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NEW AND ADVANCED MATERIALS

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INDUSTRY COMMISSION

8 March 1995

The Honourable George Gear MP
Assistant Treasurer
Parliament House
CANBERRA ACT 2600

Dear Minister

In accordance with Section 7 of the *Industry Commission ACT 1989*, we have pleasure in submitting to you the report on New and Advanced Materials in Australia.

Yours sincerely

Tor Hundloe
Presiding Commissioner

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Associate Commissioner

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ABBREVIATIONS

AAAI	Australian Association of Aerospsace Industries
AATSE	Australian Academy of Technology Science and Engineering
ABARE	Australian Bureau of Agricultural and Research Economics
ABS	Acronylitrile-butadiene-styrene
ABS	Australian Bureau of Statistics
AEC	Advanced engineering ceramic
AFM	Australian Fused Materials Pty Ltd
AGPS	Australian Government Publishing Service
AGSEI	Australian Graduate School of Engineering Innovation
AICS	Australian Inventory of Chemical Substances
AIST	Agency of Industrial Science and Technology
AIPO	Australian Industrial Property Organisation
AME	Advanced Materials Enterprise
AMIRA	Australian Mineral Industries Research Association
AMPP	Advanced Materials and Processing Program (US)
AMRDP	Australian Magnesium Research Development Project
AMRL	Aeronautical and Maritime Research Laboratories, DSTO
AMT	Australian Magnet Technology Pty Ltd
AMTP	Advanced Manufacturing Technology Program
ANSTO	Australian Nuclear Science and Technology Organisation
ANU	Australian National University
ANZSIC	Australian and New Zealand Standard Industry Classifications
APC	Advanced polymer composite
ARPA	Advanced Research Projects Agency (US)
ASTA	AeroSpace Technologies of Australia

ASTEC	Australian Science and Technology Council
ASX	Australian Stock Exchange
ATG	Australian Technology Group
BIE	Bureau of Industry Economics
BRITE	Basic Research in Industrial Technologies for Europe
BTS	Brenco Thermal Spray
CAD/CAM	Computer Aided Design/Manufacture
CAFE	Corporate Average Fuel Efficiency
CAST	CRC for Alloy and Solidification Technology
CC	Ceramic Coating
CFCL	Ceramic Fuel Cells Limited
CIS	Commonwealth of Independant States
COF	Ceramaic Oxide Fabricators
CRC	Co-operative Research Centre
CRCERT	CRC for Eye Research and Technology
CSIRO	Commonwealth Scientific Industrial Research Organisation
CVD	Chemical Vapour Deposition
DAP	Division of Applied Physics, CSIRO
DBIRD	Queensland Department of Business, Industry and Regional Development
DCP	Division of Chemicals and Polymers, CSIRO
DFS	Division of Food Science, CSIRO
DFP	Division of Forest Products, CSIRO
DH	Division of Horticulture, CSIRO
DIST	Department of Industry, Science and Technology
DITAC	Department of Industry, Technology and Commerce
DITARD	Department of Industry, Technology and Regional Development
DMPE	Division of Mineral and Process Engineering–Mineral Products, CSIRO

DMST	Division of Materials Science and Technology, CSIRO
DMT	Division of Manufacturing Technology, CSIRO
DOD	Department of Defense (US)
DOE	Department of Energy (US)
DRP	Division of Radiophysics, CSIRO
DSTO	Defence Science and Technology Organisation
EFIC	Export Finance Insurance Corporation
EMDG	Export Market Development Grants
ERDC	Energy Research and Development Corporation
EURAM	European Advanced Materials Program
FAIR	French-Australian Industrial Research Program
FDA	Food and Drug Authority
GECMS	GEC Marconi Systems
GIRD	Grants for Industry Research and Development
HTS	High-temperature superconductors
IC	Industry Commission
IC	Integrated Circuit
ICIAC	ICI Advanced Ceramics
ILP	Improved Low Pressure
IMMA	Institute of Metals and Materials Australasia Ltd
IR&D Board	Industry Research and Development Board
ISO	Industry Support Office
JECC	Japan Electronic Computer Company
LTS	Low Temperature Superconductors
MESC	Ministry of Education, Science and Culture
MITI	Ministry of International Trade and Industry (Japan)
MMC	Metal-matrix composite
MSDS	Material Safety Data Sheets
MTIA	Metal Trades Industry Association

NAIM	New and Advanced Industrial Materials
NASA	National Aeronautics & Space Administration (US)
NICNAS	National Industrial Chemical Notification and Assessment Scheme
NIES	National Industry Extension Service
NQEA	North Queensland Engineering Agencies Australia Pty Ltd
NRC	National Research Council
NSF	National Science Foundation
OECD	Organisation for Economic Co-operation and Development
OTA	Office of Technology Assessment (US)
PA	Polyacetal
PACIA	Plastics and Chemicals Industries Association Inc
PBT	Polybutylene terephalate
PC	Polycarbonate
PDF	Pooled Development Fund
PEEK	Polyetherethereketone
PET	Polyethylene terephalate
PFA	Perfluroalkoxy
PIA	Plastics Institute of Australia
PMC	Polymer-matrix composite
PMMA	Polymethylmethacrylate
PPE/PPO	Polyphenylene ether/oxide
PPS	Fluropolyphenylene sulphide
PVD	Physical vapour deposition
PVDF	Polyvinylidene fluoride
PVF	Polyvinyl fluoride
QMC	Queensland Metals Corporation
R&D	Research and development
RAC	Rojan Advanced Ceramics

REA	Rare Earths Australia
RMIT	Royal Melbourne Institute of Technology
SBIR	Small Business Innovative Research Program
SECV	State Electricity Commission of Victoria
SGP	Sol-gel processing
SMEs	Small-to medium-sized enterprises
SSM	Strategic Supply Management
ST	Surface Technologies
STA	Silicon Technologies of Australia
TAFE	College of Technical and Further Education
TCE	Taylor Ceramic Engineering
TGA	Therapeutic Goods Authority
UST	United Surface Technologies
VDC	Venture and development capital
WMC	Western Mining Corporation
WSA	Worksafe Australia

GLOSSARY

Advanced manufacturing technology	Computer controlled technologies for design, production, testing or handling of products (machine tools, robots etc) as well as advanced materials and modern manufacturing management techniques.
Advanced engineering Ceramics	Ceramics that possess superior properties to traditional ceramics – they are stronger and resist corrosion and high temperatures.
Advanced structural ceramics	Light weight ceramics, capable of withstanding intense wear and heat.
Alloys	Combinations or mixtures of chemical elements of which one is a metal. Formulated to provide particular properties or to optimise a combination of properties.
Aramid	Aramid is a generic term for fibres of the aromatic polyamide type. From this type of polymer, fibres with exceptional heat and flame resistance can be produced.
Austenitic steels	Austenitic steels are the most widely used group of stainless steels. They are non-magnetic and in addition to chromium (about 18 per cent) they contain nickel which increases their corrosion resistance.
Biocompatible	Biologically compatible. A material is biocompatible if it can coexist in contact with bodily tissues for an extended period of time.
Biomaterials	Materials used in medical devices intended to interact with biological systems.
Catalytic converters	Catalytic converters alter hydrocarbons, carbon monoxide and nitrous oxides in engine exhausts to water, carbon dioxide and nitrogen. They are composed of aluminium and small amounts of precious metals and are activated by cerium.

Ceramic	Most ceramic materials are compounds of metal atoms bonded to a non-metal, usually oxygen. The ceramic bonding mechanism produces materials that have high strengths, however, ceramic materials – which include brick, glass, china, porcelain, refractories, and abrasives – tend to be brittle, with low electrical and thermal conductivity. New processing techniques have produced tough, energy absorbing ceramics with great high-temperature resistance.
Composites	Produced when two materials are combined into a new material with properties that cannot be attained in the originals. They offer unusual combinations of stiffness, strength, weight, high-temperature performance, corrosion resistance, hardness, or conductivity. They can be combinations of metal-metal, metal-ceramic, metal-polymer, ceramic-polymer ceramic-ceramic, or polymer-polymer. Concrete, plywood, and fibreglass are typical elementary examples of composites.
Concurrent engineering	The development of a new and advanced material, and improved processing technologies, carried out in unison.
Die casting	Casting of metals or plastics into permanent moulds, made of suitably resistant non-deforming metal.
Ductility	The property of a metal which enables it to be given a considerable amount of mechanical deformation (especially stretching) without cracking.
Elastomer	(Rubber) Any number of natural or synthetic high polymers having unique properties of deformation and elastic recovery.
Electrofused	Materials fused by an electric arc.
Electrolysis	Chemical decomposition by electrical action.
Feedstock	Raw material inputs into a production process.
Ferrite	Iron-bearing compounds.

Gross value added coefficient	The proportion by which the value of an unprocessed product is increased by processing to the stage indicated.
Intermetallics	Compounds in which two or more metals are held together by metallic bonds. These compounds occur in some alloys making them more resistant to deformation. Intermetallic compounds unlike most metals and alloys remain strong at high temperatures but at normal temperatures are almost always very brittle.
Mischmetal	An alloy of cerium with small amounts of other rare earth metals.
Monolithic	The term applied to a structure made of a continuous mass of material.
Particulates	Matter in the form of separate particles.
Piezoelectric materials	Materials in which the application of a mechanical force generates an electric charge, or the application of an electric field creates a change in dimension.
Prepreg	A prepreg is the starting material for many APCs. Prepregs are fibres or cloth which have been impregnated with partially cured resin, prior to moulding.
Rare earths	Group of 17 chemical elements - not rare at all; yttrium, for example is thought to be more abundant than lead. These elements were mislabled because they were first found in truly rare minerals.
Sandcasting	Formation of shapes by pouring molten metal into a shaped cavity in a moulding flask.

Semiconductors	Used to make solid-state electronic components, semiconductors are substances whose ability to conduct electricity falls somewhere between electrical conductors, like copper and nonconductors, such as glass. The conductivity of a device made from semiconductors can be controlled, and they are therefore used in transistors, diodes, and integrated circuits.
Sintering	Metal or ceramic powders collected into a mass at temperatures below the melting point. Occurs in both powder metallurgy and ceramic firing. The result is a decrease in the surface area which increases strength, conductivity and density.
Substrate	The layer of material underlying a coating.
Superconductor	Metals, alloys and compounds which have zero electrical resistivity.
Superplasticity	The ability of an alloy to be stretched by several hundred per cent before failing..
Synroc	An Australian developed new material – a synthetic ceramic used for the long term storage of high level liquid radioactive waste.
Thixomoulding	A casting process using materials that are in a thixotropic state. This means, when the materials are in motion they flow easily, and when the materials rest they behave like a solid.
Transuranic	Elements above uranium in the periodic table.

TERMS OF REFERENCE

I, GEORGE GEAR, Assistant Treasurer, under part 2 of the Industry Commission Act 1989:

1. refer, as an Industry Development Reference, for inquiry and report within twelve months of receiving this reference, the research, development, production and processing by Australian firms and organisations of new and advanced industrial materials based on metals, ceramics, polymers and composites of those materials;

2. specify that in making its recommendations the Commission aim to improve the overall economic performance of the Australian economy;

3. request that the Commission report on:

   (a) emerging local and global trends in:

      (i) the development of industrial materials;

      (ii) processing technologies, including those that impact on the application of new materials and new industrial applications for existing materials; and

      (iii) markets for new industrial materials;

      (iv) the transfer of technology between different business sectors;

   (b) the international marketing environment, including barriers to Australian exports;

   (c) the current structure and competitiveness of the sector, including an identification of strengths and weaknesses, drawing international comparisons where appropriate;

   (d) the potential for further development and greater use of new and advanced materials including, in particular, the scope for increasing output of high value added products, and exports;

   (e) any measures which could be undertaken to remove impediments or otherwise contribute to the development and processing of new industrial materials, in ways that are consistent with the principles of efficient resource use in the economy;

   (f) the identification of groups benefiting from and disadvantaged by 3(e) above, and implementation strategies for any suggested measures;

   (g) the effects on industry, and the economy in general, of any measures recommended by the Commission; and

   (h) the research base for the industry, including the quantitative balance between the private and public sectors, sourcing of research overseas, and the relevance and capacity of the public sector research base;

4. request that the Commission quantify the extent of any assistance currently provided to relevant industries, identify if it is offered in a discriminatory manner and report on ways in which:

   (a) that assistance could be better used to promote the long term development of industry and the economy; and

   (b) the costs of adjusting to lower levels of assistance can be minimised;

5. request that, where appropriate and without disclosing material provided in confidence, the Commission report on examples of past successes and failures in relevant industry sectors, both in Australia and elsewhere, by way of case studies or other means; and

6. specify that the Commission have regard to the established economic, social and environmental objectives of governments.

George Gear

12 April 1994

OVERVIEW

This inquiry concerns the scope for greater production and use of new and advanced materials based on metals, ceramics, polymers and composites of these materials. A core issue is whether Australian industry is exploiting the growth opportunities that the materials provide to increase the output of high value-added products and exports — both by producing new and advanced materials from raw materials, and by incorporating them into products.

The development of materials, and products incorporating them, is a dynamic process — determined by technological breakthroughs and market needs. What is new and advanced today will not necessarily be new or advanced tomorrow.

Although Australia has had some success in specific areas of new material development, it is as a general rule unlikely to be a significant *producer* of new and advanced materials. The greatest potential gain to the economy lies in making the best *use* of materials.

Demand for these materials is a *derived* demand. The demand for new and advanced materials is derived from their use in, for example, components of motor vehicles, sports equipment, life-saving health devices, and machine tools that increase the productivity of Australian industry.

The proper selection and use of both existing and new materials is a critical component of the drive for international competitiveness in Australian manufacturing. A *competitive*, open Australian economy — with unimpeded flows of new materials and technological information — is a necessary, but not sufficient, condition for Australia to make the best choice when using new and advanced materials.

Australian governments are unlikely to be able to *directly* influence the extent of *production* of new and advanced materials in Australia.

However, governments can assist the utilisation of these materials by assisting to improve the awareness of the materials and their properties, and by facilitating changes in the education system and research infrastructure relating to materials.

What are new and advanced materials?

Perhaps a century ago, the range of readily available materials did not extend much beyond wood, stone, a small range of metals and alloys, and fibres. Today a much wider range of materials is to be found in most manufactured products. Materials choice is no longer a routine selection from a limited range of materials but an important business decision for manufacturers. The ubiquitous nature of just one group of materials, metals, is described in Box 1.

Box 1: Ubiquitous materials

"When we awake, we press an electric switch and current flows along a copper wire to light a bulb with a tungsten filament. If the weather is cold, an electric fire with a nickel–chromium alloy element provides heat. We wash in water that has come through copper pipes and runs out through a brass tap, plated with nickel and chromium,... we eat breakfast...[with] stainless steel or silver cutlery... in the microwave oven, the radio and the electric cooker, there are small but powerful magnets containing rare earth metals such as samarium and neodymium.

We drive to work in an automobile, which is about 80 per cent metal — mainly steel and aluminium, or we catch a train or bus, paying the fare with coins made of a copper-zinc-nickel alloy. This is only the beginning of the day during which hundreds of metal objects may be used, whether we work in a hospital, drive a tractor, operate a computer-controlled milling machine or observe the universe through a telescope."

Source: Street and Alexander, 1994.

There is no widely accepted way of defining what new materials are because of the continuum between new and traditional materials and because materials are constantly undergoing development. For practical purposes materials can be defined as *new* if they are not yet used widely in industry, and *advanced* when their properties are superior to those which are being replaced.

For many materials these characteristics (being not widely used and having superior properties) are likely to be transitory. That is, sometime in the future they might become widely used and be superseded by others with even better properties. When that stage arises, assuming it does, the materials in question are neither new nor advanced.

The importance of these characteristics cannot be over-emphasised because they have a fundamental influence on the economics of production and use. New materials will not be mass produced and benefit from the full extent of scale economies; advanced materials will be subject to all the uncertainties of scientific research and introduction to the market place.

Some of the materials considered to be new and advanced are listed in Table 1. Their principal uses are also shown in the table.

Table 1: New and advanced materials and their uses

Material	*Principal uses*
NEW CERAMICS:	
Engineering ceramics: – Partially stabilised zirconia (PSZ) – Alumina ceramics – Non-oxide ceramics – Advanced refractories	Internal combustion engines, gas turbines, cutting and grinding tools, coatings, wear applications, nozzles and combustion monitoring.
Electro ceramics: – Superconductors – Insulators – Piezoelectric ceramics – Solid electrolytes	Transducers, capacitors, integrated circuit packages, condensers, piezoelectric devices, memory elements, electricity generation and transmission.
Bioceramics: – Silicon nitride – Alumina	Artificial teeth, limbs, heart valves, tendons and bone replacement.
ADVANCED POLYMERS:	
– Engineering polymers – High performance polymers	Pipes, panels, process plants, automotive parts, electronic components, marine equipment and aerospace componentry.
METALS AND ALLOYS:	
Lightweight metal alloys: – Magnesium alloys – New aluminium alloys – Titanium alloys	Equipment for automobile, aerospace and transport industries, chemical plants, medical implants and deep sea oil drilling.
Nickel alloys	Marine and aerospace industries, batteries.
High Strength Low Alloy Steels	Automotive and construction industries.
Stainless Steels	Marine and aerospace industries.
Amorphous metals	Transformers.
Magnets	Electrical motors.
ADVANCED COMPOSITES:	
Metal-matrix composites:	Automobile, aerospace, mining, refinery, defence and transport industries.
Advanced polymer composites: – Carbon fibre reinforced polymers	Aerospace, automotive, marine, defence and sporting equipment.
Lightweight structural sandwiches	Components for railway rolling stock and in the marine and construction industries.

