded at $122,500,000 as revenue.[202] *The Deed of Transfer and Release, signed between the AMC Group of Companies, the State of Queensland, the Commonwealth of Australia, Queensland Treasury Holdings, Newmont and Leighton Contractors Pty Ltd on 6 July 2004 eliminated borrowings of $182.2 million in exchange for primarily cash of $45.5 million and Stanwell Magnesium Project assets of $11.6 million.*

The loss for 2003 financial year was $812,600,000. “Debt forgiveness” in 2004 was recorded at $122,500,000 as revenue.[203]

When project work ceased in June 2003, less than 5% of site construction had been completed.[204] The process has not been subsequently copied, duplicated or licenced.

5.3.5 HIsmelt (8) $1,020,000,000 invested*. 12% of 800,000 tonnes of pig iron produced. Built 2003 – 2005; Operated 2005-2008; Closed 2009; Dismantled 2013; Transferred to India 2014. (* The $1,020,000,000 seems to represent the total invested over the years at Kwinana, with the 2002-2008 stage being valued in an 2002 ABARE listing as $400,000,000.)

In 2013 Rio Tinto harvested 266 million tonnes of iron ore, and shipped 259 million tonnes[205], with an approximate value of $135 a tonne on contract[206]; this would give an income of just under $35 billion. This is the jewel in the crown of Rio’s operations; as they ramp up production to 290 million tonnes for 2014. Retaining, and expanding the firms majority share of profitable business has been a long term focus. Rio Tinto started its iron ore business in the Pilbara in 1966, with Mt Tom Price.

The need to meet the wishes of the Western Australian Government, in respect of new leases and “secondary processing obligations” were first addressed in 1981. CRA and formed a joint venture with Klöckner Werke to pursue the steelmaking and smelting reduction technologies. Over three decades, there were three “research” phases with three joint venture partners. There was long term iterative research process, with many worked prototypes. After two decades of trials a less than successful commercial stage was followed by dismantling and re-locating the plant to India.

Between 1984 and 1990 the first smelt reduction concept (using the 60 tonne steelmaking converter) led to the construction of a second Small-Scale Pilot Plant (SSPP) located at the Maxhütte steelworks, Bavaria. With a capacity of 10-12,000 t.p.a, the design was based on a horizontal, rotating Smelt Reduction Vessel (SRV) that used bottom tuyeres for injection of coal, oxygen, fluxes and iron ore.[207] The SSPP operated from 1984 to 1990 and, according to Tio Tinto “proved the viability of the technology.” Klöckner withdrew in 1987, and in 1989 CRA formed a 50:50 Joint Venture with Midrex Corporation.

In 1991 third phase of the Process development was the HIsmelt Research and Development Facility (HRDF), constructed at Kwinana, Western Australia; with a design capacity of 100,000 t.p.a. This was “to demonstrate the process and engineering scale-up of the core plant and to provide operating data for commercial evaluation” which sounds more marketing than research.

A horizontal vessel, (second phase) was operated from October 1993 to August 1996. However “the complexity of engineering a horizontal vessel limited its commercial viability.” Midrex (owned by Kobe Steel) withdrew 1994. A $100 million investment for producing 100,000 tonnes per year of steel was shown in ABARE 1993 report, which matches HRDF.

A water-cooled vertical vessel; the SRV designed in 1996. The improvements included top injection of solids, a simplified hot air blast lance, and a fore hearth for continuous tapping of metal and water-cooled panels to overcome refractory wear problems.

The HRDF vertical vessel was commissioned in the first half of 1997 and operated through to

May 1999. The vertical vessel (SRV) demonstrated major improvements over the horizontal vessel in terms of refractory wear, reliability, availability, productivity and simplicity in design.

The Rio Tinto website states that “the vertical vessel operation confirmed the process was ready to be scaled up to a commercial plant.”

During 2002, an unincorporated joint venture was formed between the Rio Tinto (60%), Nucor Corporation (25%), Mitsubishi Corporation (10%), and Shougang Corporation (5%) groups - for the purpose of constructing and operating an 800,000 t.p.a HIsmelt Plant. Located in Kwinana, Western Australia, the merchant pig iron facility was designed and engineered with a 6-metre hearth diameter Smelt Reduction Vessel.

On 14th May 2002 *the Australian government provided a grant of A$125 million for the development of multi-user infrastructure associated with the plant.*[208] In May 2003 Dr Gallop, Premier of Western Australia said *the State Government had committed $30 million for purchasing land and upgrading port facilities associated with the project. In stage one, the HIsmelt plant would produce 820,000 tonnes of pig iron per annum, increasing to 1.64 m.t.p.a by 2006, in stage two.*[209]

Construction of the plant commenced in January 2003. Cold commissioning of the 6-metre plant commenced in the second half of 2004. Hot commissioning at the HIsmelt Kwinana Joint Venture plant commenced in Q2 2005. Starting from November 2005 the plant was scheduled to take 3 years to ramp up to its name-plate capacity. The final hot metal production rate of 105 tonnes per hour, or 800,000 tonnes per year would consume 700kg of coal per tonne of hot metal.

It is difficult to tell when a plant transitions from research to commissioning to commercial production. In 2006 a production rate of 65 tonnes of hot metal per hour with a coal rate of 900kg per tonne of hot metal was reported. In 2007, 80 tonnes of hot metal per hour with a coal rate of 810kg per tonne of hot metal were reported.

However output, as a percentage of nameplate capacity remained at low levels shown in Table 24. Had the commissioning gone as shown in Table 25 the production figures and returns would have been very different. The price that is shown is the average price for scrap iron in USA, taken from the USGS reports, and may be a little different to payments Rio Tinto received. Table 24 shows what was produced. Table 25 shows what should have been produced according to the HIsmelt commissioning plan.

Table 24 Actual production and estimated sale value.

Year	Capacity	Output	US Scrap	Sale value
2005	4.50%	9,000	$188.51	$1,696,590
2006	11.13%	89,000	$214.00	$19,046,000
2007	14.36%	114,870	$249.00	$28,602,630
2008	10.28%	82,218	$349.00	$28,694,082
				$78,039,302

Table 25 Proposed productions and estimated sale value.

Year	Capacity	Output	US Scrap	Sales value
2006	60%	480,000	$214.00	$102,720,000
2007	90%	720,000	$249.00	$179,280,000
2008	100%	800,000	$349.00	$279,200,000
2009	100%	800,000	$208.00	$166,400,000
2010	100%	800,000	$335.00	$268,000,000
				$995,600,000

HIsmelt was described *"as a revolutionary new iron-making process developed by Rio Tinto Group. Fine iron ores and non-coking coals are injected directly into a molten iron bath, contained within a Smelt Reduction Vessel (SRV), to produce high quality molten pig iron. It can be considered both as a potential replacement for the blast furnace and as a new source of low cost iron units for the electric arc steelmaking industry."*[210] The HIsmelt@ Technology was promoted as offering: *"lower operating costs; lower capital intensity, lower environmental impact, greater raw material and operational flexibility"*to the steelmaking industry. Other benefits were in processing iron ore fines that might be high in phosphorous, and use of lower grade non-metallurgical coals. The process was to produce 4.5kg sized "pigs" of iron with low levels of slag. These pigs would be used in Electric Arc Furnaces (EAF) as a substitute for hi grade ferrous scrap iron. For this reason the price of scrap steel has been used in calculations.

Despite these claimed benefits Rio Tinto terminated the Kwinana HIsmelt plant in January 2011. Rio Tinto projected $30 million to dismantle the plant and remediate the site.[211] The technology has not yet been implemented commercially by any steelmaking plant.

The commodity prices for scrap iron and pig iron in 2006 – 2011 were close to the projections for the plant.[212] *The plant will produce 800,000 t.p.a of pig iron for shipment world-wide, with an annual value of $250 million.* This would be $312.50 per tonne. Table 26 below indicates that the commodity price went from $249/t in 2007 to $349 in 2008. So it was peaking at the time production came on stream.

Table 26 World prices for scrap steel

Year	Scrap Price US	World Steel	China Steel	China %
1991	$91.74			
1992	$83.88			
1993	$109.98			
1994	$124.58	726	92	12.67%
1995	$131.29	752	93	12.37%
1996	$126.00	758	100	13.19%
1997	$126.02	795	108	13.58%
1998	$104.07	781	114	14.60%
1999	$90.98	786	124	15.78%
2000	$92.61	845	127	15.03%
2001	$73.84	851	149	17.51%
2002	$88.21	904	182	20.13%
2003	$108.00	962	220	22.87%
2004	$205.00	1,050	193	18.38%
2005	$188.51	1,130	349	30.88%
2006	$214.00	1,170	419	35.81%
2007	$249.00	1,340	489	36.49%
2008	$349.00	1,330	500	37.59%
2009	$208.00	1,240	568	45.81%
2010	$319.00	1,400	630	45.00%
2011	$392.00	1,490	683	45.84%
2012	$375.00	1,548	717	46.32%

Table 25 also shows the doubling of world steel production, the evolution of China as the world's leading steelmaker. These are all factors that should contribute to commercial success for a plant that was technically capable of delivering the promised benefits.

The 26th March 2009 press announcement[213] by Rio Tinto, *to close its "deeply uneconomic" $400 million HIsmelt plant in Kwinana has led to 100 job losses. The mining giant announced today the troubled plant would be shut for at least a year, blaming the closure on a drop in pig iron prices and a bleak market outlook.*

The statement seems to be at odds with facts. In 2009 the price for crude steel was briefly depressed, but was higher than it had been for fifteen of the last nineteen years. It was shortly followed by scrap iron prices almost doubling, as shown in Table 34. This table also show that in the time that Rio Tinto was developing the technology the wold of steel making changed, with China becoming the world's largest steelmaker. However, China imports only 6.8 million tonnes of ferrous scrap, of the 104.7 million tonnes traded in 2011.

Had the plant scaled up to nameplate capacity it would have produced crude steel generating an income of approximately $995 million. The significantly sub optimal plant performance probably generated an income of approximately $78 million in its four years of operation. The failure to function beyond 14% of nameplate capacity seems to have been much more significant than the price of the commodity. The 800,000 tonnes of product would have only been 11.7% of Chinese scrap imports, or 0.7% of world consumption.[214] By 2011 the price for pig iron had almost doubled, but the plant was still not re-opened.

This case shows a puzzling outcome for an otherwise notably competent firm, who proceeded with detailed research and development over nearly three decades, and had adequate capital. It is an innovation failure with much in common with the one innovation success, and was the one of two projects with direct Government finance, and significant information asymmetry. This it is a case study to be used in all four hypotheses, and all twenty model parameters will be considered.

Track record: Rio Tinto is the fourth largest mining company listed in the world with 2012 revenue of $51 billion. It is a multinational diversified resources production and trading firm with five divisions, Iron ore, Energy (coal), Rio Tinto Alcan – aluminium, bauxite and alumina, Copper and diamonds. It has never been a producer of steel.

Firm focus: Firm focus is on the long term access to key resources, like iron ore, and coal, and the bauxite to aluminium supply chain. Whilst a very professional business, there is no obvious commitment to radical new process innovation, other than HIsmelt. The mine of the future project appears to be a clever utilisation of many of the best existing technologies, incrementally improved and worked into an operations system. Rio Tinto ship more iron ore from the Pilbara than BHP-Billiton.

Scale up ratio: The scale up ratios over the significant time frames of research and development fit the success model closely. However scaling up a plant that seems not work as planned, or provide expected benefit, or has potential to make a profit seems an anomaly. The key difference in scale up between Case 40 and Case 8 is that every early implementation in Case 40 seemed to work well, and was scaled up. The early implementations in Case 8 seemed to reach a failure point with departure of an experienced partner. The process then re-started with an alternative embodiment along the general theme. Thus there was no scale up building on success, rather scale up learning from failure. There is no fault in learning from failure. But when the whole exercise ends in failure, was it failure that was developed. Was failure acceptable as the process not the outcome was the objective?

Financial confidence: Rio Tinto has enjoyed strong performance, with the exception of the $ 38.1 billion Alcan purchase in 2007, which was badly mistimed. They would still enjoy strong financial confidence, and be able to raise capital at favourable interest rates, over any normal project time scale.

Profits: Rio Tinto was before 2007 the second most profitable mining firm in the world. They are noted for tightly run and well managed operations. This project was the exception. It did not perform technically as expected and absorbed Federal and State capital. Rio Tinto would have been able to claim R&D Tax concession over much of the life of the project. So whilst this project made no profit, it transferred much of the cost to the Commonwealth.

Individual Ownership and responsibility: HIsmelt over the long term of its life lacked obvious ownership beyond the corporate objectives, and few senior individuals who started in 1981, would still have been in control in 2014. Rio Tinto through their HIsmelt associated websites still promotes the process as ongoing, viable, and of value, though the experience at

Kwinana in 2008-09 was quite the opposite. There seems to be no individual champion, or personal responsibility for what has happened.

Initial process simplicity: The simplicity of the process that became HIsmelt is difficult to ascertain, as it has gone through four distinct embodiments, with 3 sets of joint venture partners over the 24 years 1981-2005. Two of these partners have after a period of collaborative operation withdrawn. These were the two with the most detailed knowledge of steel production. This might be seen as a negative assessment of the commercial potential of the process by those best informed to make an evaluation.

In a paper titled "Direct Smelting: Why Have So Few Made It?"[215] The authors list technical and financial difficulties that proponents of similar processes have experienced. These authors included HISmelt management and Rio Tinto's Chief Technologist Robin Batterham. They comment *"The time-scale for developing this type of technology is more like 20 years than 3-5 years."* At the time (2002) Rio Tinto had been working on the process for 21 years. More interesting is the comment *"The reasons why so few succeed in this area seem to be strongly related to the soundness of the starting point. If the reasons for trying (and the degree of ongoing support) are not up to the task, history suggests failure is virtually guaranteed."* As technical and economic failure was the outcome, it is reasonable to question if the starting point was sound?

Multistage scale up: The Rio Tinto developments that lead to HIsmelt were in stages that built on the prior work with new partners at each stage. Rather than multistage incremental scale up of a simple working process, these seem to be relatively large scale implementation, each one ending in failure and some learning for the next embodiment. The 1991-1997 plant of 100,000 tonnes preceded, and had many features of the 800,000 tonnes per annum plant that is this case study. By 2003 HIsmelt had 22 years of experimental and practical experience, which if based on a simple innovation like ISASMELT should have led to a similar successful outcome, but it did not. The outcome of the final 2003 - 2008 project was a commercial and technical disappointment. Production of 14.36 % of name plate capacity in the third year of operation (2007) after 26 years or research and development is difficult to interpret as success. These stages are shown in Table 27.

Table 27 Stages in HIsmelt development

Date	Stage	Tons p.a.
1981	CRA JV with Klockner Werke	
1984 to	Smelt Reduction Converter	60?
1990	Small Scale Pilot plant	12,000
1987	Klockner Werke withdrawal	
1989	CRA JV with Midrex	
1991	HRDF design build	100,000
1993-96	Horizontal Vessel operation	100,000
1997-99	SRV Vertical water cooled	100,000?
2002	New JV partners	
2003	6 metre smelt reduction vessel	(build)
2005	6 m Smelt Reduction Vessel	800,000
to	3 year ramp up	
2008	Close due to GFC	
2011	Jindal Steel and Power deal	
2014	Plant to be moved to Orissa India	

Niche demand for innovation: The demand for direct smelting technology is still potential and theoretical. Of the firms that HIsmelt saw as competitors, only one has had a degree of success, and all firms have suffered similar tribulations. Siemens VAI's Corex process has been implemented by Jindal Steel in India, as well as in Korea and South Africa. It is the most commercially successful so far. The Russian Romelt process, The Japanese Dios Process, and the American Iron Dynamics process have not yet passed the "promising" but non-commercial stage. The demand so far seems smaller than anticipated; and the difficulties as great as HIsmelt found.

The niche for direct smelting appears to be in countries with significant local gas supplies that are difficult to export, and hence of very low value. Saudi Arabia, Iran, Libya and Venezuela are examples. It is also attractive to nations with coal and iron ores with undesirable characteristics for conventional steelmaking such as India. Western Australia has exceptional quality iron ores available, a well-developed LNG export infrastructure, and a very limited market need for local iron ore production. There was limited niche demand to drive the project to completion.

Mature and well understood processes evolved: Whilst direct smelting and top submerged lance technology dates back to SiroSmelt in the early 1970's, it has not seen widespread success in iron reduction. As there are no commercial HIsmelt like iron smelting plants in operation, after more than 3 decades the process is yet to mature, and by virtue of the poor performance shown in Table 5.3.5A is not yet well understood enough.

Mature firms with complete value chain: Rio Tinto is a mature and respected firm, with one of the largest operational value chains in its Rio Tinto Alcan division. However they have not shown any interest, beyond the work in partnership with existing steel makers, to become involved in a steel making value chain of their own

Mutual benefit from decades on agreed collaboration: Rio Tinto has been in four stages of agreed collaboration with joint venture partners. Two were terminated by the other partners, and two have yet to bear commercial fruit. The agreed collaboration with the Western Australian government to meet secondary processing obligations may have given Rio Tinto the outcome they sought, but did not give the Western Australian government the outcome they were hoping for.

High level of reward for information asymmetry: Rio Tinto makes the majority of its profit from Western Australian iron ore operations. They have retained and expanded their operations in the Pilbara, and met their secondary processing obligations with the long running HIsmelt program. If one looks at outcome derived against cost invested over three decades it has been a remarkably economical and effective investment. They invested less than a third of BHP's HBI plant, and received $125 million in Federal and $30 million in state grants. The rewards for managing a preferred outcome were considerable.

High of information asymmetry and power imbalance: The level of information known to Rio Tinto in 2003 about the state of technology in their preferred direct smelting process, after twenty two years of research and development were very much superior to anything known to the Western Australian government. Whilst the Western Australian government own the iron ore resource, and negotiate the leases, they are an entity with a $25 billion a revenue stream, less than half that of Rio Tinto. Rio Tinto is probably the largest single contributor to that states revenue stream.

Driving force exists for strategic misrepresentation: The revenue from Pilbara iron ore is estimated to be $35 billion of their 2012 total revenue of $51 billion. Meeting the secondary processing obligations ensured uninterrupted access.

Asymmetrical information used to manage ignorant power: The Western Australian governments wish to produce crude steel from local iron ore fines, and export the product, was not as economically sound as the bauxite to alumina to Aluminium model. The two large resource firms that built crude steel plants to meet the secondary processing obligations both reached the same negative outcomes by widely different paths. The iron ore fines are now exported with other lump production, and a royalty is received on this by the government.

Selective strategic misrepresentation to promote investment: The investments in HIsmelt came from joint venture partners in undisclosed sums and from State and Federal Government. What benefit the joint venture partners have received is as obscure as their inputs. The majority of investment seems to have come from Rio Tinto, and was either written off their liability to pay Federal company taxes or written off under more favourable Research and development concessions, again against their Federal tax liabilities.

5.3.7 Conclusions

These three projects that involved high levels of process innovation achieved widely diverse outcomes. The first (40) received only commercial investment and succeeded exceptionally in stages over time. The other two (7 and 8) received State and Federal project funding and failed at different speeds.

Two (40 and 7) have a common seed from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in the original development of the innovations. The third (8) uses a lance furnace design that has some similarities in appearance to (40).

The key points for ISASMELT are that:

- The innovation had a brilliant and much respected[1] **individual** founder, whose name is still associated with the process. Success had a proud father, who worked and invested, and fought through the “childhood and adolescent years” of his process.

[1] John Floyd was made a Member of the Order of Australia (AM) in 1997 and received a Clunies Ross National Science and Technology Award in 1995.

- The innovation was bottom up, small in scale, low in budget, modified and improved, largely by original inventors. The inventors broke free of their state research organisation, and devoted their working lives to the commercial exploitation of the process.
- The innovation was initially able to be implemented at moderate cost, and was functional at the time it was adopted. Evolutionary Improvements, process scale up and adaption to new materials and applications followed sequentially and in many modest steps.
- Early implementations worked well and gave small scale but real commercial benefits, in resolving process problems with base metal refining and recycling. Each new stage built on, and improved on, prior success.
- The innovation was quickly recognised as intrinsically valuable, but not by CSIRO, and was the subject of fierce commercial competition. The rapid development of flotation, which transformed productivity at Broken Hill, in the decade after Federation, was driven by similar competing innovators and their developments.
- The industry that needed the innovation; quickly recognised the potential and began a systematic process of research and development.
- One firm (MIM) who wanted the innovation for their own application; and successfully applied it in increasing stages; then marketed the outcome internationally.

In contrast Australian Magnesium Corporation Limited (AMC) contracted research by CSIRO in 1987 *"to investigate cost-effective processes for producing high purity anhydrous magnesium chloride suitable for feeding to a modern magnesium electrolytic cell such as the Alcan Multipolar design. Patents on magnesite dissolution and purification were filed as a consequence of this work*[216]*."*

The key points for the AM Technology are that:

- The innovations are not publicly associated with any named innovator, or team of known collaborators. CSIRO does not welcome inquiry on this topic. In this case the failure is an orphan, apparently fathered by a committee, who were paid by the hour, and then redeployed to other work. The project "owners" were promoters rewarded by funds raised and managed, not process grown and strong financial outcome.

- The complex and multistage innovation was developed as a service on a cost plus basis, and was not fully functional outside a well-equipped research laboratory at the time it was promoted. Limited improvements and practical adaption followed.
- The economics of the project were poorly defined, and in the building of an initial mega plant, indicated that "the numbers did not add up" except at very large scale. In practice the numbers never came close to adding up. A process that only "adds up" at huge scale is not robust or practical, and the numbers have probably been massaged to get them to add up. An outsider might ask "Can we model the numbers to see the outcomes?" An insider committed to the project might have to massage the numbers till the required outcome is shown. The first is research, the second perverse and self-interested advocacy. "Massaging the numbers" is an insider practice to manipulate statistics, data, or numerical measures so that they appear to support a particular interpretation or to be better than they are and produce a desired result. This is using asymmetric information for strategic misrepresentation.
- The demonstration plant operation revealed poor operability, and very limited production percentage of nameplate capacity. Failures, both technical and commercial, at small scale were hidden and scaled up. Small projects might tolerate criticism, large projects engender defensive groupthink.
- The innovation was not widely recognised as intrinsically valuable. It was not the subject of commercial competition. It had not been duplicated since.
- The magnesium production industry has not adopted the innovation, or sought to licence it.
- After two decades there is no apparent local or international interest let alone competition. AMC has changed its name to Magontec Limited[217] and lists its activities as "*Manufacture of magnesium alloys and development and commercialisation of magnesium alloy technology*"

The key points for HIsmelt are that:

- The innovation developed in three stages of relatively large scale trial and process evolution. There were three sets of joint venture partners, with more direct interest and experience in steel production, over a twenty two year period. Direct smelting reduction was a goal seen as valuable by many international firms, who followed a similar longer time scale. The long time line and lack of early success required a corporate commitment over decades. There are no visible driving individuals in the HIsmelt project in the way that Dr John Floyd was in ISASMELT.

- The innovation seems to be top down, relatively large in scale, with an adequate budget, modified and improved in stages, by a large firm over a long time. The Australian inventor Rodney James Dry of Technology Resources Pty Ltd is named in a number (34) of HIsmelt patents[218]. But his responsibility or power to drive a successful outcome quickly within such a large organisation is not known.
- The innovation was initially (1984-1990) implemented at moderate cost, at a brown-fields site in Germany, but was quite different to the HIsmelt patent of 2000. The horizontal vessel had similarities to the puddling furnace patented by Henry Cort in 1784. It fed coal and ore in from beneath, tapped metal and slag off to one side, and was fed with hot air at 1,200° C. The HIsmelt plant of 2003-2008 was a vertical vessel with a lance feeding oxygen enriched hot air, in many ways similar to that used by ISASMETLT. The ore and coal are fed in from above at an angle, and slag and iron are tapped at different levels from different sides. The significant evolution, and creation of unique intellectual property, indicates that the first plant did not work as well as hoped.
- If the significant change over a long time period are accepted as an indication that early prototypes were less than fully successful, then the early implementations did not work well and gave few commercial benefits, in resolving process problems with base metal refining and recycling. The final 2003-2008 plant performed at such a low level production and was closed as “deeply uneconomic” so it would be logical to think that earlier plants were even less desirable, except as research tools. There is no evidence that any of the plants worked well and gave economic benefit in a commercial sense.
- The innovation that would flow from an economically successful direct reduction plant was recognised by a number of firms over the last two to three decades, but has been the subject of relatively restrained commercial competition. The benefits have been seen as less than compelling with few possible exceptions. India has low quality local iron ores and coal that make direct reduction more attractive. The demands for the HIsmelt licences, given the poor outcome from the plant operation, as yet seem potential.

MIM was driven to develop and build better lead smelters and copper smelters for their long standing Mt Isa operations. MIM was formed in 1924, and after many difficulties reached full production in 1931. They have extracted, processed and refined lead, zinc and silver, copper and gold for the last 70 years. In their first 20 years of operations they had some significant problems with process plant that did not work out as expected. Over time and painful experience they developed local expertise. MIM wanted to develop better plant with their own funds that they would then build and operate.

AMC were driven by the opportunity to transform some of the low value magnasite available at their Kunwarara site. AMC was formed in 1983 and successfully established and operated the QMAG Magnesia plant. They had no previous experience with advanced mineral processing or complex metal refining. AMC wanted to raise funds from investors to build a new type of plant, that contractors would build and they would operate with newly hired staff.

What drove Rio Tinto to invest in steel making technology, other than to meet secondary processing obligations is not clear. They had not in the past been involved in steel making, and have no published plans, or business strategy to make such investments. The Joint Venturing arrangements were always with firms who were in the steel making business. In a simple analogy, Rio Tinto wanted to be engaged in a very long scale plan to make a lunch they did not want to eat, in partnership with someone who would eat it.

MIM took on a relatively simple, well tested and developed process that they would improve and adapt to lead, secondary lead (recycled lead from batteries and lead slags) then to copper concentrates. The process was robust, and adaptable to a range of ores, wastes and fuels. The plant was low in cost, simple to produce, and used well established materials. The first production plant was estimated to cost $100 million.

Rio Tinto started with German scrap melting technology, and ended up with an Australian direct reduction process that did not work as well as projected. One might ask “Was it the journey or the goal that was important?”

MIM had slowly scaled up the size of plant over 13 years before commissioning the Case 40 ISASMELT plant in 1993. Whatever difficulties and modifications were needed had been made on the smaller scale plants over 12 years of research and development.

AMC completed their demonstration plant at Gladstone in 1998. Problems with the process are said to have delayed the completion of test work by six months, only to be completed at end of 1999.[219] Given the low output of the plant, and limited durability it is surprising that the AMC 2000 Annual Report stated on page 4 “The successful operation of the Gladstone plant provided a sound basis for the feasibility study for the Stanwell Magnesium Project.” A few lines below the same report states “AMC is in the process of finalising funding for the commercialisation of the Stanwell Magnesium Project. When commissioned, the 97,000 tonne per annum magnesium metal and alloy plant will be the world's largest and one of the lowest cost producers. “

It is difficult to understand how the operation of a $72 million “demonstration plant” that produces less than 10% of its capacity can be linked to such favourable and unequivocal projections of operation costs and performance of an unbuilt plant based on the same process.

This topic will be further explored in the section dealing with “optimism bias and strategic misrepresentation”.

Rio Tinto invested $1,020,000, apparently over twenty seven years. Whether this included the $155 million received from State and Federal Governments is unclear. If one were to suggest that the goal was to meet secondary processing obligations, then it was a remarkably cost effective investment over a long time scale.

At the least Rio Tinto and AMC had much more enthusiastic and promotional “optimism bias” than MIM. MIM were able to market their developments around the world, based on the performance of their operating plants.

The contrast in how the two firms used and reported their small scale demonstration plants is instructive. MIM used the knowledge from their 1983 12,000 tonnes per year plant to build their 1991 60,000 tonnes per year primary lead smelter at Mt Isa. The 1985 Lead slag reduction plant lead to similar sized secondary lead smelters in UK (1991) and India (2000).
The value AMC derived from their plant is best in their own words, from page 4 of the 2001 Annual Report. *“The Gladstone magnesium demonstration plant, in addition to its training*

and test work activities during the year, the site received visits from more than 300 senior bankers, brokers, insurance experts, project engineers and politicians as part of AMC's investment, due diligence and planning procedures for Stanwell. This intensive process provided, amongst other things, a great opportunity to showcase our operation and skills and in many cases the means and process of accelerating the progress of aspects pertaining to the subsequent construction of the Stanwell plant."