Sources: US Bureau of Mines, 1992 and 1994a; DITAC, 1989, 1991 and 1993; Forester, 1988; Kingsnorth, 1991; The Condensed Chemical Dictionary, 1981.

The dynamic element

There is no pre-determinable time frame for the development and uptake of a new material through the economy, nor for the life-span of a new material once it is commercialised.

The development of materials, and products incorporating them, is a dynamic process — determined by technological breakthroughs and market needs. This is illustrated by the history and use of rare earths (see Box 2).

Box 2: History of the use of rare earths

The 'industry' effectively began in 1883 with the development of the incandescent gas mantle. In the early 1900s, mischmetal, an alloy of rare earth elements was the major ingredient in lighter flints, and by the late 1940s, rare earth elements were used in the production of ductile iron, to improve its rolling and physical properties.

Developments in separation technology paved the way for new and more advanced applications of rare earths. In 1947 the first separation of adjacent trivalent rare earths was achieved using ion exchange. This was followed in 1953 by the successful use of solvent extraction.

Rare earth catalysts (used in the petroleum and automotive industries) were developed in 1962, and in 1964, europium was first used in colour televisions. In 1966 and 1967, high strength rare earth permanent magnets made from yttrium or samarium combined with cobalt were developed.

In 1970, unique hydrogen absorbing properties were discovered in a lanthanum-nickel compound and the first amorphous rare earth alloys were made. In 1972, rare earth phosphors were used in fluorescent lighting. In 1976, French scientists produced lanthanum-nickel-hydride batteries. By 1991, Japan was producing 500 batteries a month, and now produces about 7 million per month. High strength permanent neodymium-iron-boron magnets were first made in 1981.

A driving force in the development of rare earth applications has been changing market needs. Prior to the 1960s, the chemical properties of the materials were exploited, with uses including lighter flints, alloy additives and in glass. Between the 1960s and 1980s, the unique physical properties of the rare earths were exploited in phosphors and magnets, these applications requiring high degrees of purity. Since the late 1980s, rare earths have been studied for possible application in the efficient use of energy and the production of environmentally safe materials; for example, the development of small electric motors incorporating rare earth permanent magnets and the development of high efficiency electric lamps.

Source: Jackson and Christiansen, 1993

Materials are usually developed over a period of years. Once developed, it takes many years for their use to reach a level where they are widely produced. Occasionally however, a material is developed over a very short time-frame (or even accidentally), and is picked up by industry very quickly. It has been suggested that the average time required for the commercialisation of an advanced material is 20 years.

According to a recent study carried out on materials in the UK:

> Innovation in new materials has a number of characteristics that distinguish it from most other forms of technical change. It is distinctive in that the relationship between players involved in the innovation process is more complex, the time required for successful commercial exploitation is longer, and the size of investment required is usually larger than for most other forms of technological development (Department of Trade and Industry (UK), 1989b, p. 20).

Of course, what is new today will not necessarily be new tomorrow. This means that this inquiry is a ‘snapshot’ in the ongoing progress of materials discovery, development and use.

Properties and processes

Often the properties of materials are determined as much by their processing and the production technologies used as by the raw materials from which they are derived. The importance placed on production technologies is evidenced by the continued attempts to improve them. For example, the Defence Science and Technology Organisation (DSTO) has developed a combined metal surface treatment and epoxy resin bonding process, to attach boron fibre-reinforced composite patches to cracks in aircraft metallic structures (see Box 3).

The demand for new and improved processing technologies is often linked to the development of new and advanced materials. Furthermore, it is common for the development of a new and advanced materials and improved processing technologies to be carried out in unison. The term c*oncurrent engineering* is used to describe this phenomenon.

A significant difference between many of the new materials and traditional materials is that the latter are generally supplied to the users in a semi-finished form ready for final processing into a component or product. However, the newer advanced materials often do not go through a semi-finished stage. The starting material is often processed by the component or product maker directly into the finished product. This is particularly the case with composite materials. An important implication of this different approach is that the user must understand how to process the material.

Box 3: New material processes — Special surface treatments to reinforce aircraft structures

The Aeronautical and Maritime Research Laboratories (AMRL) of the Defence Science and Technology Organisation (DSTO) has developed the use of fibre-reinforced composites to repair or reinforce defective aircraft metallic structures. Special surface treatments have been developed to allow highly durable bonding of these repairs on the aircraft.

It is estimated that the development has saved the Department of Defence well over a $100 million over ten years, not including savings due to delaying the purchase of new aircraft. Because defence budgets overseas are now being reduced and consequently defence forces are seeking cost savings to increase the service life of existing equipment, demand for this development may increase. Helitech, under contract to AMRL, has recently been licensed to supply the technology to the US airforce to repair the wings of the Starlifter aircraft.

Substitution

The cost-reducing or performance-enhancing qualities of new and advanced materials enable them to substitute for more traditional materials.

The extent of substitution between new and traditional materials depends on their respective properties and costs at any point in time. New materials must compete with materials that are well trusted by consumers. Therefore, the scope for large-scale switching of materials is limited by this and the need for testing, development of new processes, and investment in new production facilities. An example of materials substitution is the use of componentry in jet aircraft engines made from advanced ceramics such as silicon nitride, where the operating environment is particularly demanding (see Box 4).

Evolutionary change

The development of all materials is predominantly an incremental process. Although ‘wonder materials’ may capture the imagination, and revolutions in materials development do occur from time to time, evolutionary developments in both traditional and new materials may be more significant in economic terms, and are expected to dominate new material developments in the foreseeable future.

While the search for new materials continues, traditional materials, such as steel and aluminium, are constantly undergoing incremental improvement. This ongoing process often delays the introduction of new and advanced materials. The critical factor for Australian industry is that the most appropriate material is incorporated into products, whether it be a traditional material, an improved traditional material or a new material. 'Fitness for purpose' is the paramount criterion in material selection.

Box 4: New materials substitution — Advanced ceramics

Rolls Royce Industries of the United Kingdom conducted a study in 1992 to assess the feasibility of using advanced ceramics in their aircraft turbine engines for an aeroplane with a 300 seat capacity and a range of 7564 kilometres.

The substitution of traditional engine components by advanced ceramic components was shown to yield the following benefits:

- 10 per cent saving in engine weight;
- 2.3 per cent increase in thrust;
- 12.5 per cent increase in the thrust to weight ratio; and
- US$7 million reduction in life-cycle cost to the customer.

Source: US Bureau of Mines, 1994a.

Why investigate new and advanced materials?

Over the last 40 years, the Cold War, the space race and the demand for civil air transport led to a quickening in the development of materials. Many in the business community saw the *commercialisation* and *uptake* of the new materials that emerged as a potential source of competitive advantage. There were real or perceived opportunities to establish new industries that increased the extent of *value-adding*. An example of a new manufacturing activity built around the uptake of a new material is National Forge's use of titanium metal from which it is forging turbine blades for jet aircraft engines (see Box 5).

The incorporation of new materials into existing products and the possibility of creating new products are also regarded as means of increasing national wealth by establishing and sustaining competitive advantage — by exploiting the potential of new materials as an *enabling* technology. For example, new polymer materials that are biocompatible have enabled the production of high value-added heart pacemakers which would not have been possible otherwise (see Box 6).

Box 5: Value adding in use — Titanium

National Forge Limited, a Victorian company, was established in 1992 from the National Forge Division of the ANI group. The company (or its predecessor) has been manufacturing precision titanium turbine blades since the early 1960s. There are only a few manufacturers of these types of turbine blades in the World.

The precision titanium turbine blades are supplied to major jet engine manufacturers — Rolls Royce in the UK and the Pratt and Whitney Group in the US. The blades are also exported to France and Korea. In 1992–93, the exported blades contributed approximately $5 million to National Forge's business. There is no Australian demand for the blades.

National Forge imports all the titanium it uses from the US and the UK — no titanium metal is produced in Australia. They use approximately 70 tonnes per year at a cost of between $20 000 and $26 000 per tonne.

National Forge is currently undertaking research, with a grant from the Industry Research and Development Board, aimed at improving the final stage in the production process, the machining of the titanium blades. This final stage of the process is a particularly labour intensive part of the overall process.

An important industry policy issue is whether Australia is making best use of the opportunities offered by new and advanced materials. Indeed this question underlies all of the Commission's industry development references, including this one. These inquiries are intended to investigate growth prospects in selected areas and identify any impediments to economic growth.

Inquiry participants claimed that the capacity to undertake research into materials is fundamental to broader scientific and technological capability. Furthermore, research into materials and material processing produces knowledge that can be applied in many applications, not just the one being investigated.

In the US, the emerging materials technologies — associated with ceramics, metal-matrix composites, inter-metallic and light-weight alloys, advanced polymers, surface-modified materials, thin films, membranes and biomaterials — have been recognised by analysts to be of economic importance and essential to long-term security and prosperity. The same analysts have indicated that Japan will invest more in R&D and commercialise new materials at a higher rate than the US. The European Community (EC) is expected to invest less in R&D than the US, but commercialise new materials at the same rate.

Box 6: Innovation with new materials — Enabling biomedical applications

The idea of using materials to replace or supplement human biological functions is not a recent phenomenon. Sutures were first used in about 4000 BC, and the implantation of gold plates for skull repair is documented back to 1000 BC.

More recent developments in the use of biomedical products containing biomaterials have radically increased the ability of medicine to improve the quality of human life.

Telectronics

Telectronics Pacing Systems, now a fully-owned subsidiary of Pacific Dunlop, commenced operating in the 1960s and presently produces implantable defibrillators, and pacemakers, and has managed to capture 18 per cent of the World market in pacemakers.

Telectronics' annual World turnover is approximately $300 million, with $10 million being earned in Australia. Telectronics spends more than $600 000 annually on research into new materials. In 1994, Telectronics discovered a malfunction in some lead wires casing giving rise to the possibility of litigation. This has arisen despite the completion of an extensive evaluation program and approval of the design by the US Food and Drug Authority (FDA).

Cardiac pacemakers are designed to provide controlled electrical stimulation to the heart in cases where irregular beating occurs. The pacemaker is largely an electronic device, battery driven and programmed at a sophisticated level to maintain heart function. Advanced polymers are used to provide electrical insulation and increase biocompatibility for the device.

Telectronics is a core participant in the CRC for Cardiac Technology, and has been working closely with CSIRO Division of Chemicals and Polymers. It has developed a new polymer in conjunction with CSIRO, for use as an insulator for pacemaker and defibrillator leads.

The experience of Telectronics in the development of the new and advanced polymer is typical of the case for many new materials, in that while only a small quantity of the polymer is used (a few grams per lead in the case of the pacemaker), without the material, Telectronics would not be able to make a $5000 product.

Current production and use

The chief user industries of new and advanced materials are in the US, Japan and Europe. For example, electrical ceramics and rare earths — two of the materials included in the case studies for the inquiry — are used extensively in the electronics and electrical goods industries. These industries are predominantly located in the three regions mentioned above.

Where products incorporating new and advanced materials are manufactured has no bearing on where they are used. As components of consumer goods, new and advanced materials appear in sales rooms around the World. Australians have at least the same propensity to use the most recent product as consumers in other industrialised countries, be it a tennis racquet or a personal computer.

Australian production

New and advanced materials based on polymers and ceramics are produced in Australia. Producers in Australia are both large trans-national corporations such as ICI, Dupont and Comalco, producing small quantities of new and advanced materials locally, smaller businesses, such as those producing advanced ceramic products and companies such as Flexichem that supply specialist polymer blends to niche industrial markets. Production of new and advanced materials in Australia is described in the context of World production in Box 7.

Box 7: New materials produced in Australia

Australia is not a large producer of new and advanced materials. Of the new and advanced materials examined as case studies for this inquiry, only advanced polymers, electrical and engineering ceramics are produced in commercial quantities in Australia. Australian production of these new materials is small relative to World production.

Below is a comparison of Australian and World production of some new and advanced materials. Aluminium, a traditional material, is included for purposes of comparison.

Material	*Australian production*	*World production*
Electrical ceramics	less than US$40 million	US$10 billion
Engineering ceramics	US$12.4 million	US$1.9 billion
Advanced polymers	not available	US$3.2 billion
Aluminium	US$4 billion	US$40 billion

Australian use

The use of new and advanced materials in the Australian manufacturing industry is limited compared with that in the main producer countries. This low usage reflects the under-representation in Australia of industries that depend heavily on new and advanced materials for product development. Nevertheless, significant value adding activity can be built upon the use of new and advanced materials in, for example, the automotive industry where Britax Rainsfords has been exporting automotive components made from engineering polymers (see Box 8), while SOLA Optical has also been successfully exporting spectacle lenses (see Box 11).

Box 8: New material use in Australia — Engineering polymers in automotive components

One of the largest users of engineering polymers in Australia is Britax Rainsfords Pty Ltd, a manufacturer of mirrors and mirror motor mechanisms for the automotive industry. The company uses blends of engineering polymers to obtain the desired properties at the lowest price. A high standard of finish is required for these products. Britax has 98 per cent of the Australian market for these automotive components, and about 60 per cent of its sales are to automotive companies in Japan, Korea and the US. The share of exports is expected to grow to 80 per cent over the next few years.

Automotive mirrors are a specialised market and different designs are developed for specific export markets. Britax designs, moulds and assembles mirrors at its plant in Adelaide. Most developments are likely to occur in improving surface finish and processing, such as reducing production cycles and waste. Production is becoming increasingly automated to ensure greater product consistency. Britax is owned by a UK firm that has plants in the UK and US. The Australian plant supplies the South East Asian market.

What drives the development of materials?

The defence and aerospace industries are significant drivers of the development of new and advanced materials. Australia does not have large defence or aerospace industries in comparison, with say, the US. Accordingly, Australian producers of new and advanced materials do not face the same incentives to continually develop new materials to meet the stringent performance needs of such industries.

Another driver of the development of new and advanced materials is the automotive industry. The automotive industry is the World's largest manufacturing activity. This means that the uptake of new materials by the automotive industry could determine to a large extent future use of new materials. Estimates of new material usage in cars by the year 2003 are presented in Box 9.

Box 9: New material usage in cars by the year 2003

Polymer usage in passenger cars is forecast to increase by 15 per cent over the next decade. The polymers that are expected to be increasingly used include polypropylene, polyethylene and nylon. Concurrently, polyvinyl chloride use is forecast to decrease.

Lightweight metal usage is expected to increase substantially. Applications of aluminium and magnesium are likely to increase. Aluminium may see gains in several strategic areas. It is expected to be used in 70 per cent of cylinder heads and 40 per cent of cylinder blocks by 2003. Aluminium is also forecast to be used in 9 per cent of car frames and 89 per cent of styled wheels by 2003. Magnesium is forecast to be used in a wide variety of applications including various housings, instrument panel components and seat frames.

Powdered metals, metal-matrix composites and other materials are expected to be increasingly used in engine components such as camshafts, crankshafts, connecting rods and pistons.

Source: University of Michigan Transportation Research Institute, 1994.

Australian producers and users will be affected by overseas environmental regulations aimed at reducing fuel use in motor vehicles. These regulations, although presently mainly confined to the US and Germany, are likely to increase the demand for many new materials World wide, because of the importance of these countries in the global automotive industry.

Occasionally, materials result from research that is not motivated by a demand to produce a material or process with any particular application in mind. The work of researchers may lead, sometimes through serendipity, to the development of materials that have numerous applications, but which have not been previously identified. The process of developing materials in this way for commercial use is known as *supply-push*.

An Australian example of the development of a significant material is partially stabilised zirconia, or PSZ (see Box 10).

Box 10: Australian materials research — Zirconia ceramics

Success

The techniques for producing advanced zirconia ceramics were pioneered in Australia in 1972 by CSIRO Division of Materials Science and Technology. CSIRO developed an extremely tough and impact resistant ceramic referred to as partially stabilised zirconia (PSZ). This has since been used as a reference point for the development of other zirconia ceramics World wide, including yttria-stabilised zirconia and cubic-stabilised zirconia.

International producers of advanced zirconia ceramics have since produced many products that utilise the material's excellent mechanical, electrical and thermal properties. These products include ceramic scissors, industrial knives and wear parts. In Australia, CSIRO's PSZ was patented and is now sold by ICI Advanced Ceramics in the form of manufacturing inputs such as valve components and can-seaming rollers used in the manufacture of metal cans. While turnover for ICI Advanced Ceramics is still small (approximately $6 million), its growth prospects are excellent, particularly as it continues to penetrate international markets.

CSIRO's breakthrough with PSZ also facilitated the development of the patented $SIRO_2$ Oxygen Sensor, which has become a World-leading technology. The sensors are produced in Australia by Ceramic Oxide Fabricators and sold primarily to the US, where the business has a market share of approximately 90 per cent.

... and uncertain future

Following a joint collaborative research project between CSIRO and ICI to design a process for the production of high purity zirconia powder, Z-Tech was formed in 1988. The company became the largest production plant in the World for high purity zirconia, which was to be used as feedstock for the international advanced ceramics industry. Although the project added further value to Australia's mineral sands resources, market expectations were not realised for a number of reasons, including the following:

- initial growth forecasts were clearly overly optimistic;
- the technical advantage derived from CSIRO's technology was quickly countered by US and Japanese 'catch-up'; and
- the recession reduced output in the automotive and electronics industries by approximately 25 per cent — both heavy (potential) end users of Z-Tech's product.

The plant had been operating at less than 25 per cent of its 400 tonne a year capacity and was de-commissioned in 1992. The South Korean Hanwha Corporation bought the plant in 1994 and intends to recommission it in the near future.

What determines producer competitiveness?

To remain competitive in a World of ever changing consumer tastes and technological advances requires use of new processes, new materials and new business techniques according to circumstances. To be first in the market with a new product or a cost-saving process is to create, for the short-term at least, a competitive advantage. For a nation as a whole, its competitive advantage is not only influenced by what individual businesses do, but by the existence of valuable factor endowments (such as minerals) and the physical and social infrastructure that have been created, usually by governments.

Strengths and weaknesses

Australian producers of new and advanced materials are thought by many to have a competitive advantage because of their access to relatively cheap supplies of minerals. For example, Australia has abundant endowments of bauxite and finds it economic to add value by processing it into alumina and aluminium. The latter can be used to form aluminium-based alloys.

Australia also has substantial supplies of monazite that are produced as a by-product of rutile and zircon mining. Monazite is the feedstock for the production of rare earths.

However, raw materials are quite often a minor part of the cost of producing new materials. Further, any competitive advantage gained through cheap access to minerals diminishes if other competitive advantages in the production chain are lacking — for example, access to the appropriate skills and technological support.

The small size of the Australian market and the type of manufacturing undertaken means that Australia is relatively unattractive as a major outlet for large overseas producers of new and advanced materials. This provides some scope for import replacement by Australian producers, particularly if they target niche markets.

Although *local production* of some new and advanced materials to meet local demand makes economic sense, there are factors that can frustrate production for export. Australia's geographical isolation from the major user industries is a cost factor in exporting materials, but it is not necessarily so in exporting high value products incorporating new or advanced materials.

Competitive advantage derives as much from the *use* of new materials as from their production. However, the use of new and advanced materials does not depend on them being produced in Australia. For example, Australian-made titanium products are manufactured from imported metal, and advanced polymers are blended from imported resins and additives.

Down-stream processing or value adding will only occur if potential producers believe it is profitable. It will only take place if the return on the primary value-adding inputs — land, capital and labour — is at least equivalent to that in other activities.

What are the overall prospects for production?

Demand for new and advanced materials depends to a large extent on whether they are competitive as substitutes for traditional materials — taking into account any price premium they can attract because of superior performance or manufacturing cost savings associated with their use. Where there are economies in large-scale production, the competitiveness of new materials is determined by the overall level and expected growth of demand.

World demand for most of the new and advanced materials is generally considered to be growing strongly. However, with the benefit of hindsight, some growth forecasts have generally proved to be over-optimistic (University of Michigan Transportation Research Institute, 1992). The US Bureau of Mines (1994a) reports that failure to foresee the technical problems associated with incorporating particular materials into products and the 1990–92 recession were the main reasons why some forecasts have had to be drastically revised downward.

In the long term, cyclical fluctuations are less important than underlying trends. One such trend is the inevitable scientific search for new materials and processes. This is a quest driven by both human curiosity and economic factors (satisfying consumer demand, seeking to maximise profit). The other obvious trend is a tendency toward stricter environmental controls (pertaining to vehicle emissions, recycling and disposal of wastes), and these are expected to provide further impetus for the development and use of lighter, stronger and recyclable materials.

Although Australia has had some success in specific areas of new material development, it is as a general rule unlikely to be a significant *producer* of new and advanced materials. In the case of many new and advanced materials, there are moderate production economies — which are difficult to achieve with a new material early in its life-cycle. Commercially viable production therefore requires a large local market and, if this is not the case, a reliance on exports to capture these economies. In this respect, the Commission was advised by producers of new and advanced materials that Australia is disadvantaged by the absence of major user industries to provide adequate local demand. Further, inquiry participants indicated that Australian producers of materials would have difficulty in capturing production economies by exporting. The Commission was advised that overseas users of highly processed materials favour local suppliers because of the strong emphasis they place on just-in-time purchasing, and close customer relations.

In Chapter 9, a number of areas are identified where new economic activity in the *production* of new and advanced materials could occur in the future. However, the Commission believes that normal market forces, particularly relating to raw material supply, technology and niche markets, will be the determinants. Most of this activity will be undertaken by larger, established companies and, apart from continuing to support strategic R&D in this area, there is little influence that the Government can or should have.

Presently there are two good examples of investigations pertaining to the production of new and advanced materials. One is a feasibility study of rare earth production being undertaken by Ashton Mining. The other is a magnesium metal study being undertaken by a consortium in Queensland.

What are the overall prospects for use?

It is not necessarily the production of new and advanced materials in Australia that is important. The greatest potential gain to the economy lies in making the best *use* of materials and, where appropriate, exploiting new and advanced materials to increase the competitiveness of Australian manufactures — SOLA Optical (see Box 11) and Telectronics (see Box 6) are two businesses that have achieved success in this way. Indeed, it is imperative that this is the case if Australian firms are to become and remain competitive.

The fundamental question must therefore be asked as to whether the current level of uptake of new and advanced materials in Australian industry is optimal. While there is no direct means of determining this, the evidence received during the inquiry strongly suggests that the uptake is not optimal.

Box 11: Successful use of new and advanced materials — SOLA Optical

SOLA Optical, owned by AEA Investors Inc, has grown from a small Adelaide-based company into the World's largest producer of plastic spectacle lenses. The SOLA Group, with sales in excess of $400 million per year, has manufacturing plants in eleven countries, and employs over 5000 people World wide, with 700 employed in Australia. SOLA invests over $8 million in Australian R&D each year. In 1994, half of their sales were in the US, with SOLA claiming to have 30 per cent of the world market.

Today almost 60 per cent of spectacle lenses are made from plastic materials instead of the traditional mineral glass. The most common plastic is allyl di glycol carbonate (ADC) which is lighter, easier to tint, and has greater impact resistance than glass.

In recent years there have been significant advances in both plastic lens materials and scratch resistant coatings. An example of this is the development by SOLA of Spectralite®. The Spectralite products combine a new lens material, a new manufacturing process and a new coating resin with new designs which provide a superior end-product. Since their first release in 1991, the Spectralite products have received four Awards of Excellence from the US Optical Laboratories Association.

Over one-third of SOLA's World wide sales value comes from products that did not exist five years ago. This is testimony to the importance of the continual development of both materials and design technology by the SOLA Optical group.

What are the advantages of a better use of materials?

New and advanced materials can improve the competitiveness of the manufacturing sector by improving the quality and performance, or lowering the cost of the products that incorporate them. Materials are generally intermediate goods — usually only one of many inputs required for the manufacture of final products. The properties they bring to final products are often crucial to the product's performance and commercial success. The demand for new and advanced materials is therefore heavily influenced by the corresponding demand and supply conditions in final-product markets.

The uptake of new and advanced materials facilitates awareness and the diffusion of technology to many sectors of the economy. By this process the economy as a whole benefits.

New and advanced materials also provide innovative manufacturers with opportunities to establish a competitive advantage, capture market niches and earn high returns on their entrepreneurial skill. Competitive advantage can be maintained by manufacturers improving the technology incrementally through 'learning-by-doing'.

The commercialisation and uptake of new and advanced materials is associated with the simultaneous development of technologies allowing the materials to be incorporated into products. These technologies often have wider application than just the new material for which they were designed. The diffusion of such new technologies was regarded by inquiry participants as an important spin-off of new material development and commercialisation.

Achieving a better use of materials

The Commission has identified three interrelated areas which contribute to less than optimal use of new and advanced materials and which are within the ability of Government to influence. These are:

- a lack of awareness amongst many firms, particularly small-to medium-sized enterprises (SMEs), as to the appropriate use of materials including new and advanced ones;
- shortcomings in the educational system relating to training in materials, at both the technical and professional level; and
- problems in the research and development area in relation to the adequacy of facilities and the transfer of technology.

Increased awareness

The Commission considers that Australian firms are not necessarily making the most appropriate decisions about the use of new and advanced materials, because compared with most other industrialised countries there is a low level of awareness of their availability and properties.

The larger businesses involved with new and advanced materials tend to have more highly skilled staff and modern equipment than do smaller businesses. They often have international links and therefore are aware of developments occurring overseas. However, in Australia, there are not many large businesses that use new and advanced materials, and as a general rule SMEs are unaware of their properties and uses.

Inquiry participants also argued that although potential users of new and advanced materials are aware of their higher up-front costs compared with traditional materials and the risks involved in their incorporation into products, they are often unaware of their overall superior performance and cost-effectiveness.

The Commission considers that decisions are often not being made on the basis of comparing the whole-of-life costs of competing materials. It draws attention to the benefits to be had from adopting a life-cycle costing approach.

Inquiry participants stressed the importance of certain core generic competencies. In particular, knowledge of materials selection, of compatibility within systems, and of design requirements, and an understanding of processing technologies were raised. It was suggested that these competencies are critical to the appropriate use of materials.

There seemed to be a general concurrence that a knowledge base exists in Australia within materials suppliers, research institutions, the universities and private consultants on most aspects of the proper selection and use of new materials. The problem is in linking this knowledge with the needs of manufacturing firms. Improvements to the education and training system and in the infrastructure and management of public sector R&D institutions will contribute to solutions to this problem but other means of awareness raising need to be strengthened.

Experience both overseas and in Australia demonstrates that an effective extension service activity is required. The *AusIndustry* programs are filling an important function in this area and the establishment of organisations such as the Monash University Centre for Advanced Materials Technology, the Queensland Manufacturing Institute (QMI) and the newly formed Materials Institute of Western Australia (MIWA) are examples of institutions with the potential to play a significant role in providing extension services to industry. However, more needs to be done. Because being aware is not dissimilar to being educated — one does not appreciate the benefits until one has gone through the process — there is a role for government.

The Commission considers that more State-based co-operative organisations providing extension services in the materials area are required.

The *AusIndustry* program incorporating NIES plays a key role in augmenting the resources needed for awareness raising. However, concerns have been expressed that advice in materials has been given a relatively low profile in some States.

Where insufficient attention is being given to materials, a solution is to replicate institutions such as QMI and MIWA.

The Commission finds that *AusIndustry* should re-examine the emphasis on materials selection and materials use in its programs, to ensure that both these matters are receiving proper recognition.

The Commission also finds that to the extent that greater efforts need to be made in extension and technology transfer, encouragement should be given to State-based organisations which co-ordinate existing activities; and the infrastructure support funds of the *AusIndustry* Technology Access program should be used to support initiatives in materials utilisation.

Education and training

Inquiry participants questioned whether education and training in Australia provide sufficient awareness of material properties and processes, or the knowledge of how to make best use of new and advanced materials. If there is a deficiency in this regard, it represents an impediment to efficient production and use of materials. In a number of Northern European countries and in Japan, the technological sciences and engineering enjoy a higher standing in the community than they do in Australia. Education and research institutions in these countries place considerable emphasis on collaboration between educational institutions, government and industry, and promote high quality vocational (or sub-tertiary) training for its own sake, and as a desirable precursor to higher level education. Industry also generally makes considerable investment in on-the-job training in these countries.

Three issues requiring immediate attention were identified. First, there was the proposition that there was a shortage of people trained in materials science and related disciplines. Second, it was argued that there had been a decline in the materials content of existing science, engineering and related courses. Third, it was argued that university laboratories were not being maintained and upgraded to keep apace of advances and new challenges in materials science.

What the number of people who should be trained at both professional and sub-professional levels should be — given the size of the Australian economy, its population and demography — is difficult to answer. The consensus view expressed to the Commission is that there is a need for greater availability of certificate and associate diploma courses in materials engineering in the TAFE system.

There is also a generally expressed opinion that the training of professionals involved in design and production has declined to an unsatisfactory level; that is, the materials content of courses and the manner in which such was taught was sub-optimal. Again, what the appropriate mix of disciplines should be is a difficult question to answer.

It is also difficult to reach firm conclusions as to what is the optimal total allocation of funds for laboratories and related infrastructure. In as much as there is inadequate infrastructure for teaching, the problem can be partially addressed by co-operative ventures such as QMI and MIWA (discussed above).

Without pre-empting the answers that will come from detailed consideration of these issues by the full range of interested parties, there is a *prima facie* case that increased resources will have to come from both industry (via industry associations) and government (in as much as it addresses education, training, R&D and industry information needs by allocating new funds or by re-allocating existing funds).

There are two investigations presently underway which should help answer some of these questions. The first is a group sponsored by the Institute of Engineers, and the Australian Academy of Technology, Science and Engineering (AATSE) formed to review training and research in materials. This group is called the National Council for Materials.

The second initiative is an Inquiry into Engineering Education, being undertaken by the Institute of Engineers, AATSE and the Council of Engineering Deans.

The allocation of resources for modern materials laboratories and equipment is an issue for Government to address in the context of competing demands; but, the importance of adequate education and training in materials science cannot be over-emphasised.

Continuing education is also an essential element in keeping abreast of new and emerging trends in technology, particularly in areas where it is developing rapidly. The Commission notes the important role being played by the professional associations in this area.

Access to technology and research and development

Access to technology is vital to both producers and users of new and advanced materials. R&D is one important mechanism for gaining access to new technology. Australia does not have policies targeted specifically at new and advanced material producers and users. Instead, assistance is provided through general assistance schemes, such as the 150 per cent R&D tax deduction and the CRC program.

Many new materials manufacturers and research organisations take advantage of such assistance. Producers and users reported that programs are fairly well conceived and targeted. Some expressed dissatisfaction with the administrative burden associated with applying for assistance. However, some of these concerns have been addressed through changes that have occurred with the introduction of the *AusIndustry* program.

Research institutions (such as the CRCs, CSIRO, DSTO, ANSTO, and universities) are involved to a significant degree in the development of new and advanced materials.

Research institutions provide a national knowledge-base and the skilled scientists and engineers required for innovation. Strong industry links based on long-term collaboration will ensure that this resource best meets Australia's requirements. In order to fulfil this role institutions must be equipped with up-to-date equipment and facilities.

On the evidence presented to the Commission, there is a shortfall in infrastructure in research institutions particularly in universities, and particularly related to materials processing.

That said, progress is being made on forging more productive links with industry, but more can be achieved. Bringing together research teams and capital equipment from various research organisations and tertiary institutions into a multi-disciplinary research cluster (in a low cost manner) will assist new and advanced materials development. The aggregation of research infrastructure and funding into specific clusters such as the QMI could enable the development of the technical infrastructure necessary for a range of people to fully understand new and advanced materials. Students and researchers could be trained with 'hands-on' experience, which would be more readily passed on to industry. Representatives from industry would have a 'one-stop-shop' to access state-of-the-art information; that is, such clusters will also enhance the interaction between the research institutions and industry.

A very recent initiative to allow for greater collaboration in research has come to the Commission's attention. It is a proposal by the National Council for Materials to form an organisation based on the Australian Institute of Nuclear Science and Engineering (AINSE) model. The organisations objective is to enhance and promote access to expensive research infrastructure and make it open to a range of users (for example, university researchers and research organisations) on a fee-paying basis. By this mechanism scale economies in research are achieved. The Commission is of the view that this is a sound proposition.

The CRC program has made contributions in this area but the Commission has noted some problem areas with the CRC concept (see Chapter 10). One is the issue of co-location as recommended by Professor Slatyer in his conceptualisation of CRCs. The second is the question of access to CRCs, in terms of becoming a member or being informed of research findings.

The Commission believes that the present review of the CRC program could fruitfully address these issues.

1 THE INQUIRY

The primary focus for the inquiry is the scope for greater production and use of new and advanced materials based on metals, ceramics, polymers and composites of these materials. A core issue is whether Australian industry is exploiting the growth opportunities that the materials provide, to increase the output of high value-added products and exports — both by producing new and advanced materials from raw materials, and by incorporating them in manufactured products.

The terms of reference for the inquiry direct the Commission to report on among other things:

- emerging development and market trends in new and advanced materials;
- processing technologies;
- technology transfer and the research base;
- competitive strengths and weaknesses;
- impediments to development; and
- the nature and extent of government assistance.

The terms of reference also request that the Commission report on examples of past successes and failures by way of case studies. A number of case studies, most based on specific materials and two on user industries, are presented in the B series of appendices of this report. They are not a comprehensive coverage of the field of new materials and their uses. While the case studies aim to be informative in their own right, they serve another purpose and that is to ascertain if there are common themes which might explain the rate of uptake of new and advanced materials.