The value that Rio Tinto received beyond satisfying the Western Australian Government's requirements is difficult to quantify.

MIM was marketing to existing smelters, to buy a process that they used themselves profitably. AMC were marketing to finance providers and powerbrokers; seeking to raise capital. Rio Tinto was meeting a state government obligation to maintain their iron ore leases.

Cases 7 and 8 are in contrast to Case 40 in almost every respect in every model shown on Sheet 8 of Appendix. They are almost opposites at every point on Sheet 9 of Appendix.

Case 40 was the lowest budget and best outcome. Cases 7 and 8 utilised $2 billion of investment, much from governments and produced negative outcome.

Chapter 6
Government involvement in value adding and asymmetric information

"It is error alone which needs the support of government. Truth can stand by itself."
- Thomas Jefferson

6. GOVERNMENT INVOLVEMENT IN VALUE ADDING AND ASYMMETRIC INFORMATION

6.1 Introduction

There must be government involvement in every resource project as the state owns the resource for the benefit of the people. They seek to extract economic and political value from the terms under which they allows access. Royalties, typically between 4.7% and 7.8% are a valuable and regular income for states. Value adding to processing resources within the state enables further streams of taxable economic value, more widely spread wealth creation and high paid jobs. These have direct and indirect revenue implication, and economic multiplier effects for the state. Governments also set and enforce the environmental standards for the operation. These change over time, and are now much more comprehensive than in the past.

Governments seek both economic and political return from resource access. These can be contradictory, in that maximising economic return can be based on best past practice for the type of resource. Political advantage may ideological, or pragmatic. Governments have long held values and may require support of particular interest groups.

Uranium mining has been intensely political, especially in South Australia. The Government has urgently wanted the royalties and economic activity, from Olympic Dam. But they have sought to manage the uranium issue, with local processing and value adding. That this has led to an outcome that may be less than optimum for the state and the operator, and is explored in the Olympic Dam case study.

Gold mining is only moderately political, with State Governments largely content to collect a share of revenue. The modern exception is in the growing opposition to the use of cyanide in the extraction process in NSW. The largest mine in NSW is the Cadia Hill copper and gold mine with a $2 billion investment. They chose not to refine the gold or copper but ship them as concentrate. This reduces risk and capital investment for the operator, but increases rail freight and port charges. The concentrate is shipped in containers with between 25 and 26% copper by mass and 75 to 80 grams per tonne of gold[220]. The other 73-74% is fine crushed rock. The value of the concentrate is around $2,000 per tonne, or about $34,000 per 17,000 kg container.

Value adding is the processing of a resource to the most refined and highest value commodity, which is hopefully integrated into a local manufacturing value chain. To give a simplistic example, bauxite is valued at around $30 a tonne, alumina at around $300 a tonne; and aluminium until recently was around $3,000 a tonne. Transforming the aluminium into a motor vehicle could increase the value, the input of skilled human labour, by between $30,000 and $60,000 more per tonne.

The opposite to value adding is concentrate shipping. In this process an ore is concentrated to a balance between transport costs and the value to the refiner for their needs and processes. The metal content might be between 20% and 30%, and poly-metallic ores are common. Refining ores often represents an environmental challenge, as well as a technical and economic risk. The purchaser in China, Japan or Korea accepts these risks and develops the refining technology. The concentrate usually feeds an existing refinery that may be closely linked to the next steps in the value chain.

Australia is the world’s largest exporter of low valued bauxite, with 73 million tonnes shipped in 2012. Bauxite has traded as low as $19 per tonne (in 2003)[221] and as high as $39 (in 2011).[222] Through government value adding requirements, Australia is also produces 20.4 million tonnes of alumina in 2011-12. Approximately 17.1 million tonnes of alumina was exported in 2011-12, with estimated revenue of $6.03 billion for the year; or about $352 per tonne.

Starting in the 1960’s The Western Australian Government tied access to Bauxite to establishment of an alumina refinery. Other states followed, and this has become an accepted practice. Whilst there are some financial stresses on a number of Alumina refineries in 2013, over nearly 50 years the linking of profitable value adding in return for access to bauxite deposits has been successful. This is explored in the alumina case studies.

Australia has the second largest reserves of bauxite in the world, about 22% of total. Far more precious is nickel, valued at between $22,890 (2011) and $17,600 (2010).[223] Australia is the leading resource holder, with 28.4% of world total.[224] This is larger than the next two resource holders, Brazil on 11.9% and New Caledonia on 9.7%. Yet failure to master processing of laterite ores has seen nickel exports stagnate.

Australia is the largest exporter of iron ore in the world, with 525 million tonnes in 2012[225] contributing $ 62.7 billion of export revenue[226].

In contrast to the successful government intervention the mature technology of alumina production, there was little Government interest in the five innovative laterite nickel cobalt process plants that failed in the 18 year period. There was strong Western Australian government intervention, to develop new and innovative steel making technologies; along similar lines to what had been achieved with bauxite and alumina. But this involvement achieved quite an opposite result.

Thus the comparison in government intervention is; why did it work so well for bauxite to alumina and so poorly for iron ore to crude steel?

A secondary consideration is why the South Australian government has received so little benefit from so much involvement in the Olympic Dam case.

A third consideration is why Refining failed so often (15 projects of 44) and Concentration was so risk free (all 23 projects succeeded.) All failures were refining operations.

6.2 Hypothesis 3: "That the role of government involvement in value adding was negative for more innovative processes"

6.2.1 Distributional data of factors that make up inputs for prediction

Government was involved in all sixty seven projects. This was largely benign application of standard lease conditions for fifty projects. There was mutually beneficial working of a well-tested collaboration model with large corporations in value adding in eleven bauxite-alumina-aluminium process projects. There was malignant involvement where they sought non-commercial value adding outcomes that doomed or retarded five projects.

The first group are in the lower risk majority to the right of sheet 6 of the appendix. They mostly succeeded worked, and where they failed, this was more associated with lack of firm competence.

The second group are highlighted with a purple marker in line 13. The involvement worked rather well for many decades from the mid 1960's to 2008 when the world changed. The changes were not the fault of, or within the control of government. The world economy, and especially the role of China had changed in ways that were large beneficial for Australia, except for processed aluminium price.

The last group are in positions 1 to 5 on the left of the sheet. In these cases what the governments wanted was not achieved, and the scale of the failure meant that the outcomes would be most unlikely in the future. These included the only two projects (Cases 7 & 8) in which State and Federal Governments made cash inducements of over $100 million. Government may not be able to pick winners, but they were able, with uncanny accuracy to back some of the largest failures.

Governments like to "think big" thus had the greatest negative impact where a large plant with high technology made a miraculous transformation, or made a complex (Case 48) from a politically unacceptable commodity (copper with uranium enclosed) into a "good" product like copper with the last traces of Uranium removed, and uranium that would be sold to selected markets.

An investor who avoided projects that had government involvement other than standard lease conditions, avoided large scale up, and all value adding, would have face few risks. No concentration projects failed. The alumina and aluminium plants built when the government involvement worked well; are today poor investments.

Investing where the government is not, is a better policy in the long term. Governments do not involve themselves to make investor rich; they become involved to achieve social and political objectives. At best make the investor only poorer in the long run.

Where the government invests capital, the investor should run and not look back. In the two cases it occurred, it was an indication of failure to follow.

6.2.2 Distributional data on execution, performance and outcome

In the five cases of malignant involvement, the construction delay and cost overrun was, on average 2.6 times worse than projected. The production output of nameplate capacity was an average of 34%. The outcome was four failures and the profitless stalling of the largest value mine in the country.

In the eleven cases of alumina and aluminium the firm competence of the operating firms, and the maturity of the process were indicators for a good enough outcome. Construction delay was on average only 8%, cost overrun 18%. These are comparable with the averages for the fifty more firm competent projects. The production output of nameplate capacity was an average of 87%. This is measurably, but not badly below the 99% achieved by the averages for the fifty more firm competent projects.

6.2.3 Wagerup 2 refinery upgrade (Case 24) $285,000,000 invested. 9.6% over budget, on time delivery. 440,000 tonnes of extra Alumina produced. Built 1997-1999

The Wagerup alumina refinery upgrade is an example of the seven alumina projects between 1993 and 2007. Six (Cases 21, 25, 27, 28, and 30) were upgrades to existing refineries, only Yarwun (29) was a new operation. An upgrade is a vote of confidence in a business that is making money and can make more by doing the same at greater volume. There is little risk or uncertainty, or there was until mid-2008. Just after Rio Tinto had paid a premium price of $38.1 billion US for Alcan, the market for Aluminium and hence Alumina collapsed.

Between August 2008 and March 2009 the price of Aluminium fell from $3,300 US per tonne to $1,300 US per tonne and has only slowly crawled back up to a little over $1,600 per tonne in early 2014. All this was a storm cloud on a far distant horizon when Alcoa originally began operations at Wagerup in 1984. The refinery is in close proximity to the Alcoa's Willowdale bauxite mine in the Darling Range and 70kms from the Bunbury port. At this stage expanding an alumina refinery was like the first sentence of "Anna Karenina" by Leo Tolstoy. "All happy families are alike; each unhappy family is unhappy in its own way."

Today the refinery has the capacity to produce 2.6 million tonnes of alumina from bauxite mined at Willowdale. This ore is transported by conveyor and refined to produce smelter grade alumina, which in turn is transported by rail to the Bunbury port for export to aluminium smelters around the world.

The 1994-95 expansion (Case 21) was apparently brought in on budget and in the 12 months projected. The second, (this Case 24 the 1997-1999 expansion) experienced an apparent

9.62% cost growth, but was delivered in the 24 months projected. Data on successful plant expansions is relatively slight, as they are internal projects, built within an existing, and operational structure. In terms of invested dollars in to tonnes per annum of alumina out, Wagerup 2 was the best investment in Alumina refineries in this period. Table 27 shows dollars invested to tonnes of new production. Case 27 the QAL efficiency upgrade was for environmental improvements, rather than increased production. Table 28 shows the bauxite to alumina projects in the database.

Table 28 Bauxite to Alumina projects

Case	Project	Years built	Investment	New Output	$ per tonne
21	Wagerup # 1	1993	$150,000,000	200,000	$750
24	**Wagerup # 2**	**1997-1999**	**$285,000,000**	**440,000**	**$648**
25	Worsley Alumina	1997-2000	$1,000,000,000	1,250,000	$800
28	Pinjarra Upgrade	2003-2006	$550,000,000	600,000	$917
29	Yarwun Alumina Refinery	2001-2004	$1,500,000,000	1,400,000	$1,071
30	Alcan Gove G3 Expansion	2004-2007	$2,700,000,000	1,800,000	$1,500

It is interesting to note how cost per tonne escalated in the early 2000’s and this has continued. A third stage expansion was proposed with a cost of $3 billion dollars. This was put on hold in 2008, and is unlikely to be re-visited soon.

In the period between 1964, when Alcoa opened their first alumina refinery in Kwinana, and 2008, when the market changed there were 44 years of stability, when firms and government understood the process and the outcomes. In this happy time the secondary processing obligations to transform a proportion of the bauxite harvested into higher value alumina, as the contract to access the resource worked well. Both side received the benefits they expected, and governments thought the model was universal, rather than case specific.

Wagerup 2 was the pinnacle of a mature and well understood process, built by an experienced team, who had repeatedly and incrementally improved their skills on one brownfields site. The drop in cost per tonne from $750 to $648 indicates a mastery of the detail, best achieved by constant practice in a focused field of endeavour. This was at least as much an example of evolved “firm competence” as an optimum of positive outcome from government involvement in mandated value adding.

Alcoa of Australia had been focused on transforming the initially challenging local bauxite resources into refined alumina for 33 years when this project started. They were part of the value transformation chain started in Pittsburgh USA in 1888 when 24 year old Charles Martin Hall started the Pittsburgh Reduction Company with $2,000 that his 33 year old partner Alfred E. Hunt had raised. Charles assisted by his older sister Julia Brainerd Hall had invented the process in a shed behind their home two years earlier. 25 year Paul Heroult in France had made the same discover in similar basic surroundings in the same year. Hence the Hall-Heroult process name.

In the first years of production they reduced the market price of Aluminium from $4.86 a pound to 70 cents, and made a profit. This firm became "The Aluminum Company of America", or Alcoa in 1907. At 70 cents a pound, aluminium was useful higher cost, but lower weight alternative to steel. It found limited application in automobiles and then more so in aircraft. Two wold wars, fought increasingly with aluminium aircraft drove the building of massive refining capacity that in 1946 was looking for new applications.

From locating new supplies of bauxite, every step in the transformation into an aluminium soft drink can, or aluminium window frames, Alcoa, and other large competitors encompassed the complete value chain. This contrasts the steel industry where Vale of Brazil, Rio Tinto and BHP-Billiton of Australia supply iron ore to steel smelting mills in China or Europe. The steel mills supply rolled sheets to consumers who might then make a car, or long products like rails or structural steel for buildings. The steel value chain is broken at each major transformation step.

Between 1964 and the completion of Wagerup 2 in 1999, Alcoa had entered into many secondary processing obligation agreements with the Government of Western Australia. Both sides understood the other, and could depend on the outcome based on past delivered and shared outcomes. Alcoa made a profit from the Alumina; the W.A. government received the benefits of investment in plants, and local employment and supply contracts. Both sides agreed to the deal, and received the outcomes they expected from the collaboration. There was a low level of information asymmetry, and no need for strategic misrepresentation. Both sides did what they had done for decades, and had little reason to think it would change.
The low value of Bauxite, typically $20-30 per tonne, means that the logistics and cost of

shipping it would be high proportional to sale price. Willowdale is more than 100 km from coastal ports. The logistics cost as a percentage of the value for a $300 product like alumina is 10 to 15 times more attractive.

The success of almost all examples of government involvement in value adding, by secondary processing obligations, with bauxite and alumina, over many years, obscured the failure of the same concept applied to almost every other commodity. Value adding makes sense when it builds on natural advantages, and where the operator makes a profit. This was the case with Australian alumina and aluminium till 2008.

Alcoa matches the parameters as a competent firm. There is little innovation or information asymmetry. To get maximum value from the case study it will be examined by the parameters of Government involvement and Asymmetric information models. It is a positive example for both.

Mature and well understood processes evolved: The process of transforming bauxite to alumina by Alcoa in Australia was by 1997 one of the most mature and well understood processes.

Mature firms with complete value chain: By 2007 Alcoa had been in every stage of the Aluminium value chain for a century.

Mutual benefit from decades on agreed collaboration: Alcoa stared this collaboration in 1964, and both sides have positive expectations of the other based on long experience and practice. The agreement is an accepted custom.

Low level of reward for information asymmetry: As the agreement is an accepted custom, to break the trust would have a high cost and low reward. There is very little information asymmetry in this process or arrangement. Both sides know just how it works.

The project made a profit: Till 2008, and probably after that as it was a lower cost producer.

Low of information asymmetry and power balance: As above, there is little information asymmetry and a comfortable balance.

Limited motivation for strategic misrepresentation: The problems facing the alumina industry are common to both firm and government; and outside Australia.

Open and commercial access to resources: A number of firms process Alumina in Western Australia under the same agreements.

Little information noise on good projects: There is very little publicity given to these projects. The publicity starts when they fail, as the Alcan Alumina plant at Gove did in late 2013. Yet after some noise and movement in the media it was accepted that the reasons were economic and could not be altered, and the story went quiet again.

Profit as expected: Were delivered for the firm and benefits to Government.

6.2.4 HBI project at Boodarie (Case 1) $3,370,000,000 Invested. 349% over budget. 83% delivery delay. Built 1995-1999. Written down 2000. Closed 2004. Demolished 2011.

The Boodarie HBI project saw $3,370,000,000 (Aust)[227] invested to produce between 2,000,000 and 2,300,000 tonnes per year of Hot Briquetted iron pellets. This transformed iron fines with 62% iron to briquettes with 92% iron content[228]. The plant was opened in 1999 written down as loss by BHP in 2000 and closed in May 2004. It was scrapped and dismantled in August 2006[229] and finally demolished with explosives in 2011.[230] But the access to Pilbarra Iron Ore under favourable conditions was retained and expanded. The financial loss from the project was largely transferred to Commonwealth taxpayers through careful structuring that seemed to anticipate project failure. The benefits to the people of Western Australia were negligible, and possibly negative in the longer term.

The project was to meet the secondary processing obligations that enabled BHP to access, harvest and ship iron ore. To continue and expand access to the ore they had to build a process plant and they did. Between 2001 and 2011 BHP-Billiton increased iron ore capacity from 69 million tonnes a year to 122.7 million tonnes a year.[231] At the peak prices of $150 a tonne achieved that year and in 2008[232] this was an $18.4 billion dollar income stream.

ABARE September 2010 gives an average price for iron ore as $137.45 a tonne. At the same time the cost of producing a tonne of iron ore, including all infrastructure costs was estimated at $35 / t[233]. The harvested ore is on or near the surface, and is close to specification. The 426 km down-hill rail link to the port is a crucial logistic factor. This is the BHP owned and operated Mount Newman Railway that runs to Port Headland. It hold the world's record for the heaviest freight train operation, a 7.3 km long train of 683 wagons and 8 locomotives, with a total mass of 99,734 tonnes, carried 82,000 tonnes of iron ore on 21st June 2001. Using the ABARE 2010 price this one train load was valued at $11.3 million.

Pilbara ore deposits are of exceptional quality, easily recovered, requiring minimal beneficiation. The ore is possibly the highest profit, lowest risk commodity it is possible to mine and ship. Access to this resource is a prize for which almost any price or loss would be paid.

The upward variability over time of how much the HBI project would cost, or when it would produce, as supplied to ABARE was a warning signal as to what followed. This is shown in Table 29.

Table 29 Growth in Boodarie HBI cost over time as shown in ABARE reports.

ABARE Date	Proposed Output	Proposed Completion	Proposed Cost $ U.S.
1995	2 Mt DRI	Mid 1997	750,000,000
1996	2.2 Mt HBI	Mid 1997	1,500,000,000
June 1997	2.25 Mt HBI	1998	1,700,000,000
Dec 1997	2.25 Mt HBI	1999	2,400,000,000
1999	2 to 2.3 Mt HBI	Completed	2,600,000,000

The reason for this Hot Briquetted Iron project, even as early as 1994 [234] was political. BHP did it to access the valuable ore. They succeeded. But the contract did not specify that the project should work or be economical to work. It was not and failed.

On 31 March 1994, the Western Australian State Government agreed to delete all secondary processing obligations in respect of these agreements in exchange for a new secondary processing obligation and limits on production from three mining areas: Mining Area C, Yandi and Jimblebar. The new secondary processing obligation requires BHP Minerals Pty

Ltd, alone or in association with others, to spend $400 million (in 1993 dollars) on the further processing of iron ore or on an alternative investment approved by the Minister for Resources Development. Further processing is defined to include the production of iron and steel, direct reduced iron, hot briquetted iron, iron carbide sinter or pellets. No time limit is given for this investment. The Agreement provides for the consideration of alternative investments in lieu of further processing if further processing proves not to be technically or economically feasible. Until this obligation has been fully discharged, production from Mining Area C, Yandi and Jimblebar will be subject to tonnage limitations. The Western Australian State Government has agreed that the obligation to invest a further $400 million (in 1993 dollars) will be treated as satisfied when the construction of the first train of the HBI Plant at Port Hedland has been completed and commissioning has commenced (i.e. when the first hot briquette of iron from that train is produced).

The cost estimate of producing the HBI was around $80 (US) per tonne and the sale price was initially around $135 (US) per tonne[235]. Thus profits per year might be in the region of $121 million (US) per year, which seems non-commercial, give the final size of the $2.6 billion U.S. capital investment. To achieve even such modest returns the new process must work perfectly from commissioning, which is rarely the case with new technology implemented at large scale. The ramp up in production through 1999 to 2003 was troubled and consumed unplanned operation expenses. This is shown in Table 30.

Table 30 Production as percentage of nameplate capacity

Year	Production	% of Nameplate
1999	314,000	13.65%
2000	556,227	24.18%
2001	1,236,000	53.74%
2002	1,026,000	44.61%
2003	1,936,000	84.17%
2004	694,000	30.17%

The losses incurred in this failed project were written down against BHP-Billiton's Australian taxation liabilities by $2.6 billion. This accounting had the effect of reducing the company tax paid on other successful projects. The Australian Taxation Office fought a vigorous action to recover $2.2 billion. This action was unsuccessful in 2010. Thus the losses incurred were indirectly borne by Australian taxpayers.

The consideration that the project might not work, technically or economically, seems to have occurred relatively early on. BHP was writing down the project in 2000 as production struggled to reach 24%. The project finance structuring was exceptionally competent at planning for the losses that eventually occurred. The quality of this aspect of project planning was only publicly realised in March 2010, when BHP comprehensively beat the Australian Tax Office (ATO) in the conclusion of a long running case.[236] The ATO had sought payment of $2.2 billion in tax.

The long-running case relates to two bad debts that were written off by BHP Finance after loans were made to two subsidiaries. One loan was for the ill-fated construction of a plant in Western Australia to produce briquettes from iron ore fines (particles) in a bid to turn them into a valuable product -- and to satisfy an obligation imposed by the WA government that BHP had to be involved in secondary processing of iron ore.

The project suffered several setbacks from its inception in 1995 until 2000, when the financing company decided to write off $1.8bn of the $2.2bn owed. This development also ran into problems and BHP Finance wrote off $310.9 million in the 2000 financial year. One of the issues in both the original case and the appeal was whether BHP Finance was actually in the business of lending money. The court heard the company had no employees and paid management fees to BHP. The tax office argued it was merely an "appendage" to BHP, and not in the business of lending money, but the court rejected this argument.

This case is a negative example of a “new process” project, a “government involvement in value adding” project, and an “asymmetric information” project. From a commercial perspective the access to the iron ore leases was the main game; and the game player with the most knowledge and game skills won. There is no suggestion that BHP behaved other than within the relevant state and federal laws, regulations and agreements; for the ultimate benefit of their shareholders.

BHP made steel between 1915 and 2002, when they spun off their steelmaking plants as independent entities. They quit steel-making as it was unprofitable and declining. They were better informed as to the economics of iron and steel production within the world market than any other local firm. It was not a business they wanted to be in. This was in contrast to the willingness to add value to bauxite to alumina and aluminium by firms who were making all these steps as part of their then profitable businesses.

BHP made the investments, structured the tax losses, built the plant, and produced HBI. They met the obligation and gained the resource access. BHP had achieved what they sought, they did as Government required.

What did the government hope to achieve? In a statement[237] of 21st July 1999 The W.A. Premier Richard Court and Resources Development Minister Colin Barnett opened the plant.

The Premier said that when the first shipment of briquettes left Port Hedland bound for South Korea in May this year, a dream long held by successive governments to add value to Western Australia's iron ore exports was realised.

"While Western Australia has long been an important player in the world's iron ore industry, it is through downstream processing of the State's vast reserves of iron ore that the true potential of the industry will be achieved," he said.

Mr Barnett said development of the HBI project fulfilled BHP's secondary processing obligations as outlined in the Iron Ore Processing Agreement Act 1994, negotiated between the State Government and the company.

He said one of the Government's primary objectives was to maximise further processing opportunities for the ongoing benefit of the Western Australian community.

"In order to achieve this objective, the Government has introduced reforms to progressively deregulate the energy market causing gas prices to fall around 50 per cent in the Pilbara," Mr Barnett said.

"The Government also maintains the vision of a sophisticated steel industry for Western Australia and to achieve this end, the Department of Resources Development is working with several international companies to investigate steel and other value-added iron ore projects for the Pilbara and Mid-West regions."

In retrospect this is not the most well considered Government vision. Steel production is dominated by nations who generate the greatest economic returns from transforming the steel into useful manufactured products for their own or export markets. China, The European Union, Japan and the United States represent 70% of world steel production. China alone is almost half the world market. South Korea has a population twice that of Australia, but produces 14 times the volume of steel. They have a vibrant export economy with shipbuilding and passenger vehicles, as well as exports of merchant steel.

The concept of investing energy into melting iron ore once to increase the concentration from 63% to 92%, then shipping it to a market where it would once again be melted to produce a final product is not the best use of resources. It uses almost twice the energy of melting once at the steel plant.

In 2000 BHP used the resources shown in Table 31 to produce 556,227 tonnes of "BoodarieTM iron" of which 326,037 tonnes were shipped. The values shown in this table are "best estimates" of the market value in 2000, and may differ from the actual price paid. If this is even close to what BHP were recording in their private internal costing, it would explain why they were writing off the investment in the same year. The government initiative to add value, on these estimates, seems to have directed $3 in value that could otherwise been sold or exported, to produce a $1 of a value added commodity. This seems to be a unique definition of value adding applicable only to a government with vision.

BHP operated the plant to gain access to a resource that would $18 billion a year a decade later. Their vision was much better informed. That there was information asymmetry is obvious. Whether there was strategic misrepresentation is questionable. There is no public record of the government asking BHP if the project would work. BHP's obligation was to their shareholders. Telling government facts they do not want to hear may not have been a priority.

Table 31 Resources consumed to produce HBI iron

Input	Volume	Unit	Value $	Estimate 2000
High Grade Iron Ore Fines	1,764,940	tonnes	30	$52,948,200
Power	218,267	Mwhr	80	$17,461,360
Natural Gas	17,044	TJ	2500	$42,610,000
Water	3,063,527	tonnes		
Magnesium Oxide	2012	tonnes		
Graphite Emulsion	521 000	litres		
				$113,019,560
Output				
HBI	326027	Tonnes	135	$44,013,645
Loss on production				$69,005,915

The Western Australian Government appeared not to have the quality of information or understanding as to markets, production costs or profits in business that BHP did. They did not achieve the benefits they sought, and left a poisoned legacy for high value adding technology projects. BHP achieved their goal, and passed on most the cost of the wasted exercise to the Australian taxpayer. They still do not wish to make steel in Australia.

The production of crude steel, Direct Reduced Iron, Hot Briquetted iron or similar is a mature and well understood process, when carried out by firms with long established competence. Midrex a division of Japanese Kobe Steel supply the technology for 60.5% of the worlds' production of 74 million tonnes of DRI.[238] This represents 4.7% of world steel production in 2012.

The DRI processes works best in nations that are cut off from world trade, have large supplies of natural gas they cannot sell or otherwise usefully use; and have a need for an indigenous steel supply for defence and national development. Three of the five Midrex plants that began operation in 2012 were in Iran; at IGISCO in Yazd, a second module at Khorasan in Mashad, and the first of two modules at South Kaveh Steel in Kish. Iranian trade is restricted by sanctions imposed by the U.S. government, or under U.S. pressure by the international community through the United Nations Security Council.

The processes selected by BHP and Rio Tinto were unique, novel and untested. They were the opposite of a mature and well understood process evolved over multiple worked embodiments. The Midrex processes, like alumina refining, were evolved, low- risk, known processes with little information asymmetry. Whilst BHP was a mature firm, it was one that had chosen to exit steel making for good reasons. Rio Tinto has never been a steel producer and after 33 years of research and development has shipped its failed and deeply uneconomic DRI process plant to India. They were not part of a value chain as was the case with alumina. The collaboration with the Western Australian Government was one of indirect and rather perverse benefits. Neither firm wanted to make crude steel, or made any profit from crude steel, but they achieved the iron ore access they sought. Both sides sought one sided benefits, the state up front, the firms, long term. The level of information asymmetry was significant. There was no record of performance by the firms in these endeavours on which government could base a predictable outcome. The firms at best did not tell the government what it did not want to hear. Thus there was a high level of information asymmetry, and possibly strategic misrepresentation by omission.

This case study raises questions for all four models and hypotheses, so all twenty parameters will be briefly addressed.

Track record of implementation: BHP-Billiton is a competent and successful firm in resources accessing, extraction, concentration, logistics, marketing and financial matters. It is the world’s largest mining company, and has been trading with growing success since 1885. It has a poor record at implementing radically innovative processing technologies, and is not particularly adept at complex processing technologies. This is now understood within the firm’s management. They choose to do what they are good at, and selectively now avoid what they are less skilled at.