The terms of reference for the inquiry are reproduced on page xxiv.

Overseas, the importance of the role of new and advanced materials in international competitiveness has been well recognised. The report to the UK Government by the Advisory Council on Science and Technology (1992) and that by the US National Materials Advisory Board (1993) both emphasised the importance of materials in the economic performance of modern industrial societies.

1.1 What are new and advanced materials?

Perhaps a century ago, the range of readily available materials did not extend much beyond wood, stone, a small range of metals and alloys, and fibres. Today, a much wider range of materials is to be found in most manufactured products. Materials choice is no longer a routine selection from a limited range of materials options but an important business decision for manufacturers.

There is no widely accepted way of defining what new materials are because of the continuum between new and traditional materials, and because materials are constantly undergoing development. Generally, materials are defined as *new* because they are not yet used widely in industry and *advanced* when their properties are superior to those of which are being replaced.

For many materials these characteristics (not being widely used and having superior properties) are likely to be transitory. That is, sometime in the future they might become widely used or be superseded by others with even better properties. When that stage arises, assuming it does, the materials in question are neither new nor advanced.

The importance of these characteristics cannot be over-emphasised because they have a fundamental influence on the economics of production and use. New materials will not be mass produced and benefit from the full extent of scale economies; advanced materials will be subject to all the uncertainties of scientific research and introduction to the market place. These characteristics mean that it is not appropriate to make direct economic comparisons with traditional materials.

Of course, what is new today will not necessarily be new tomorrow. This means that this inquiry is a ‘snapshot’ in the ongoing progress of materials discovery, development and use.

The critical factor for Australian industry is that the most appropriate material is incorporated into the design of products, whether it be a traditional material or a new material. ‘Fitness for purpose’ is the paramount criterion in material selection.

New materials can be categorised into two groups, *structural* or *effect* materials. This report is primarily concerned with structural materials, although some effect materials are discussed.

Structural materials perform mechanical functions and enhance performance through superior properties, such as increased toughness and hardness, lower density, heat and corrosion resistance, and ease of processing (such as easier casting and machining). Examples of structural materials are metal-matrix composites (MMCs) or engineering polymers.

Effect materials have certain intrinsic properties such as electrical conductivity or magnetism which form the basis of devices such as electronic chips or sensors. Examples of effect materials mentioned in this report include superconductors and piezoelectric ceramics. However, there are major effect materials that have not been covered in this report. For instance, semiconductors and photovoltaic devices containing effect materials are used by Australian firms in a number of applications.

1.2 Properties

Factors resulting in the adoption of new and advanced materials are incremental improvements in:

- strength-to-weight;
- fracture toughness;
- particular physical properties (for example, conductivity generally for effect materials);
- corrosion resistance; and
- processing characteristics (for example, casting and forging).

Some of the materials considered to be new and advanced are described in Table 1.1.

An advantage of some of the current generation of new and advanced materials is the improved ability to tailor them for a specific application. For example, it is possible to manufacture a polymer with specific characteristics by controlling the input of additives and reinforcements, or by developing a polymer alloy. The alloy of the two polymers, polyphenylene ether (PPE) and polystyrene (PS), for example, has better strength and stiffness than either polymer on its own (refer to Appendix B4 which examines advanced polymers and composites in detail).

A significant difference between many of the new materials and traditional materials is that the latter are generally supplied to the users in a semi-finished form ready for final processing into a component or product. However the newer advanced materials often do not go through a semi-finished stage. The starting material is often processed by the component or product maker directly into the finished product. This is particularly the case with composite materials. An important implication of this different approach is that the user must understand how to process the material.

Table 1.1: The properties of some new and advanced materials

Material	*Principal uses*
NEW CERAMICS:	
Engineering ceramics: – Partially stabilised zirconia (PSZ) – Alumina ceramics – Non-oxide ceramics – Advanced refractories	Internal combustion engines, gas turbines, cutting and grinding tools, coatings, wear applications, nozzles and combustion monitoring.
Electro ceramics: – Superconductors – Insulators – Piezoelectric ceramics – Solid electrolytes	Transducers, capacitors, integrated circuit packages, condensers, piezoelectric devices, memory elements, electricity generation and transmission.
Bioceramics: – Silicon nitride – Alumina	Artificial teeth, limbs, heart valves, tendons and bone replacement.
ADVANCED POLYMERS:	
– Engineering polymers – High performance polymers	Pipes, panels, process plants, automotive parts, electronic components, marine equipment and aerospace componentry.
METALS AND ALLOYS:	
Lightweight metal alloys: – Magnesium alloys – New aluminium alloys – Titanium alloys	Equipment for automobile, aerospace and transport industries, chemical plants, medical implants and deep sea oil drilling.
Nickel alloys	Marine and aerospace industries, batteries.
High Strength Low Alloy Steels	Automotive and construction industries.
Stainless Steels	Marine and aerospace industries.
Amorphous metals	Transformers.
Magnets	Electrical motors.
ADVANCED COMPOSITES:	
Metal-matrix composites:	Automobile, aerospace, mining, refinery, defence and transport industries.
Advanced polymer composites: – Carbon fibre reinforced polymers	Aerospace, automotive, marine, defence and sporting equipment.
Lightweight structural sandwiches	Components for railway rolling stock and in the marine and construction industries.

Sources: US Bureau of Mines, 1992 and 1994a; DITAC, 1989, 1991 and 1993; Forester, 1988; Kingsnorth, 1991; The Condensed Chemical Dictionary, 1981.

The properties of materials are thus determined as much by their processing, and the production technologies used, as by the raw materials from which they are derived.

The demand for new and improved processing technologies is therefore often inextricably linked to the development of new and advanced materials. Furthermore, it is common for the development of a new and advanced material and improvement of processing technologies to be carried out in unison. The term c*oncurrent engineering* is used to describe this phenomenon.

1.3 Material life-cycles

The development of all materials is predominantly an incremental process.

> Innovation in new materials has a number of characteristics that distinguish it from most other forms of technical change. It is distinctive in that the relationship between players involved in the innovation process is more complex, the time required for successful commercial exploitation is longer, and the size of investment required is usually larger than for most other forms of technological development (Department of Trade and Industry (UK), 1989b, p. 20).

There is no pre-determinable time frame for the development and uptake of a new material through the economy, nor for the life-span of a new material once used in production. History suggests that materials are usually developed over a period of years. Once developed, it takes many years for their use to reach a level where they are readily incorporated into production, their penetration depending on both new markets and substitution in established materials-using markets. Professor Tegart suggests that the average time required for the commercialisation of an advanced material is 20 years (sub. 4, p. 4).

Although ‘wonder materials’ may capture the imagination, and revolutions in materials development do occur from time to time, evolutionary developments in both traditional and new materials may be more significant in economic terms, and are expected to dominate developments in the foreseeable future. In its submission to the inquiry CSIRO stated:

> New structural materials are likely to displace traditional materials in an evolutionary rather than revolutionary manner. New materials tend to displace traditional materials at the margin and hence work their way into the market in niche applications where existing materials are performing at their limit, and probably not very well (sub. 19, p. 5).

CSIRO acknowledged that there are exceptions to this evolutionary process:

> The US Space program is an example. Conventional materials simply could not do many of the jobs and new ones had to be developed (sub. 19, p. 5).

Here the driving force was what CSIRO terms 'the things the community wants to do', such as launch a space program.

Other exceptions to the gradual path include the invention of what are termed *biomaterials*. In this case, the universal human desire for good health, coupled with concerted research efforts and the occasional 'lucky break' have resulted in very significant advances in medical products.

In general, choice of material depends on both properties and cost. It is important that cost is understood in its proper economic context. That is, it is not just the up-front cost of a material but rather the life-cycle cost associated with its use that is relevant. The concept of life-cycle cost acknowledges that there are a number of elements to the cost of a material: raw material cost, fabrication cost, longevity, and disposal cost.

In this context, a new and advanced material may find application by reducing the cost of production, even though the cost of the material itself may be higher than the material it replaces. For strict comparability purposes, the cost of all materials needs to be assessed over their entire life.

Substitution and the creation of new products

The cost-reducing or performance-enhancing qualities of new and advanced materials enable them to substitute for traditional materials. In some cases, the improvement to performance enables new products to be developed, thereby creating new demands. For example, many of the rare earths are vital inputs for the production of electrical products. According to Madigan:

> ... they [rare earths] are a *sine qua non* for a number of the things that we have got used to thinking are essential to our way of life – TV and computer screens, clean motor car exhausts, fluorescent lights, Walkman radios, electric car accessories, lasers, ceramics, ultra violet glass screens, colour printing (Madigan, 1993).

1.4 Development drivers

By and large, new and advanced materials are intermediate products. Usually they are only one of many inputs required for the manufacture of a certain end-product — although they may be crucial to that product.

New and advanced materials are constantly being developed. But how do developments in these intermediate materials come about?

Demand-pull

New and advanced materials are frequently developed in response to an observed consumer and industry demand for a material possessing particular characteristics which were previously unavailable. The pressure for development of this kind is known as *demand-pull*.

According to the Industry Research and Development Board:

> Industry demand for new and improved materials for existing products is one important driver of new materials technology development. Requirements in this category are manifest in demands for both incremental improvements on existing materials, and in replacement of traditionally used materials with entirely new substitutes. Both kinds of developments lead to product improvements and/or improved manufacturing economics, ultimately benefiting the competitiveness of manufacturers (sub. 24, p. 1).

The automotive industry is the World's largest manufacturing activity and, together with aerospace, is a significant source of demand for new and advanced materials.

As consumers and governments become increasingly environmentally conscious, the demand for new and advanced materials is likely to increase accordingly. New materials will play a role in meeting consequential requirements for improved fuel efficiency, fewer emissions, and recyclability from automotive manufacturers.

Most new materials and the associated advanced processing technologies covered in this report have applications in the automotive industry. These include:

- Aluminium and magnesium alloys — which bring with them many of the properties of steel and iron, but weigh less and have processing advantages (Appedices B1 and B6 respectively);
- Ceramics — for specific applications such as exhaust manifold liners, piston crowns and turbocharger turbines (Appendix B3);
- Polymers — these materials bring with them a range of properties including light weight, ease of casting and quality finishes (Appendix B4);
- Iron and steel — although by no means 'new materials', it was stressed by several participants involved in the automotive industry that developments in these two materials should not be overlooked. Iron and steel play such a large role in the automotive industry that optimising their use, and the development of new high strength and micro-alloy steels, could overshadow other new material developments (Appendix B11); and
- New processing technologies — new casting, welding, surface coating and die stamping technologies. Much of their focus is linked to optimising the

use of ‘old’ materials such as iron and steel, and adapting existing processes to cope with new materials (Appendix B8).

Supply-push

Developments in materials may result from research that is not motivated by a demand to produce a material or process with any particular application in mind. The work of researchers may lead, sometimes through serendipity, to the development of materials that have numerous applications, but which have not been previously identified. Attempts to commercialise developments of this kind are known as *supply-push*.

By and large, it is the researcher rather than potential users, or final consumer, who will be most aware of the properties and potential beneficial uses of a new development.

With a material that has been developed in this fashion, the researcher is faced with the problem of either tapping into a latent demand or generating a new demand. However, this is not an easy task. A report written by the Prime Minister’s Science Council commented that:

> There have been serious market disconnects between the R&D providers and the market, namely industry, particularly in relation to the commercialisation process or phase. Consequently industry has failed to fully take-up the benefits of public sector R&D or develop adequately its own R&D capacity (1992).

This challenge of generating demand for a new material is far greater than when the material has been developed in response to demand-pull pressures.

1.5 Structure of the report

World and Australian production and use of new materials, and the production and use of the selected case study materials is documented, in a broad sense, in the following chapter. The major Australian research institutions involved in materials research, and assistance provided to research and development are reviewed in Chapter 3. The processes involved in commercialising new materials are considered in Chapter 4. Supply and demand conditions for new and advanced materials are discussed in Chapters 5 and 6 respectively.

The factors that determine competitiveness of new material producers are outlined in Chapter 7, along with comments on the nature and operation of markets for materials. One of the key terms of reference for the inquiry, namely, the potential for further value added in production and use of new materials in Australia is addressed in Chapter 8.

The potential for further *production* and *use* is discussed in Chapter 9. Finally, the factors inhibiting greater *use* are discussed in Chapter 10. There is a discussion in this chapter of what role government might play in addressing these impediments.

Case studies of both specific materials and specific market segments are covered in Appendices B1 to B12.

Detailed reviews of education, training and awareness relating to materials and of research assistance are contained in Appendices C1 and C2 respectively.

2 PRODUCERS AND USERS

The World wide experimentation with, and production of, new and advanced materials is increasing to meet the growing demands of users requiring materials with superior performance. This chapter provides a general overview of World wide producer and user activity, before summarising the position with respect to particular new and advanced materials, namely, aluminium alloys, metal-matrix composites, engineering and electrical ceramics, advanced polymers and composites, rare earths, magnesium, titanium metal and alloys, steel, such as high strength low alloy steels, and nickel metal and alloys.

2.1 World and Australian production

The producers and users of new and advanced materials are predominantly located in the World's major industrialised centres, the US, Japan and Europe. The bulk of Australian imports of these materials come from these three places. For example, more than 90 per cent of World production of advanced polymer composites (APCs) is produced by fewer than 30 businesses, with twelve in the US, ten in Europe and several in Japan (US Bureau of Mines, 1994a).

Compared with traditional materials such as iron, steel and aluminium, the value and volume of new and advanced materials production is relatively small as shown in Tables 2.1 and 2.2 respectively.

Table 2.1: Value of materials production, 1993–94 ($ million)

Material	*Australian production*	*World production*	*Australian exports*
Traditional			
Steel	3 217	442 770	1 115
Primary aluminium	2 353	37 018	1 772
New and advanced			
MMCs	na	76	na
Rare earths	nil	540	nil
Magnesium	nil	1 071	nil
Advanced ceramics	17	18 053	4
Advanced polymers	na	4 320	32[a]
Titanium sponge	nil	600	nil

a Value for 1992–93.
na not available.
Note: All figures Australian dollars.
Sources: ABARE, 1994a,c; DITARD, 1993a; Lewis, 1993; CRB, 1993; ABS 1993a; New Materials International, 1994c.

Table 2.2: Materials production 1993, (kilotonnes)

Material	*Australian production*	*World production*	*Australian exports*
Traditional			
Steel	6 810	718 000	2 360
Iron ore	116 500	921 000	107 600[a]
Primary aluminium	1 300	15 150	979
Primary nickel [d]	88	840	86
New and advanced			
MMCs	na	0.5	na
Rare earths	nil	67[b]	nil
Magnesium	nil	255	nil
Advanced ceramics	na	na	na
Advanced polymers	na	14 000[c]	8[b]
Titanium sponge [c]	nil	62	nil

a 1989 level.
b 1992–93 level.
c 1992 level.
d Primary refined nickel.
na not available.
Sources: ABARE, 1994a,c; DITARD, 1993a; Lewis, 1993; CRB, 1993; ABS 1993a; Plastics News International, 1993.

Australian production

Australian production of new and advanced materials is small relative to World production, both in terms of the volume and value of output. A number of the materials examined in this report, such as magnesium and titanium, are not produced at all.

In Australia, production of new and advanced materials is concentrated in polymers and ceramics. Broadly speaking, Australian producers are either large trans-national corporations such as BHP, ICI, Dupont and Comalco, producing small quantities of new and advanced materials locally, or smaller businesses, such as those producing advanced ceramic products and niche suppliers of chemicals.

The production of traditional materials, such as steel and aluminium (including improved versions of those materials), is currently of great economic significance to the Australian economy, however, new and advanced materials production may play a significant role in the future.

2.2 World and Australian use

New and advanced materials are used predominantly in high-performance applications, particularly in the military and aerospace industries, where the performance of the material is more important than its cost (OTA, 1988).

Other common uses are in high technology applications in the automobile, biomedical and electronics industries. For example, the automobile industry accounts for approximately 79 per cent of the World demand for metal-matrix composites (US Bureau of Mines, 1994a).

Table 2.3 lists the main uses of selected materials. Although domestic production of new and advanced materials is on a relatively small scale, use of the materials in the Australian manufacturing industry is widespread, as the listing of uses in Table 2.3 suggests.

The application of new and advanced materials is sometimes impeded because they have to compete with traditional materials used in established production facilities. If existing plant and equipment is not approaching the end of its useful life, there is an 'opportunity cost' in not continuing to use it. There will be a reluctance to replace 'sunk' capital with new processing equipment. Nevertheless, dynamic changes in either the supply technology for the material, or in new applications, can always change the relative attractiveness of a material and its substitutability *vis a vis* rival traditional materials.

The automotive industry is the major user of new and advanced materials in Australia, particularly advanced polymers and metal alloys. The automotive industry has been accused of being too conservative in its selection of materials, although the contrary view is that this simply reflects a realistic assessment of the commercial risks involved. The notion that the local industry is conservative overlooks the fact that, as a general rule, the important decisions on vehicle design and the use of materials are not made in Australia but in the overseas design offices.

A somewhat similar situation pertains to aircraft components. Australia manufactures some aircraft components, essentially as a sub-contractor to US and European aircraft manufacturers. Accordingly, the Australian firms do not make the final, or crucial, decisions on the selection of materials. Furthermore, materials have to be certified for use in aircraft.

Materials certification for use in critical aircraft structures is very time consuming and expensive for any prospective producer. For these reasons the Aeronautical and Maritime Research Laboratories (AMRL) and the Co-operative Research Centre (CRC) for Aerospace Structures do not consider that materials development targeted at this market is an economically viable research activity for Australia.

Table 2.3: Uses of selected new and advanced materials

Material	*Principal uses*
NEW CERAMICS:	
Engineering ceramics: – Partially stabilised zirconia (PSZ) – Alumina ceramics – Non-oxide ceramics – Advanced refractories	Internal combustion engines, gas turbines, cutting and grinding tools, metal forming tools, coatings, wear applications, nozzles and combustion monitoring.
Electro ceramics: – Superconductors – Insulators – Piezoelectric ceramics – Solid electrolytes	Transducers, capacitors, integrated circuit packages, condensers, piezoelectric devices, memory elements, superconductors and fuel cells.
Bioceramics: – Silicon nitride – PSZ – Alumina	Artificial teeth, limbs, heart valves, tendons and bone replacement.
ADVANCED POLYMERS:	
– Engineering polymers – High performance polymers	Pipes, panels, process plants, automotive parts, electronic components, marine equipment and aerospace componentry, spectacle lenses, medical implants.
METALS AND ALLOYS:	
Lightweight metal alloys: – Magnesium alloys – New aluminium alloys – Titanium alloys	Equipment for automobile, aerospace and transport industries, chemical plants, medical implants and deep sea oil drilling.
Nickel alloys	Marine industries, batteries, catalysts.
High strength low alloy steels	Automotive and construction industries.
Stainless steels	Marine and aerospace industries, general engineering and cutlery manufacture.
Amorphous metals	Transformers.
Magnets	Electrical motors.
ADVANCED COMPOSITES:	
Metal-matrix composites:	Automobile, aerospace, mining, refinery, defence and transport industries.
Advanced polymer composites: – Carbon fibre reinforced polymers	Various, including aerospace, automotive, marine, defence and sporting equipment.
Lightweight structural sandwiches:	Components for railway rolling stock, and for use in the marine and construction industries.

Sources: US Bureau of Mines, 1992 and 1994a; DITAC, 1989, 1991 and 1993; Forester, 1988; Kingsnorth, 1991; TheCondensed Chemical Dictionary, 1981.

The producers of military equipment tend to experiment to a greater extent (and with more costly materials) than other users of new and advanced materials. Most of Australia's military hardware likely to incorporate these materials is purchased from overseas suppliers or has been designed overseas. Information provided by AMRL indicates that development of advanced materials for Australian military applications focuses on uses that extend the life of existing equipment, as a means of delaying new equipment purchases.

The production and use data for each of the new and advanced materials dealt with as case studies for the inquiry are summarised in the remainder of this chapter.

2.3 Aluminium alloys

Only the recently developed advanced aluminium alloys can be regarded as new and advanced materials. Primary aluminium is the base material for all aluminium alloys and aluminium-based metal-matrix composites (MMCs).[1] The latter are discussed in the following section.

World production of aluminium alloys is impossible to determine with any accuracy due to the practice of including aluminium alloy production with primary aluminium statistics. However, much aluminium would be used in alloy form.

Production and usage

The level of World production of primary and secondary (recycled) aluminium is approximately 19.4 million tonnes per year (Street and Alexander, 1994). Aluminium and its alloys are used widely in the automotive, aerospace, marine, packaging, building and mining industries, and in the production of sporting equipment.

Australia is a major producer of primary aluminium but, because of the absence of user industries, presently advanced aluminium alloys are produced only for research purposes.

See Appendix B1 for more information relating to aluminium and its alloys.

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1 Metal-matrix composites (MMCs) consist of a metallic alloy, commonly aluminium, interspersed with added particulates or fibres of a ceramic compound such as silicon carbide or graphite, which function as a reinforcement to the base alloy (Street and Alexander, 1994). The reinforcement is vital because it determines the mechanical properties of the composite.

2.4 Metal-matrix composites

World production of MMCs, which are predominantly aluminium based, is approximately 500 tonnes, with a value of US$56 million. This is expected to increase to 1100 tonnes by the year 2002. The US produces half the World's MMCs (US Bureau of Mines, 1994a). Other estimates suggest that usage could be considerably higher and perhaps reach up to 20 000 tonnes per year by 2003 (sub. 67).

In terms of weight, the automotive sector was the largest World wide user of MMCs in 1992, but used only a quarter of the MMCs produced in value terms. In contrast, the aerospace industries used only 17 per cent of World MMC production by weight, but 67 per cent in terms of value. The relatively high value of MMCs used in the aerospace industries is due to labour intensive fabrication and low-volume production (US Bureau of Mines, 1994a).

See Appendix B2 for more comprehensive information relating to MMCs.

2.5 Advanced ceramics

Advanced ceramics comprise both advanced engineering ceramics and advanced electrical ceramics.

Advanced engineering ceramics

Advanced engineering ceramics (AECs) differ from traditional ceramics — clay products and whitewares — by possessing superior properties, such as high temperature strength and toughness. They use higher purity feedstocks, involve relatively sophisticated production techniques and are used in more demanding environments (for example, engine parts and cutting tools). AECs comprise both ceramic components and ceramic coatings.

AECs are used in a host of industries, including automotive, aerospace, mining, refining, power generation, textiles, and pulp and paper making. Some major uses are:

- cutting and machining tools that exhibit excellent hardness and heat resistance qualities;
- bearings and drills that are highly abrasion resistant;
- components for automotive use (such as valves, seals, rods and piston rings, turbine blades for use in turbo chargers, wear parts for use in reciprocating engines); and

- biomedical components requiring materials with high biocompatibility (such as bioceramic dental implants).

Production and usage

World production of AEC components was worth approximately US$1.9 billion in 1992, with the major producers being in Japan (Kyocera), the US (Nortons and Coors) and Germany (Feldmuhle and Hoechst Ceramtec). Production is expected to double by 1997 (Advanced Ceramics Report, 1994).

World production estimates for ceramic coatings are difficult to obtain. However, the US Department of Commerce (1993) suggests that the figure is approximately $1 billion.[2] Ceramic coatings are regarded as the fastest growing application of advanced ceramics.

The AEC industry in Australia is only just beginning to develop, being comprised of four small manufacturers. Total output of ceramic components is estimated to be approximately $10 million per annum (excluding production of refractory components).[3] Australia was, however, a leader in the development of one of the new advanced engineering ceramics, namely partially stabilised zirconia (PSZ).

Output of ceramic coatings in Australia is in the region of $7 million per annum, with approximately seven small specialist producers.

See Appendix B3 for more comprehensive information relating to AECs.

Advanced electrical ceramics

Advanced electrical ceramics are relatively new types of high performance ceramics. They are used in a wide number of applications which utilise one or more unique physical properties, for instance piezoelectric devices, capacitors, integrated circuit packaging and optical fibre systems. They therefore all fall into the category of *effect* materials as defined in Chapter 1.

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2 This figure should be treated with caution because the US Bureau of Export Administration’s estimates are based on the assertion that the ceramic coatings market represents 9 per cent of the total advanced ceramic market of $11.3 billion. The US Bureau of Export Administration’s estimates also suggest that World wide demand for AEC components is 18 per cent of the total advanced ceramics market (approximately $2.1 billion).

3 Refractory components are used as lining materials in vessels containing molten metal and in other high-temperature metallurgical applications requiring materials with a melting point above that of the metals being used.

Production and usage

World production of advanced electrical ceramics in 1992 was valued at US$10.25 billion (Advanced Ceramics Report, 1994). There is general agreement that the growth rate of advanced electrical ceramics production is now slower than that for engineering ceramics. However, the forecast is that by 1997 the value of production will have increased to US$14.4 billion.

More than half of the value of World production of advanced electrical ceramics occurs in Japan (Kyocera, Murata and Sonycorp), with the US (Corning and Cooper) producing over 20 per cent. Other major producer countries are France (Compagnie de Saint-Gobain) and the Netherlands (Philips). Taiwan is also emerging as a major force in electrical ceramics.

The reason for production being concentrated largely in Japan and the US is that these two countries possess large consumer electronics industries, the main users of advanced electrical ceramics. Approximately 50 per cent of World electrical ceramics production is used in the integrated circuit package and capacitor segments of the electronics industry.

Advanced electrical ceramics production in Australia is very small by comparison. This is consistent with Australia’s small end-user industries, particularly the electronics industry. GEC Marconi Systems, a subsidiary of GEC Marconi (UK), is the only producer of advanced electrical ceramics in Australia. The business previously traded as Plessey Australia and, under its new owners, it continues to produce piezoelectric ceramics, mainly for military use such as in underwater acoustic detection devices.

Australia has significant research programs in the development of new superconducting materials and ceramic fuel cells, which could lead to production opportunities in the future.

See Appendix B3 for more comprehensive information relating to advanced electrical ceramics.

2.6 Advanced polymers and advanced polymer composites

Polymers are produced by synthesis from basic chemicals. Fillers or reinforcing materials are often added to increase strength. Stabilisers, which protect the polymer from the environment, and colours, may also be added.

Polymers may be classified as commodity, engineering or high performance. Commodity polymers are versatile and have been widely used for many years; however, they do not perform well at high temperatures. Engineering and high performance polymers, on the other hand, are able to perform well in more demanding environments, and are generally considered to be new and advanced materials.

Advanced polymer composites (APCs) are comprised of a polymer matrix reinforced by fibres or fabrics. Traditional composites that have been in use for many decades include fibreglass, which is comprised of a commodity resin reinforced with discontinuous, low-stiffness fibres. Advanced polymer composites, on the other hand, usually contain high performance continuous fibres of carbon, boron or other materials, which result in a material that is lightweight and has superior strength and stiffness compared with traditional composites such as fibreglass.

Production and usage

In 1992, World production of advanced polymers was US$3.2 billion (New Materials International, 1994). World production of APCs in 1992 was 13 700 tonnes, valued at US$4.3 billion, of which more than half was produced in the US, and over 30 per cent in Europe.

There is little production of either advanced polymers or of APCs in Australia. Some compounding of advanced polymers occurs in Australia, but the base resins are imported.[4] Imports of advanced polymers totalled 70 000 tonnes in 1992–93.

The major users World wide of APCs and advanced polymers are the aerospace, automotive, telecommunications, electronic appliance, and construction industries (US Bureau of Mines, 1994a). Significant Australian users are in the appliance, biomedical and telecommunications industries.

The major Australian users of the more high technology APCs are the aerospace industry and the military. APCs are also used in marine hulls and fittings, and railway passenger rolling stock. Most APCs used in Australia, such as resin impregnated carbon fibre, are imported.

See Appendix B4 for more comprehensive information relating to both advanced polymers and APCs.

2.7 Rare earths

Rare earths is a collective term used to describe a group of seventeen chemically similar metallic substances. They include the lanthanides plus yttrium and

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4 Compounding is where polymeric resins are mixed with additives, fillers and reinforcements.

scandium. In the majority of applications rare earths are used because of their unique spectral, electronic or magnetic properties.

Production and usage

World production of rare earths in 1989 was estimated at 67 000 tonnes (Jackson and Christiansen, 1993). World production is dominated by Rhone Poulenc in France, Molycorp in the US, CIS producers and a number of producers in China. China has displaced Australia as the major raw material source for Rhone Poulenc. The US, Japan, China and the CIS are the major consumers of rare earths. Australia does not currently have a rare earth processing industry, nor is it a significant user of rare earths.

Rare earths are valued most for their application in a number of high technology industries which are predominant in the US, Japan and Europe. Examples of applications includes three way catalytic converters, television screens, heat resistant ceramics, and high-strength permanent magnets. The latter are produced in Australia.

See Appendix B5 for more comprehensive information relating to rare earths.

2.8 Magnesium

In 1883, magnesium was being produced by the electrolytic reduction of magnesium chloride, and by the turn of this century, World production was about 10 tonnes a year. The focus in this report is on new processing technologies and new uses of magnesium in the manufacture of, for example, automotive parts.

Magnesium is used in aluminium alloys, automotive and other componentry, the desulphurisation of steel, and electrochemical applications. It is easier to machine than many other metals. Recently, the demand for lighter automobiles, and the material’s suitability for use in new casting techniques have renewed interest in the material.

Production and usage

Magnesium production in the Western World is about 250 000 tonnes per year. Two businesses, Dow and Norsk Hydro produce about 60 per cent. Production is currently below capacity, with capacity utilisation of around 76 per cent.

Although Australia does not produce magnesium, it imports about 6000 tonnes each year — 85 per cent of this is used in the production of aluminium alloys.

By comparison with the rest of the Western World, Australia is a relatively high user of magnesium because of the country's large aluminium industry.

Magnesium makes up about 1 per cent of standard aluminium alloys. World wide, this accounts for about 130 000 tonnes of magnesium each year, or about 56 per cent of total production. In addition, about 31 000 tonnes of magnesium is used each year in die casting processes. This accounts for around 13 per cent of World magnesium use. Most of this is used in automotive components.

See Appendix B6 for more comprehensive information relating to magnesium.

2.9 Titanium metal and alloys

Titanium is a commonly used metal in military and aerospace applications. Titanium metal is as strong as steel, but 45 per cent lighter. These characteristics have led to 80 per cent of titanium metals and alloys being used in jet engines, the airframes of civil and military aircraft, and in space and missile applications.

Titanium is commonly sold as titanium sponge, a porous form of the metal which is produced as an intermediate product, before its further processing into metal ingot form.

Production and usage

Production of titanium sponge and titanium metal is concentrated in the CIS, the US and Japan. China is also a small producer of titanium sponge. In 1992, three countries, the US, Japan and the CIS, accounted for 95 per cent of world capacity in titanium sponge production. Excluding producers in the CIS and China, there are only six businesses in the World producing titanium sponge and seventeen producing titanium metal (Metals Bulletin Monthly, 1993).

In 1993, it is estimated that there was approximately 50 per cent excess production capacity for titanium sponge (Towner and McAllister, 1994).

The US is the dominant user nation of titanium mill products.[5] In 1993, civil aircraft and military aerospace accounted for approximately 70 per cent of these products used in the US. Non-aerospace uses of titanium are in the chemical industry, power generation plants, biomedicine, fuel gas desulphurisation, automotive applications and recently in tubular pipes in offshore oil drilling platforms (Gambogi, 1994). Titanium is used in leisure and sporting goods,

5 Titanium mill products refer to the specific forms of titanium including sheet, strip, plate, bar, billet, wire, foil or tubing.

such as bicycles, in spectacle frames and in architectural applications (Nishimura, 1991).

There is no production of titanium metal in Australia. Australia supplies the raw materials ilmenite and rutile to the US and other countries for use in the production of titanium sponge. In the 12 months to June 1994, Australia imported 184 tonnes of titanium metal, mainly from the US and the UK (ABS, Foreign Trade Statistics).

National Forge, in Melbourne, is the largest single user of titanium in Australia. The company produces blades for aircraft engines, using titanium imported from the US and the UK. Use of titanium by other Australian manufacturers tends to be for small volume applications. For example, products made from titanium are used in Australian chemical processing and power plants, for connecting rods in racing motorcycles, and in the biomedical industry.

See Appendix B7 for more comprehensive information relating to titanium.

2.10 Steel

The steel industry plays a large role in the Australian economy. Production of steel in Australia represents about one per cent of total World production. In 1993–94, steel exports were about $1.2 billion which represented around 4.5 per cent of total merchandise exports.

Recent developments in steel-making technology and advances in steel alloys could have major impacts on Australia's economic performance. Changes to the steel industry could have a far greater impact in the short to medium term, at least, than many of the new and advanced materials mentioned elsewhere in this report.

There are several areas in which advances are occurring in steel making technology — electric arc furnace technology, the adoption of continuous casting technology and direct smelting. These advances in steel making technology could impact significantly on existing steel, iron ore and coking coal industries in Australia.

Innovation is occurring in alloy steels and in stainless steels. It is aimed at counteracting recent inroads made into traditional steel markets by substitute materials, such as aluminium and plastics. Steel grades in use today were not commercially available twenty years ago. The new grades have allowed the thickness and weight of steel used in many products to be reduced thus retaining steel's competitive position.

Production and usage

World steel production has trebled from around 200 million tonnes in 1950 to around 700 million tonnes in the 1980s. This increase was mainly the result of increased use in industrialised nations.

More recently, world steel production in 1992 and 1993 was around 725 million tonnes, well below the 786 million tonnes produced in 1989.

Only two companies produce steel in Australia. The majority of production in Australia is carried out by BHP's Steel Group — around seven million tonnes each year. BHP Steel sells about $5.4 billion per annum worth of steel products into both the domestic and international market, and is in the top 18 steel producing companies in the World. The other is Smorgon Steel which produces steel products using a scrap-based minimill at Laverton near Melbourne.

BHP spend about $60 million a year on steel research. This represents about one per cent of all R&D in Australia, or 2 per cent of private R&D funding.

See Appendix B11 for more information relating to the steel industry.