Firm focus in particular endeavour: Like Rio Tinto they are diversified, but Iron ore and energy, particularly coal are both firms financial strength. BHP and Rio Tinto are both focused on accessing and transporting relatively low value commodities like iron ore and coal. In the field of moving and selling \$100 to \$200 a tonne bulk resources they are exceptionally focused and skilled. In the period 1993 – 2010 BHP-Billiton started four of the twelve new process innovation projects. All failed. This is not where the firm is focused or see their future. They are demonstrably not good at it.

Step scale up ratio from previous success: BHP had previously run conventional steel production plants, which they diversified away from due to the low or negative profits. No large pilot or demonstration plant was built for the relatively new and unproven HBI technology. From their research and engineering studies, BHP was confident of success, and that most significant technical issues had been addressed.[239] In this they were mistaken.

Financial confidence engendered by firm: BHP-Billiton is able to finance any project they choose at favourable interest rates.

Profit: BHP-Billiton make significant profits from their core commodity iron and coal business, and most other endeavours. They have no track record of success or profit from new process innovation. This project made no profit, only billion dollar loss.

Individual Ownership and responsibility: The HBI process used the Finmet process, developed by Fior de Venezeula and Voest Alpine of Austria. This was developed from the Fluidised Iron Reduction (FIOR) process developed by Esso Research to utilise low value natural gas. There were no operational FIOR plants, and the one operational plant in Venezuela was not built at the time BHP started the HBI project. There was thus no individual inventor in Australia, or possibly the world to champion the project or take responsibility for its operation.

Initial process simplicity: The Finmet process is complex, multistage, and uses hydrogen at high temperatures and pressures. Only one plant in the world exists, in Orinoco Venezuela, which has been subject to major problems with the 12 atmosphere gas pressure system. It appears to operate at about 40% nameplate capacity. Unlike the ISASMELT process this process is not easy to duplicate in a lab at low cost, and thus lacks initial process simplicity.

Multistage scale up: There was none. From research and engineering studies to the largest man-made object in Australia in one expensive infinite scale up. In retrospect this seems to maximise risk and invite failure.

Niche demand for innovation: At the time, a use for iron ore fines was sought. The problem no longer exists. The fines are shipped to the customer in China and they can use them. The demand for HBI iron is more limited and ephemeral than originally projected.

New process, not well understood: The process was in 1995, demonstrably new, and not well understood. Today it is not new, and few would seek to understand, given the outcomes.

Mature firms with complete value chain: BHP had a full value chain in steel till around this time, when it exited the low margin steel making business. They had been the major local steel maker for eight decades and could see where the local market was heading. They chose to exit. The HBI plant production was for export and to meet secondary processing obligations. It would be an interesting, though rhetorical question to ask: "Given how experienced BHP was at steel making technology and associated economics, why did they choose the Finmet process, and implement it in such a high risk manner?

One sided benefits sought up front: It could be argued that both sides sought self-beneficial outcomes that would be paid for by someone else. The W.A. Government wanted a value adding steel industry paid for by resource firms. The resource firms wanted to meet their state obligations, and largely pass the cost to the Commonwealth taxpayer. This was not a well-considered "virtuous circle", but a "vicious circle". Both terms refer to a complex chain of events that reinforces itself through a feedback loop.[240]

High level of reward for information asymmetry: As BHP met its state obligations, and after a long court case passed on most of the costs to the Commonwealth taxpayer, there was a high level of reward for the information asymmetry.

High of information asymmetry and power imbalance: BHP had the definitive information asymmetry over the WA government in that they were the major steel producer in the country. They were also many times the financial power of the state, and able to stand up to the Commonwealth on tax payment issues, and win.

Driving force exists for strategic misrepresentation: BHP and Rio Tinto were compelled to implement business undertakings that seemed outside their preferred commercial direction. There is reason to believe that these ventures could never be profitable, and were in implementation commercial disasters.

Asymmetrical information used to manage ignorant power: In retrospect the application of the value adding model that worked so well with the aluminium production chain was not applicable to iron ore fines. The firms had to manage the mandated actions by the state. They did. There was no written obligation that the plants should work. They did not.

Selective strategic misrepresentation to promote investment: BHP sought no external investment, but managed their investment through remarkably tax effective internal structures. The Australian Taxation Office vigorously opposed these schemes, but lost.

6.2.5 Olympic Dam Expansion (Case 48) $1,600,000,000 invested. 91% of 116,000 t of Copper and 1,500 t of Uranium oxide produced. Built 1996 - 1999

Olympic Dam is the world's largest uranium deposit and it is estimated to contain approximately one third of the world's total Reasonably Assured Resources (RAR).

This is also the world's largest RAR of uranium recoverable at costs of less than US$80 a kilogram, with more than 40 per cent of world's resources in this category.[241] Australia is estimated to have about 13 per cent of the world's economic resources of copper, the second largest after Chile and ahead of Peru, Mexico, the USA, Indonesia and China. 63.7% of this copper is under Olympic Dam, 55.4 million tonnes of it, [242] theoretically worth $450 billion.

For every tonne of copper, there are 19 kg of uranium, about 3.5 ounces of silver and 0.4 of an ounce of gold. The separation of these four valuable resources from the average of 51 tonnes of tough rocks containing them, and each other, is a challenge and a curse.

With late 2013-early 2014 low value for Uranium, of around $35 a U.S. Pound, BHP Billiton has a large copper deposit with a politically difficult uranium impurity. Most of the resources is 350 metres below the desert, and will require removal of 2,050,000,000 tonnes of rocks over 5 years to begin to access the ore. Table 32 shows recent production. This may be contrasted with production shown Table 33 from 8 years earlier under different management.

Table 32 2012-2013 Financial Year Production and estimated value

Commodity	Mass	Value	Proportion
Copper (t)	166,200	$1,227,719,400	72.32%
Uranium (t)	4,066	$310,654,598	18.30%
Gold (oz)	113,246	$141,557,500	8.34%
Silver (oz)	880,000	$17,600,000	1.04%
Total estimate		$1,697,531,498	

Mineral processing at Olympic Dam began in 1988, initially producing 45,000 tonnes per annum (t.p.a) of copper plus associated products of uranium oxide, gold and silver. Between 1997 and 1999 there was a major expansion (Case 48) of the mine and minerals processing plant and in recent years annual copper production has averaged about 180,000 tonnes, with 4,000 tonnes of uranium oxide, 80,000 ounces of gold and 800,000 ounces of silver.[243]

The Olympic Dam expansion of 1996-99 saw $1.6 billion invested, but it was not till 2004 that the complex refining plant was fully sorted out. In this time random process problems and unexpected commodity price events damaged WMC's cash flow, and led to their being taken over in 2005 by BHP-B. These random events were the solvent fires of 1999 and 2001 that stopped production.

In 1995, when the planning for the expansion was taking place, copper was selling at $3,000 a tonne. It fell to $ 1688 in December 1997 and was as low as $1,378 in March 1999.[244] Prices remained below $2000 till November 2003. WMC was bleeding cash from plant repair, lost production and low prices. By June 2006, a year after BHP-B took over, the market had changed. The price rose from $2,524 in June 2005 to $8,045 in May 2006.

The rate of return on investment in this project was not good to start with. The complexity of the process plant was dictated by political demand for shipping copper without any uranium in it. The fate that WMC suffered is probably fresh in the mind of BHP-B management who have in 2012 declined, despite intense political pressure, to invest again in a $30 billion expansion with high value adding refining.

WMC was an exceptionally competent firm at finding a valuable resource, and implementing a complex processing plant to transform it. That this would often involve unforseen difficulties is part of being at the cutting edge of new plant operation. WMC was diligent and determined in working through these types of problems, and making the process work. They were unable to make enough profits to cover resolving the difficulties at Olympic Dam and Phosphate Hill at once. BHP-B took over WMC in June 2005, and unexpectedly enjoyed exceptional profit as the production from the worked up plants rode a wave of commodity price increases.

WMC might have managed the impact of a difficult plant at Olympic Dam and the unexpected loss of revenue from commodity price drop; if it had been their only iron in the fire. But they had a second major plant with as many difficulties and an awful drop in price; at the same time.

In parallel, WMC decided in December 1996 to invest $700 million to build a 975,000 tonne a year plant to produce high-analysis ammonium phosphate fertilizer. They specified $500 million of plant, and had it installed on time and close to budget. The problems were in getting it to work and selling the production at a profit.

In the first year of operation, at Phosphate Hill (Case 13) only one third of nameplate capacity was reached and the $278 per tonne price that had been anticipated had fallen to only $154. So instead of an estimated income of $271 million there was probably an income of around $50 million. Much of this would have been absorbed into the frantic work to bring the plant up to capacity.

Table 33 Production returns before and after upgrade

	1996 before	Upgrade extra	1999 WMC	2000 WMC	2001 WMC	2002 WMC	2003 WMC	2004 WMC	2012 BHP-B
Nameplate Copper		116,000							
Total Production	75,444		138,272	200,423	200,523	178,120	160,080	224,731	168200
Extra production			62,828	124,979	125,079	102,676	84,636	149,287	92,756
% of Nameplate			54.16%	107.74%	107.83%	88.51%	72.96%	128.70%	79.96%
Nameplate Uranium		1,500							
Total Production	1,652		3,221	4,539	4,379	2,890	3,203	4,404	4,066
Extra production			1,569	2,887	2,727	1,238	1,551	2,752	2,414
% of Nameplate			104.60%	192.47%	181.80%	82.53%	103.40%	183.47%	160.93%

The result was that WMC had two complex plants, absorbing scarce capital to make them work, producing less output, which then sold at a lower price than anticipated. The irony is that the random price variation for Phosphate Hill's production moved steadily up to $948 per tonne by 2008. The obligations for complex and high performance value adding, which was accepted in 1982, was a way to sell Copper, Gold and Silver that were free of uranium.

This case study raises questions for two models and hypotheses, Firm competence and Government Involvement in Value adding so eight parameters will be addressed.

Track record: WMC had a track record of successful, but barely profitable operations at Olympic Dam. They had been operating since 1988 a plant a production rate of 45,000 tonnes of copper, 1,700 tonnes of uranium oxide and 70,000 ounces of gold. The expansion in Case 48, built between 1996 and 1999 was to produce 116,000 extra tonnes of Copper and 1,500 extra tonnes of Uranium oxide. It involved new solvent extraction technology, which they sorted out after two difficult to explain fires. The ore body at Olympic dam is complex, and the requirements to separate out the Uranium from the copper onerous. WMC showed a technical firm competence at a high level, especially for a firm that was processing as many diverse resources as they were.

WMC were competent at their Western Australian sulphide nickel operations, competent at their poly-metallic copper, uranium, gold and silver deposit at Olympic Dam, but were not at the top level of technical competence with a complex process and new plant like Phosphate Hill. Whilst they had operated small fertilizer distribution facilities, and a sulphuric acid plant at Kalgoorlie (Case 12) they had not operated a multi process plant producing high specification fertilizers. They had also not been very profitable in their fertilizer distribution business. Whilst it might be argued that anticipating random variations in commodity price is far more luck than skills, this was not an area where WMC had either skills of luck.

Firm focus: WMC was a little more focused than BHP-Billiton, but both were diverse firms with multiple process trains running at once. They were not the acknowledged masters or innovators in any of them. WMC was somewhat more focused on undertaking difficult processes on complex resources and making them work. In this the only firm who they could be compared to was Mount Isa Mines (MIM). MIM also was taken over. Neither firm could be compared to firms like Tronox or ConocoPhillips who were masters of superior process technology, and able to implement this in a focused area with exceptional results.

Scale up: Olympic Dam was an expansion and a manageable scale up from existing plant. The capital involved was rather large compared to the value of the firm and the profits were smaller that had been hoped. The second large project at Phosphate Hill, in parallel, with difficulties, and low profits was probably “a bridge too far.”[245]

Financial: WMC was about one tenth the size of BHP in 2005. Their cash flow from 2004 operations had risen from $676 million during 2003 to $1,422 million during 2004. BHP's Net operating cash flow in 2005 was 8.9 billion.

Mature and well understood processes evolved: The process plant installed by 1999 had some new elements in the solvent extraction that WMC in time and after some expensive fires resolved. It was not a new process like the AMC Magnesium project, but it was not a mature project like the Wagerup 2 Alumina refinery. The cost and complexity or operating a poly metallic refinery requiring high levels of separation between the copper and uranium, in a remote desert, may have been under appreciated by the government.

Mature firms with complete value chain: WMC was a mature firm, but did not control the value chain, nor could them much influence it or model future events. WMC sold refined commodities into the market and rode the waves.

Mutual benefit from decades on agreed collaboration: WMC derived little benefit from Olympic Dam in the time they operated it. Sir Arvi Parbo, WMC Chairman is quoted as saying “we didn’t make any money out of it” Hugh Morgan CEO of WMC “speculates that WMC put more cash into Olympic Dam in real terms than it took out.”[246] The South Australian Government receives around $60 million a year in royalties. Neither side has received anything like the rewarding outcomes they hoped for. This may be the largest reserve of Uranium in the world, and Australia’s largest potential Copper mine, but it has been in close to a loose-loose stasis for nearly three decades, with no sign of early resolution.

Low level of reward for information asymmetry: The information that WMC built up, relating to the low profits that could be made by operating a complex refining operation in remote and difficult conditions were not secret. They were not what government wanted to hear. They wanted to hear that Olympic Dam was the panacea to the state's economic problems, and that business would invest billions to make their model of reality come true. Business has declined to do so, but with diplomatic statements. The value of the operation is linked to world demand for uranium. The Fukushima disaster of 11th March 2011, and a retreat from nuclear power generation in Europe and USA may make the world largest reserve of uranium a liability rather than an asset; but neither firm nor government will say so.

6.2.6 Conclusions

Case 24, the Wagerup 2 Alumina plant expansion, showed how well the model of government mandated secondary value adding can work. From 1964 to 2008 this model added value for the states and the firms. After 2008 only the fall in Aluminium, and hence alumina price spoiled the model and saw the first closure of the Alcan Gove alumina refinery in 2013. The four parameters of the proposed Government involvement in value adding success model are based on the great success achieved with alumina refineries.

Case 1, the BHP Boodarie HBI project is the opposite model, where the model of government mandated secondary value adding failed. The project was not economically viable, the firm did not want to do it, they did so to achieve a more valuable concession, and a perverse outcome was delivered. The four parameters of the proposed Government involvement in value adding failure model are based on the destruction of value achieved with crude steel plants.

Case 48, the Olympic Dam expansion project (96-99) is an intermediate in the model. It has not failed, but is less that the success desired by state or firm. It is midway between the success and failure models. Unless the state critically examines its model of government mandated secondary value adding, and what can be economically achieved the present unproductive stasis may continue.

In all three cases the value of the commodity has been one of the most important factors. The bauxite –alumina-aluminium value chain is different to the coal and iron ore to steel chain. Iron ore and coal are both \$100 to \$200 a tonne commodities that are best combined at the point where steel is made, shaped and utilised. Bauxite is a \$30 a tonne commodity and the energy input to enable the conversion to alumina takes place separately to final, and equally energy intensive final stages of aluminium production. Aluminium is "frozen electricity" and alumina is "crystallised natural gas". Alumina at around $300 a tonne is cost effective to transport from where the bauxite is available and the gas cheap to where the electricity is surplus and well below average cost.

The production of crude steel, as HBI or DRI involves melting the metal once to produce the semi-finished product, and shipping a product to another country where a similar energy input is applied a second time to melt it again to make finished steel. This was and is only economic in unusual circumstances, where natural gas or to a lesser extent low rank coal is very low in price, and the final stage in the electric arc furnace has low cost electricity. These circumstances did not apply in Western Australia. The problem of what to do with fines was resolved as firms and customers managed to ship them, and process them economically.

Value adding is politically attractive, but has become economically less attractive over the time fame of this study. Australia has a natural advantage in possession of the resources, and a demonstrated competence at recovering them, and concentrating them for shipment. The consuming nations now have more sophisticated process plants that can accept concentrates, and economically refine them at the point where they are utilised. Australian process plants have not demonstrated significant economic advantage in refining, and few refineries have been built since 2005.

The positive government involvement in value adding in alumina and aluminium worked out as planned for more than four decades. Then changes occurred in the markets for energy and the market for the final product. The price that could be achieved for the final product fell by half and stayed down, and the cost of energy, especially natural gas went up, and stayed up.

Both processes are energy intensive, with tonne of alumina consuming around 14.5 Gigajoules of heat, usually from natural gas. Aluminium consumes around 15 thousand kilowatt hours of electricity per tonne. There are about 2 tonnes of alumina in a tonne of aluminium; so the tonne of aluminium ultimately has 29 GJ of gas embedded in addition to the electricity. The variable prices for natural gas and the input this has on Alumina is shown in Table 34.

The price of heavy bunker fuel oil is show at 15.5 cents a MJ, being based on a price of $620

U.S. per tonne ex-Singapore. This was the fuel used at the Gove Alumina refinery, where the plant was closed in 2013.

Table 34 Energy invested in Alumina and Aluminium

Data	Cost	14.5 GJ	Input	% of sale	In Al
2005	2.5	14.5	$36.25	10.98%	$72.50
US	4	14.5	$58.00	17.58%	$116.00
2013	8	14.5	$116.00	35.15%	$232.00
Export	10	14.5	$145.00	43.94%	$290.00
Tokyo	18	14.5	$261.00	79.09%	$522.00
Bunker	15.5	14.5	$224.75	68.11%	$449.50

In Table 33 the cost of 2.5 cents a GJ, suggested by DomGas, a W.A. peak energy user group[247]; is for 2005, and $8 is for 2013. Most Alumina refineries would have long term supply contracts at perhaps even more favourable rate, but when these expire will need to renegotiate under a regime where the market price has increased significantly. The 10 cents a MJ is around the export price now being achieved for LNG shipments, and these gas producers would need to be convinced to sell to an alumina refinery at a much lower cost than the international market offered. The 18 cents per GJ is the 2014 spot price for LNG delivered to Tokyo.

In July 2008 the price of Aluminium was $3,071.24 and alumina was $384.40[248] , by February 2009 Aluminium had fallen to $1,330.20. Alumina followed down to $253.54 in June 2009. In February 2014 Aluminium is between $1,800 and $1,900 Australian.

As the alumina to produce a tonne of aluminium will cost around $750, electricity price is the major cost in producing aluminium. In Western Australia, (simply as an example) the domestic electricity price is 43 cents a kW/hr, and the official “large business high voltage” rates are 19 cents in peak, and 13 cents off peak. An aluminium smelter requires 24 hour a day, uninterruptable supply, preferably for between 1.4 and 2.2 cents a kW/hr. The Kurri Kurri smelter in NSW, which paid 2.7 cents a kW/hr[249] closed in June 2012.

Table 35 shows a variation of electricity supply prices to an Aluminium smelter and the impact it has on production cost.

Table 35 Cost of electricity used to produce a tonne of aluminium at various tariffs.

Cents / kWh	For 1 t of Al
1	$150
1.4	$210
2	$300
2.2	$330
2.7	**$405**
3	$450
4	$600
5	$750
13	$1,950
19	$2,850
43	$6,450

The cost of production, and distribution of electricity is widely variable, but estimates of between 3 and 5 cents a kW/hr for the production of electricity from black or brown coal are common. The price paid by aluminium smelters is usually "commercially confident", but one example would be the Portland Aluminium smelter in Victoria. To win this investment for the state, Premier John Cain committed Victorians in 1984 to supply electricity for 1.4 cents a kW/hr for 30 years (1986-2016). The cost of this "less than half price" subsidy is estimated at $4.5 billion.[250]

Thus the form of government involvement in value adding that has succeeded has done so at a price of discounted electricity and natural gas, ultimately underwritten by the taxpayers and domestic consumers of the state. If they continue to support, or "co-invest" even more generously in the face of rising energy costs, then government desired value adding will continue. Where government balks at the cost of the subsidy required, as the Northern Territory did with the Gove alumina refinery, then the refineries close. The detailed analysis of the benefits a state citizen receives, paying both taxes and buying electricity at 30 times the price it is sold to a smelter is not well established.

An analogy may be made with a sign on the wall of an engine performance shop "Speed costs money, how fast do you want to go?" Value adding costs money from the state economy, every day of the life of the plant. How much value adding do Government really want to pay for is now a question.

Government involvement in Cases 1 and 8 was unusual. It mandated these projects as a condition of another more valuable lease. The plants were built and they shipped a small proportion of their projected production. The lease conditions were met. The plants closed and were demolished. $3.4 billon had been spent, with a negative outcome for local research and innovation. No new process was evolved, no new production exported, no new jobs created, no value was added.

Case 7 was a creature of a government wish to plan and manage a command economy. It utilised public sector research and the largest public investment made in resource innovation. It was the embodiment of the Light Metals Action Agenda. Here government was trying to create new high tech industries that met their preferred models of development. The failure was unique. A billion dollars was invested and only 5% of a plant built. The residual value was just over 1%. No other project was as absolutely under-performing and so under-delivered.

Case 48 is the most valuable mineral resources in the country. Table 49 shows the value of the identified resource in the ground; the earlier Table 40 show present production. The $686 billion of resources is being extracted at approximately $1.7 billion a year. At this rate the mine will operating sustainably for more than 400 years. The people of South Australia who own the resource are receiving around $60 million in royalties per year. This is a return of 1/10,000th of the value of the resource per year.

The mine never made a profit for the firm who built the plant. They were taken over due to their failure to make a profit. The new owners have been so frustrated with demands and restrictions placed on their proposed expansion that it has been shelved. It is unlikely they are making any significant profits now and are more focused on not losing more. The project has been locked in a “no win” stasis for 24 years. The operating firms cannot make a good return on investment. The government and people of South Australia have yet to receive a benefit in proportion to the value locked up 350 metres underground.

Table 36 shows the value of the Olympic Dam deposit at recent market prices.

Table 36 Value of Olympic Dam resource

Metal	Unit	Mass	2/2014 Value	U.S. Dollar	Australian Dollar
Copper	Tonnes	78,523,200	$7,000.00	$549,662,400,000	$631,795,862,069
Uranium U3O8	Tonnes	489,760	$79,520.00	$38,945,715,200	$44,765,189,885
Gold	Ounces	314,695	$1,244.00	$391,480,580	$449,977,678
Silver	Ounces	427,947,019	$19.10	$8,173,788,063	$9,395,158,693
				$597,173,383,843	$686,406,188,325

Case 2 was the largest investment by Japanese business in Australia refining plant. It saw the investment of $600 million in new process plant into a brownfields site. The Japanese firms did not understand how business was done in NSW. The local people did not wish to understand how the Japanese wanted to do business. There has been no Japanese investment in resource processing in Australia since.

Japan is the most important trading partner for NSW. They buy 27.4% of the states' exports. China buys only 17.4%. The two most important products NSW exports are $13 billion of coal and $2 of copper concentrates. The refining of the concentrates into metal now takes place in Japan. The Port Kembla copper refinery was recently demolished with explosives.

The exceptionally adverse outcomes achieved with crude steel (Cases 1 and 8) and magnesium (Case 7) involvement seem to have tempered Governments enthusiasm to intervene in value adding.

6.3 Hypothesis 4 "That information asymmetry leading to strategic misrepresentation was associated with project failure"

6.3.1 Distributional data of factors that make up inputs for prediction

Information asymmetry indicators are subtle and subjective to determine before an event. They are easier to suggest after the event. As with government involvement, there must be an information asymmetry in all sixty seven projects. The inside proponents knew much more than an outside observer with public data. Thus judgement of the level of information asymmetry and the level of responsibility accepted by management is based on many case studies. Where informed management is planning to avoid responsibility for project outcome whilst actively promoting the project as a great investment, information asymmetry is visible. Where projects were selectively financed from the least informed, or government then information asymmetry is visible. Where the management has a significant stake in success and a personal risk in failure, information asymmetry is less likely. The difference between a person making a significant but honest error of judgement, and a person planning to act for own advantage to the limit of the law, is difficult to determine in advance. Their own wealth at stake is a good indicator.

The model proposed in Chapter Thee covers the points used to allocate the risk ratings. In sheet 7 of the appendix the twelve projects with the greatest information asymmetry and avoidance of responsibility all failed. These failures would not have been unexpected by well informed investors. They were probably even less unexpected to their proponents.
The forty five projects with the lower level of information asymmetry and higher levels of responsibility (.4 or .5) by proponents were safe investments, with good outcomes.

The complex interactions between innovation, government involvement and information asymmetry help to explain why otherwise highly respected firms might have used information asymmetry and strategic misrepresentation.

6.3.2 Distributional data on execution, performance and outcome

The twelve projects with the greatest information asymmetry and avoidance of responsibility experienced an average of 77.5% construction delay, and 2.15 x cost over-run. Production performance was on average 28.3% of nameplate capacity, and none paid back their investments. The average, theoretical payback was 145 years in contrast to an average of a little over 4 years for successful projects.

6.3.3 Sunrise Dam (Case 45) $130,000,000 invested. On budget, 8.3% under time delivery. 206% of 100,000 oz. of gold produced in first year! Built 1996 – 1997

Asymmetric information can have a negative connotation, should the insider group with the better information seek advantage for themselves by transferring responsibility for losses to the less informed outside investor. But in this case the most informed group, the proponents, were as open with their information as is commercially prudent and then out-performed expectations. This is associated with higher levels of the firm competence model, and this case study will be examined as meeting both models.

Firm competence is the ability of a business entity to successfully complete the task they have proposed; meeting or exceeding the aim, to achieve a favourable outcome … one better than the investors might reasonably have expected, compared to the median outcomes.

The Sunrise Dam Gold Mine is located 55 km south of Laverton, Western Australia. It is presently fully owned by South African registered AngloGold Ashanti. In 1997 Acacia Resources Ltd achieved the measurably most positive outcome over projection for any transformation project in this study. The team, which had devolved from Biliton PLC, sought to transform hard rock with about 3 to 4 parts per million of gold into solid gold bullion. They proposed to produce 3,110 kg of gold. At the end of the first year of operation they had produced 6,407 kg of gold.

They achieved this miracle by a process of selecting and setting aside for initial production the richest ores, which allows a plant to recover the most gold as quickly as possible. The plant was designed to process a million tonnes of ore a year. If fed ore of 3 ppm gold then somewhat less than 3 tonnes of gold will be produced. Depending on the nature of the ore and the skill of the operators there is usually around a 90% recovery rate. Acacia aimed for a 20% gold recovery by gravity, (for coarse visible gold) and 72.5% recovery by cyanide leaching. This enabled the rapid repayment of the capital invested in the plant, and is an indication of an astute and financially conservative management.

The crush plant commissioned in February 1997, and the first Gold pour was on 27th March 1997.[251] The process plant was a copy of Union Reefs plant which had been successful three years earlier. In the three years of operation any troubles had been revealed, worked out and process improvements implemented. The risk at Sunrise Dam was minimal due to resolving the technical risks on an earlier plant, of similar scale and design. They were cloning success.

The process plant was constructed on budget and in 11 months rather than 12 as proposed. Due to the relatively low gold price at the time of $359 per ounce the team needed to quickly over produce to pay back the bank debt incurred in construction and return exceptional performance for the shareholders. The proposed production would have yielded an income of around $35 million US dollars; instead they achieved $72 million US dollars. At the prevailing exchange rate in 1997-1998 (1.34 to 1.59 Australian $ to 1 $ U.S.) they came very close to generating enough income to pay off the project in the first year.

The firm had an exceptional knowledge and competence with both the ore and the process. The ore body was thoroughly explored between 1994 and 1996, and had run tests on the geology and treatment chemistry of the three main ore types. Incremental improvements in plant operation skills from the earlier plant enabled an ore throughput 18% greater than design. Consumption of consumables (cyanide, lime, grinding media and electricity) were able to be reduced to between 90% and 60% of design calculation. The operators were masters of the ore and the process.

The preferentially selected ores, which contained much more "visible gold" enabled gravity recovery to reach 45% of gold recovered, leaving 50.5% to be recovered by leaching. The total recovery rate was 95.6%. The greater production, at lower costs, and with very limited start up difficulties indicates the "firm competence" built up from Union Reefs and previous gold mine activities.

Acacia did seek to test the "financial confidence" of the market to fund the project, and were able to achieve a credit line almost twice the size of the proposed investment. This was financed against the income of their other existing and profitable gold mine, as well as the new project. Shareholders were rewarded in 1998 with an increase in earnings per share of 112% on the year before, which also has the effect of making the share much more desirable, and hence worth more to sell.[252] Financiers recovered their capital and interest with minimal risk.