2.11 Nickel metal and alloys

Nickel metal is strong, workable and corrosion resistant, with chemical properties that allow it to be used as an alloy. Nickel alloys and nickel-bearing stainless steels are highly resistant to corrosion and oxidation and have excellent strength and toughness at elevated temperatures.

Production and usage

Kuck (1992) reports that in 1991, World mine capacity for nickel was 1.11 million tonnes and refinery and smelter capacity was 1.17 million tonnes. In 1991, there were 19 countries involved in mining and 27 in the refining and smelting of nickel. However, six countries accounted for approximately 70 per cent of total World mining capacity and nine countries accounted for 70 per cent of total World smelting and refining capacity.

Australia has developed an internationally competitive nickel industry providing 8 per cent to 10 per cent of the world's nickel supply. ABARE estimated that in 1993 Australia produced 88 000 tonnes of primary nickel, which was approximately 10.5 per cent of World production. The value of Australian exports of primary nickel in 1992–93 was $640 million (Manson, Gooday and Meek, 1994).

In 1993, Western World consumption of nickel was 685 000 tonnes which was well below capacity (INSG, 1994). The major use of nickel is in stainless steel which is used very widely in modern economies. High nickel alloys are used in the aerospace and marine industries and in other applications requiring high temperature strength and corrosion resistance. Other uses of nickel are in nickel plating, and batteries.

There is no stainless steel production in Australia with all requirements being met by imports of ingots and mill products. Nickel alloys for aerospace applications are being produced by a new company in WA.

Appendix B12 discusses nickel metal and alloys in detail.

3 RESEARCH INSTITUTIONS AND RESEARCH AND DEVELOPMENT ASSISTANCE

Most of the research and development on new and advanced materials in Australia is undertaken in public sector research institutions (such as CSIRO, DSTO, ANSTO, CRCs and the universities). These institutions are responsible for most of the scientific breakthroughs that occur in Australia. Working in collaboration with, or as consultants to, the private sector, these institutions are responsible for a considerable amount of the laboratory testing that can lead to commercialisation of materials.

The private sector is also directly involved in materials research, an example is BHP's Melbourne Research Laboratories which has a significant materials program. Comalco's Thomastown Research Laboratory and CRA's Advanced Technology Centre in Perth also have significant materials programs.

In the main, private sector R&D in the materials field is undertaken with the support of general schemes, such as the 150 per cent tax concession, syndication of R&D and the Competitive Grants for Research and Development. There are also government schemes which apply to the commercialisation of innovations.

This chapter outlines the contribution of research institutions to new and advanced materials development in Australia, and the industry assistance provided through the various R&D schemes. Research in materials in Australia has recently been revised by Polymear (1994).

3.1 CSIRO

CSIRO is Australia's principal research agency. It is governed by a Board comprising up to ten members, one of whom is the Chief Executive. Approximately 7400 staff are employed in six research institutes. CSIRO is required to obtain 30 per cent of its funds from external sources, with the Commonwealth Government appropriation providing the balance. As reported in the Commonwealth Government's 1993–94 *Science and Technolog*y budget statement:

> While CSIRO is funded primarily by direct appropriations from the Commonwealth, an increasing proportion of its funds come from external sources. These include collaborative ventures with industry, granting schemes funded by both industry and government, and earned revenue (DIST, 1994a).

In 1992–93, external sources contributed 33.1 per cent of CSIRO's revenue and in 1993–94, it is estimated that about 31 per cent of funding will come from outside the organisation (CSIRO, 1994a).

CSIRO's involvement in new and advanced materials ranges from strategic materials research, co-operative projects, through to working on a fee-for-service basis for clients developing materials and processes.

CSIRO involvement with new materials

CSIRO has a long history of involvement with the development of advanced materials. The CSIRO Division of Tribophysics, led by Dr Walter Boas, gained a World wide reputation during the 1940s and 1950s in the basic science of metal deformation and in a number of other areas of materials behaviour. In the present era material research is spread over many divisions of the organisation (see Table 3.1).

CSIRO has explained its approach to materials research in the following terms:

> CSIRO has a distinguished record in a number of areas of materials research. Moreover CSIRO has become increasingly focused in recent years on working with Australian industry partners in the development and application of materials for identified markets. Generally this involves developing the most appropriate material to meet the end-product requirements. Indeed it is important that the major part of any research program in new industrial materials should be product-driven or applications-linked rather than the development of a new material for its own sake (sub. 19, p. 1).

Examples of CSIRO research into new materials are described in Box 3.1. Some of this research is undertaken under the umbrella of the CRC program.

Table 3.1: New materials research by CSIRO, 1994

Areas of materials research	*CSIRO Division*	*Commercial partners*
Light-weight metal alloys		
Magnesium	DMT, DMST	Queensland Metals
Aluminium-titanium alloys	DMT, DMST	
Titanium	DMST	
Advanced composites		
Carbon fibre reinforced composites	DMST, DCP, DFP	ASTA, Hawker, Boeing
Biomaterials		
Polymers	DCP	Nucleus
Ceramics	DMST	
Packaging materials		
Active packaging polymers	DMST, DFS, DH	ANL Limited
Materials characterisation	DMST, DAP, DCP, DFP, DMPE	
New ceramics		
Zirconia	DMST/DMPE	ICI - NILCRA
Rare earth magnets	DAP	SEMCOR
Semiconductors	DRP	Department of Defence
Alumina ceramics	DMST	Alcoa
Non-oxide ceramics	DMST	Western Mining JV
Superconducting sensors	DAP	BHP
Solid electrolytes	DMST	Ceramic Fuel Cells Limited
High performance polymers		
Polymers and blends	DCP	ICI, Huntsman
Conductive polymers	DCP	Memtec
Fibre membranes	DMST	
Metals and alloys		
Ferrous alloys	DMST, DMT	BHP
Rare earths	DAP	

Note:
DMST Division of Materials Science & Technology.
DAP Division of Applied Physics.
DCP Division of Chemicals and Polymers.
DMT Division of Manufacturing Technology.
DFP Division of Forest Products.
DMPE Division of Mineral & Process Engineering / Mineral Products.
DRP Division of Radiophysics.
DH Division of Horticulture.
DFS Division of Food Science.

Source: CSIRO, sub. 19, p. 6.

Box 3.1: Some of the current materials research within CSIRO

Ceramics processing: This project is being undertaken in collaboration with local businesses, such as ICI Advanced Ceramics, the Coal Corporation of Victoria and Commercial Minerals Ltd. It involves the development of techniques for making powders from local raw materials and the fabrication of ceramic bodies into monolithic and composite components.

The project aims to improve the chemical resistance, wear performance and manufacturing processes of ceramics and refractories for use by industry in harsh environments. CSIRO estimates the local market to be $50 million a year and the potential for import replacement to be about $30 million.

Solid oxide fuel cells: The aim of this project is to develop a solid oxide fuel cell for electricity generation. The project is currently focussing on prototype construction and the long-term testing of operating characteristics. CSIRO estimates the local market to exceed $200 million over the next 10 to 15 years with considerable export potential.

Light alloys and intermetallics: The focus of this project is developing alloying and processing strategies, including rapid solidification processing which is used to develop light-weight, corrosion resistant alloys based on titanium and iron aluminides.

Automotive magnesium alloys: The aim of this project is to develop magnesium alloys that have higher strengths, greater creep resistance and more ductility than the alloys currently available. It will initially concentrate on developing an age-hardening alloy based on AZ91 (the most commonly used magnesium casting alloy, comprising 9 per cent aluminium and 1 per cent zinc).

Commercial success will depend upon the ability of the Australian die casting industry to capture significant automotive markets for magnesium components.

Electrochemical technology: The aim of this project is to enhance metal corrosion protection through improvements to rare earth based conversion coatings.

Active packaging: This project is aimed at developing packaging membranes for Australian horticultural products. Conventional packages are inert barriers that protect the product from the outside environment. Active packaging extends the life of the product by controlling the composition of the surrounding atmosphere. Active systems and membranes are being developed for low cost control of package atmosphere to extend the shelf life of fresh produce and processed foods.

3.2 Defence Science and Technology Organisation

As well as providing general scientific and technological advice to the Department of Defence, the Defence Science and Technology Organisation (DSTO) contributes to new and enhanced defence capabilities by evaluating acquisition options, and developing technologies to meet specific Australian defence requirements and conditions. DSTO also seeks to extend the life of defence equipment, and to reduce the operational and maintenance costs of this equipment (Department of Defence, 1993). In the field of new materials, DSTO states its role as:

- providing the science and technology base for through-life support of Service equipment containing these materials;
- advising on the procurement of equipment made of new materials;
- developing new materials or processes, where there is no other option; and
- using new materials to repair or improve the performance of existing equipment (sub. 25, p. 1).

Industry Support Office (ISO)

In 1993 the Industry Support Office (ISO) was established to encourage Australian and international businesses to use DSTO skills and innovations to increase the technical and commercial performance of their businesses. The ISO was formed in recognition of the fact that many of the technological advances and know-how developed within DSTO are of potential benefit to industry in areas other than defence.

The Defence White Paper released in 1994 states that the objectives of interaction between DSTO and industry is:

> ... to help industry become better able to support the capabilities we need to defend Australia [and] to contribute through industry to wealth creation (Department of Defence, 1994, p. 130).

However, the transfer of knowledge and expertise to industry must not undermine DSTO's primary objective of providing for Australia's defence. The White Paper clearly states that:

> ... commercial activity is secondary to supporting defence science to the rest of the Defence Organisation; it is a by-product of, and does not drive, the Defence Science and Technology Organisation's focus on support for defending Australia (Department of Defence, 1994, p. 130).

Adopting this criterion, the ISO can facilitate relationships between DSTO and businesses by providing project management, risk management, technology management, and strategic advice, enabling firms to benefit from DSTO's resources. DSTO said:

> In addition to supporting Defence, DSTO has the mission to support Australian industry through the Industry Support Office (ISO).
>
> - The ISO is an organisation established to provide a permanent link between DSTO and Industry;
> - can employ DSTO capabilities to aid industry through contract arrangements;
> - can transfer technologies developed by DSTO to industries through flexible business arrangements; and
> - ISO's aim is to enhance industry and Australian defence self-sustainability (sub. 25, p. 1).

DSTO research program

Research at DSTO is divided into five programs, one of which is materials research. The objective of the materials research program is to:

> enhance the safety of Australia through the application of materials science and technology to improve the performance and cost effectiveness of maritime operations, naval platforms, explosive ordinance and personnel protection (Department of Defence, 1993).

The materials research program is divided amongst the following divisions:

- Ship Structures and Materials — investigating material competencies in fibre reinforced polymer composites, elastomers (polymers with unique properties of deformation and elastic recovery), engineering and optical plastics, ceramics, and metal technologies (such as welding technology and fracture mechanics);
- Airframes and Engines — currently investigating materials such as advanced fibre composites; and
- Optoelectronics — specialising in materials for vision enhancement and eye protection.

Examples of practical applications of DSTO research are contained in Box 3.2.

DSTO interacts with both industry and research organisations, locally and overseas. DSTO is involved with the following CRCs:

- Aerospace Structures;
- Polymer Blends;
- Maritime Engineering; and
- Materials Welding and Joining.

Box 3.2: Some practical applications of DSTO material research

HMAS Sydney Superstructure Reinforcement: Marine superstructures made out of light non-ferrous alloys are susceptible to fatigue cracking in heavy seas. DSTO has developed large carbon-fibre patches to reinforce the structure, reducing the bending strains and hence reducing the susceptibility to fatigue. Two patches have been applied to the deck of the HMAS Sydney and their effectiveness is being monitored.

Fuel cells as power sources: Fuel cells are an extremely efficient, clean, power source, as well as being silent and producing pure water as a by-product, making them ideal for defence applications (particularly independent propulsion for submarines and portable power sources for remote localities). DSTO has commissioned a 5kW solid polymer electrolyte fuel cell system.

Source: Department of Defence, 1993.

3.3 Australian Nuclear Science and Technology Organisation

The Australian Nuclear Science and Technology Organisation's (ANSTO) role is to undertake research and development in nuclear science and associated technologies, to contribute to Australia's industrial innovation and development, and to environmental and health management (DIST, 1994a).

New material research and development at ANSTO

The major area of materials-related activity at ANSTO is in ceramics. A major part of this activity is concerned with the development of Synroc (see Box 3.3). ANSTO expertise has also been applied to R&D on a number of engineering and electrical ceramics projects, in collaboration with firms producing ceramics.

In relation to new and advanced materials, ANSTO sees an important function as providing pilot plant facilities for producers, thus removing some of the risk of developing processes and products. A representative of ANSTO expressed the view that their facilities could provide a testing ground for new and advanced materials which are not available at any other organisation in Australia.

ANSTO's nuclear reactor at Lucas Heights is the only source of neutrons in Australia. Neutrons have a number of applications in research on new and advanced materials.

Box 3.3: The development of Synroc

Synroc is an advanced ceramic comprising titanate materials chosen for their geochemical stability and their collective ability to immobilise radioactive elements present in high-level nuclear waste.

Initially discovered by Dr Ted Ringwood of the ANU, it was developed by ANSTO over a twenty year period at a cost of approximately $27 million. Although Synroc offers significant technical advantages over the currently used glass materials for high level waste disposal, commercialisation has not as yet occurred due to:

- the very large existing investment in glass technology;
- the need to obtain complex regulatory approvals; and
- the tendency of many countries to store used nuclear fuel rather than process it and dispose of waste.

However, some recent developments have opened up commercial prospects which are being actively pursued. These are:

- the need to dispose of large quantities of high level waste generated by the US military nuclear program over the last forty years, much of which cannot be incorporated into glass; and
- development of techniques for separating *transuranic* elements from high level waste and separately disposing of this waste. Synroc is suited to this application.

3.4 Co-operative Research Centres

The Co-operative Research Centres (CRCs) program was introduced in May 1990. Its goal is to foster links between tertiary institutions, government funded research organisations and private businesses.

There are 61 CRCs in the program. Commonwealth funding at around $138 million a year makes the CRC program one of the major initiatives in recent Australian science policy, although it should be noted that on average each centre receives only $2 million per year.

Rationale for the CRC scheme

When details of the CRC program were announced in March 1990, the principal objective of the initiative was to ensure that Australian research and research training remained at the forefront, specifically in areas of greatest importance to the country.

CRCs were established to rectify a perceived or real gap in the institutional organisation of science in Australia — the absence of large integrated research teams with links to 'users' of research. The rationale behind the CRC program is outlined in Box 3.4.

Box 3.4: The rationale behind the CRC program

Before the establishment of the Co-operative Research Centre (CRC) program it was felt that although Australia's combined scientific and technological resources were substantial they were too dispersed, both geographically and institutionally. This made it difficult to establish the concentrations and networks of researchers needed to keep pace with rapid scientific and technological change occurring internationally. The duplication of facilities and equipment was also considered wasteful.

The CRC scheme, devised by the then Chief Scientist Ralph Slatyer, was developed after analysis of major research programs in other countries, and consultation with representatives from Australia's science community. Slatyer stated that the basic approach would be to relocate and link outstanding university, CSIRO and other research groups, whenever and wherever appropriate, into CRCs with facilities concentrated in one location.

> Most research funding in Australia is from institutional sources and flows down from management through administrative channels to operational units and individual researchers. Except in the Commonwealth science agencies and the Institute of Advanced Studies at the Australian National University, this pattern of funding has not enabled large integrated research teams to be built and, even in those organisations, has caused difficulties. Competitive funding sources, such as the Australian Research Council, the National Health and Medical Research Council and the Rural industry research bodies have also, with few exceptions, had difficulty in building such teams (Slatyer, 1993).

Thus the pattern of research funding in Australia was held to have contributed to a relatively low level of co-operative research in Australia within institutions and between universities, between universities and CSIRO, between State organisations and those funded by the Commonwealth, between corporate sector research groups and those which were publicly funded and between different firms.

In redressing this deficiency in Australia's research effort, CRC resources were to be linked as effectively as possible to the various sectors of the economy, the work of the centres was to be focused on research areas which underpin existing or emerging industry sectors and industrial firms were to provide a commercial focus where necessary.

Establishing a CRC

There are two requirements that must be met in order to establish a CRC. First, ‘core’ participants — organisations providing the major contribution to the centre’s activity, staffing, infrastructure and other resources — are each required to sign a legally binding agreement with the Commonwealth Government. The agreements define the commitments — typically for a period of five to seven years — covering strategies, milestones, outcomes and performance indicators that apply to the centre’s activities in research, technology transfer, industry co-operation and education.

Second, each centre must also include at least one higher education institution among its core participants in order that the education and research training objectives are met. Beyond these requirements, the CRCs have a wide variety of organisational arrangements.

CRCs involved in new and advanced materials

Of the existing 61 CRCs, a number are undertaking research related to new and advanced materials. Those primarily concerned with materials are:

- Aerospace Structures;
- Alloy and Solidification Technologies (CAST);
- Eye Research and Technology;
- Materials and Welding Technologies;
- Polymer Blends; and
- International Food Manufacturing and Packaging Science.