The five model criteria for Firm Competence are:

Track record: Acacia Resources had grown from a prior experienced and successful team and had established, operated and upgraded the Union Reefs Gold Mine at Pine Creek in the years they had worked together as Acacia Resources (AAA on ASX).

Firm focus: Acacia was a low cost Gold miner and refiner. They had reduced their production cost from $348 to $293 per ounce.[253] They sold their 40.1% interest in the Blendevale zinc-lead project in Western Australia, to concentrate on gold.

Scale up: The Sunrise Dam plant was a duplicate of the Union Reefs plant with some incremental improvements.

Financial: In 1997 Acacia had established a five year unsecured $225 million syndicated revolving credit facility to underpin future growth. At that time they had a net debt position at year end was $29.5 million. They had forward sale contracts at year end totalled 2.02 million ounces of gold at an average price of $588 an ounce… with production costs of $ 293 per ounce.

Profit: Producing an extra 3.3 tonnes of gold, whilst modestly reducing operational costs equals wonderful profit for the investors. I suspect they were well pleased.

The five model criteria for information asymmetry in resource projects are:

Low level of information asymmetry and power balance: As Sunrise Dam plant was a duplicate plant there was little that was not known and public. Acacia had made some modest incremental improvements, and felt they could get a little better performance at Sunrise Dam. They did.

Limited motivation for strategic misrepresentation: Acacia knew their ore body, and plant, and had more than enough capital. They were a trusted team, and thus had the most to lose by lack of veracity.

Open commercial access to resource: Acacia had achieved the license to operate, under standard conditions, without any unusual impediments. Gold mining in the Western Australia desert is mature, and as long as the royalty payment is made the government has little interest to be involved.

Modest use of information asymmetry by successful firms: Acacia was a successful medium sized firm with an excellent track record, and access to finance under favourable conditions. They were known as very good at what they did, and the market respected them for it. Investors like the security and profit, and in this case a larger firm liked the team, the assets, and the lack of risk and bought them at a premium in a trade sale.

Profit made as expected: The profit was much greater than expected. The only information asymmetry was in not announcing how well they were planning to do in advance. Competent firms rarely need to advertise. The astute investor learns quickly enough.

6.3.4 Bulong Nickel and Cobalt from Laterite plant (Case 4) $250,000 Invested. 8.7% over budget. 50% delay in completion. Built 1997 – 1998

Between 1997 and 1999 three new process plants were built to extract nickel and cobalt from laterite ores, which represent 72% of Australian nickel reserves, rather than the more easily processed sulphide ores, which had largely been exploited, and where declining grades were a factor.

Australian reserves of nickel held in identified laterite deposits is reported at 24 million tonnes[254] which would have a theoretical value of around $324 billion (US) dollars at the January 2014 (London Metals Exchange) price of $13,500 a tonne. Australian reserves of nickel are 30% of world reserves and twice as large as any other supplier. The Nickel price had risen from $5,293 per tonne in 1993, to $6,340 in 1994, to $8,228 in 1995, giving encouragement to enthusiasts with limited experience and less capital.

Preston Resources was a small firm, with multiple lease sites that might have gold, or nickel, but no production or facilities. They were planning a $700 million Nickel plant at Marlborough in Queensland that would purportedly produce 28,000 tonnes of Nickel. Their issue and paid share capital was below $10,872,135 according to their 1997 Annual Report.

They had $2 million in the bank[255] which seems a little short of required, when they entered into a deal with Resolute to purchase their Bulong HPAL Nickel Cobalt plant that was nearing completion. Preston shareholders were advised in September 1998 that Bulong, was *"an outstanding opportunity". "The cash flow that Bulong will generate from the second half of this financial year will create a sound financial base to assist the financing of Marlborough on the most attractive terms possible."* Shareholders were told construction of the Bulong processing plant was 95 per cent complete, and that *"There are many financial, technical, physical and practical benefits for Preston in owning and operating two world-class lateritic nickel/cobalt projects. The immediate advantage arising from the Bulong acquisition has been to provide access to technology, technical expertise, personnel and* *services in the construction, commissioning and operation of the lateritic nickel plant. This has already proved of enormous benefit in the planning of Marlborough. The Company will draw on the Bulong experience in the construction and commissioning of Marlborough over the next two years."* The $700 million Marlborough plant was never built.

The debt incurred to purchase Bulong was $319 million, which proved difficult to finance. The firm was seen as a credit risks in a high technical risk endeavour. $140 million was raised at 12% p.a. interest, and this was 40% undersubscribed with Barclays Bank having to put in $56 million as underwriters. Resolute retained 41% of the project as vendor finance, and new shares were issued driving down the price. Initial shareholder who had paid as much as $3 saw shares fall to 27 cents before they were suspended.

A 1998 explanatory memorandum to shareholders forecast production of 3477 tonnes of nickel and 477 tonnes of cobalt in 1998-99, ramping up to 9600 tonnes of nickel and 900 tonnes of cobalt in 2002. Projected revenue from Belong was $68 million, of which $8 million would be net profit.[256] In retrospect this is a painfully thin margin, and signals high risk. Production in 1998-99 was only 460 tonnes of nickel. Operating revenue in 1998-99 was $3.1 million, resulting in an $18.5 million loss. Revenue reached $63 million the following year but the loss soared to $97 million. This contrasted the claim made in the 1999 Annual Report that: "At Belong we have a world class lateritic nickel and cobalt resource, proven metallurgical processes, integrated refineries, and we are set to produce metal in the lowest cost quality." In 2000-01, the loss from production jumped to $247 million.

In the same 1999 Annual Report the firms accountants, Arthur Andersen stated: *"Should the equity capital raising not prove successful and the Belong nickel/cobalt operations not achieve positive cash flows, there is significant uncertainty whether the company will be able to continue as a going concern and therefore whether it will realise its assets and extinguish its liabilities in the normal course of business and at the amounts stated in the financial statements."*

By 2002, production output totalled 6331 tonnes of nickel or 66% of the projected 9600 tonnes. In 2003 the project was in the hands of the bond holders, who were owed about $300 million. The bondholders, led by Barclays called in KPMG as receivers in May 2003. Even with the high price for nickel in 2003[257] of $9,629 per tonne the theoretical income of $61 million a year could not cover production costs, debt servicing and the need to import sulphur and produce sulphuric acid locally. The WMC Kalgoorlie Acid Plant could not provide enough acid for the Belong operations. The 1% Nickel in the ore was mixed in with 6% Magnesium, both of which react in the acid. Rather than a Nickel plant with a magnesium impurity, the plant was a magnesium mine with a nickel residual.

Belong was closed for maintenance in October 2003 and was not re-opened. In April 2004 the plant was sold for $15 million, realising just 5 cents return for every dollar lost. Preston Resources Ltd became Chrome Corporation Limited between 2005 and 2009, transforming into Pacific Nguni Minerals Ltd between the 2nd and 4th of December 2009, then to Pacific Nguni Limited after that. Their 2013 Annual Report discloses a loss of $ 2,696,695, up from a loss of $2,326,986 the year before. It is presently investigating a number of gold opportunities in locations from Papua New Guinea to Mexico, much as it did as Colonial Resources from 1990 to 1995, before becoming Preston resources, where we started the story.

Firms and their management team develop a track record. There are many indicators in this story to indicate asymmetric information and strategic misrepresentation. The case study will consider the criteria for firm competence, new process innovation and asymmetric information models. There was no unusual government involvement.

Track record of implementation: Preston had not run a process plant before this time.

Firm focus in particular endeavour: Other than proposing two unique and challenging plants on opposite sides of the country at once, without capital or experience, none.

Step scale up ratio from previous success: Infinite, no prior success.

Financial confidence engendered by firm: Very little, not enough capital, at interest rates not high enough to balance the significant risk.

Profits: None in any of the three models.

Individual Ownership and responsibility: They bought a plant from another firm under financial duress, without the capital to complete the job, or the experience to do it. No one went to jail. There was low ownership and responsibility.

Initial process simplicity: The HPAL process is high pressure, high temperature process using sulphuric acid. In Australian four plants have tried and four failed. The initial plant at Moa Bay in Cuba took three owners and decades to be sorted out. This is not a simple process or one that can be worked at small scale.

Multistage scale up: None, they bought an almost complete plant as is where is.

Niche demand for innovation: Nickel and Cobalt have high commodity values, and are available from laterite ores. However the desire to do so by HPAL is now restrained and other processes are being tried.

High of information asymmetry and power imbalance: This was an ill-considered, high risk gamble, and the projections made were at best wildly optimistic hopes.

Driving force exists for strategic misrepresentation: Given the circumstances there was little alternative.

Asymmetrical information used to manage ignorant power: There was no ignorant power (misguided government) involved**.** The ignorant were the financiers and investors.

Selective strategic misrepresentation to promote investment: In the examples shown, the exceptionally positive projections to raise "almost certain loss" risk capital, seems to be strategic misrepresentation.

6.3.5 Bendigo Gold Mine (Case 40) $250,000,000 invested. 16.3% over budget, on time delivery. 26.8% of 83,000 ounces of gold produced. Built 2005 – 2006.

Bendigo Gold Mine sought to re-visit the days of the of the 1851 Victorian Gold rush, when up two tonnes a week of gold was being recovered by miners with little more than picks and shovels. There are 32,151 troy ounces of gold in a metric tonne and at 2013 values about $51.5 million dollars (Australian) each tonne. Between 1851 and 1954 the Bendigo Goldfields produced 22 million ounces, or 684 tonnes of gold[258]. At today's prices this would be $35 billion value in gold. This is a fantastic introduction to an exciting story; that took a long time to tell and a short time to disprove. From 2001 to 2005 Annual reports were published rich with detailed and extensive geological analysis, building the case for investments.

Bendigo Gold N.L. (No Liabilities) the firm that formed Bendigo Gold proposed the simple idea that gold mining had not stopped in 1954 due to lack of gold, but for the reasons of "Large number of companies with small lease holdings", "mine ventilation" and "mine dewatering." They went on to state "*It was not depletion of gold, head grade averaged 17 g/t in the main production zone regardless of depth*"[259]. This is a bold statement that should have alert the experienced investor to caution. The story of reopening an old gold mine, as the proponents "have found more gold down there" is popular. It is the most retold story presented for low value high risk new gold mines. The hope for undiscovered treasure and the investors' capital rarely last long. This is not to say that there is not gold still left in old sites, but as in Case 39 it is in the slag heap, not the bottom of the mine.

The proponents claimed that there was 13 million ounces of gold potentially recoverable and that the mine would run for 25 years. The mine in fact started operation in the October of 2006, as a 600 000 tonnes per year (of ore) processing plant. The plant design was that about 80 per cent of the gold would be recovered through a series of gravity circuits, with the balance of about ten per cent recovered via flotation and subsequent leaching of flotation concentrate.

"In early 2007 it became clear that the initial ore reserves had been overestimated, leading to an immediate change of strategy from production to exploration." It is not the usual practice to build a processing plant then revert to exploration to find the ore to feed it.

Mining and processing ceased in May 2007, with the plant having processed 176 000 tonnes at an average grade of 5.4 g/t gold for 26 735 oz. of gold. An additional 3122 ounces of gold were produced during commissioning and decommissioning in 2006 and 2007.

If the ore had contained the "average 17 grams per tonne" as boldly claimed, and the plant operated at 600,000 tonnes per annum, then each tonne of ore would have contained .5466 of an ounce of gold, and production of gold would have been 327,974 ounces. This would have brought in an income stream of $207 million dollars in the first year; at the then modest price of $630.35 Australian per ounce[260]

In fact the 29,857 ounces produced were but 9.1% of that proposed for the first year of operation. The closure of the mine after only 8 months indicates that the management were aware of how badly they had estimated the ore, and equally how quickly the investors' funds had been depleted.

By 2008 the investment presentation[261] claimed only 8.1 g/t ore, noted that it was highly variable, and announced that 8558 ounces had been produced. By 2010 a net profit of $11.2 million was declared, and a final dividend of 0.5 cents per share was declared on 26 August 2010.[262]

In 2011 the company changed its name to Unity Mining Limited and sought to raise further capital with the issue of 510 million more shares.[263] This would dilute whatever value the existing shareholders still had. Market capitalisation was listed as $51 million dollars, and the value of the enterprise was listed as $12 million. This was a very poor return for the investors, who had on the advice offered by the promoters, sunk more than $250 million into the venture.

The advice contained in presentation and prospectus was shown to be wildly optimistic and a poor projection of what would happen. Whether this was extraordinary professional misjudgement, or strategic misrepresentation, or just random bad luck is difficult to prove.

The proponents were not without extensive and relevant experience, many were senior and respected members of the Australasian Institute of Mining and Metallurgy. Their actions in promptly and accurately disclosing the problems; and then seeking practical solutions to the situation meet the ethical and legal requirements. The question of how they could make such fundamental mistakes in ore classification, after such a long and detailed analysis of a well-known ore body is difficult to understand.

The facts are that the expert projections as to the grade of ore, and thus the suitability for mine operation were wrong by more than 90%. Investors accepted the presentations of trusted and experienced geologists and made a significant investment. The fault in the estimation of grade was quickly discovered and revealed after the investment had been spent. The investors lost almost all their capital.

It could be argued that there was no information asymmetry, as the proponents were as surprised as the investors at how little gold was in the seams. However given the long experience of the proponents, and the long history of the site, this seems an unusual outcome.

6.3.6 Conclusions

Moral hazard is described by economist Paul Krugman[264] "any situation in which one person makes the decision about how much risk to take, while someone else bears the cost if things go badly."

There is little evidence of information asymmetry leading to strategic misrepresentation in the fifty two projects that succeeded. In six of the fifteen failures the outcome seems to have been genuine error or unexpected accident. But in nine of the failures there is significant information asymmetry leading to probable strategic misrepresentation.

In every case the taxpayer took a proportion of the loss, as a failure pays no corporate tax, and often has the ATO as a creditor. In four cases the Australian taxpayer would have indirectly funded a major share of the losses and in two of these the Commonwealth and State were investors. Where an investor detects strategic misrepresentation in a prospectus, they would be wise to stop. Where government has also invested they should run.

The commonwealth tax payer bore much of the cost and losses from four new process innovation projects that were built by the two leading firms in Australia. Cases 1, 7 and 8 had higher levels of research and development, which would have attracted tax concessions. Cases 1 and 11 had exceptionally beneficial finance arrangements that saw the losses converted beneficially in to tax losses. This was found to be within the law. Cases 9 and 10 saw large tax write downs for a very profitable firm, which had the indirect consequence of lower the tax the firm paid.

The careful thought put into managing the financial effects of failure was sadly not matched by the expertise at implementing successful new process innovation.

Table 37 shows where the majority of financial losses fell over 15 failed projects.

Table 37 Information asymmetry and who bore the cost

Case		IA	Taxpayer	Investor	Firm
1	HBI	Yes	X		
2	Southern				X
3	Murrin	Yes		X	
4	Bulong	Yes		X	
5	Cawse	Yes		X	
6	Stuart	Yes		X	
7	AMG	Yes	X	X	
8	Hismelt	Yes	X		
9	Ravens		Indirect		X
10	Yabulu		Indirect		X
11	Beenup		X		
33	Skardon	Yes		X	
46	Mt Todd			X	X
52	WVL			X	X
60	Bendigo	Yes		X	
15		9	4	9	5

Chapter 7
Concluding discussion and future outlook

"All truth passes through three stages. First, it is ridiculed. Second, it is violently opposed. Third, it is accepted as being self-evident." - Schopenhauer

7. CONCLUDING DISCUSSION AND FUTURE OUTLOOK

7.1 The outsider view of resource project success and failure

Resource projects between 1993 and 2010 were the largest chemical engineering projects in Australia. Resource exports were the engine of national prosperity. Resource projects were the private sector investment steps to exploit the publicly owned minerals and energy. These projects were a driving force in the national economy and their success contributed to the tax base of the Commonwealth and States.

Successful projects made up 73% of investments, unsuccessful 27%. Failure destroyed $ 12 billion of investment and changed investment patterns away from local new process innovation. Valuable resources of nickel, cobalt, copper and uranium are now underutilised.

The failure of 99% of investment in new process innovation stopped investment in local innovation by 2005. No new process plants have been built since. Failed projects did not make a profit. Their production averaged less than 29% of their design capacity and they were unable to pay back investments. These process plants have been demolished with few exceptions. The few rejuvenated plants produce at sub optimal rates. New processes failed to unlock value from complex ores and declining grades. This was an adverse outcome for innovation.

Successful projects made profits, paid taxes and royalties, contributed to high wages and grew. Almost all produced more than 90% of their nameplate capacity, and most paid back the initial investments in less than 5 years. One firm has exported its new process technologies around the world but was taken over due to financial difficulties in 2003. Australia largest and most successful resource firms were unsuccessful with new process innovation and now focus on incremental improvements.

An outsider view was adopted to avoid bias. An outsider view looks at what happened, focusing on system cost and performance. It is an investor view rather than a proponent view. A database of sixty seven projects with initial investment over $ 100 million was built. The database includes all projects like a census. It has enough cases to be statistically robust, and over a time frame long enough to see trends. The data is displayed in positional display in the appendix. Case studies were used to understand what happened. Five simple models with five parameters from greatest risk to least risk were developed to describe the inputs and outcomes observed. These models gave robust indication or project failure before the first concrete is poured or steel cut on a project.

The success of competent firms in processing natural gas into LNG gave an investment boom in this sector. In 2011 it was more than 91% of new investment in elaborate resource transformation. Between 1993 and 2010 the proportion was 20.5%. The failure of projects that sought to transform complex mineral resources led to a drop in investment for noble metals investment from an average over 18 years of 26.4% down to 3.6% in 2011.

The gulf between competent and successful outcomes and failure was wide. Cost over-run, and completion delay was between 5 and 6 times worse on average for failed projects than successful projects. Twelve case studies were detailed to support the four hypotheses. They were chosen to contrast the best and worst outcomes and the inputs that caused them.

From the public domain data the simplest models that would explain the outcomes were developed. These cover firm competence, innovation success models, interactions of government in value adding processes and strategic misrepresentation in mega projects.

7.2 Firm competence

Projects failed where they lacked firm competence. More challenging projects, such as refineries, failed more frequently than less challenging projects like concentration plants. Fifteen of forty four refineries failed (34%). Yet twenty three of twenty three (100%) concentration plants succeeded. Competent firms, with extensive market experience preferentially selected this minimal local value adding option, as it cut investment costs and risk. New start-up firms with limited firm competence and optimism bias launched complex value adding refineries, and failed.

Projects undertaken by international firms with long track records of firm competence, such as LNG, Alumina and Aluminium projects all succeeded. Eight of fifteen failed projects were firms quite new to the process and with limited experience. They did not know how to fly and crashed. Two failed projects (Cases 2 and 46) were from foreign firms experienced only in their home market who were apparently unaware how different conditions were in Australia. Both experienced a run of calamitous misfortunes at a time when their home financial position was under severe challenge. But five failed projects were implemented by the two largest and most profitable firms in Australia and in the world's mining industry. The three other hypotheses explored and explained this anomaly.

Inexperienced firms ran out of money, and could not get any more. They ran out of money because their project implementation was substandard. Their production costs were much higher than planned and output was lower than planned.

Whilst some developed their skills and knowledge in the specific process area, it was not fast enough to overcome the initial shortfalls. In three projects (Cases 3, 9 and 10) the firms had mastered some new skills but failed. The new owner who bought the plant for cents in the dollar invested, gained hard won skills and plant most economically. These buyers of these distressed plants were able to accept production of 50% of nameplate capacity as they had only paid 10% of the costs. They then went on to make moderate profits on the flawed plant by building on the competence attained in the struggle for production. Failure in these cases was competence building.

The problems with large and rapid scale up have become well known. The two failure case studies (Case 7 and Case 1) destroyed $4.37 billion on a large scale plant. There small scale test and development was not done to the point where the process was fully understood or successful.

The role of adequate capital to complete a difficult project was different between a one project start-up firm and a difficult project in an otherwise prosperous firm. Small firms failed when there was not enough capital available to overcome difficulties. Starting a project without enough money to complete it and cover incremental costs in sorting out the new process was a strong indication of lack of firm competence. The management either were ignorant of the investment required to do the job right, or chose to proceed for less noble reasons.

The first eight projects to the left of sheet 4 of the Appendix, Cases 7, 33, 6, 3, 4, 52, 5, and 60 all ran out of money and failed. They were one project start-up firms, with the highest risk.

All the original firms are gone, and with them almost all of the investor's capital.

The next seven projects were part of firms with multiple operations. They failed when their parents decided to stop the loss of capital. An alternative might have been that the project had met a more important objective explored in other hypotheses.

Firms like BHP-Billiton and Rio Tinto are exceptionally competent at what they do well, iron ore, coal and other well established processes. They lacked firm competence in the new process area, and the outcomes showed this.

Firm competence was defined as an organisation with a track record of successful implementations in the specific area where they have built unique skills. Firms evolved these skills by building on previously successful projects that they then improved. These competent firms were able to raise capital at preferential rates from the best informed financiers as their projects had regularly made profits.

A lack of firm competence was shown by starting a project in where the firm did not have experience or a process focus. They were shown to not understand the ore or process. They built large scale plants without an evolution of knowledge creation gained from smaller successful plants. These plants had greater cost over-run in budget, longer time to operation and disappointing production. The high costs and low revenue killed them. The smaller firms had found finance from less informed investors at high rates of interest. They could not pay back as they never made a profit and failed.

This failure was predictable from the model of firm competence.

7.3 New process innovation

Only 1% of investment in innovative new processes succeeded. Investment on $ 100 million plus plants using local innovation new processes stopped in 2005. Resource firms have chosen to be the second or third to implement a proven and tested new technology. Business preferred innovation stripped of risk. Australia became a difficult place to develop new processes, as eleven of twelve new process projects had failed. All new process projects after 1994 failed.

Two projects with little innovation failed for reasons not connected with innovation. Two projects with modest innovation but large scale up without any process evolution to build on also failed. Scale up without building knowledge of ore and process from earlier small scale work is identified as a major risk factor.

Sheet 5 of Appendix placed to the left the projects that indicate the greatest risk. 13 were at extreme risk, in that their model was one indicating failure.

Sadly eight of the nine firms with innovative new process projects were also not competent at implementing innovation successfully. Alternatively it could be argued they were following a model that has a high probability of failure.

There is a risk in comparing many failures with a single success. The many failures had five factors in common. They had management with limited responsibility or ownership of the outcomes. The new processes were initially complex and became more complex as the evolved. There is evidence in some cases that processes that were still not successful were scaled up too early. The small scale testing and process evolution was truncated and the step to a mega scale project was fast. Firms scaled up quickly as they saw the market as crowed and want to be first. These processes made a loss from small scale to large and failed.

This successful Case 40 was the contrast. There was individual ownership of the initial process development, and responsibility that each stage worked before progressing to the next step. The initial simple process evolved to meet new ores and market opportunities. There was a strong niche demand for the unique productivity increase provided by the innovation. The process worked and made a profit at each stage of development, and did not need to be built at huge scale to get the numbers to add up.

A more complex innovation model is shown in sheet 9 of the Appendix with contrasting characteristics of the eleven failed mega projects and Case 40.

7.4 Government involvement in value adding

Government involvement in value adding was successful in eleven projects valued at $8.37 billion. One of these projects (Case 30) was recently closed. Governments wanted to receive extra economic benefits from value adding in their state. Firms wanted low cost energy for what were very energy intensive refining operations. Alumina refineries needed natural gas cheaply and aluminium refineries needed very low cost electricity.

These eleven successful projects were all mature and well understood processes. Alumina and Aluminium production are a century old technology operated by large and stable firms with a long track record. These firms had complete control of the value chain till recently and were used to collaboration with Government for mutual benefits. There is a low level of information asymmetry with each side having a good idea of how the other will act. These firms built and operated refineries in return for low cost energy supply. Till 2008 they made a profit doing this. Then a drop in the price for aluminium to almost half and increasing energy costs fractured the mutual benefit model.

Government involvement in value adding was unsuccessful in four projects valued at $8.57 billion. All have been closed and demolished. The other (Case 48) has been stalled for a decade, with little profit and no expansion. In contrast to the collaborative give and take in the successful projects the five failures were uneconomic expectations for complex processes. Cases 7, 8 and 1 were new process innovations by firms without skill or focus in the technology. Case 48 has evolved into a standoff where the governments' requirements for political outcomes frustrated the firms desire to operate the project profitably. In case 2 the Government wanted foreign investment in a sensitive area, but without matching considerations. The Japanese firm had not understood how different business was in Australia than Japan. They failed and closed the plant and there has been no further Japanese investment in refining or value adding in Australia since.

Government desire to be involved in value adding peaked in the years 2001 -2003, when it was policy to create new industries from public sector research and government fiat. The loss of all the capital invested by government in Cases 7 and 8 tempered this enthusiasm. The multi-billion dollar waste of capital in Case 1 was largely passed on to the Commonwealth through the tax system.

7.5 Asymmetrical Information and strategic misrepresentation

Asymmetrical information leading to strategic misrepresentation and adverse outcomes were an undesirable combination. In 16 cases studied asymmetric information led to strategic misrepresentation with avoidance of responsibility. This misrepresentation and avoidance of responsibility preceded and signalled an adverse outcome. Their misrepresentations and subsequent loss of credibility destroyed the projects, many firms, and the invested capital.

An investor who could have discerned the strategic misrepresentation would have avoided all these failed projects. The one unusual case was Case 16. Here the plant worked well and was a desirable and profitable asset. The strategic misrepresentation was between the entrepreneur who thought he owned the plant and an Australian bank that was more successful in court with their claims of ownership. Debt and lifestyle seem inextricably mixed up with hardnosed commercial opportunism.

Strategic misrepresentation in innovative resource projects destroyed credibility for this class of projects. Technology projects to unlock value only proceeded after 2005 when they are second or third embodiments of a proven overseas development. Adoption of the best overseas processes after others have taken the risks and losses was economically rational. Yet it was at odds with the innovation policies and investment in research and development, promoted by Governments in the past.

A natural reaction from investors to strategic misrepresentation was to adopt a sceptical outlook. They restricted their investments to projects with minimal risk that have been tried and profitable many times. This transformed the vast majority of new investment flows into three areas of relatively assured profit, LNG, iron ore and coal. Mineral resources that suffered from decline in grade or increased complexity of ore structure were progressively ignored.

There was a linkage between failures in the 1993 to 2010 period, and where investments flowed to as a result. New process innovation went from 25.3% of all investments before 2005 to zero after. The wrong innovation models, the wrong government involvement and the high association between strategic misrepresentation and failed innovation projects forced this investment sector closed.

7.6 Relationships between success and failure

At the extremes failure and success are diametrically opposite. This is shown in Sheet 8 of the appendix. Five models, each with five points are modelled from the data taken from the 67 projects.

The four risk areas examined in the four hypotheses had similar structures and key points. They were overlapping models in that the worst failure could encompass the worst examples of all four hypotheses. However there was a middle ground where competent firms ran into difficulties and were taken over.

Two of the most competent firms at developing new processes, and implementing complex technologies with diligence and perseverance were Mount Isa Mines (MIM) and Western Mining Corporation (WMC). They failed respectively between 2003 and June 2005. MIM had been the one firm to bring a new process innovation plant (Case 40) to successful production and world-wide licence sales. WMC had located and brought into production the Olympic Dam resource, underground mine, and complex processing plant. This was probably the most valuable single noble metal deposit in the world. The total value of the resource was estimated at $686 billion.

From 1924 till 1947 MIM was financially challenged, and dependant on creditors. They mined difficult ore bodies, and had long faced difficulties in processing the rich but complex ores. This led in 1962 to their being a founding sponsor of the Australian Minerals Industry Research Association ("AMIRA") at the University of Queensland, which led to the formation of the Julius Kruttschnitt Mineral Research Centre.[265] MIM became the world leader in developing new mineral processing technologies as a response to declining grades, complex ores, metal price variations and increased production costs. They were the only firm to invest so much, and so successfully over a long time period. Their unique firm competence in innovation and commercial application was sadly not matched by same skills at accessing new ores in a timely manner, or managing high confidence in their financial abilities. Production of ores at the main facility fell from 5 million tonnes in 1994 to 1.2 million in 2002[266].

The prices MIM received for their copper fell from $3,009 in January 1995, to $1,587 in

April 2003. Lead fell from $667 to $437 in the same time.

The Swiss based firm Xstrata, first listed on the London Stock exchange in 2002 were able to access more than $3 billion U.S to purchase MIM between April and June 2003. Xstrata had enjoyed the confidence of the financial market in a way that MIM did not. This financial confidence factor was probably the most significant element these two firms lacked. Both firms failed to convince markets and investors that they could be solidly profitable.

Western Mining had been caught with low cash flow and two large projects with significant technical difficulties that required time and capital to resolve at a time when the commodity prices for their output turned down. The difficulties experienced by Olympic Dam were described in Section 6.2.5. Two fires in their solvent extraction unit in December 1999 and October 2001 stopped production at a time when production was required to provide capital for rebuilding. This alone should not have been fatal, but for similar troubles at Phosphate Hill (Case 13). Phosphate Hill was slow to reach nameplate capacity. WMC persevered and reached the design goals, but this came at increased cost in further delay and investment. Then the commodity price fell to almost half that was projected, and the expected revenue of around $271 million a year, or $813 million in first 36 months, was in fact only $155 million. In 2003 WMC made a profit of only $245 million. Three technical difficulties at once were hard to imagine, but the collapse of the commodity price at the same time was unable to be managed. WMC was purchased by BHP-Billiton for $9.2 billion, which was accepted by the shareholders at $7.85 a share as a reasonable return.

The irony is that BHP-Billiton sold Phosphate Hill, only to watch as production held steady at close to nameplate capacity and the price of Ammonium Phosphate climbed to $967 in 2008. In that year the income was estimated at $948 million, more than six times that received in the vital first 36 months. The unexpected events can works in two directions.

7.7 Why did new process innovation fail so often?

New process innovation that has radically transformed resource processing has a long history. The Bayer Alumina process and Hall Heroult process were developed by brilliant inventors working under what were primitive conditions, with little capital. The flotation process was developed by practical if unscientific and competing individuals around Broken Hill in the early 1900's. These inventors were confronted with a unique challenge of extracting silver, lead and zinc from ores already mined and crushed ore. In stages they succeeded and transformed how ores are processed to extract the precious metals. In 1887 John MacArthur built on earlier work by Faraday to develop the cyanide extraction process for gold. The rewards from these discoveries were significant increases in gold recovery and mine productivity. Pervious processes were quickly replaced by the economic advantages offered by the radical new process. So the first two ingredients are a brilliant individual and a strong financial incentive.

The Pidgeon process for magnesium production was developed in 1940. Wartime demand for light alloys for aircraft gave the work urgency. Dr Pidgeon was working for the Canadian National Research Council. His simple method is still the basic process for most of the world's magnesium production. Dr John Floyd was working at CSIRO when he started work on the process that became Case 40, though he later left and founded his own firm.

It was not important that these great inventors worked alone or in a Government research laboratory. Over time the latter has displaced the former over the last century. What was important was the ownership of the process by its named parent. This parent nurtured the process through many stages to commercial success.

In all these cases the innovation was relatively simple, worked quickly, and showed potential for resolving a problem that had significant economic need. The need was relatively specific, a niche market. For MacArthur it was fine gold in South Africa, for John Floyd it was sulphide base metals and later recycling lead.

The processes worked from the start, and at each scale up were refined and improved. In some cases the utility of the simple invention was refined to cover new resource applications. These successful processes were simple and robust. The inventor looked for a reward from the outcome of the process. They wanted to take a share of the profits to be made.

The contrast in the failed projects was the opposite. The inventor was not well known and had little parental role in the project. Management were paid for the process not necessarily the outcome. Reward by the hour invested is a different dynamic to reward for outcome. Initially complex processes usually involve many hours, even years of further work and development. The Case 8 process took almost 30 years to fail through three embodiments.

An initially complex process is often not robust, and to achieve an outcome becomes more complex. If the economic advantage from working a small plant is absent there is a temptation to increase the scale to a point where there is a theoretical advantage. On paper this may have looked good, but in practice it has only led to huge failures.

The five point innovation model encapsulates these points.

Government involvement and strategic misrepresentation are two more elements of new process innovation failure. Government has been a notable poor picker of winners. Their investments of hundreds of millions of dollars have gone unerringly to projects that failed.

7.8 How could new processes succeed?

On sheet 9 of the Appendix there is an expansion of the five point model into 33 points of difference between a successful model for new process innovation and the model shown repeatedly to fail. This would also apply to smaller businesses associated with resources processing. It was based on the case studies in Chapters 5 and 6 and on two innovative firms in the $25 to $50 million a year turnover. These are Gekko Systems of Ballarat and Russell Mineral Equipment of Toowoomba. New process innovation has been shown to have the greatest chance of success at smaller scale and with a simple process. The outcomes from the largest firms new process innovation projects were so negative they would be unlikely to repeat them.

7.9 Opportunity for future research

An opportunity for further research would be in utilising the methods, factors and models developed in this research to understand and explain the outcomes of poorly performing public sector projects. The outsider methodology of reference class forecasting (RFC) is used in this thesis could well have been applied to Australian transport infrastructure projects, especially those that involved tunnels. These tunnel projects have a notable shortfall in insider or "expert" prediction of usage volume and hence toll revenue collectable.

Four such tunnel projects have failed quickly and spectacularly. Lane Cove Tunnel (-$ 470 m loss) and Cross City Tunnel ($500 m debt) in NSW; River City (-$1.56 b write down) and

BrisConnections Airport Link ($4.8 b invested now in receivership) in Queensland.

These failures have damaged both investors and the credibility of experts. The four tunnels have a total length of 17.2 km, and an apparent loss of $ 7.33 billion dollars, or $426 million per km.

To give an example of “expert” prediction being inaccurate, Arup (a global firm of consulting engineers) forecast that approximately 179,000 vehicles would use Airport Link daily after six months of operation. Instead, by December 2012, actual traffic numbers were averaging around 47,000 per day or 26 per cent of the forecast, despite tolls being discounted.

Arup are being sued by investors in a class action for damages at the moment, as are AECOM, for their River City forecasts.

Appendix

The following appendix section represents the data collected on the 67 projects studied and analysed in this thesis. The data format is in ‘sheets’ reflecting reference to its original presentation in spreadsheet format in MS Excel workbook (Appendix.xlsx).

Appendix Sheet 1

Case	Project	Refinery	Concentrate	Capital Success	Capital Failed	Fail	To produce per year	Product/s	Name plate	Price (est)	Production	Lost Production	Outcome
	New Process Plants												
1	HBI Boodarie	1			$3,370,000,000	1	2.250,000 t of 90% Fe HBI	Crude steel HBI	2,250,000	$335		$753,750,000	Failed
2	Southern Copper	1			$600,000,000	1	120,000 t Copper cathode	Copper refinery	120,000	$7,504		$900,480,000	
3	Murrin-Murrin	1			$1,000,000,000	1	45,000 t of Ni	Nickel	45,000	$21,710		$976,950,000	Failed & sold
							& 3,000 t of Cobalt	Cobalt	3,000	$47,040		$141,120,000	
4	Bulong	1			$250,000,000	1	9,000 t on Nickel	Nickel	9,000	$21,700		$195,300,000	
							& 630 t of Co	Cobalt	630	$47,040		$29,635,200	
5	Cawse	1			$378,000,000	1	8,400 t if Ni	Nickel	8,400	$21,710		$182,364,000	
							& 1,700 t of Cobalt	Cobalt	1,700	$47,040		$79,968,000	
6	Stuart Oil Shale Project	1			$480,000,000	1	1,600,000 barrels (159 litre) oil	Shale oil	1,600,000	$100		$160,000,000	
7	AMG-CSIRO	1			$1,000,000,000	1	97,000 tonnes of magnesium	Magnesium	97,000	$3,100		$300,700,000	
8	HIsmelt	1			$1,020,000,000	1	800,000 t of Hiron (pig iron)	Crude steel DRI	800,000	$335		$268,000,000	
9	BHP-B Ravensthorpe	1			$2,450,000,000	1	220,000 t of Ni/Co hydroxide for Yabulu	Nickel Hydroxide	50,000	$21,710		$1,085,500,000	
	sent to							Cobalt Hydroxide	1,400	$47,040		$65,856,000	
10	Yabulu expansion	1			$510,000,000	1	45,000 t on Ni & 1,800 t of Cobalt	Nickel / Cobalt Refinery					
11	Beenup	1			$300,000,000	1	600,000 t of ilmenite (low grade)	Ilmenite	600,000	$70		$42,000,000	
							20,000 t of zircon	Zircon	20,000	$1,124		$22,480,000	
40	ISASmelt	1		$110,000,000			210,000 of copper	Copper	210,000	$7,504	$1,575,840,000		
	Gas transformed												
12	Kalgoorlie Acid Plant	1		$145,000,000			500,000 tons of sulphuric acid	Acid (Sulphuric)	500,000	$50	$25,000,000		Environmental
13	Phosphate Hill	1		$750,000,000			1,000,000 tonnes Ammonium phosphate fertiliser	Ammonium Phosphate	1,000,000	$800	$800,000,000		Troubled firm
14	NW Shelf Train 4		1	$2,700,000,000			4,200,000 tonnes of liquid natural gas	LNG	4,200,000	$453	$1,902,600,000		Success
15	Darwin LNG		1	$1,750,000,000			3,500,000 tonnes of liquid natural gas	LNG	3,500,000	$453	$1,585,500,000		
16	Burrup Fertilisers	1		$800,000,000			760,000 tonnes Ammonia (for fertiliser)	Ammonia	760,000	$400	$304,000,000		
17	NW Shelf Train 5		1	$2,600,000,000			4,400,000 tonnes of liquid natural gas	LNG	4,400,000	$453	$1,993,200,000		
18	Yarwun Ammonium Nitrate	1		$145,000,000			300,000 t of ammonium nitrate	Explosives	300,000	$600	$180,000,000		
19	Kwinana CSBP	1		$400,000,000			260,000 t of ammonium nitrate	Explosives	260,000	$600	$156,000,000		
	Alumina & Aluminium												
20	Tomago Expansion #1	1		$600,000,000			140,000 t extra	Aluminium	140,000	$2,278	$318,920,000		
21	Wagerup # 1	1		$150,000,000			200,000 t of extra Alumina	Alumina	200,000	$293	$58,600,000		
22	Boyne Smelters Expand	1		$1,000,000,000			230,000 tonnes of extra aluminium	Aluminium	230,000	$2,278	$523,940,000		
23	Tomago Expansion #2	1		$200,000,000			40,000 t extra	Aluminium	40,000	$2,278	$91,120,000		
24	Wagerup # 2	1		$285,000,000			440,000 t of extra Alumina	Alumina	440,000	$293	$128,920,000		
25	Worsley Alumina	1		$1,000,000,000			1,250,000 extra tonnes of alumina	Alumina	1,250,000	$293	$366,250,000		
26	Tomago Efficiency improve	1		$210,000,000			70,000 t extra	Aluminium	70,000	$2,278	$159,460,000		
27	QAL Efficiency improve	1		$175,000,000			Improved environmental performance	Alumina	0	$293	$0		
28	Pinjarra Upgrade	1		$550,000,000			600,000 tonnes of Alumina	Alumina	600,000	$293	$175,800,000		
29	Yarwun Alumina Refinery	1		$1,500,000,000			1,400,000 tonnes of Alumina	Alumina	1,400,000	$293	$410,200,000		
30	Alcan Gove G3 Expansion	1		$2,700,000,000			1,800,000 t of Alumina	Alumina	1,800,000	$293	$527,400,000		
	Mineral Sands												
31	TiWest Kwinana TiO2	1		$110,000,000			70,000 t TiO2 pigment	TiO2 Pigment	70,000	$2,900	$203,000,000		
32	Iluka Synthetic Rutile	1		$134,000,000			130,000 tonnes synthetic rutile	Synthetic Rutile	130,000	$760	$98,800,000		
33	Skardon River Kaolin	1			$130,000,000	1	175,000 tonnes kaolin	Kaolin	175,000	$120		$21,000,000	
34	Ginko & Broken Hill Plant		1	$176,000,000			59,000 t of Rutile	Rutile	59,000	$860	$50,740,000		
							41,000 t of Zircon	Zircon	41,000	$1,124	$46,084,000		
							136,000 t Ilmenite	Ilmanite	136,000	$100	$13,600,000		
							110,000 t Leucoxene	Leucoxene	110,000	$450	$49,500,000		
35	Douglas		1	$284,000,000			98,000 t of Rutile	Rutile	98,000	$860	$84,280,000		
							135,000 t of Zircon	Zircon	135,000	$1,124	$151,740,000		
							200,000 t of Ilmenite	Ilmanite	200,000	$100	$20,000,000		
							10,000 t of Leucoxene	Leucoxene	10,000	$450	$4,500,000		
36	Murray Basin Stage 2		1	$240,000,000			220,000 t of Rutile	Rutile	220,000	$860	$189,200,000		
							180,000 t of Zircon	Zircon	180,000	$1,124	$202,320,000		
37	Eucla Basin		1	$390,000,000			300,000 t of Zircon	Zircon	300,000	$1,124	$337,200,000		
	(Jacinth-Ambrosia)						120,000 t of Ilmenite	Ilmanite	120,000	$100	$12,000,000		
							30,000 t of Ilmenite	Ilmanite	30,000	$100	$3,000,000		
38	Kwinana TiO2 Stage 2	1		$120,000,000			45,000 t of TiO2 Pigment	TiO2 Pigment	45,000	$29,000	$1,305,000,000		
	Noble metals												
39	SuperPit (Kaltails)	1		$100,000,000			695,000 oz Gold recovered from Tailings	Gold	695,000	$1,200	$834,000,000		
41	Kambalda		1	$105,000,000			37,000 t of nickel concentrate	Nickel	37,000	$21,710	$803,270,000		
42	Mt Keith		1	$450,000,000			28,000 t of Nickel in concentrate	Nickel	28,000	$21,710	$607,880,000		

43	Osborne		1	$160,000,000			33,000 t of copper	Copper	33,000	$7,504	$247,632,000		
							and 40,000 oz of Gold	Gold	40,000	$1,200	$48,000,000		
44	North Parkes		1	$255,000,000			70,000 t of Copper	Copper	70,000	$7,504	$525,280,000		
							and 50,000 oz of gold	Gold	50,000	$1,200	$60,000,000		
45	Sunrise Dam	1		$130,000,000			100,000 ozs of gold	Gold	100,000	$1,200	$120,000,000		
46	Mt Todd	1			$330,000,000	1	260,000 oz gold	Gold	260,000	$1,200		$312,000,000	
47	Cadia Hill		1	$441,000,000			300,000 oz of Au	Gold	300,000	$1,200	$360,000,000		
							and 23,000 t of Cu	Copper	23,000	$7,504	$172,592,000		
48	Olympic Dam expansion	1		$1,600,000,000			1,500 t of U3O8	Copper	116,000	$7,504	$870,464,000		
							& 116,000 t of Cu extra	Uranium	1,500	$134,400	$201,600,000		
49	Ernest Henry		1	$350,000,000			95,000 t of Copper	Copper	95,000	$7,504	$712,880,000		
							& 120,000 oz of gold	Gold	120,000	$1,200	$144,000,000		
50	Mt Isa Anode Expansion	1		$285,000,000			75,000 t of anode copper	Copper	75,000	$7,504	$562,800,000		
51	Enterprise		1	$370,000,000			117,500 t of Cu	Copper	117,500	$7,504	$881,720,000		
52	Windimurra Vanadium	1			$200,000,000	1	7,200 tonnes of Vanadium pentoxide V2O5	Vanadium	7,200	$15,680		$112,896,000	
53	Ridgeway		1	$376,000,000			360,000 oz of Gold	Gold	360,000	$1,200	$432,000,000		
							26,0000 t of Cu	Copper	26,000	$7,504	$195,104,000		
54	Granny Smith	1		$150,000,000			400,000 oz of gold	Gold	400,000	$1,200	$480,000,000		
55	Telfer		1	$1,200,000,000			800,000 oz Au	Gold	800,000	$1,200	$960,000,000		
							& 30,000 t of Cu	Copper	30,000	$7,504	$225,120,000		
56	Fosterville	1		$117,000,000			110,000 ozs Gold	Gold	110,000	$1,200	$132,000,000		
57	St Ives	1		$125,000,000			50,000 ozs of Gold	Gold	50,000	$1,200	$60,000,000		
58	Lake Cowal	1		$440,000,000			250,000 oz of gold	Gold	250,000	$1,200	$300,000,000		
59	Nifty sulfide copper		1	$148,000,000			60,000 t of copper concentrate	Copper	60,000	$7,504	$450,240,000		
60	Bendigo Gold Mine	1			$250,000,000	1	83,000 oz of Gold in first 3 years	Gold	83,000	$1,200		$99,600,000	
61	Boddington / Wandoo		1	$3,250,000,000			600,000 oz Au	Gold	600,000	$1,200	$720,000,000		
							& 22,500 t of Cu	Copper	22,500	$7,504	$168,840,000		
62	Prominent Hill		1	$1,150,000,000			104,000 t of Copper	Copper	104,000	$7,504	$780,416,000		
							115,000 oz of Gold	Gold	115,000	$1,200	$138,000,000		
	Base metals												
63	McArthur River		1	$290,000,000			160,000 t of Zinc	Zinc	160,000	$2,240	$358,400,000		
							& 45,000 t of Lead	Lead	45,000	$2,106	$94,770,000		
64	Cannington		1	$460,000,000			175,000 t of Pb	Lead	175,000	$2,106	$368,550,000		
							50,000 t of Zn	Zinc	50,000	$2,240	$112,000,000		
							and 750 t of Ag	Silver	750	$570,663	$427,997,250		
65	Century		1	$1,100,000,000			450,000 t of zinc	Zinc	450,000	$2,240	$1,008,000,000		
66	Korea Zinc (Sun Metals)	1		$530,000,000			170,000 t of zinc	Zinc refinery	170,000	$2,240	$380,800,000		
							and 325,000 t of Sulphuric Acid	Sulphuric Acid	325,000	$50	$16,250,000		
67	George Fisher		1	$270,000,000			170,000 t Zn	Zinc	170,000	$2,240	$380,800,000		
							100,000 t Pb	Lead	100,000	$2,106	$210,600,000		
		44	23				& 155 t Au	Silver	155	$570,663	$88,452,765		
				$33,076,000,000	**$12,268,000,000**	15					**$29,694,172,015**	**$5,749,599,200**	
				72.94%	27.06%						83.78%	16.22%	
			Success	$33,076,000,000						Annual Success	$29,694,172,015		
			Failed	$12,268,000,000						Annual Failed	$5,749,599,200		
			Total Invested	$45,344,000,000						Annual Total	$35,443,771,215		

Appendix Sheet 2

Case	New Process Plants	Best estimate of final project cost	Original ABARE projected cost	Cost growth	Start	Complete	Actual project build time	Projected (ABARE) build time	Delay	Outcome
	(New techniques to transform)									
1	HBI Boondarie	$3,370,000,000	$750,000,000	349.33%	30/06/1995	28/02/1999	44.0	24.0	83.33%	Failed
2	Southern Copper	$600,000,000	$220,000,000	172.73%	30/05/1996	30/05/2000	48.0	18.0	166.67%	
3	Anaconda / Murrin-Murrin	$1,000,000,000	$900,000,000	11.11%	1/03/1997	1/05/1999	26.0	18.0	44.44%	Sold
4	Bulong	$250,000,000	$230,000,000	8.70%	1/04/1997	30/09/1998	18.0	12.0	50.00%	
5	Cawse	$378,000,000	$150,000,000	152.00%	1/08/1997	28/02/1999	19.0	12.0	58.33%	
6	Stuart Oil Shale Project	$480,000,000	$250,000,000	92.00%	1/08/1997	28/02/1999	18.0	12.0	50.00%	
7	AMG-CSIRO Stanwell	$1,400,000,000	$720,000,000	94.44%	1/12/01 abare	Dec 2004 Aim	Never completed	36.0		
8	HIsmelt	$1,020,000,000	$300,000,000	240.00%	1/01/2003	1/04/2005	27.0	24.0	12.50%	
9	BHP-B Ravensthorpe	$2,450,000,000	$720,000,000	240.28%	1/04/2005	26/05/2008	38.0	27.0	40.74%	
10	Yabulu expansion	$510,000,000	$200,000,000	155.00%	1/04/2005	26/05/2008	38.0	27.0	40.74%	
11	Beenup	$300,000,000	$100,000,000	200.00%	1/07/1993	1/12/1996	35.0	24.0	45.83%	
40	ISASmelt	$110,000,000	$100,000,000	10.00%	1/08/1992	1/03/1993	7.0	7.0	0.00%	
	Average for reference sub class	**$989,000,000.00**	**$386,666,666.67**	**143.80%**			**28.9**	**20.1**	**53.87%**	
Case	**Gases transformed**	**Best estimate of final project cost**	**Original ABARE projected cost**	**Cost growth**	**Start**	**Complete**	**Actual project build time**	**Projected (ABARE) build time**	**Delay**	
	(LNG, Fertilizer & Explosives, Acid plants)									
12	Kalgoorlie Acid Plant	$145,000,000	$145,000,000	0.00%	1/03/1995	1/03/1996	12.0	12.0	0.00%	Enviro
13	Phosphate Hill	$750,000,000	$750,000,000	0.00%	31/12/1996	1/12/1999	35.0	36.0	-2.78%	Trouble
14	NW Shelf Train 4	$2,700,000,000	$2,300,000,000	17.39%	1/06/2001	30/09/2004	39.0	36.0	8.33%	Success
15	Darwin LNG	$1,750,000,000	$1,500,000,000	16.67%	1/06/2003	1/02/2006	32.0	32.0	0.00%	
16	Burrup Fertilisers	$800,000,000	$630,000,000	26.98%	1/04/2003	1/04/2006	36.0	30.0	20.00%	
17	NW Shelf Train 5	$2,600,000,000	$2,400,000,000	8.33%	1/08/2005	30/08/2008	37.0	36.0	2.78%	
18	Yarwun Ammonium Nitrate	$145,000,000	$135,000,000	7.41%	1/10/2005	1/08/2006	10.0	12.0	-16.67%	
19	Kwinana Ammonium Nitrate	$400,000,000	$140,000,000	185.71%	31/10/2005	31/10/2008	36.0	24.0	50.00%	
	Average for reference sub class	**$1,161,250,000**	**$1,000,000,000**	**32.81%**			**29.6**	**27.3**	**7.71%**	
Case										
	Light metals	**Best estimate of final project cost**	**Original ABARE projected cost**	**Cost growth**	**Start**	**Complete**	**Actual project build time**	**Projected (ABARE) build time**	**Delay**	
	Alumina and Aluminium									
20	Tomago Expansion 1	$600,000,000	$600,000,000	0.00%	1/01/1993	31/12/1993	12.0	12.0	0.00%	
21	Wagerup expansion 1	$150,000,000	$150,000,000	0.00%	1/01/1995	31/12/1995	12.0	12.0	0.00%	
22	Boyne Smelters Expand	$1,000,000,000	$800,000,000	25.00%	30/03/1995	1/03/1998	36.0	36.0	0.00%	
23	Tomago Expansion 2	$200,000,000	$200,000,000	0.00%	30/06/1997	31/03/1999	21.0	18.0	16.67%	
24	Wagerup expansion 2	$285,000,000	$260,000,000	9.62%	1/12/1997	1/12/1999	24.0	24.0	0.00%	
25	Worsley Alumina	$1,000,000,000	$750,000,000	33.33%	1/12/1997	1/05/2000	29.0	30.0	-3.33%	
26	Tomago Efficiency improve	$210,000,000	$210,000,000	0.00%	1/12/2002	1/12/2007	60.0	60.0	0.00%	
27	QAL Efficiency improve	$175,000,000	$175,000,000	0.00%	1/01/2003	31/12/2003	12.0	12.0	0.00%	
28	Pinjarra Upgrade	$550,000,000	$400,000,000	37.50%	1/08/2003	31/12/2006	28.0	16.0	75.00%	
29	Yarwun Alumina Refinery	$1,500,000,000	$1,500,000,000	0.00%	26/10/2001	1/10/2004	33.0	36.0	-8.33%	
30	Alcan Gove G3 Expansion	$2,700,000,000	$1,200,000,000	125.00%	1/10/2004	1/10/2007	36.0	36.0	0.00%	
	Average for reference sub class	**$760,909,090.91**	**$567,727,273**	**20.95%**			**27.5**	**26.5**	**7.27%**	
Case										
	Mineral Sands	**Best estimate of final project cost**	**Original ABARE projected cost**	**Cost growth**	**Start**	**Complete**	**Actual project build time**	**Projected (ABARE) build time**	**Delay**	
31	TiWest Kwinana TiO2	$110,000,000	$110,000,000	0.00%	30/09/1995	30/09/1997	24.0	24.0	0.00%	
32	Iluka Synthetic Rutile SR2 Kiln	$134,000,000	$134,000,000	0.00%	30/09/1995	30/09/1997	24.0	24.0	0.00%	
33	Skardon River Kaolin	$130,000,000	$70,000,000	85.71%	1/07/1997	1/12/1999	15.0	12.0	25.00%	
34	Ginko & Broken Hill Seperation Plant	$176,000,000	$163,000,000	7.98%	20/02/2005	20/02/2006	12.0	12.0	0.00%	
35	Douglas	$284,000,000	$270,000,000	5.19%	30/04/2005	30/05/2007	24.0	12.0	100.00%	

36	Murray Basin Stage 2	$240,000,000	$180,000,000	33.33%	30/04/2008	31/10/2009	18.0	18.0	0.00%
37	Eucla Basin	$390,000,000	$400,000,000	-2.50%	31/10/2008	31/10/2010	24.0	24.0	0.00%
38	Kwinana TiO2 Pigment	$120,000,000	$100,000,000	20.00%	30/04/2008	31/10/2010	30.0	30.0	0.00%
	Average for reference sub class	**$198,000,000**	**$178,375,000**	**18.71%**			**21.4**	**19.5**	**15.63%**
Case	**Nobler metals**	**Best estimate of final project cost**	**Original ABARE projected cost**	**Cost growth**	**Start**	**Complete**	**Actual project build time**	**Projected (ABARE) build time**	**Delay**
	Copper Gold - Sulphide Nickel & Vanadium								
39	SuperPit (Kaltails)	$100,000,000	$100,000,000	0.00%	1/06/1989	30/09/1999	123.0	97.0	26.80%
41	Kambalda Expansion	$105,000,000	$105,000,000	0.00%	30/06/1993	31/12/1994	18.0	18.0	0.00%
42	Mt Keith Sulphide Nickel	$450,000,000	$450,000,000	0.00%	1/12/1993	1/12/1994	12.0	12.0	0.00%
43	Osborne	$160,000,000	$160,000,000	0.00%	1/01/1994	1/08/1995	20.0	20.0	0.00%
44	North Parkes	$255,000,000	$255,000,000	0.00%	1/12/1994	15/12/1996	24.0	24.0	0.00%
45	Sunrise Dam	$130,000,000	$130,000,000	0.00%	1/05/1996	19/04/1997	11.0	12.0	-8.33%
46	Mt Todd	$330,000,000	$208,000,000	58.65%	1/06/1996	1/06/1997	12.0	12.0	0.00%
47	Cadia Hill	$441,000,000	$442,000,000	-0.23%	1/10/1996	1/08/1998	22.0	23.0	-4.35%
48	Olympic Dam expansion	$1,600,000,000	$1,400,000,000	14.29%	1/12/1996	1/12/1999	36.0	36.0	0.00%
49	Ernest Henry	$350,000,000	$300,000,000	16.67%	1/04/1997	1/02/1998	22.0	20.0	10.00%
50	Mt Isa Anode Expansion	$285,000,000	$285,000,000	0.00%	1/06/1997	31/12/1998	18.0	18.0	0.00%
51	Enterprise	$370,000,000	$370,000,000	0.00%	1/04/1998	30/08/2000	28.0	28.0	0.00%
52	Windimurra Vanadium	$200,000,000	$110,000,000	81.82%	1/12/1998	1/12/1999	12.0	12.0	0.00%
53	Ridgeway	$376,000,000	$286,000,000	31.47%	1/05/2000	19/04/2002	23.0	23.0	0.00%
54	Granny Smith (expand)	$150,000,000	$150,000,000	0.00%	30/06/2001	30/06/2002	12.0	12.0	0.00%
55	Telfer	$1,200,000,000	$1,000,000,000	20.00%	1/03/2003	1/02/2005	23.0	24.0	-4.17%
56	Fosterville	$117,000,000	$117,000,000	0.00%	14/11/2003	20/04/2005	17.0	16.0	6.25%
57	St Ives	$125,000,000	$125,000,000	0.00%	21/11/2003	30/11/2004	12.0	12.0	0.00%
58	Lake Cowal	$440,000,000	$270,000,000	62.96%	1/04/2004	1/04/2006	24.0	24.0	0.00%
59	Nifty sulfide copper	$148,000,000	$70,000,000	111.43%	30/06/2004	30/06/2005	12.0	12.0	0.00%
60	Bendigo Gold Mine	$250,000,000	$215,000,000	16.28%	30/05/2005	30/05/2006	12.0	12.0	0.00%
61	Boddington (Wandoo)	$3,250,000,000	$735,000,000	342.18%	1/03/2006	23/07/2009	40.0	32.0	25.00%
62	Prominent Hill	$1,150,000,000	$530,000,000	116.98%	30/04/2007	31/12/2008	24.0	20.0	20.00%
	Average for reference sub class	**$520,956,521.74**	**$339,695,652**	**37.93%**			**24.2**	**22.6**	**3.10%**
Case									
	Baser Metals	**Best estimate of final project cost**	**Original ABARE projected cost**	**Cost growth**	**Start**	**Complete**	**Actual project build time**	**Projected (ABARE) build time**	**Delay**
	Zinc, lead and silver								
63	McArthur River	$290,000,000	$290,000,000	0.00%	30/09/1993	30/09/1995	24.0	24.0	0.00%
64	Cannington	$460,000,000	$450,000,000	2.22%	30/06/1995	30/10/1997	28.0	28.0	0.00%
65	Century	$1,100,000,000	$750,000,000	46.67%	30/06/1996	21/12/1999	42.0	24.0	75.00%
66	Korea Zinc (Sun Metals)	$530,000,000	$530,000,000	0.00%	30/07/1997	30/11/1999	28.0	28.0	0.00%
67	George Fisher	$270,000,000	$270,000,000	0.00%	1/04/1998	30/08/2000	28.0	28.0	0.00%
	Average for reference sub class	**$530,000,000.00**	**$458,000,000.00**	**9.78%**			**30.0**	**26.4**	**15.00%**