Materials research is also a significant activity of the following CRCs:

- Australian Maritime Engineering;
- Intelligent Manufacturing Systems and Technologies;
- Australian Photonics;
- Cardiac Technology;
- Water Quality and Treatment; and
- Diagnostic Technologies.

Commonwealth funding to the CRCs which are primarily focussed on materials represents about 9 per cent of the total Commonwealth funding for CRCs (see Table 3.2).

Table 3.2: Commonwealth funding to CRCs primarily concerned with materials ($millions)

CRC	*Commonwealth funding*
Aerospace Structures	17.0
Material Welding and Joining	13.5
Polymer Blends	9.3
Alloy and Solidification Technologies	13.5
Eye Research and Technology	14.5
International Food Manufacturing and Packaging Science	14.0
All new and advanced material CRCs	81.8

Source: Co-operative Research Centres Program, 1993.

Participation in these CRCs is broad-based, with on average six core participants in each. Participants in each CRC primarily involved with materials are listed in Table 3.3.

The CRCs involved in new materials technologies are briefly discussed below.

CRC for Aerospace Structures

The CRC is focusing on improving the design and reducing the cost of producing carbon fibre, and has recently had its funding extended by $3 million. Two programs are described below.

The *Improved Manufacturing Program* is being undertaken with CSIRO. The project aims to establish a carbon fibre manufacturing industry in Australia by finding a cost competitive method of producing carbon fibre. New ways of injecting resins and new stitching processes are being investigated as part of the project.

The *Improved Design Program* aims to reduce component weight of materials used in aerospace and marine components, while at the same time improve efficiency. The program focuses on the design of integrally stiffened thin-skinned structures made from traditional prepreg materials, and on the analysis of the newer textile-based materials.

Table 3.3: Core participants in new and advanced material related CRCs, 1995

CRC	*Core participants*
Aerospace Structures	Aerospace Engineering, RMIT Aeronautical Engineering, University of Sydney Mechanical and Manufacturing Engineering, University of NSW Monash University Aeronautical Research Laboratory, DSTO Aerospace Technologies of Australia Hawker de Havilland Ltd
Materials Welding and Joining	ANSTO BHP, Divisions of Sheet and Coil, and Slab and Plate Products CSIRO, Division of Manufacturing Technology Departments of Mechanical and Chemical Engineering, University of Adelaide Departments of Materials Engineering and Mechanical Engineering, University of Wollongong Welding Technology Institute of Australia
Polymer Blends	Materials Engineering Department, Monash University CSIRO, Division of Chemicals and Polymers RMIT Ltd ICI Operations Ltd Chemplex Pty Ltd DSTO, Materials Research Laboratory
Alloy and Solidification Technology	The University of Queensland CSIRO, Division of Manufacturing Technology Comalco Research Centre Comalco Foundry Products Australian Automotive Technology Centre The Australian Magnesium Research and Development Project
Eye Research and Technology	University of New South Wales, Cornea and Contact Lens Research Unit, Centre for Biomedical Engineering, and Schools of Optometry, Physics and Mechanical Engineering Queensland University of Technology, School of Optometry University of Western Australia, School of Optometry University of Western Sydney, School of Biological Sciences CSIRO, Divisions of Chemicals and Polymers and Biomedical Engineering University of Melbourne, National Vision Research Institute Optometric Vision Research Foundation Allergen Australia Pty Ltd Capricornia Contact Lend Pty Eycon Lens Laboratories Pty Ltd

Table 3.3: Core participants in new and advanced material related CRCs, 1995 (cont.)

CRC	*Core participants*
International Food Manufacture and Packaging Science	Arnotts Goodman Fielder Pacific Dunlop ANL Pratt Industries BTR Nylex (as ACI) Department of Applied Chemistry, Swinburne University of Technology; Department of Biochemistry, University of Melbourne; Department of Chemical Engineering, University of Queensland; Packaging Centre, Victoria University of Technology; CSIRO Division of Materials Science and Technology, and Food Science and Technology; Victorian Department of Agriculture's Australian Food Research Institute; and Horticultural Research and Development Corporation.

Source: Co-operative Research Centres Program, 1993.

CRC for Materials and Welding Technologies

Research at the CRC for Materials and Welding Technologies includes investigating the metallurgical and materials science aspects of changes in materials structure and properties during welding and joining. Its work on new and advanced materials is concentrated in the *Joining Advanced Materials* subprogram.

This program involves research into:

- welding thermally modified structures (for example, low-alloy and carbon steels);
- weld metal cracking of high strength structural steels;
- developing improved materials and procedures for joining coated steels; and
- microwave induced plasma-jet joining of structural steels.

CRC for Polymer Blends

The CRC for Polymer Blends focuses on the formation of polymer blends and alloys to meet pre-determined performance specifications. The aim is to identify and develop new compatibilising agents — chemicals used for mixing to produce materials with new properties.

The project not only aims to develop new technologies for the design, manufacture and processing of polymer blends and alloys — but to also develop commercially attractive polymer blends and alloys (from olefin, styrene, vinyl and other polymeric base materials) and blends based upon recycled waste polymers.

CRC for Alloy and Solidification Technologies

The CRC for Alloy and Solidification Technologies (CAST) focuses on the development of casting technologies to suit the new aluminium and magnesium alloys.

Work funded by an IR&D Board grant currently undertaken by CAST includes investigating new forms of cast iron. The material, produced using scrap from cars as feedstock, possesses qualities superior to existing cast iron. It is an example of the modification of a very old material through a new process.

CRC for Eye Research and Technology

The CRC for Eye Research and Technology (CRCERT), amongst other work, is undertaking a research program into biomaterials involving four inter-related projects. The projects — in materials testing, development of new materials and surfaces, development of an artificial cornea, and investigation of tear ocular surface and biomaterial interactions — are aimed at identifying factors that influence device biocompatibility and understanding the relationship between material properties and device performance.

CRC for International Food Manufacture and Packaging Science

The CRC for International Food Manufacture and Packaging Science will investigate preservation methods to enable long distance transport of fresh Australian food products to overseas markets. The preservation techniques will be combined and tailored to suit particular applications. Novel preservation methods include polymer alloy packaging and natural peptides (compounds of two or more amino acids).

The programs will also address environmental issues associated with packaging of food products, with research into biopolymers for use as packaging materials and recycling of fibre based packaging.

The CRC Review

In late 1994, the Federal Minister for Industry, Science and Technology, Senator Peter Cook established the Co-operative Research Centres Evaluation Steering Committee. Although the review is not trying to evaluate the final achievements of the CRC program, it is examining whether the CRC program is developing processes, such as effective research support, good links with industry, good co-operation and effective education projects, to make the long term objectives achievable.

It is clearly too early to judge the success or otherwise of the existing CRCs. The CRC concept is an extremely important and interesting experiment in science policy. From the point of view of furthering materials science, and bridging the gaps between widely dispersed scientists and users of scientific information, the existing arrangements could have a significant shortcoming.

To the extent that close interaction between scientists and users is important, the most cost-effective arrangements would be close geographical clustering. This would appear to be a principle underpinning Slatyer’s original concept. To a significant extent this has not occurred — and this may be an impediment to the successful outcomes from the scheme.

However, the Department of Industry, Science and Technology (DIST) thought the cost of closer geographical proximity may be prohibitive:

> The fundamental principle of the CRC program is that research effort in Australia will become more effective through closer collaboration between the various existing public sector research groups in specific fields and through better integration of the research user into the planning and management of the research effort. While the former aspect can be achieved in some cases through relocation of existing efforts into a single site, the costs of doing so is likely to be prohibitive (sub. 58, p. 2).

A completely different, but significant problem identified by a number of participants relates to difficulty of access to CRCs (and, most importantly, their research output) by firms, particularly, but not exclusively, SMEs, which are not formal members of a CRC. Clearly, there are difficulties involved in bringing existing or potential competitors together in what are ‘joint venture’ research arrangements.[1] However, there is a public good aspect of CRCs and the widest possible sharing of benefits is another issue which the present review could fruitfully consider.

A review is currently underway of the CRC program and no doubt these questions will be addressed as part of the review.

3.5 Universities

Materials research is an important activity in a number of Australia universities. New and advanced materials research at universities in Australia ranges from

1 It can be noted that Morris-Suzuki (1994) claims that this issue was not a problem in collaborative R&D in Japan, where industry associations and government research agencies shared R&D, but individual firms in the area competed fiercely.

specific centres researching materials to basic research in areas such as applied physics, chemistry and engineering.

Universities are involved in many of the CRCs mentioned above. However there are many universities undertaking some of their materials research outside the CRCs.

Due to the inter-disciplinary nature of materials research, it can occur in a wide variety of departments in any one institution. Some universities have formed centres to co-ordinate materials research and teaching. One example of this is at the University of Technology, Sydney.

> The Centre for Materials Technology at the University of Technology, Sydney is a multi-disciplinary group of researchers investigating all aspects of materials preparation, characterisation and application. The Centre has its nucleus in the Faculty of Science (Materials Science, Chemistry and Physics) with significant activity also in Electrical Engineering. The focus of the Centre is on materials characterisation and applications of materials, a growth area in the Centre is the development of new materials and new applications for recently synthesised-materials (sub. 10, p. 1).

Universities provide expertise and testing facilities to businesses, often on a fee-for-service basis. An example of this is the University of Western Sydney (UWS).

> The UWS — Macarthur has agreed to provide a testing service to the Plastics and Rubber industries in NSW on a fee for service basis (sub. 31, p. 1).

The main tertiary institutions involved in materials science and their specific focus are listed in Table 3.4. The list does not include universities and their respective departments or centres where materials science is not the main focus.

The role of research institutions and universities in assisting new materials producers and users

The main strength of Australia's universities and principal research institutions is to be a repository of state-of-the-art knowledge on which the community can draw — including firms producing or using new and advanced materials.

Where the focus is applied research with a potential commercial application in mind, there are obvious advantages in forming links with industry.

It is generally not possible for business, particularly smaller producers and users, to keep abreast of emerging trends in new and advanced materials, particularly in a field where developments are rapidly occurring. Research institutions and universities can play a crucial role here. However, they can only do so if they have the resources (in terms of laboratories and researchers) to match the best in the World. Various participants have cast doubt on the

Table 3.4: New and advanced material research at Australian universities

Institution	*Centre, School or Department*	*Main research activities*
ANU	Centre for the Science and Engineering of Materials	Materials characterisation Electro-optic materials Surface active materials
Curtin University of Technology	Physical Sciences	Powder metallurgy
Monash University	Materials Engineering Centre for Advanced Materials Technologies	Polymer engineering Steel alloys Light metal alloys Ceramics Corrosion Optical materials
RMIT	Aerospace Engineering	Composites
University of Queensland	Mining and Metallurgical Engineering	Metal casting Wear resistant steels Corrosion and surface coatings Powder metallurgy Amorphous metals
University of NSW	Materials Science and Engineering Centre for Applied Polymer Science	High temperature corrosion Steel metallurgy Ceramics Polymer chemistry
University of South Australia	Chemical Technology Ian Wark Research Institute Gartrell School of Mining and Metallurgy	Surface properties and treatments Polymer chemistry
University of Sydney	Centre for Advanced Materials Technology	Composites
University of Technology, Sydney	Department of Materials Science Centre for Materials Technology	Ceramics Materials characterisation Optical materials
University of Wollongong	Materials Engineering Chemistry	Steel processing Welding HTCs Polymer Chemistry

Source: Compiled by the Industry Commission.

ability of Australian research institutions to play this role. This they claim is a consequence of a 'downgrading' of science in general, and the problem is exacerbated by the diminished attention paid to materials science, and maintenance of state-of-the-art laboratories in universities.

The issue of better linking industry and educational institutions, and the role the latter can play in raising awareness of materials is discussed further in Chapter 10 and Appendix C1.

3.6 Research and development assistance

Participants drew the Commission's attention to the amounts of money spent on new materials research in the US, Japan, and Europe. The Federation of Materials Societies estimated that in the US alone about US$1.18 billion was spent on materials research in 1988.

Several large programs dedicated to advanced materials have been established overseas, including:

- US Advanced Materials and Processing Program (AMPP);
- Industrial Science and Technology Frontier Program in Japan;
- EU programs, such as the Basic Research in Industrial Technologies for Europe (BRITE) and the European Advanced Materials Program (EURAM); and
- the *Materials Matter* program developed by the Department of Trade and Industry in the UK.

Further information on these programs is provided in Appendix C2.

Assistance to materials research in Australia

The majority of assistance to research in Australia is not targeted specifically at new and advanced material producers and users.

Both the Commonwealth and, to a lesser degree, State Governments, have developed schemes to help promote private sector research and development that potentially assists new and advanced material producers and users.

Information provided to the Commission suggests that many new materials manufacturers or research organisations have taken advantage of one of these generic forms of government assistance. Businesses have found that these programs are fairly well conceived and targeted, although some expressed dissatisfaction with the administrative burden associated with applying for assistance. However, some of these concerns have been addressed by changes to the schemes through the *AusIndustry* initiatives.

Tax concessions for research and development

Since 1985, Australian companies have been able to claim 150 per cent of their R&D expenditure as a tax deduction. In 1993–94, this represented about $415 million in tax revenue foregone. The *Working Nation* White Paper changed this program, by reducing the threshold for eligible tax expenditure on R&D from $50 000 to $20 000. This change was aimed at bolstering the accessibility of research to small- and medium-sized enterprises (SMEs). To claim the concession companies must register each year with the IR&D Board.

Small-sized businesses in the pre-commercialisation phase of developing a material, and which were not making any profits to ‘write-off’ against R&D expenditure, obviously did not find the 150 per cent tax concession for R&D to be of any benefit. However, larger, established companies stated that the scheme was useful.

R&D syndication

A program for the syndication of research is also in operation. Syndication, in this sense, occurs when a researcher or inventor joins with others (for example, existing firms with a similar interest) to participate in a major research project, viewed as too risky for one single business to undertake, or beyond the financial resources of the researcher or inventor. The latter provides research skills while the other partners provide financial backing.

Syndication assists researchers and innovative firms which are not yet profitable to join with established companies to provide resources for research and development.

> Syndication is a specialised part of the tax concession program which provides the opportunity for projects which are too big or too risky for any one company to undertake, to be carried out by a group of companies. It is essentially a financing scheme that provides companies with access to scarce critical-mass finance for close-to-the-market R&D projects (DIST, 1994a).

Changes as a result of the *Working Nation* White Paper, include lowering the R&D expenditure threshold for participation in R&D syndication from $1 million to $0.5 million.

The main concern participants expressed about syndication was the high legal costs associated with forming agreements between the parties. However, the Commonwealth Government is attempting to reduce these costs by developing a generic syndication structure under the *AusIndustry* program.

If the tax concession schemes are not suited to new and advanced materials development, producers and users may still utilise the Competitive Grants Scheme.

Competitive Grants for Research and Development

Competitive Grants for Industry Research and Development are available for researchers and businesses that cannot take full advantage of the tax concession schemes. The IR&D Board stated:

> The program is also able to support:
>
> - collaborative R&D activities that are high risk but could provide extensive benefit to Australia; and
> - trial and demonstration activities between technology developers and potential customers (sub. 59, p 3).

The competitive grants program provides support to industry of around $40 million a year. Indeed, several firms used as illustrative case studies in this report had their beginnings with GIRD grants (such as Flexichem and Cochlear).[2]

A number of participants found that although the grants were useful (and often the only way in which their projects could go ahead), the administrative burden of applying for a grant was excessively bureaucratic. However, they recognised that this must be weighed up against the need for accountability.

The application procedure for the Competitive Grants Scheme has recently been simplified. Applicants are now required to submit an expression of interest for IR&D Board Committee consideration. If the project is considered to meet specified criteria, the applicant is invited to submit a full application for consideration.

Under the new scheme, the Manufactured Products Committee of the IR&D Board is responsible for assessing applications concerned with the development of new and advanced materials.

Concerns were raised over the lack of feedback on unsuccessful applications. If an application was refused, applicants were not given advice on how they could improve their proposal, and were not given a chance to 'talk to' their submission.

The IR&D Board is addressing these concerns:

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[2] GIRD (Generic IR&D) grants were an early program of the IR&D Board which has now been incorporated into the Competitive Grants Scheme.

> The Board is aware of recent complaints by applicants about lack of direct access to committees. This matter was considered at the IR&D Board meeting of 4 December 1994. Members discussed mechanisms for achieving a balance between concerns that the Board be more accessible to applicants and the requirement that the program is administered efficiently, effectively and with due consideration to matters of equity. It is proposed, that where judged necessary, Board or Committee members will have direct contact with applicants by phone or in person, particularly to clarify issues of concern (sub. 59, p. 4).

Notwithstanding perceived or real shortcomings, many felt that the various assistance schemes were encouraging a new materials 'culture' in Australia, and that there was a more co-operative pursuit of materials research due to the networking which was encouraged. ANSTO said in reference to the GIRD (and CRC) schemes:

> The schemes have been successful in producing a change of culture and have encouraged a more cooperative pursuit of materials technology development between the various sectors. The funding of projects has been relatively modest by international standards and it may be too early to judge the outcomes of the R&D (sub. 29, p. 1).