Appendix Sheet 3

	Factors		
		Greatest risk .1	**Considerable risk .2**
Item	***Visible before project start***		
1	**Past record of firm**	New firm	Firm with short history
2	**Process focus of firm**	New to specific transformation process	Limited experience in key skills area
3	**Scale-up ratio**	New project at infinite scale (no previous operation)	New project at 5 x scale or more of previous success
4	**Financial confidence**	Financed by least informed at higher risk rates	Finance or bonds at risk rates
5	**Innovation type**	New technology with radical innovation	Radical technology with long pilot testing
6	**Government involvement**	Government wants non commercial political outcome	Unfavourable conditions challenge commercial outcome
7	**Value-adding level**	Value adding to meet lease condition	Elaborate transformation value add refinery
8	**Information Asymmetry**	Highest level information asymmetry without responsibility	High level information asymmetry with some responsibility
	Calculated before project build		
9	**Commodity value**	*Calculated average value of commodity 3 years prior opening*	*from ABARE or USGS*
10	**Pay-back plan measure**	*At full Name Plate Capacity with average commodity price*	*over three years prior to plant opening calculation*
	Actual project build factors		
11	**Time management**	*Projected and reported times from ABARE and other data*	
12	**Cost management**	*Projected and reported costs from ABARE and other data*	
	Shown after project operation		
13	**Production performance**	*Average actual production over first 3 years or part*	*there of if less than 3 years*
14	**Return (actual pay back)**	*At actual production with average commodity price*	*over three years after plant opening*
15	**Life of Firm**	Firm de-listed or "Phoenixed"	Existing but at low production level
16	**Life of Process**	No more similar process projects since	No more similar process projects by firm since

Median risk .3	**Limited risk .4**	**Least risk .5**	
New to country	Mostly good outcomes over some years	Firm with long record of superior outcomes	**Qualitative**
Diversified firm with variety of applicable skills	Stronger skills in more closely allied fields	Close focus on incremental improvement with specific skill	**Qualitative**
New project 2-5 x previous plant success	Duplication of success more than 100% scale up	Duplication of successful plant less than 100% scale up	**Qualitative**
Commercial finance	Internally financed by firm	Financed by best informed at favourable rates	**Qualitative**
Tested process with significant innovation	Mature technology with some novel elements	Mature technology with only incremental improvements	**Qualitative**
Normal lease conditions	Favourable infrastructure and breaks delivered	Government invests for long term for economic outcome	**Qualitative**
Mature and well understood process for refining	Modest value adding semi finish transformation	Only that level of concentration needed to ship commodity	**Qualitative**
Medium level information asymmetry with more responsibility	Modest information asymmetry with responsibility	Limited information asymmetry with accountability	**Qualitative**
			Quantitative
			Quantitative
			Quantitative
			Quantitative
			Quantitative
			Quantitative
Taken over and operational	Firm with variable results	Firm with good regular returns	**Qualitative**
Other firms have duplicated successfully outside Australia	Firm built / expanded one more plant	Project pipeline of similar plants	**Qualitative**

Appendix Sheet 4

	Firm competence													
	Positional (least to most)	1	2	3	4	5	6	7	8	9	10	11	12	13
	Case	**7**	**33**	**6**	**3**	**4**	**52**	**5**	**60**	**2**	**1**	**9**	**11**	**46**
	Identification	**Stan**	**Skardon**	**Stuart**	**Murrin**	**Bulong**	**Wind**	**Cawse**	**Bendigo**	**South**	**HBI**	**Raven**	**Beenup**	**Mt Todd**
	Firm	**ANM**	**AKL**	**SPP**	**ANL**	**RSG**	**WVL**	**CTR**	**BDG**	**JAP**	**BHP**	**BHP**	**BHP**	**Pegasus**
	Pre-project factors													
1	**Past record of firm**	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.3	0.4	0.4	0.4	0.3
2	**Process focus of firm**	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3
3	**Scale-up ratio**	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.4
4	**Financial status**	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.4	0.4	0.2
	Least to most competence	0.4	0.4	0.5	0.5	0.5	0.5	0.7	0.7	1	1.2	1.2	1.2	1.2
	Financial calculations													
9	**Commodity value**	94.47%	87.50%	147.44%	88.75%	88.02%	36.07%	71.00%	208.62%	89.32%	71.43%	77.74%	144.04%	73.77%
10	**Pay-back plan measure**	180.6	148.6	428.6	54.1	66.5	40.5	63.6	178.1	65.4	322.7	44.0	120.9	79.1
	Project build measures													
11	**Time management**	Never	125%	150%	144%	150%	100%	158%	100%	267%	183%	141%	146%	100%
12	**Cost management**	2000%	186%	192%	111%	109%	182%	252%	116%	273%	347%	340%	300%	159%
	Project performance measures													
13	**Production performance**	0.00%	1.20%	31.25%	54.35%	11.11%	50.00%	36.63%	26.82%	50.00%	17.78%	10.00%	27.83%	88.46%
14	**Return (actual pay back)**	Never	12381.00	930.16	114.30	798.75	224.47	254.29	318.22	146.43	2541.18	565.87	327.20	121.25
	(Some figures nominal not estimates*)	*												
15	**Life of firm**	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.5	0.5	0.5	0.1
16	**Life of process**	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.1	0.1
	Colour key													
	Project failed (12)													
	Project failed but restarted (3)													
	Firm financial trouble (15)													
	Environment or efficiency (4)													
	Builder still operating (31)													
	Closed after operation (2)													
	An anomalous result													

			Average												
14	15				16	17	18	19	20	21	22	23	24	25	26
10	**8**				**56**	**13**	**16**	**12**	**65**	**19**	**50**	**63**	**51**	**49**	**62**
Yabulu	**Hismelt**				**Foster**	**Phosp**	**Burrup**	**K Acid**	**Century**	**Kwin AN**	**Anode**	**McArth**	**Enter**	**Ehenry**	**Promin**
BHP	**RIO**				**PSV**	**WMC**	**BPFL**	**WMC**	**ZFX**	**WES**	**MIM**	**MIM**	**MIM**	**MIM**	**OZL**
0.4	0.4				0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
0.3	0.3				0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4
0.2	0.2				0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
0.4	0.4				0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3
1.3	1.3				1.4	1.4	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
77.74%	202.24%		103.88%		200.83%	55.04%	133.67%	97.14%	82.44%	138.64%	66.15%	107.89%	89.32%	67.53%	118.41%
9.2	228.4		135.34		70.7	66.1	63.0	198.9	49.8	93.2	36.5	36.0	41.2	29.8	40.9
141%	113%		144.14%		106%	97%	120%	100%	175%	150%	100%	100%	100%	110%	120%
255%	340%		225.86%		100%	100%	127%	100%	147%	286%	100%	100%	100%	117%	217%
10.00%	11.92%		28.49%		76.23%	63.14%	100.00%	98.94%	118.84%	100.00%	100.00%	63.92%	100.00%	105.19%	100.23%
117.79	947.24		1413.44		46.19	190.12	17.13	206.90	50.60	67.26	55.11	52.56	46.11	42.59	33.60
								*			*	*	*		
0.5	0.5				0.3	0.3	0.3	0.3	0.3	0.5	0.3	0.3	0.3	0.3	0.3
0.2	0.1				0.2	0.2	0.2	0.3	0.2	0.3	0.2	0.2	0.2	0.2	0.2

27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
67	**34**	**66**	**54**	**57**	**58**	**43**	**25**	**40**	**48**	**42**	**41**	**59**	**64**	**39**	**44**
Gfish	**Ginko**	**Sun**	**Gsmith**	**StIves**	**Cowal**	**Osborne**	**Worsley**	**ISASMELT**	**OD**	**Mt Keith**	**Kambal**	**Nifty**	**Cannin**	**SuperP**	**Parkes**
MIM	**BMX**	**KOR**	**ABX**	**ABX**	**ABX**	**ABX**	**BHP**	**MIM**	**WMC**	**WMC**	**WMC**	**AB**	**BHP**	**ABX**	**RIO**
0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5
0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.5	0.4
0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4
1.5	1.5	1.5	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.7	1.7
76.10%	123.98%	92.41%	147.10%	184.76%	208.62%	95.31%	114.02%	106.30%	78.15%	102.30%	93.21%	335.25%	85.20%	84.91%	77.25%
26.0	53.0	60.9	32.6	190.5	104.0	44.6	72.7	3.6	133.7	62.1	10.0	28.6	67.0	10.2	32.9
100%	100%	100%	100%	100%	100%	100%	97%	100%	100%	100%	100%	100%	100%	127%	100%
100%	108%	100%	100%	100%	163%	100%	133%	100%	114%	100%	100%	100%	102%	100%	100%
100.00%	100.00%	117.65%	79.93%	100.00%	88.53%	119.62%	100.00%	100.00%	90.52%	129.01%	91.80%	87.16%	122.86%	100.00%	100.00%
34.22	42.77	62.29	27.73	103.09	56.33	39.82	63.79	3.41	173.87	47.04	11.67	9.80	62.07	12.03	42.65
*		*	*	*		*		*		*	*	*			*
0.3	0.5	0.5	0.4	0.4	0.4	0.4	0.5	0.3	0.3	0.3	0.3	0.3	0.5	0.5	0.5
0.2	0.4	0.2	0.4	0.4	0.4	0.4	0.2	0.5	0.2	0.2	0.2	0.2	0.2	0.3	0.3

43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
22	**30**	**45**	**31**	**32**	**35**	**36**	**37**	**28**	**29**	**61**	**20**	**23**	**26**	**53**	**27**
Boyne	**G3**	**Sunrise**	**TiO2**	**Rutile**	**Douglas**	**MB 2**	**Eucla**	**Pinj**	**Yarwun**	**Bodd**	**Tom 1**	**T E 2**	**T Effic**	**Ridge**	**QAL**
RIO	**AL**	**AGG**	**Tiwest**	**ILU**	**ILU**	**ILU**	**ILU**	**AWAC**	**RIO**	**NEM**	**RIO**	**RIO**	**RIO**	**NCM**	**RIO**
0.5	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.5	0.4
0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.4	0.5
0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
1.7	1.7	1.8	1.7	1.7	1.7	1.7	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
88.64%	97.37%	73.77%	99.31%	124.42%	108.02%	112.41%	93.90%	120.81%	105.56%	135.82%	79.80%	97.31%	103.64%	156.89%	100.00%
63.7	46.1	81.0	20.0	38.0	32.2	15.3	27.5	59.1	79.4	83.6	51.4	80.6	34.9	49.3	60.0
100%	100%	92%	100%	100%	200%	100%	100%	175%	100%	125%	100%	117%	100%	100%	100%
125%	192%	100%	100%	100%	105%	133%	98%	138%	100%	442%	100%	100%	100%	100%	100%
100.00%	65.31%	205.96%	100.00%	100.00%	90.00%	90.18%	100.00%	100.00%	91.43%	120.00%	100.00%	100.00%	100.00%	110.89%	100.00%
71.91	72.51	53.34	20.17	30.54	55.38	15.28	28.42	48.89	82.24	50.00	64.45	82.87	33.69	23.90	60.00
			*	*					*		*	*	*	*	*
0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.5
0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3

59	60	61	62	63	64	65	66	67		Average	Positional (least to most)
21	**47**	**14**	**24**	**38**	**55**	**18**	**15**	**17**			**Case**
Wag 1	**Cadia**	**T4**	**Wag 2**	**TiO2 (2)**	**Telfer**	**Yarwun**	**Darwin**	**T5**			**Identification**
AWAC	**NCM**	**WPL**	**Alcoa**	**Tiwest**	**NCM**	**ORI**	**COP**	**WPL**			**Firm**
											Pre-project factors
0.5	0.5	0.4	0.5	0.5	0.5	0.5	0.5	0.5		0.39	**Past record**
0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		0.39	**Firm focus**
0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.4	0.5		0.37	**Scale-up**
0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.5	0.5		0.34	**Financial status**
1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.9	2		1.48	
											Financial calculations
113.10%	71.94%	123.70%	125.10%	100.00%	224.60%	133.67%	172.64%	151.79%		116.85%	**Commodity**
78.6	63.0	50.1	54.3	29.0	109.5	38.9	40.5	42.2		57.44	**Pay-back (plan)**
											Project build measures
100%	96%	108%	100%	100%	96%	100%	100%	103%		107.96%	**Time manage**
100%	100%	117%	110%	120%	120%	100%	117%	100%		121.73%	**Cost manage**
											Project performance measures
100.00%	98.35%	91.67%	100.00%	100.00%	77.80%	100.00%	100.00%	94.55%		99.80%	**Production**
69.50	85.94	44.18	43.43	28.96	57.65	29.10	23.48	29.41		53.96	**Return (actual pay back)**
*						*					
0.5	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5		0.42	
0.3	0.4	0.5	0.3	0.3	0.4	0.3	0.5	0.5		0.32	**Outcome**

Appendix Sheet 5

	New Process Innovation														Average
	Positional (least to most)	1	2	3	4	5	6	7	8	9	10	11	12	13	
	Case	**7**	**6**	**3**	**4**	**5**	**11**	**2**	**1**	**9**	**52**	**33**	**10**	**8**	
	Identification	**Stan**	**Stuart**	**Murrin**	**Bulong**	**Cawse**	**Beenup**	**South**	**HBI**	**Raven**	**Wind**	**Skardon**	**Yabulu**	**Hismelt**	
	Firm	**ANM**	**SPP**	**ANL**	**RSG**	**CTR**	**BHP**	**JAP**	**BHP**	**BHP**	**WVL**	**AKL**	**BHP**	**RIO**	
3	**Scale up ratio**	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	
5	**Innovation type**	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.2	0.2	
	Simple risk number	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.4	0.4	
	Financial calculations														
9	**Commodity value**	94.47%	147.44%	88.75%	88.02%	71.00%	144.04%	89.32%	71.43%	77.74%	36.07%	87.50%	77.74%	202.24%	
10	**Pay-back plan measure**	180.6	428.6	54.1	66.5	63.6	120.9	65.4	322.7	44.0	40.5	148.6	9.2	228.4	
	Project build measures														
11	**Time management**	Never	150%	144%	150%	158%	146%	267%	183%	141%	100%	125%	141%	113%	151.50%
12	**Cost management**	2000%	192%	111%	109%	252%	300%	273%	480%	340%	182%	186%	255%	340%	251.67%
	Project proformance measures														
13	**Production performance**	0.00%	31.25%	54.35%	11.11%	36.63%	27.83%	50.00%	17.78%	10.00%	50.00%	1.20%	10.00%	11.92%	26.01%
14	**Return (actual pay back)**	1000.00	930.16	114.30	798.75	254.29	327.20	146.43	2541.18	565.87	224.47	12381.00	117.79	947.24	1,612.39
	(Nominal rather than estimate*)	*													
15	**Life of firm**	0.1	0.1	0.2	0.1	0.1	0.5	0.1	0.5	0.5	0.1	0.1	0.5	0.5	0.00%
16	**Life of process**	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.1	0.2	0.1	0.24
	Local R&D	1												1	
	First in country	1	1					1	1					1	
	Closed or demolished	1	1		1	1	1	1	1					1	
	Colour key														
	Project failed (12)														
	Project failed but restarted (3)														
	Firm financial trouble (15)														
	Environment or efficiency (4)														
	Builder still operating (31)														
	Closed after operation (2)														
	An anomalous result														
	New Process Innovation (12)														

	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
	40	**60**	**13**	**56**	**65**	**46**	**50**	**63**	**62**	**34**	**44**	**30**	**32**	**35**	**36**	**37**
	ISASMELT	**Bendigo**	**Phosp**	**Foster**	**Century**	**Mt Todd**	**Anode**	**McArth**	**Promin**	**Ginko**	**Parkes**	**G3**	**Rutile**	**Douglas**	**MB 2**	**Eucla**
	MIM	**BDG**	**WMC**	**PSV**	**ZFX**	**Pegasus**	**MIM**	**MIM**	**OZL**	**BMX**	**RIO**	**AL**	**ILU**	**ILU**	**ILU**	**ILU**
	0.4	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	0.2	0.4	0.3	0.4	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	0.8	0.8	0.9	1.2	1.2	1.2	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
	106.30%	208.62%	55.04%	200.83%	82.44%	73.77%	66.15%	107.89%	118.41%	123.98%	77.25%	97.37%	124.42%	108.02%	112.41%	93.90%
	60.0	178.1	66.1	70.7	49.8	79.1	36.5	36.0	40.9	53.0	32.9	46.1	38.0	32.2	15.3	27.5
	100%	100%	97%	106%	175%	100%	100%	100%	120%	100%	100%	100%	100%	200%	100%	100%
	110%	116%	100%	100%	147%	159%	100%	100%	217%	108%	100%	192%	100%	105%	133%	98%
	100.00%	26.82%	63.14%	76.23%	118.84%	88.46%	100.00%	63.92%	100.23%	100.00%	100.00%	65.31%	100.00%	90.00%	90.18%	100.00%
	60.00	318.22	190.12	46.19	50.60	121.25	55.11	52.56	33.60	42.77	42.65	72.51	30.54	55.38	15.28	28.42
	*															
	0.3	0.1	0.3	0.3	0.3	0.1	0.3	0.3	0.3	0.5	0.5	0.5	0.4	0.4	0.4	0.4
	0.5	0.1	0.3	0.2	0.2	0.1	0.2	0.2	0.2	0.4	0.3	0.3	0.5	0.5	0.5	0.5
	1															
	1															

30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
53	**31**	**64**	**12**	**38**	**14**	**17**	**16**	**19**	**54**	**57**	**58**	**66**	**43**	**51**	**49**	**67**
Ridge	**TiO2**	**Cannin**	**K Acid**	**TiO2 (2)**	**T4**	**T5**	**Burrup**	**Kwin AN**	**Gsmith**	**StIves**	**Cowal**	**Sun**	**Osborne**	**Enter**	**Ehenry**	**Gfish**
NCM	**Tiwest**	**BHP**	**WMC**	**Tiwest**	**WPL**	**WPL**	**BPFL**	**WES**	**ABX**	**ABX**	**ABX**	**KOR**	**ABX**	**MIM**	**MIM**	**MIM**
0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
0.4	0.4	0.5	0.5	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
1.6	1.6	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
156.89%	99.31%	85.20%	97.14%	100.00%	123.70%	151.79%	133.67%	138.64%	147.10%	184.76%	208.62%	92.41%	95.31%	89.32%	67.53%	76.10%
49.3	20.0	67.0	198.9	29.0	50.1	42.2	63.0	93.2	32.6	190.5	104.0	60.9	44.6	41.2	29.8	26.0
100%	100%	100%	100%	100%	108%	103%	120%	150%	100%	100%	100%	100%	100%	100%	110%	100%
100%	100%	102%	100%	120%	117%	100%	127%	286%	100%	100%	163%	100%	100%	100%	117%	100%
110.89%	100.00%	122.86%	98.94%	100.00%	91.67%	94.55%	100.00%	100.00%	79.93%	100.00%	88.53%	117.65%	119.62%	100.00%	105.19%	100.00%
23.90	20.17	62.07	206.90	28.96	44.18	29.41	17.13	67.26	27.73	103.09	56.33	62.29	39.82	46.11	42.59	34.22
0.4	0.5	0.5	0.3	0.5	0.5	0.5	0.3	0.5	0.4	0.4	0.4	0.5	0.4	0.3	0.3	0.3
0.4	0.4	0.2	0.3	0.3	0.5	0.5	0.2	0.3	0.4	0.4	0.4	0.2	0.4	0.2	0.2	0.2

47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
28	**29**	**61**	**47**	**15**	**21**	**25**	**48**	**42**	**59**	**39**	**41**	**22**	**45**	**23**	**24**	**26**
Pinj	**Yarwun**	**Bodd**	**Cadia**	**Darwin**	**Wag 1**	**Worsley**	**OD**	**Mt Keith**	**Nifty**	**SuperP**	**Kambal**	**Boyne**	**Sunrise**	**T E 2**	**Wag 2**	**T Effic**
AWAC	**RIO**	**NEM**	**NCM**	**COP**	**AWAC**	**BHP**	**WMC**	**WMC**	**AB**	**ABX**	**WMC**	**RIO**	**AGG**	**RIO**	**Alcoa**	**RIO**
0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
2	2	2	2	2	2	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
120.81%	105.56%	135.82%	71.94%	172.64%	113.10%	114.02%	78.15%	102.30%	335.25%	84.91%	93.21%	88.64%	73.77%	97.31%	125.10%	103.64%
59.1	79.4	83.6	63.0	40.5	78.6	72.7	133.7	62.1	28.6	10.2	10.0	63.7	81.0	80.6	54.3	34.9
175%	100%	125%	96%	100%	100%	97%	100%	100%	100%	127%	100%	100%	92%	117%	100%	100%
138%	100%	442%	100%	117%	100%	133%	114%	100%	100%	100%	100%	125%	100%	100%	110%	100%
100.00%	91.43%	120.00%	98.35%	100.00%	100.00%	100.00%	90.52%	129.01%	87.16%	100.00%	91.80%	100.00%	205.96%	100.00%	100.00%	100.00%
48.89	82.24	50.00	85.94	23.48	69.50	63.79	173.87	47.04	9.80	12.03	11.67	71.91	53.34	82.87	43.43	33.69
0.5	0.5	0.5	0.4	0.5	0.5	0.5	0.3	0.3	0.3	0.5	0.3	0.5	0.5	0.5	0.5	0.5
0.3	0.3	0.3	0.4	0.5	0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.4	0.3	0.3	0.3

64	65	66	67		
27	**55**	**18**	**20**		
QAL	**Telfer**	**Yarwun**	**Tom 1**		
RIO	**NCM**	**ORI**	**RIO**		
0.5	0.5	0.5	0.5		
0.5	0.5	0.5	0.5		
2.5	2.5	2.5	2.5		
100.00%	224.60%	133.67%	79.80%		117.75%
60.0	109.5	38.9	51.4		61.12
100%	96%	100%	100%		107.67%
100%	120%	100%	100%		122.50%
100.00%	77.80%	100.00%	100.00%		98.24%
60.00	57.65	29.10	64.45		61.15
0.5	0.5	0.5	0.5		
0.3	0.4	0.3	0.3		

Appendix Sheet 6

	Government Involvement in value adding											
	Positional (least to most)	1	2	3	4	5		6	7	8	9	10
	Case	**7**	**8**	**1**	**2**	**48**		**9**	**6**	**3**	**4**	**33**
	Identification	**Stan**	**Hismelt**	**HBI**	**South**	**OD**		**Raven**	**Stuart**	**Murrin**	**Bulong**	**Skardon**
	Firm	**ANM**	**RIO**	**BHP**	**JAP**	**WMC**		**BHP**	**SPP**	**ANL**	**RSG**	**AKL**
	Pre-project factors											
6	**Government involvement**	0.1	0.1	0.1	0.1	0.1		0.2	0.3	0.3	0.3	0.3
7	**Value-adding level**	0.1	0.1	0.1	0.2	0.2		0.2	0.2	0.2	0.2	0.2
	Most to least Government	0.20	0.20	0.20	0.30	0.30		0.40	0.50	0.50	0.50	0.50
	involvement in value adding											
	Financial calculations											
9	**Commodity value**	94.47%	202.24%	71.43%	89.32%	78.15%		77.74%	147.44%	88.75%	88.02%	87.50%
10	**Pay-back plan measure**	180.6	228.4	322.7	65.4	133.7		44.0	428.6	54.1	66.5	148.6
	Project build measures											
11	**Time management**	Never	113%	183%	267%	100%		141%	150%	144%	150%	125%
12	**Cost management**	2000%	340%	480%	273%	114%		340%	192%	111%	109%	186%
	Project performance measures											
13	**Production performance**	0.00%	11.92%	17.78%	50.00%	90.52%		10.00%	31.25%	54.35%	11.11%	1.20%
14	**Return (actual pay back)**		947.24	2541.18	146.43	173.87		565.87	930.16	114.30	798.75	12381.00
15	**Life of firm**	0.1	0.5	0.5	0.1	0.3		0.5	0.1	0.2	0.1	0.1
16	**Life of process**	0.1	0.1	0.1	0.1	0.2		0.2	0.1	0.2	0.2	0.1
	Colour key											
	Project failed (12)											
	Project failed but restarted (3)											
	Firm financial trouble (15)											
	Environment or efficiency (4)											
	Builder still operating (31)											
	Closed after operation (2)											
	An anomalous result											
	Alumina & Aluminium (11)											

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
52	**5**	**46**	**13**	**19**	**50**	**66**	**40**	**31**	**38**	**32**	**18**	**60**	**56**	**11**	**10**
Wind	**Cawse**	**Mt Todd**	**Phosp**	**Kwin AN**	**Anode**	**Sun**	**ISAMelt**	**TiO2**	**TiO2 (2)**	**Rutile**	**Yarwun**	**Bendigo**	**Foster**	**Beenup**	**Yabulu**
WVL	**CTR**	**Pegasus**	**WMC**	**WES**	**MIM**	**KOR**	**MIM**	**Tiwest**	**Tiwest**	**ILU**	**ORI**	**BDG**	**PSV**	**BHP**	**BHP**
0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.2
0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.60	0.60	0.60	0.60
36.07%	71.00%	73.77%	55.04%	138.64%	66.15%	92.41%	106.30%	99.31%	100.00%	124.42%	133.67%	208.62%	200.83%	144.04%	77.74%
40.5	63.6	79.1	66.1	93.2	36.5	60.9	3.6	20.0	29.0	38.0	38.9	178.1	70.7	120.9	9.2
100%	158%	100%	97%	150%	100%	100%	100%	100%	100%	100%	100%	100%	106%	146%	141%
182%	252%	159%	100%	286%	100%	100%	100%	100%	120%	100%	100%	116%	100%	300%	255%
50.00%	36.63%	88.46%	63.14%	100.00%	100.00%	117.65%	100.00%	100.00%	100.00%	100.00%	100.00%	26.82%	76.23%	27.83%	10.00%
224.47	254.29	121.25	190.12	67.26	55.11	62.29	3.41	20.17	28.96	30.54	29.10	318.22	46.19	327.20	117.79
0.1	0.1	0.1	0.3	0.5	0.3	0.5	0.3	0.5	0.5	0.4	0.5	0.1	0.3	0.5	0.5
0.2	0.2	0.1	0.2	0.3	0.2	0.2	0.5	0.4	0.3	0.5	0.3	0.1	0.2	0.1	0.2

27	28	29	30	31	32	33	34	35	36	37	38	39	40	43	44
12	**54**	**57**	**58**	**39**	**45**	**30**	**35**	**36**	**37**	**61**	**55**	**34**	**43**	**20**	**27**
K Acid	**Gsmith**	**StIves**	**Cowal**	**SuperP**	**Sunrise**	**G3**	**Douglas**	**MB 2**	**Eucla**	**Bodd**	**Telfer**	**Ginko**	**Osborne**	**Tom 1**	**QAL**
WMC	**ABX**	**ABX**	**ABX**	**ABX**	**AGG**	**AL**	**ILU**	**ILU**	**ILU**	**NEM**	**NCM**	**BMX**	**ABX**	**RIO**	**RIO**
0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.4
0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.2	0.3
0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.70	0.70	0.70	0.70
97.14%	147.10%	184.76%	208.62%	84.91%	73.77%	97.37%	108.02%	112.41%	93.90%	135.82%	224.60%	123.98%	95.31%	79.80%	
198.9	32.6	190.5	104.0	10.2	81.0	46.1	32.2	15.3	27.5	83.6	109.5	53.0	44.6	51.4	
100%	100%	100%	100%	127%	92%	100%	200%	100%	100%	125%	96%	100%	100%	100%	100%
100%	100%	100%	163%	100%	100%	192%	105%	133%	98%	442%	120%	108%	100%	100%	100%
98.94%	79.93%	100.00%	88.53%	100.00%	205.96%	65.31%	90.00%	90.18%	100.00%	120.00%	77.80%	100.00%	119.62%	100.00%	
206.90	27.73	103.09	56.33	12.03	53.34	72.51	55.38	15.28	28.42	50.00	57.65	42.77	39.82	64.45	
0.3	0.4	0.4	0.4	0.5	0.5	0.5	0.4	0.4	0.4	0.5	0.5	0.5	0.4	0.5	0.5
0.3	0.4	0.4	0.4	0.3	0.4	0.3	0.5	0.5	0.5	0.3	0.4	0.4	0.4	0.3	0.3

45	46	49	50	41	42	47	48	51	52	53	54	55	56	57	58
28	**29**	**24**	**25**	**23**	**26**	**22**	**21**	**64**	**65**	**16**	**63**	**51**	**49**	**62**	**67**
Pinj	**Yarwun**	**Wag 2**	**Worsley**	**T E 2**	**T Effic**	**Boyne**	**Wag 1**	**Cannin**	**Century**	**Burrup**	**McArth**	**Enter**	**Ehenry**	**Promin**	**Gfish**
AWAC	**RIO**	**Alcoa**	**BHP**	**RIO**	**RIO**	**RIO**	**AWAC**	**BHP**	**ZFX**	**BPFL**	**MIM**	**MIM**	**MIM**	**OZL**	**MIM**
0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3
0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.5	0.4	0.5	0.5	0.5	0.5	0.5
0.70	0.70	0.70	0.70	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
120.81%	105.56%	125.10%	114.02%	97.31%	103.64%	88.64%	113.10%	85.20%	82.44%	133.67%	107.89%	89.32%	67.53%	118.41%	76.10%
59.1	79.4	54.3	72.7	80.6	34.9	63.7	78.6	67.0	49.8	63.0	36.0	41.2	29.8	40.9	26.0
175%	100%	100%	97%	117%	100%	100%	100%	100%	175%	120%	100%	100%	110%	120%	100%
138%	100%	110%	133%	100%	100%	125%	100%	102%	147%	127%	100%	100%	117%	217%	100%
100.00%	91.43%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	122.86%	118.84%	100.00%	63.92%	100.00%	105.19%	100.23%	100.00%
48.89	82.24	43.43	63.79	82.87	33.69	71.91	69.50	62.07	50.60	17.13	52.56	46.11	42.59	33.60	34.22
0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3
0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

59	60	61	62	63	64	65	66	67
44	**42**	**59**	**41**	**53**	**14**	**17**	**47**	**15**
Parkes	**Mt Keith**	**Nifty**	**Kambal**	**Ridge**	**T4**	**T5**	**Cadia**	**Darwin**
RIO	**WMC**	**AB**	**WMC**	**NCM**	**WPL**	**WPL**	**NCM**	**COP**
0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.90
77.25%	102.30%	335.25%	93.21%	156.89%	123.70%	151.79%	71.94%	172.64%
32.9	62.1	28.6	10.0	49.3	50.1	42.2	63.0	40.5
100%	100%	100%	100%	100%	108%	103%	96%	100%
100%	100%	100%	100%	100%	117%	100%	100%	117%
100.00%	129.01%	87.16%	91.80%	110.89%	91.67%	94.55%	98.35%	100.00%
42.65	47.04	9.80	11.67	23.90	44.18	29.41	85.94	23.48
0.5	0.3	0.3	0.3	0.4	0.5	0.5	0.4	0.5
0.3	0.2	0.2	0.2	0.4	0.5	0.5	0.4	0.5

Appendix Sheet 7

	Information Asymmetry												
	Positional (least to most)	1	2	3	4	5	6	7	8	9	10	11	12
	Case	**7**	**33**	**60**	**1**	**8**	**4**	**5**	**3**	**9**	**6**	**52**	**46**
	Identification	**Stan**	**Skardon**	**Bendigo**	**HBI**	**Hismelt**	**Bulong**	**Cawse**	**Murrin**	**Raven**	**Stuart**	**Wind**	**Mt Todd**
	Firm	**ANM**	**AKL**	**BDG**	**BHP**	**RIO**	**RSG**	**CTR**	**ANL**	**BHP**	**SPP**	**WVL**	**Pegasus**
8	**Asymmetric Information**	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
	Financial calculations												
9	**Commodity value**	94.47%	87.50%	208.62%	71.43%	202.24%	88.02%	71.00%	88.75%	77.74%	147.44%	36.07%	73.77%
10	**Pay-back plan measure**	180.6	148.6	178.1	322.7	228.4	66.5	63.6	54.1	44.0	428.6	40.5	79.1
	Project build measures												
11	**Time management**	Never	125%	100%	183%	113%	150%	158%	144%	141%	150%	100%	100%
12	**Cost management**	2000%	186%	116%	480%	340%	109%	252%	111%	340%	192%	182%	159%
	Project performance measures												
13	**Production performance**	0.00%	1.20%	26.82%	17.78%	11.92%	11.11%	36.63%	54.35%	10.00%	31.25%	50.00%	88.46%
14	**Return (actual pay back)**		12381.00	318.22	2541.18	947.24	798.75	254.29	114.30	565.87	930.16	224.47	121.25
15	**Life of Firm**												
16	**Life of Process**												
15	**Life of firm**	0.1	0.1	0.2	0.5	0.5	0.1	0.1	0.2	0.5	0.1	0.1	0.1
16	**Life of process**	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.2	0.1
	Project failed (12)												
	Project failed but restarted (3)												
	Firm financial trouble (15)												
	Environment or efficiency (4)												
	Builder still operating (31)												
	Closed after operation (2)												
	An anomalous result												

13	14	15	16		17	18	19	20	21	22	23	24	25	26
2	**11**	**10**	**16**		**56**	**13**	**65**	**66**	**62**	**34**	**64**	**12**	**19**	**54**
South	**Beenup**	**Yabulu**	**Burrup**		**Foster**	**Phosp**	**Century**	**Sun**	**Promin**	**Ginko**	**Cannin**	**K Acid**	**Kwin AN**	**Gsmith**
JAP	**BHP**	**BHP**	**BPFL**		**PSV**	**WMC**	**ZFX**	**KOR**	**OZL**	**BMX**	**BHP**	**WMC**	**WES**	**ABX**
0.3	0.3	0.3	0.3		0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
89.32%	144.04%	77.74%	133.67%		200.83%	55.04%	82.44%	92.41%	118.41%	123.98%	85.20%	97.14%	138.64%	147.10%
65.4	120.9	9.2	63.0		70.7	66.1	49.8	60.9	40.9	53.0	67.0	198.9	93.2	32.6
267%	146%	141%	120%		106%	97%	175%	100%	120%	100%	100%	100%	150%	100%
273%	300%	255%	127%		100%	100%	147%	100%	217%	108%	102%	100%	286%	100%
50.00%	27.83%	10.00%	100.00%		76.23%	63.14%	118.84%	117.65%	100.23%	100.00%	122.86%	98.94%	100.00%	79.93%
146.43	327.20	117.79	17.13		46.19	190.12	50.60	62.29	33.60	42.77	62.07	206.90	67.26	27.73
0.1	0.5	0.5	0.3		0.3	0.3	0.3	0.5	0.3	0.5	0.4	0.3	0.5	0.4
0.1	0.1	0.2	0.2		0.2	0.2	0.2	0.2	0.2	0.4	0.2	0.3	0.3	0.4

27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
57	**58**	**63**	**43**	**51**	**49**	**67**	**48**	**44**	**59**	**30**	**31**	**32**	**35**	**36**
StIves	**Cowal**	**McArth**	**Osborne**	**Enter**	**Ehenry**	**Gfish**	**OD**	**Parkes**	**Nifty**	**G3**	**TiO2**	**Rutile**	**Douglas**	**MB 2**
ABX	**ABX**	**MIM**	**ABX**	**MIM**	**MIM**	**MIM**	**WMC**	**RIO**	**AB**	**AL**	**Tiwest**	**ILU**	**ILU**	**ILU**
0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
184.76%	208.62%	107.89%	95.31%	89.32%	67.53%	76.10%	78.15%	77.25%	335.25%	97.37%	99.31%	124.42%	108.02%	112.41%
190.5	104.0	36.0	44.6	41.2	29.8	26.0	133.7	32.9	28.6	46.1	20.0	38.0	32.2	15.3
100%	100%	100%	100%	100%	110%	100%	100%	100%	100%	100%	100%	100%	200%	100%
100%	163%	100%	100%	100%	117%	100%	114%	100%	100%	192%	100%	100%	105%	133%
100.00%	88.53%	63.92%	119.62%	100.00%	105.19%	100.00%	90.52%	100.00%	87.16%	65.31%	100.00%	100.00%	90.00%	90.18%
103.09	56.33	52.56	39.82	46.11	42.59	34.22	173.87	42.65	9.80	72.51	20.17	30.54	55.38	15.28
0.4	0.4	0.3	0.4	0.3	0.3	0.3	0.3	0.5	0.3	0.5	0.5	0.4	0.4	0.4
0.4	0.4	0.2	0.4	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.4	0.5	0.5	0.5

42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
37	**38**	**28**	**61**	**14**	**18**	**39**	**41**	**22**	**45**	**25**	**40**	**29**	**42**	**50**
Eucla	**TiO2 (2)**	**Pinj**	**Bodd**	**T4**	**Yarwun**	**SuperP**	**Kambal**	**Boyne**	**Sunrise**	**Worsley**	**ISAMelt**	**Yarwun**	**Mt Keith**	**Anode**
ILU	**Tiwest**	**AWAC**	**NEM**	**WPL**	**ORI**	**ABX**	**WMC**	**RIO**	**AGG**	**BHP**	**MIM**	**RIO**	**WMC**	**MIM**
0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
93.90%	100.00%	120.81%	135.82%	123.70%	133.67%	84.91%	93.21%	88.64%	73.77%	114.02%	106.30%	105.56%	102.30%	66.15%
27.5	29.0	59.1	83.6	50.1	38.9	10.2	10.0	63.7	81.0	72.7	3.6	79.4	62.1	36.5
100%	100%	175%	125%	108%	100%	127%	100%	100%	92%	97%	100%	100%	100%	100%
98%	120%	138%	442%	117%	100%	100%	100%	125%	100%	133%	100%	100%	100%	100%
100.00%	100.00%	100.00%	120.00%	91.67%	100.00%	100.00%	91.80%	100.00%	205.96%	100.00%	100.00%	91.43%	129.01%	100.00%
28.42	28.96	48.89	50.00	44.18	29.10	12.03	11.67	71.91	53.34	63.79	3.41	82.24	47.04	55.11
0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.3	0.5	0.5	0.5	0.3	0.5	0.3	0.3
0.5	0.3	0.3	0.3	0.5	0.3	0.3	0.2	0.3	0.4	0.3	0.5	0.3	0.2	0.2

57	58	59	60	61	62	63	64	65	66	67		Average	Positional (least to most)
23	**24**	**26**	**53**	**27**	**17**	**47**	**15**	**55**	**20**	**21**			**Case**
T E 2	**Wag 2**	**T Effic**	**Ridge**	**QAL**	**T5**	**Cadia**	**Darwin**	**Telfer**	**Tom 1**	**Wag 1**			**Identification**
RIO	**Alcoa**	**RIO**	**NCM**	**RIO**	**WPL**	**NCM**	**COP**	**NCM**	**RIO**	**AWAC**			**Firm**
0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		0.38	**Misrepresentation**
													Financial calculations
97.31%	125.10%	103.64%	156.89%		151.79%	71.94%	172.64%	224.60%	79.80%	113.10%		112.45%	**Commodity value**
80.6	54.3	34.9	49.3		42.2	63.0	40.5	109.5	51.4	78.6		73.99	**Pay-back plan measure**
													Project build measures
117%	100%	100%	100%	100%	103%	96%	100%	96%	100%	100%		113.91%	**Time management**
100%	110%	100%	100%	100%	100%	100%	117%	120%	100%	100%		173.51%	**Cost management**
													Project performance measures
100.00%	100.00%	100.00%	110.89%		94.55%	98.35%	100.00%	77.80%	100.00%	100.00%		82.34%	**Production performance**
82.87	43.43	33.69	23.90		29.41	85.94	23.48	57.65	64.45	69.50		336.33	**Return (actual pay back)**
0.5	0.5	0.5	0.4	0.5	0.5	0.4	0.5	0.4	0.5	0.5		0.38	**Project outcomes**
0.3	0.3	0.3	0.3	0.3	0.5	0.4	0.5	0.4	0.3	0.3		0.28	

Appendix Sheet 8

Parameter	Failure outcome model	Success estimation model
Profit	The project and the firm made a loss	The project and the firm made a profit
Production	Production less than 70% nameplate capacity in 36 months	Production better than 90% of planned output
Return	CRoI more than double industry average < 106 months	Calculated Return on Investment > 105 months
Firm life	Firm has ceased, been taken over, been deregistered	Firm is alive, grows and evolves
Process life	Process is no longer worked, or only worked sub optimally	Transforming process is worked and duplicated
	Firm Competence failure model	**Firm Competence success model**
Track record	Limited or no relevant track record of success	Track record of successful implementation
Firm focus	Limited or no prior firm focus in area endeavour	Firm focus in particular area of endeavour
Scale up ratio	Large scale up from previous similar project success	Modest scale up from previous similar project success
Financial confidence	Firm financed at high interest from least informed	Firm engenders financial confidence from best informed
Profit	The firm and the project made a loss	The firm and its projects regularly made a profit
	New process innovation failure model	**New process innovation success model**
Ownership	Management with limited responsibility or ownership	Individual Ownership and responsibility
Simplicity	Initially complex process that became more complex	Initial process simplicity that evolved
Evolution steps	Rapid scale up to mega scale without evolution	Multistage incremental scale up with evolution
Demand	Many firms chasing same perceived opportunity	Niche demand for innovation
Profit	The process made a losses from start to finish	The process made profits quickly and repeatedly
	Government Involvement failure model	**Government Involvement success model**
Understood process	New process, not well understood	Mature and well understood processes evolved
Mature firm	New firms with less established value chains	Mature firms with complete value chain
Shared benefits	One sided benefits sought upfront	Mutual benefit from decades on agreed collaboration
Reward for misinform	High level of reward for information asymmetry	Low level of reward for information asymmetry
Profit	The project made a loss despite government investment	The project made a profit after government involvement
	Asymmetric Information failure model	**Asymmetric Information success model**
Asymmetry balance	High of information asymmetry and power imbalance	Low of information asymmetry and power balance
Need for misinform	Driving force exists for strategic misrepresentation	Limited motivation for strategic misrepresentation
Power management	Asymmetrical information used to manage ignorant power	Open and commercial access to resources
Infomation "noise"	Loud strategic misinformation to promote investment	Little information noise on good projects
Profit	The project made a loss that was unexpected	The project made a profit that was expected

Appendix Sheet 9

	Process innovation success characteristics	Process innovation failure characteristics
	Ownership and responsibility	
1	Direct	Indirect
2	Individual inventor and or small team, investors and owners	Multiple organisations acting in more diverse collaborative service mode
3	Hope to get reward at successful completion	Funding is up front or contractually assured (business fund raising and budget)
4	Risk is personal and often linked to personal assets	Risk is carried by investors and unrelated to managers own assets
5	Strong responsibility for out come	Limited personal responsibility for outcome, often carefully limited
6	Personal, reputation and financial loss from failure	Paid by hour, regardless of outcome
7	Rewards flow only from success	Managing failure slowly can have adequate rewards
8	Failure is pain and shame	Failure can be later re-defined or spun (especially with Government)
9	Process makes early productivity increases that lead to profits	Process fails to makes early productivity increases that leads to massive loss
	Complexity and performance	
10	Initially simple, and incrementally more complex	Initially complex, and incrementally even more complex
11	Works at the micro scale, and shows utility at every scale up stage	Needs mega-scale project to "make numbers add up"
12	Simple system low cost at small scale, incremental improvements economical	Complex system expensive to implement at small scale
13	Relatively easy and quick to implement with low cost resources	High costs in working systems encourage fast scale up
14	Early trial and measurement of outcome is practical	Early trial is more focused around "proving" demonstration or producing samples
15	Rapid modification at small scale is practical and economical	Change is difficult as system is complex and change unwelcome in rapid scale up
16	Complexity evolves with process incremental improvements over a longer time	Complexity evolves beyond the capacity to manage it successfully
17	Firm wants to use its new process to increase its own productivity	Firm uses new process to promote investment flow
	Step up stages and benefits	
18	Multi stage scale up steps and improvements	Quickly to mega scale … we know all the answers or have to pretend so
19	Many moderate iterative scale up steps in process development	Must be big like dinosaur to be safe from competition
20	Incremental improvements in process, and knowledge base, with low cost and risk	Mega scale needed to get numbers to add up
21	Advantage in being able to fail fast, change cheap, learn quickly at smaller scale	Hubris in thinking "we know it all"… long delay in acknowledging failure
22	Complexity evolves with process incremental improvement steps over time	Complexity catches unwary and unprepared
23	New process delivers more product for lower cost	New process delivers little product for greater costs
24	Often build on brown fields site	Often built on greenfields site
25	Scale up of a successful process is often done quietly by firm	Loud promotion indicates risk, the term "fast track" indicates extreme risk
	Niche demand and uptake	
26	Small focus a "micro climate" not visible to larger predators	Widely visible demand, perhaps enthusiastically overestimated or overstated
27	Strong unmet demand for product and process visible to practitioners	Alternative supply exists, but biased perceptions leading to phantom opportunity
28	Existing processes inadequate for transforming resource	Existing processes transform the resource at lower cost than new
29	New type of cheap and abundant resource requires new process	Cheap and abundant resource remain largely untransformed
30	Unique transformation advantage relatively easy to establish	Unique transformation advantage more difficult to establish
31	Few players in early stages	Many players in a rush, for what they see as easy
32	Firms that have unique need and expertise to do it	Firms that see an abstract need and lack the skills to implement fully
33	Firms with similar unique needs adopt process world wide quickly …	Firms in similar business do not adopt new process …
	because the new process transforms the market and makes others obsolete	because it fails to perform well enough to be worthwhile

References

[1] Data from Australian Bureau of Agricultural and Resource Economics (ABARE), located in Canberra, is an Australian government economic research agency noted for its professionally independent research and analysis.

[2] Failure is usually first noted in the economic media, by experts like Trevor Sykes in Australian Financial Review, then conformed in later Company Annual Reports.

[3] Success can be found in the statistics of Company Annual Reports, that exceed market expectation, paid dividends, saw the share price rise; as well as in professional publications, such as papers presented at Australasian Institute of Mining and Metallurgy (AusIMM) conferences.

[4] As described in: Torries, Thomas. F., (1998) "Evaluating Mineral Projects: Applications and Misconceptions" Society for Mining Metallurgy and Exploration, Inc. and Runge, Ian. C., (1998) "Mining Economics and Strategy" Society for Mining Metallurgy and Exploration, Inc

[5] From Database built from Government statistics, Company Annual Reports, Trade literature, professional publication, and media articles. All data is from the public domain.

[6] Blum, M. L., & Naylor, J. C. (1968). "Industrial psychology; its theoretical and social foundation" .Harper & Row. "Industrial and operational psychology... simply the application or extension of psychological facts and principles to the problems concerning human beings operating within the context of business and industry"

[7] The work and methods of Ed Merrow and Independent Project Analysis is completely proprietary and based on data from operations not available to the public.

[8] Hume, David., (1739) "A Treatise of Human Nature". London: John Noon. p. 469.

[9] Trevor Sykes as Pierpont in Australian Financial Review of Friday, 14th June 2002 "Skardon River still in crocodile country."

[10] Cutler, Terry., (2008) "Venturous Australia" report on National Innovation System.

[11] Russel Mineral Equipment, Gekko Systems, and Xstrata Technologies being proud examples.

[12] Mudd, Gavin. M., "The Sustainability of Mining in Australia - Key Production Trends and Their Environmental Implications for the Future." Monash University and the Mineral Policy Institute. Revised April 2009.

[13] Malone, Ed., (2011) "The Cadia Valley Mines A mining Success Story." The Australasian Institute of Mining and Metallurgy.

[14] http://www.dfat.gov.au/geo/fs/aust.pdf Accessed 5th December 2013

[15] http://www.maelgwyn.com/birthplaceflotation.html#top

[16] http://www.austehc.unimelb.edu.au/guides/mine/historicalnote.htm

[17] http://ipaglobal.com/

[18] US Department of Energy, Energy Information Review 2006.

[19] http://www.nytimes.com/2008/03/03/business/worldbusiness/03cnd-oil.html?_r=1&hp

[20] RAND Corporation is an independent non profit organisation with 950 researchers and a budget of $ 230 million US in 2008. http://www.rand.org/about/glance.html

[21] http://www.ipainstitute.com/home/about/faculty/ed_merrow.aspx

[22] http://www.rand.org/pubs/authors/m/merrow_edward_w.html

[23] Merrow, Edward. W., (1978) "Constraints on the commercialization of oil shale." RAND Corp, for U.S. Dept of Energy.

[24] Merrow, Edward. W., (1979) "A review of cost estimation in new technologies" RAND Corp, for U.S. Dept of Energy.

[25] http://www.cos-trust.com/Theme/COS/files/COS_2008_eAnnnual/the_syncrude_project.html Accessed 3rd May 2009

[26] McNulty, T.P., (1998) "Innovative Technology: It's Development and Commercialisation" Chapter 1 in "Managing Innovation in the Mineral Industries" edited by Kuhn, M.C., Published by Society for Mining, Metallurgy and Exploration Inc.

[27]Presented in PowerPoint form at Plant Operator's Forum 2004: Things That Actually Work!

[28] Halbe,D. 2003. Business Aspects and Future Technical Outlook for Hydrometallurgy. Hydrometallurgy – Fifth International Conference in Honour of Professor Ian Ritchie – Volume 2: Electrometallurgy and Environmental Hydrometallurgy, Young, C., et al, editors. TMS, 2003, 1091-1104.

[29] Gold mines are somewhat more "standard" than copper operations, and thus the cost for a particular size plant is easy to calculate accurately, as is the effect on gold out put, and hence cash flow.

[30] As little as 1% over project life cycle

[31] Twigge-Molecey, C. (1999) "Key Issues in Successful Technology Transfer". Proceedings of the International Symposium on Issues in Technology Transfer, Quebec.

[32] Cawse, Bulong and Murrin Murrin.

[33] Nice, R.W., (2004) "The Western Australian Nickel Laterite Projects– What Have We Learned? Personal communication.

[34] Flyvbjerg, Bent, Mette K. Skamris Holm, and S0ren L. Buhl, 2005, How (In)accurate Are Demand Forecasts in Public Works Projects? The Case of Transportation, Journal of the American Planning Association, vol. 71, no. 2, Spring, pp 131-146

[35] HM Treasury, 2003, The Green Book: Appraisal and Evaluation in Central Government, Treasury Guidance (London: TSO)

[36] Flyvbjerg, Bent, (2005) Measuring Inaccuracy in Travel Demand Forecasting: Methodological Considerations Regarding Ramp Up and Sampling, Transportation Research A, vol. 39, no. 6, pp 522-530

[37] Flyvbjerg, Bent,. (2007) "Policy and Planning for Large-Infrastructure Projects: Problems, Causes, Cures." Environment and Planning B: Planning and Design, vol. 34, pp 578-597

[38] Hume, David. (1739) "A Treatise of Human Nature" Book III, part I, section I.

[39] Milton Friedman, Milton. (1953) "The Methodology of Positive Economics" University of Chicago Press (1953), 1970, pp. 3-43

[40] Einhorn, H.J., and Hogath, R.M., (1981) "Behavioural decision theory: Process of judgement and choice." Ann. Rev. Psychol. 32:53-88

[41] Holcombe, R. (1989), Economic Models and Methodology, New York: Greenwood Press

[42] Baumol, William & Blinder, Alan (1982), Economics: Principles and Policy (2nd ed.), New York: Harcourt Brace Jovanovich

[43] Varian, Hal, R. "How to build and economic model in your spare time" Uni of California, Berkley. Working paper revised 25th July 2009

[44] Quote from Albert Einstien

[45] Varian, Hal, R. (1992) "Microeconomic Analysis" 3rd edition. Norton & Co.

[46] Twitchett, D., Loewe, M., and Fairbank, J.K. (1986) "Cambridge History of China: The Ch'in and Han Empires 221 B.C.-A.D. 220". Cambridge University Press.

[47] Scheidel, Walter. Rome and China: comparative perspectives on ancient world empires. Oxford University Press (2009), p. 28.

[48] Anglo Saxon Chronicle. Available online at http://omacl.org/Anglo/

[49] Finance Minister to Louis XIV from 1665 to 1683.

[50] Ireland had been conquered by Oliver Cromwell 1649-1653 and he sought to pay for the war by selling the lands of the defeated rebels.

[51] A poll tax could be in the form of individual liability to work on state directed improvements, such a building a pyramid or a bridge, road or castle. When levied in precious metal coin it is often difficult to collect, and much hated. A consumption tax in imported luxuries, is paid by people who had cash, and could pay.

[52] William Petty was a gifted amateur, who sought knowledge for please and discovery.

[53] Halley, Edmond. (1693) "An Estimate of the Degrees of the Mortality of Mankind, drawn from curious Tables of the Births and Funerals at the City of Breslau; with an Attempt to ascertain the Price of Annuities upon Lives."

[54] Dunlop, Ian, A. (1992) "The Scottish Ministers' Widows' Fund 1743-1993". Hyperion Books, Edinburgh.

[55] http://www.scottishwidows.co.uk/

[56] Ferguson, Niall. (2008) "The ascent of money" Penguin Books. USA.

[57] http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/Publications_Archive/archive/hihinsurance Accessed 10th December 2013

[58] Westfield, Mark., (2003) "HIH : The Inside Story Of Australia's Biggest Corporate Collapse" John Wiley

[59] Commonwealth of Australia (2003) THE FAILURE OF HIH INSURANCE Volume I A corporate collapse and its lessons. The HIH Royal Commission. The Hon Justice Owen Commissioner

[60] Kahneman, D. and Tversky, A., (1979) "Prospect theory: An analysis of decisions under risk." Econometrica, 47, No 2 pp. 263-291

[61] Lovallo, D. & Kahneman, D. (2003) "Delusions of success: How optimism undermines executives' decisions", Harvard Business Review, July, pp. 56–63.

[62] Kahneman, Daniel., and Tversky, Amos., (1982) "Intuitive Predictions: Biases and Corrective Procedures" in "Judgement and Uncertainty: Heuristics and biases." Cambridge University Press 1982.

[63] Flyvbjerg, Bent,. (2008) "Curbing Optimism Bias and Strategic Misrepresentation in planning: Reference Class Forecasting in Practice." European Planning studies Vol. 16, No 1, January 2008

[64] Flyvbjerg, B., (2006) "From Nobel Prize to Project Management: Getting Risks Right." Project Management Journal, vol. 37, no. 3.

[65] Lovallo, Dan and Daniel Kahneman, 2003. "Delusions of Success: How Optimism Undermines Executives' Decisions," Harvard Business Review, July Issue, pp. 56- 63.

[66] Flyvbjerg, B., (1998) "Rationality and Power: Democracy in Practice" University of Chicago Press.

[67] Flyvbjerg, B., (2007) "Megaproject Policy and Planning: Problems, Causes, Cures" Thesis Aalborg University.

[68] Flyvbjerg, B., (2009) "Survival of the un-fittest : why the worst infrastructure gets built-and what we can do about it" Oxford University Press.

[69] Dawes, Robyn, M., "The Robust Beauty of Improper Linear Models in Decision Making" American Psychologist Vol. 34, No. 7, pp. 571-582 July 1979.

[70] Meehl, Paul, E., (1954) "Clinical vs. Statistical Prediction: A Theoretical Analysis and a Review of the Evidence ", University of Minnesota Press.

[71] Apgar, Virginia (1953). "A proposal for a new method of evaluation of the newborn infant". Current Researches in Anaesthesia and Analgesia. July-August 1953

[72] Kuhn, Martin. C., (ed) "Managing Innovation in the Mineral Industry" SME Society for Mining, Metallurgy and Exploration, Inc. (1998) Chapter 1 by Terry McNulty utilising Halbe's financial analysis.

[73] Kahneman, Daniel., (2011) "Thinking Fast and Slow" Farrar, Strauss and Giroux. New York.

[74] Prahalad, C.K. and Hamel, G. (1990) The core competence of the corporation, Harvard Business Review. pp. 79–91.

[75] 430-354 b.c. Greek historian and author.

[76] Xenophon (1914), Dakyns, Henry Graham, trans., Stawell, F. M., ed., Cyropaedia: The Education of Cyrus, London: Macmillan. Also available online as Project Gutenberg release # 2085 Book VIII, Ch 2, Stanza 5

[77] 384-322 b.c. Reputedly in lecture notes from his Lyceum in Athens between 335 and 323 B.C.

[78] Smith, Adam (1776). An Inquiry into the Nature and Causes of the Wealth of Nations. W. Strahan and T. Cadell, London

[79] http://en.wikiquote.org/wiki/Warren_Buffett

[80] Charles Darwin (1871). "The Descent of Man" (w). pp. Introduction, page 4.

[81] Russell, Bertrand (2009). The Basic Writings of Bertrand Russell, Volume 10. Taylor & Francis. p. 676.

[82] Kruger, J., & Dunning. D,. (1999). "Unskilled and Unaware of It: How Difficulties in Recognizing One's Own Incompetence Lead to Inflated Self-Assessments". Journal of Personality and Social Psychology

[83] Dunning, D., Johnson, K., Ehrlinger, J., and Kruger, J., (2003). "Why people fail to recognize their own incompetence". Current Directions in Psychological Science

[84] Toyota and Honda motor companies would be examples of growing core competency, acknowledged by market success, and competitor esteem.

[85] HBI Boodarie, Ravensthorpe, Yabulu, Beenup. Discussed in a visit made to BHP-B HQ in Melbourne.

[86] Prahalad, C.K. (1993), "The role of core competencies in the corporation", Research Technology Management, Vol. 36 No.6, pp.40-7.

[87] http://www.conocophillips.com.au/en/business/production/dlng/pages/index.aspx

[88] OECD (2005) Oslo Manual : Guidelines for Collecting and Interpreting Innovation Data, 3rd edition, OECD and European Commission, Paris.

[89] Schumpeter, Joseph., (1934) Translated into English as "The Theory of Economic Development: An inquiry into profits, capital, credit, interest and the business cycle." (1911) In German as "Theorie der wirtschaftlichen Entwicklung."

[90] Pol, E., & Carrol, P., (2006) "An Introduction to Economics with Emphasis on Innovation" Innovation Planet Publisher

[91] 2002 Frascati Manual THE MEASUREMENT OF SCIENTIFIC AND TECHNOLOGICAL ACTIVITIES OECD Publications.

[92] Baumol, W.J., (2002) “The free market innovation machine: Analysing the growth miracle of capitalism.” Princeton University Press

[93] Australian Bureau of Statistics (2006) “Innovation in Australian Business 2003” Cat No 8158.0

[94] Productivity Commission report (2007) Public support for Science and Innovation.

[95] Commonwealth of Australia (2009) “Innovation: Powering Ideas. An Innovation Agenda for the 21st Century.” Senator Kim Carr, Minister for Innovation, Industry, Science and Research.

[96] Kealey, T., (1997) “The economic laws of scientific research.” Palgrave Macmillan

[97] Davidson, S., (2006) “Back to basics: why government funding of science is a waste of our money.” Institute of Public Affairs.

[98] Rogers, Mark., (1998) “The definition and measurement of innovation” Melbourne Institute working paper No. 10/98

[99] Griliches, Z., (1990) “Patent statistics as economic indicators: A survey” Journal of Economic Literature 28

[100] Basberg, B., (1987) “Patents and the measurement of technological change: A survey of the literature.” Research Policy 16

[101] Van der Panne, G., van Bers, C., & Kleinknecht, A., (2003) “Success and Failure of Innovation: A literature review.” International Journal of Innovation Management. Vol. 7 No. 3 (Sept 2003) pp. 1-30

[102] Carr, A., (1996) “Managing the change process: A field book for change Agent Consultants .” Coopers & Lybrand, London.

[103] Bessant, J. (1993) "The lessons of failure: learning to manage new manufacturing technology." International Journal of Technology Management, 8(2), 197–215

[104] Wind, Y. & Mahajan, V. (1988) “New product development process. A perspective for re-examination.” Journal of Product Innovation Management, 5, 304–310

[105] Australian Productivity Commission. "Inquiry into Regulatory Burden in Australia’s upstream oil and gas sector." 2009 Tina Hunter

[106] https://cgc.gov.au/attachments/article/36/Mining%20revenue.do Accessed 11th December 2013

[107] BHP BILLITON OPERATIONAL REVIEW FOR THE QUARTER ENDED 30 SEPTEMBER 2013 Published 22nd October 2013

[108] Russell, Christopher,. "BHP "determined" to push ahead with Olympic Dam but only after new mining techniques are thought through." The Adelaide Advertiser 21st August 2013

[109] The Parliament of the Commonwealth of Australia, "Getting a better return" Inquiry into increasing the value added to Australian raw materials. Second report House of Representatives Standing Committee on Industry, Science and Resources September 2001 Canberra

[110] www.dsd.wa.gov.au/documents/000278.Cam.Kneen.doc Accessed 13th January 2014

[111] "Australia Leading the Light Metal Age" Light Metals Action Agenda, Strategic Leaders Group, Report to Government,. August 2001

[112] Curnow, David. (2003) The latest on the beleaguered Stanwell magnesium project, near Rockhampton. ABC Radio report http://www.abc.net.au/stateline/qld/content/2003/s999713.htm Accessed 14th January 2014

[113] Cauchi, Stephen,. (2003) "Magnesium smelter failure hits CSIRO revenue." The Age (Melbourne) Science reporter. 6th June 2003.

[114] Minerals Council of Australia, (1999) submission no. 13, to Inquiry into increasing the value added to Australian raw materials.

[115] Australian Productivity Commission, Review of the Regulatory Burden on the Upstream Petroleum (Oil and Gas) Sector: Draft Research Report (2008), XLVII.

[116] Gravelle, Hugh; Ray Rees (2004). Microeconomics. Essex, England: Prentice Hall, Financial Times. pp. 314–346.

[117] http://www.nobelprize.org/nobel_prizes/economic-sciences/laureates/2001/press.html Accessed 17th March 2014.

[118] Akerlof, G.A., (1970) “The market for lemons: Quality uncertainty and the market mechanism.” Quaterly Journal of Economics 84. 3

[119] Spence, A. M. (1973). "Job Market Signaling". Quarterly Journal of Economics (The MIT Press) 87 (3): 355–374

[120] Stiglitz, (1975) “The theory of screening, education and the distribution of income.” The American Economic Review Vol 65, No 3

[121] Kain, John, F., (1990) "Deception in Dallas: Strategic Misrepresentation in Rail Transit Promotion and Evaluation", Journal of the American Planning Association, 56:2, 184-196,

[122] Jones, L.R. and K.J. Euske, 1991, "Strategic Misrepresentation in Budgeting," Journal of Public Administration Research and Theory, vol. 1, no. 4, pp. 437- 460.

[123] Presently holds the chair as BT Professor of Major Programme Management at Oxford University's Saïd Business School. He was previously Professor of Planning at Aalborg University, Denmark and Chair of Infrastructure Policy and Planning at Delft University of Technology, The Netherlands.

[124] Flyvbjerg, Bent, Mette K. Skamris Holm, and Søren L. Buhl, "Underestimating Costs in Public Works Projects: Error or Lie?" Journal of the American Planning Association, vol. 68, no. 3, Summer 2002, pp. 279-295.

[125] NSW Premier Joe Cahill announced the approval of the Opera House in 1957, with a proposed cost of $ 7 million and completion date of 1963. He had been dead for 14 years when the building was completed in 1973 at a cost of $ 102 million.

[126] Estimates of traffic flow through both the Cross City Tunnel and Lane Cove Tunnel now seem to be examples of "strategic misrepresentation" at worst, or "optimism bias" at best, yet have left investors with losses around $ 1 billion.

[127] Flyvbjerg, Bent,. "Survival of the unfittest: why the worst infrastructure gets built—and what we can do about it." Oxford Review of Economic Policy, Volume 25, Number 3, 2009, pp.344–367

[128] Sykes, Trevor,. (1978) "The money miners: The Great Australian Mining Boom 1969-70" Wildcat Press
Sykes, Trevor,. (1988) "Two Centuries of Panic: A History of Corporate Collapses in Australia" Allen & Unwin
Sykes, Trevor,. (1997) "The bold riders: Behind Australia's Corporate Collapses" Allen & Unwin, 2nd edition.
Sykes, Trevor,. (2003) "The number$ game", Allen & Unwin, 2nd edition.

[129] Green-fields here means a site where there is no history on mining, and usually very little form many miles around. A brown-fields site, and Broken Hill and Mt Isa are two examples have a century of experience, and reasonably well developed infrastructure.

[130] Williams took no action against AFR for these words, and did not return the payment. This backs Pierpont's thesis that actions to enforce laws is not always strong.

[131] BHP Annual Report 1997 Page 66

[132] "BHP has a victory in its $2.2bn tax case" by Susannah Moran in "The Australian" of 18th March 2010.
[133] Mas-Colell, A.,Whinston, M., and Green, J., (1995), "Microeconomic Theory." Chapter 14, 'The Principal-Agent Problem', p. 477.

[134] Holmstrom, B. (1979) "'Moral hazard and observability.". Bell Journal of Economics, Vol 10. No 1 pp. 74-91.

[135] http://www.businessdictionary.com/definition/moral-hazard.html

[136] Arrow, K.J., (1963) "Uncertainty and the welfare economics of medical care" American Economic Review, 53 (5)

[137] Hulsmann, J.G., (2006) "The political economy of moral hazard" Politicka Ekonomie, 1

[138] Kotowitz, Y,. (1987) "Moral Hazard" pp. 549-551 in "The New Palgrave" Macmillan London

[139] Balakrishnan. S,. & Koza, M. P., (1993) "Information Asymmetry, adverse selection and Joint Ventures." Journal of Economic Behaviour and Organisation. 20

[140] Akerlof, George.A., and Romer, Paul, M., (1993) "Looting: The Economic Underworld of Bankruptcy for Profit." Brookings Papers on Economic Activity, 2:1993

[141] http://www.asic.gov.au/asic/asic.nsf/byheadline/05-91+Rodney+Adler+sentenced+to+four-and-a-half+years%27+jail?openDocument Accessed 31st December 2013

[142] BHP-Billiton 2012 Annual Report.

[143] http://www.bloomberg.com/apps/news?pid=newsarchive&sid=amwoD_HGgwYU&refer=uk Accessed 27th November 2012

[144] http://www.onyxprojects.com.au/2013/02/hismelt-kwinana-plant-deconstruction-demolition-removal-and-lease-clean-up/ Accessed 12th March 2013.

[145] http://www.isasmelt.com/EN/Installations/Pages/Installations.aspx Accessed 12th March 2013

[146] http://www.xstratatech.com/EN/Pages/Home.aspx Accessed 12th March 2013

[147] Graham, Loren (1996). The Ghost of The Executed Engineer: Technology and the Fall of the Soviet Union

Harvard University Press.

[148] Blainey, Geoffrey,. (1960) “Mines in the spinifex” Angus and Robertson Publishers. Pp. 112-113

[149] Malone, Ed., (2011) “The Cadia Valley Mines” A mining success story. Published by AusIMM. p.130

[150] http://minerals.usgs.gov/minerals/pubs/commodity/bauxite/bauximcs07.pdf Accessed 18th February 2013

[151] http://minerals.usgs.gov/minerals/pubs/commodity/bauxite/mcs-2013-bauxi.pdf Accessed 18th February 2013

[152] http://minerals.usgs.gov/minerals/pubs/commodity/nickel/mcs-2013-nicke.pdf Accessed 18th February 2013

[153] https://www.ga.gov.au/image_cache/GA20563.pdf Accessed 18th February 2013

[154] http://minerals.usgs.gov/minerals/pubs/commodity/iron_ore/mcs-2013-feore.pdf Accessed 18th February 2013

[155] http://www.dfat.gov.au/geo/fs/aust.pdf Accessed 18th February 2013

[156] "he commanded that his chair should be set on the shore, when the tide began to rise. And then he spoke to the rising sea saying “You are part of my dominion, and the ground that I am seated upon is mine, nor has anyone disobeyed my orders with impunity. Therefore, I order you not to rise onto my land, nor to wet the clothes or body of your Lord”. But the sea carried on rising as usual without any reverence for his person, and soaked his feet and legs." from Henry of Huntingdon's twelfth-century Chronicle of the history of England.

http://faculty.history.wisc.edu/sommerville/123/Canute%20Waves.htm
Accessed 31st October 2013

[157] Jones, L.R., and Euske, K.J., (1991) “Strategic misrepresentation in budgeting” Journal of Public Administration Research and Theory 4: 437-460

[158] Bator, Fancis, M., “The anatomy of market failure” The Quarterly Journal of Economics, Volume 72, Issue 3, August 1958 p.p. 351-379.

[159] McLean, B., Elkind, P., (2003) “Smartest Guys in the Room: The Amazing Rise and Scandalous Fall of Enron” Portfolio.

[160] http://www.abc.net.au/pm/content/2009/s2672299.htm Accessed 12/09/11

[161] Kearney, Simon. “$2bn black housing mystery” The Australian 2nd September 2006

[162] http://www.abares.gov.au/publications

[163] http://www.nla.gov.au/

[164] Liker, J., (2003), The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer, First edition, McGraw-Hill.

[165] The advice came whilst we both waited for a “red eye flight” from Perth to Melbourne, well after midnight.

[166] http://www.connect4.com.au.ezproxy1.library.usyd.edu.au/subscribers/ Accessed 12/9/11

[167] http://www.usgs.gov/ Accessed 13/9/11

[168] http://www.balticexchange.com/ accessed 19/09/2011

[169] Montgomery, Carl T.; Smith, Michael B. (2010-12-105). "Hydraulic fracturing. History of an enduring technology" (PDF). JPT Online (Society of Petroleum Engineers): 26–41. Accessed 4th December 2013

[170] http://www.nwsalng.com.au/news/2008/NORTH-WEST-SHELF-VENTURE-PRODUCES-FIRST-LNG-FROM-TRAIN-5-PRODUCTION-FACILITY Accessed 5/03/11.

[171] Woodside "PhaseVLNGUpdate2.pdf downloaded 5/03/11.
[172] http://www.woodside.com.au/Our-Business/Pluto/Pages/default.aspx Accessed 4th March 2013

[173] Australian Industry Participation "Darwin_LNG-Casestudy.pdf" under The Supplier Access to Major Projects (SAMP) program.

[174] Slide presentation "The Darwin LNG Plant – Pioneering Aeroderivative Turbines for LNG Refrigeration Service" GE Oil & Gas Conference, Florence, Italy January 29-30, 2007

[175] Andress, D.L., (1996) "The Phillips Optimised Cascade Process A quarter century of improvements."
[176] BHP-Billiton Presentation "Cannington Overview" 3rd June 2005

[177] BHP Billiton. OPERATIONAL REVIEW FOR THE QUARTER ENDED 30 SEPTEMBER 2013 Published 22nd October 2013.

[178] http://www.mining-technology.com/projects/cannington/ Accessed 7th January 2014

[179]

http://www.powerhousemuseum.com/australia_innovates/?Section_id=1060&article_id=10076&behaviour=view_article Accessed 7th February 2013

[180] http://www.csiropedia.csiro.au/display/CSIROpedia/SiroSmelt Accessed 14th March 2013

[181] http://www.csiropedia.csiro.au/display/CSIROpedia/SiroSmelt Accessed 21st January 2014

[182] http://www.isasmelt.com/EN/Installations/Pages/Installations.aspx Accessed 21st January 2014

[183] Annual Report for Australian Magnesium Corporation Limited (ANM on stock exchange) for 2002. Page 8

[184] http://www.theage.com.au/articles/2003/04/17/1050172707696.html Accessed 7th October 2013

[185] Auditor-General of Queensland (2004) REPORT NO. 8 2003-04 "Results of Audits Performed for 2002-03 as at 31 March 2004" Prepared Under Part 6 Division 3 of the Financial Administration and Audit Act 1977

[186] Cauchi, Stephen,. (2003) "Magnesium smelter failure hits CSIRO revenue" The Age 6th June 2003

[187] CSIRO Media Release (2000) "AMC and CSIRO in R & D Alliance" Available in 2007 at http://www.csiro.au/files/mediarelease/mr2000/PrAMCCSIRO.htm Now removed.

[188] "Flash burn" by Kate Askew July 5 2003 "Magnesium smelter failure hits CSIRO revenue" The Age 6th June 2003.

http://www.smh.com.au/articles/2003/07/04/1057179165561.html Accessed 14th March 2013

[189] Australian Magnesium Corporation Limited (2000) "The AM Process From Magnesite to Magnesium"

[190] http://minerals.usgs.gov/minerals/pubs/commodity/magnesium/mcs-2013-mgmet.pdf Accessed 21st January 2014

[191] AUSTRALIAN MAGNESIUM CORPORATION LIMITED 2002 Annual Report

[192] "Flash burn" by Kate Askew July 5 2003
http://www.smh.com.au/articles/2003/07/04/1057179165561.html Accessed 14th March 2013

[193] http://www.magnesium-elektron.com/markets-applications.asp?ID=7 Accessed 21st January 2014

[194] See European Patent Office EP 0 725 761 B1, which also names the inventors.

[195] CSIRO Process Magazine - Issue 2, 1999

[196] http://minerals.usgs.gov/minerals/pubs/commodity/magnesium/mgmetmcs04.pdf Accesed 8th January 2014

[197] http://www.chemlink.com.au/magnesium_oz.htm Accessed 8th January 2014

[198] https://www.asic.gov.au/asic/asic.nsf/byheadline/03-195+Australian+Magnesium+Corporation?openDocument Accessed 29th July 2013

[199] Australian Financial Review, Tuesday, December 23rd, 2003; Pierpont's dubious distinction awards for 2003.

[200] CSIRO Process Magazine - Issue 2, 1999

[201] Australian Magnesium Corporation Limited 2003 Annual Report 2003, Page 5.

[202] AUSTRALIAN MAGNESIUM CORPORATION LIMITED 2004 Annual Report

[203] AUSTRALIAN MAGNESIUM CORPORATION LIMITED 2004 Annual Report

[204] Australian Magnesium Corporation Limited 2003 Annual Report 2003, Page 5.

[205] http://online.wsj.com/news/articles/SB10001424052702304149404579323182709220994?mg=reno64-wsj&url=http%3A%2F%2Fonline.wsj.com%2Farticle%2FSB10001424052702304149404579323182709220994.html Accessed 20th January 2014

[206] http://www.rba.gov.au/publications/smp/boxes/2012/aug/b.pdf Accessed 20th January 2014

[207] Much of the material in this section is an edited reproduction of text shown at the History section of the Rio Tinto HISmelt website: http://www.hismelt.com/EN/HT_PageView.aspx?pageID=3 accessed 22nd June 2011.

[208] http://www.asiaminer.com/magazine/current-news/news-archive/41/338-australia-ceremony-marks-worlds-first-commercial-hismeltr-plant.html Accessed 20th January 2014

[209] http://www.min-eng.com/ops/oz/1.html Accessed 20th January 2014

[210] http://www.hismelt.com.au/EN/HT_PageView.aspx?pageID=6 accessed 7/6/11

[211] Peter Klinger, “Rio terminates Kwinana HIsmelt plant” The Western Australian, 19th January 2011.

[212] http://www.miningaustralia.com.au/Article/HIsmelt-pushing-boudaries/73544.aspx accessed 30th March 2009.

[213] http://www.thewest.com.au/default.aspx?MenuID=32&ContentID=132450 Accessed 30th March 2009.

[214] World Steel Association (2013) “World steel in figures 2012”

[215] Dry,,R.J., Batterham,, R.J., Bates, C.P., and D P Price, D.P. (2002) Direct Smelting: Why Have So Few Made It?

[216] Koenig, R., Baker, G., and Goebel, B. “The Stanwell Magnesium Project – Providing New Environmental Standards for Magnesium Production.” Green Processing Conference, held at Cairns, Queensland, 29-31st May 2002.

[217] Magontec Annual Report 2012.

[218] U.S. Patent 6475264 B1 "Direct smelting process" giving a clear description of the HIsmelt process.

[219] Travel report by Mark Young of Sandvik Steel, dated 18th May 1999. Sandvik were supplying special corrosion resistant steels and alloys for the distillation and crystallisation processes. This was not original equipment, but repair in progress materials specification.

[220] Malone, Ed., (2011) "The Cadia Valley Mines" A mining success story. Published by AusIMM. p.130

[221] http://minerals.usgs.gov/minerals/pubs/commodity/bauxite/bauximcs07.pdf Accessed 18th February 2013

[222] http://minerals.usgs.gov/minerals/pubs/commodity/bauxite/mcs-2013-bauxi.pdf Accessed 18th February 2013

[223] http://minerals.usgs.gov/minerals/pubs/commodity/nickel/mcs-2013-nicke.pdf Accessed 18th February 2013

[224] https://www.ga.gov.au/image_cache/GA20563.pdf Accessed 18th February 2013

[225] http://minerals.usgs.gov/minerals/pubs/commodity/iron_ore/mcs-2013-feore.pdf Accessed 18th February 2013

[226] http://www.dfat.gov.au/geo/fs/aust.pdf Accessed 18th February 2013

[227] http://www.smh.com.au/news/business/bhp-about-to-quit-briquette-plant/2005/08/07/1123353206811.html Accessed 25th February 2013

[228] The BHP Hot Briquetted Iron Plant. Public Environmental Report 2001. BHP Presentation.

[229] Boodarie Iron Hot Briquette (HBI) Equipment Dismantling and Sale Information Package.
42 slide Powerpoint presentation. With enquiries directed to Machinery Brokers Australia. August 2006. Taken from BHP-Billiton Website 25th October 2007

[230] https://www.youtube.com/watch?v=0WYyHRa1ciM Accessed 14th January 2014

[231] BHP Annual Report 2011 Page 30.

[232] http://www.theaustralian.com.au/business/mining-energy/iron-ore-spot-prices-to-hit-record-in-2011/story-e6frg9df-1225982269328 Accessed 14th January 2014

[233] Presentation by Paul McTaggart, Global head of Metals and Mining for Credit Suisse, to AusIMM 15/06/2011.

[234] BHP Annual Report 1997 Page 66

[235] Brochure issued by Western Australian Department of Industry and Resources; Investment Attraction Division titled "Opportunities in Western Australia, Direct Reduced Iron and Pig Iron from World-Class reserves of Iron ore" Accessed from website on 3rd December 2006.

[236] "BHP has a victory in its $2.2bn tax case" by Susannah Moran in "The Australian" of 18th March 2010.

[237] http://www.mediastatements.wa.gov.au/Lists/Statements/DispForm.aspx?ID=112635 Accessed 12th December 2007

[238] Midrex 2012 Direct Reduction Statistics available from http://www.midrex.com/handler.cfm/cat_id/153/section/company Accessed 14th January 2014.

[239] AusIMM (2009) "The new research and development tax incentive. Consultation paper response."

[240] Schlesinger, L. and Heskett, J. (1991) Breaking the cycle of failure in services, Sloan Management Review, vol. 31, spring 1991

241 http://www.ga.gov.au/minerals/mineral-resources/uranium.html Accessed 22nd January 2014

242 http://www.ga.gov.au/minerals/mineral-resources/copper.html accessed 22nd January 2014

243 BHP-Billiton, (2009) "Olympic Dam Expansion EIS Mining and Processing"

244 The commodity prices quoted are from ABARE Commodity prices.

245 "A bridge too far" refers to the British military operation in World War Two called "Operation Market Garden". Between 17–25 September 1944 the largest airborne operation of the war attempted to capture a series of bridges in the Netherlands and Germany and end the Second World War by Christmas 1944. The failure to capture the last bridge at Arnhem rendered the capture of the rest of limited military use. The war continued for another eight months, and German forces held most of Holland till 5th May 1945. A 1974 book by Cornelius Ryan about these events was titled "A bridge too far". The title came from a remark attributed to British Lieutenant-General Frederick Browning, deputy commander of the First Allied Airborne Army, who told Field Marshal Bernard Montgomery, the operation's architect, before the operation: "I think we may be going a bridge too far." Lack of understanding as to the strength and nature of German forces in the area, and unexpected weather conditions are blamed for the failure.

246 Upton, David,. (2010) "The Olympic Dam Story" Upton Financial PR, Armidale Victoria.

247 http://www.domgas.com.au/reports_alliance.html accessed 21st August 2014

248 ABARE commodity spread sheet. Appendix ???

249 Turton, Hal., (2002) The Aluminium Smelting Industry. Structure, market power, subsidies and greenhouse gas emissions. Published by The Australia Institute.

250 http://www.smh.com.au/environment/alcoa-deal-locks-in-jobs--and-emissions-20100301-pdl8.html#ixzz2sywrdPc5 accessed 11th February 2014.

251 Lethlean, W.R., and Banovich, P.J., (Metallurgist and Project Manager) "Sunrise Dam Gold Mine-Concept to Production." Published in "Mineral Processing Plant Design, Practice and Control Proceedings, Volume 2. Published by Society for Mining, Metallurgy and Exploration, Inc. 2002.

252 AAA Acacia Resources Annual Report 1998.

253 AAA Acacia Resource Annual Report 1997.

254 http://minerals.usgs.gov/minerals/pubs/commodity/nickel/mcs-2012-nicke.pdf Accessed 8th January 2014

255 Sykes, Trevor,. (Pierpont) Australian Financial review of 28th July 2000 "Second -worst takeover of "98"

256 Sykes, Trevor,. (Pierpont) Australian Financial review of 6th June 2003 "For sale: plagued nickel project"

257 USGS figures from http://minerals.usgs.gov/minerals/pubs/commodity/nickel/nickemcs05.pdf accessed 19th March 2013.

258 Hanson, R.J., CEO of Bendigo Mining Limited, in Paper "Bendigo – Stepping through the issues" presented at AusIMM Project Evaluation Conference Melbourne, Vic, 21 - 22 April 2009

259 Slide 8 of Presentation by Bendigo Mining N.L of 9th of June 2004.

260 January 2007 Gold price by ABARE tables.

261 Managing Director and CE)'s Address and presentation to 2008 AGM of Bendigo Gold.

262 Bendigo Mining 2010 Annual Report.

[263] Unity Mining Presentation of 29th March 2011

[264] Krugman, Paul (2009). "The Return of Depression Economics and the Crisis of 2008". W.W. Norton Company Limited

[265] Lynch, Alban., (2011) "The legend of P9 The first 20 years" Accessed online at http://www.jkmrc.uq.edu.au/Portals/0/The%20Legend%20of%20P9.pdf 17th February 2014.

[266] Chen, J.J. and Varley, G., (2002) "Extraction of 5 Orebody crown pillar at the Isa Lead Mine, Mount Isa Mines Limited, Mount Isa, Queensland, Australia," in: Underground Operators' Conference, Townsville, Queensland, 29–31 July 2002 (The Australasian Institute of Mining and Metallurgy: Melbourne.)