Concessional loans for the commercialisation of technical innovation

Because it is considered that financial capital is not readily available to SMEs, the Commonwealth Government has put in place a scheme of concessional loans for the commercialisation of technical innovations. Concessional loans are available for technology orientated firms with less than 100 employees which have the capacity to successfully manage the commercialisation process. The loans can provide up to 50 per cent of the finance for commercialisation. Concessional rates of interest apply to the loans after three years. This program will provide $48 million over a period of four years.

Grants from the Australian Research Council

The Australian Research Council has a number of research granting schemes which support basic and applied research in the universities. The programs of most importance in the materials field are:

- Large grants — materials and materials processing is a priority area in this program;
- Collaborative grants — these support collaboration between industry and the universities and in the last round 20 per cent of the approved projects related to materials R&D;
- Postgraduate Research Awards (Industry) — this scheme supports collaboration with industry; and

- Special Research Centres and Key Centres — six of the 18 Special Research Centres are concerned with materials R&D.

Major National Research Facilities Program

The *Working Nation* White Paper established a major national Research Facilities Program with total funding of $60 million over eight years.

Initial applications are currently being reviewed with a decision expected by June 1995. Of the 35 applications currently being assessed one is related to the materials area, namely, a proposal to establish a high energy laser materials processing facility. Funds will, however, only be sufficient to fund two or three of the 35 applications.

National Nanotechnology Facility

Funding of $3 million has been provided in 1993–94 for the establishment of the National Nanotechnology Facility to support the work already undertaken by 13 research groups in Australian universities, DSTO and CSIRO. The facility will be run by a consortium of four CRCs. It should assist Australian firms which aim to enter this innovative field. Further information on nanotechnology is provided in Box C2.1.

4 COMMERCIALISATION OF NEW AND ADVANCED MATERIALS

Commercialisation is the process that comes after research and development, and encompasses all other stages of a product's life-cycle, up to and including production and sale. Typically, the activities in the process include:

- market analysis, which may indicate the need for further research and development to refine the product;
- pilot plant or prototype construction;
- development of the processes and procedures necessary for the efficient manufacture, distribution and marketing of a product or process;
- establishment of a full scale production facility, including tooling and design for manufacture; and
- production and sale.

Because commercialisation often involves further research it can be difficult to delineate commercialisation from research and development. Nevertheless, commercialisation is usually identified as the most expensive part of the three-stage process of research, development and commercialisation.

The initiative for beginning the commercialisation process can stem from two sources:

- *technology* or *supply push* — when product development is a result of research or a technical breakthrough; or
- *demand pull* — when there is a pre-existing market demand for a new or better product.

The significant difference in the commercialisation process for technology push products compared to demand pull products is that for the former the potential purchasers need to be made aware of the new product and the benefits of its use. It is only through the provision of this information that demand for the product will be generated.

There have been many studies conducted on the process of commercialisation, but few which specifically refer to materials. Two recent Australian studies are the report by the Task Force on Commercialisation of Research (the so called Block Report, 1991) and the Business Council of Australia's (1993), *Managing the innovating enterprise*. Reports dealing with innovation and commercialisation have also been produced by the Bureau of Industry Economics and the Department of Industry Science and Technology.

4.1 Some crucial issues

In relation to the commercialisation of new materials specifically, the study *Materials Matter*, conducted in the UK for the Department of Trade and Industry, highlighted the following problems:

> Innovation in new materials has a number of characteristics that distinguish it from most other forms of technical change. It is distinctive in that the relationship between players involved in the innovation process is more complex, the time required for successful commercial exploitation is longer, and the size of investment capital required is usually larger than for most other forms of technological development (Department of Trade and Industry (UK), 1989b, p. 20).

These three problems — complexity in relationships, time to achieve returns, and the scale of the investment — have been raised by participants in the course of the inquiry.

Complexity

The issue of complexity arises from the relationship between organisations undertaking research and development and those responsible for commercialising a new product. A characteristic which typifies commercialisation of a new material is that development of both the material and the end product in which it is incorporated move in parallel. Therefore, the organisation undertaking the product commercialisation must have either the technological capability to fully understand the science underlying the new material or it must have worked very closely with the organisation responsible for developing the material. The Centre for Materials Technology at the University of Technology, Sydney, stated that:

> Real technology transfer can only occur when industry and research organisations have been working together on a problem from the early stages ... Acquiring a new technology either requires understanding of all facets of a technology, or being involved in the research and development phase (sub. 10, p. 2).

The decision to replace a traditional material with a new and advanced material will often require changes to the production process and product specifications. The IR&D Board expressed the view at Public Hearings that, while larger companies in Australia are aware of, and are using, new and advanced materials, their more widespread use in Australian industry will only be achieved by encouraging smaller businesses to begin using these materials (transcript p. 162). At present, these smaller businesses may be unable, rather than unwilling, to use these materials.

Time and patient capital

The long time taken for commercialisation of materials or materials production technologies is another problem, particularly if the product or process is radically different from that which exists. Inquiry participant Mr Russell Jackson noted:

> Considerable time can elapse between the release of a new material and its application in industry. This is because the material may need further process refining of its properties in order to make it more user-friendly to potential customers (sub. 13, p. 2).

Often this is not appreciated by lending institutions or other investors, creating funding difficulties. Professor Tegart, University of Canberra, commented that:

> ... time horizons for investment returns [are] say 2-5 years compared to the 20 years needed as average for commercialisation of an advanced material (sub. 4, p. 4).

The Australian National University (ANU) concurred, noting:

> The long timescale for commercialisation of most new materials ... requires a source of capital which is unusually patient (sub. 51, p. 6).

Scale diseconomies

The high cost and investment required is another common problem in the commercialisation of new materials relative to traditional materials. This is largely due to long development times as well as low production volumes that prevent the achievement of scale economies. By definition, new and advanced materials will be produced in low volume — when a material comes to be produced in high volume it is no longer new or advanced.

High cost, however, does not unduly hinder new and advanced materials development for military use, but is a disadvantage for commercial producers and users. Professor Tegart from the University of Canberra, commented on this:

> Because advanced materials may cost as much as 100 times more on a weight basis than conventional materials such a steel or aluminium, their first use has generally been in the less cost-sensitive areas ie military. However, because military production runs are generally small, there is little incentive to develop low cost, mass production manufacturing processes that would make the materials more attractive for commercial application (sub. 4, p. 4).

Size of the market

The process of commercialising new materials presents particular problems because of Australia's industry base. It is one in which there are few Australian user industries and only small quantities of any particular material are demanded. Thus, for most of the materials, an Australian producer is likely to be reliant on sales into overseas markets if commercialisation is to be successful.

The NSW Department of Mineral Resources noted that:

> Companies engaged in research, development and commercialisation of new and advanced materials are largely dependent on accessing export markets, as domestic demand alone for these materials is generally insufficient to support such industries (sub. 5, p. 2).

However, as the ANU observed, overseas market access is not an easy panacea for Australian companies:

> One of the greatest difficulties [in commercialisation] arises from the fact that only the large trans-national corporations have ready access to worldwide markets for new materials (sub. 51, p. 5).

Awareness of materials

Knowledge of advances in materials science, the technical demands of working with new and advanced materials, together with low levels of material processing skills in industry, can create difficulties in the commercialisation of products incorporating such materials. The National Materials Advisory Board (US) acknowledged this when it reported:

> Advanced materials technology often eclipses the experience and knowledge base of practicing design engineers and manufacturing engineers (1993).

In agreeing with this view, Professor Grant Steven suggested that without the technical competence and experience in working with advanced materials technology, firms would be reluctant to experiment by substituting new materials for more traditional ones.

> It is often the various 'fears' that get in the road of the proper decision to change for a 'better' (newer) material. Universities, material suppliers and software suppliers could do much to 're-educate' the potential user of new materials (sub. 12, p. 2).

Unproven products

Another factor is the risk in commercialising unproven new materials. The ultimate test of product performance is its use. However, testing requires a final product to be assembled and used. Until this has occurred, there is no certainty that a material developed in the laboratory will perform to expectations in the field. The Centre for Materials Technology, University of Technology, Sydney, explained that:

> Significant problems are faced in the introduction of new materials into production ... In many cases companies do not want to 'experiment' with new materials (and therefore new processes) for benefits which have only been demonstrated in the laboratory (sub. 10, p. 2).

The Department of Materials Engineering, Monash University, is currently facing this problem of an 'unproven' product hindering the funding and hence commercialisation process of fibre optic sensors.

> ... it has proved very difficult to obtain funding for the next stage of prototype development. Industry generally takes the view that it is cheaper to buy the I.P. [intellectual property] when the concept is proven, [and] venture capital groups want to see an 'independent market analysis' (sub. 32, p. 2).

While this caution and reluctance to experiment is in one sense understandable, the delay in waiting until a concept is proven, often negates any competitive advantage that may have arisen from being first into a new market niche. Nevens *et al* found:

> ... companies that are first to market with products based on advanced technologies command higher margins and gain share (1990, p. 155).

Demonstration projects

During the course of the inquiry, participants have noted that demonstration projects may provide a means of reducing the risk associated with the first use of a product. The NSW Government identified demonstration projects as:

> One option for increasing awareness and facilitating the replacement of current practices with new technology (sub. 50, p. 3).

A demonstration project would involve significant cost in using the new material in a full scale and fully functional product. Nevertheless, the Department of Trade and Industry (UK) comment that such projects can provide:

> ... confidence in new technologies before the irrevocable commitment of major project funding [is required]...
>
> [Consequently] demonstrators will speed up the process of industrial exploitation of innovations in the materials field and they will also encourage further innovations (1985, pp. 50–51).

Organisations such as the Queensland Manufacturing Institute (QMI) provide a capability for the production of prototypes which are an essential component of any demonstration program.

4.2 Diffusion of materials technology

Technological diffusion is the process by which knowledge is transferred from originators to purchasers or imitators. Diffusion is not simply a matter of purchasing technology 'off the shelf' — users of new technology require an understanding of the particular technology and how it should be incorporated into the production process. The diffusion of materials technology has recently been reviewed by Wardrop (1992).

The initial source of much new and advanced materials technology in Australia are trans-national enterprises with Australian subsidiaries. For these firms the focus tends to be on the adaptation of materials for use in Australian products; that is, on the incremental improvement of materials and material processes. However, the process of transfer of technological knowledge from parent company to subsidiary is not always straightforward.

Some participants consider that Australia's geographical isolation is a barrier to the diffusion of technology. Even within trans-national businesses, some Australian subsidiaries are not fully aware of the activities of the parent and its subsidiaries in other countries.

The level of awareness and rate of diffusion of advanced technology generally is thought to be sub-optimal in Australia. The Prime Minister's Science Council, when referring to advanced manufacturing technology (AMT), of which new and advanced materials are a subset, found that:

> The level of adoption of Advanced Manufacturing Technology (AMT) by Australian manufacturing industry is uneven and generally lagging behind that in competitor nations (1992, p. 8).[1]

The prevalence of small producers and, particularly, users of new and advanced materials in Australia may militate against rapid diffusion. The ABS found:

> ... a strong relationship between the employment size of an establishment and the acquisition of advanced technology. Larger manufacturers were more likely to be using advanced technology (1993a).

The lack of suitable skills within businesses may be another reason for a slow rate of diffusion. The Taskforce on Commercialisation of Research expressed the view that:

> There is ... a lack of skills in bringing about the transfer of technology from the public sector to the private sector, to enable the rest of the commercialisation process to take place (1991, p. 3).

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1 AMT encompasses advanced materials and their processing, together with computer-aided aspects of design, production and management systems.

How these various impediments are being — or can be — addressed is the subject matter of Chapter 10.

5 SUPPLY ISSUES

New and advanced materials are described as such because of their properties, which in turn determine their suitability for use in particular applications.

5.1 Production technologies

The properties of materials are often determined as much by their processing and the production technologies used, as by the raw materials from which they are derived. Consequently, technical change may involve either a product or process development, or both. The technology may be embodied in physical items such as tooling and equipment, or in process knowledge of how such equipment is to be used effectively.

Processes can impart new properties to a material, be it new or traditional. They can also be a key element in a material's commercial prospects by reducing costs and creating a competitive advantage which can influence the extent of demand. For example, heat treatment is critical in determining the quality of some metal products. In the case of advanced hot-worked steels, incorrect heat treatment can render the part useless (sub. 13).

In certain circumstances, a production technology is so critical that a new material cannot be produced without it. For example, Surface Technologies in Melbourne uses the Physical Vapour Deposition (PVD) method to deposit ceramic titanium nitride on the surface of metal machine tools. In coating the substrate with titanium nitride, a new coated metal (or material) is, in effect, produced. Further, the ceramic-coated metal in the tool has quite different properties from an uncoated metal tool with which it competes, and which it potentially replaces.

The production technology selected for manufacturing new materials or production of a final product will affect the efficiency and cost of production. For example, the powder metallurgy process provides an alternative to the traditional steps of forging or casting hot metal, and in the production of some metal components it eliminates machining (see Appendix B8).

The importance placed on production technologies is evidenced by the continued attempts to improve them. For example, there is now a global trend to develop continuous, rather than batch production technologies, thus reducing production costs. CSIRO have noted this trend in steel production, aluminium production cells, and casting of billet, slab and strip (sub. 19).

Finally, the development of improved or new production technologies can lead to a decrease in the rate of uptake of new and advanced materials if the new processes also reduce the cost of competing with traditional materials.

5.2 Economies of scale and scope

Economies of scale occur when increasing production volumes permit significant lowering of average cost. Because of the small volumes in typical production runs, scale economies are rarely exhibited and are not a feature of new and advanced materials supply. Once volumes become large and scale economies occur, the material is, by definition, neither new nor advanced.

Economies of scope are likely to be more important for some new materials than economies of scale. Economies of scope are characterised by cost reductions achieved through the jointness of some costs in producing differentiated products. The associated increase in product variety enables producers to be flexible in fulfilling customer needs. There are significant economies of scope where new and advanced materials (such as engineering ceramics) are tailor-made.

Economies of scope can be difficult to achieve. The use of more specialised materials, unique design, and the level of skills required are all expensive to duplicate, and can discourage entry into niche markets. The market for engineering ceramics has only been able to support a limited number of domestic engineering ceramic producers, each having exploited the available economies of scope through specialist production.

5.3 Access to technology

There are various means whereby new technology can be acquired. Four common methods are:

- a direct tie-up with a firm which already has the technology, usually a foreign firm, exchanging some financial independence for the benefits of access to technology;
- purchase of a licence to use patented knowledge;
- ‘reverse engineer’ existing technology; and
- undertake original research and development.

In Australia in the present era, new technology is usually obtained through research or the purchase of licences, although some exchange of knowledge occurs through business networks.

Research may be completed in-house, contracted-out or done in collaboration with organisations such as CSIRO and the universities. Some manufacturers have been concerned about both the cost of externally generated research and the propensity for research institutions to make unrealistic market forecasts and projections for their research output. Such unrealistic market forecasts may be a consequence of research institutions being requested to justify research applications on the grounds that commercial success will result.

Research and development undertaken by large trans-nationals in Australia tends to be applied research directed at adapting products developed overseas, rather than basic research. This is particularly so in the production of advanced polymers and advanced polymer composites. This behaviour is consistent with the results of other studies of research activities by trans-national firms. Such studies indicate that these firms undertake little of their basic research outside the country in which they have their headquarters. There are exceptions, however, where research is undertaken overseas to utilise the services of particular scientific specialists (Caves, 1982).

Most new materials technologies can be purchased from overseas. Research associated with new and advanced materials occurs mainly in the US, Europe and Japan. Other nations involved to a significant extent are (in order of significance) Germany, UK, France and Sweden (Malaman, 1990).

Licensing is a common means of obtaining technology. For example, ACL Bearings, Tasmania, produces powders and components using powder metallurgy, having obtained the technology by acquiring a license for the main piece of machinery necessary for powder metallurgy, namely the press. Similarly, Australian firms producing and using polymers and ceramics have obtained licenses to gain access to technologies developed overseas. However, the purchase of technologies can involve a number of problems. Several case study participants indicated that where it is proposed to purchase technology, the innovators, who are potential competitors, are often unwilling to licence the latest technology, wishing instead to retain control of the intellectual property.

5.4 Control of intellectual property

The term ‘intellectual property’ refers to knowledge that has some potential commercial value. Intellectual property usually results from research and development.

Patents can be sought by an innovator to ensure the exclusive ownership of knowledge or intellectual property. Patents give the innovator exclusive legal rights to exploit an innovation for a period of time. Such rights allow innovators to sell the intellectual property through licensing agreements, should they wish to.

The justification for granting exclusive rights is that without legal protection the benefits of innovation would not necessarily be captured by the innovator, and the incentive to innovate could be diminished. Hence, many countries have developed a system of intellectual property rights using patents and technology licences. The holders of these rights are able to seek legal redress if anyone imitates the invention within the period for which intellectual property rights have been granted.

Notwithstanding the safeguards that are meant to be provided by the patent system, some participants in the inquiry have chosen to rely on secrecy to protect their intellectual property. This has been because they are concerned that patenting their technology would alert their competitors to the development. This concern is particularly relevant with new materials, where innovations often involve new processes rather than new products, and so are relatively difficult to protect from imitation using the patent system.

Potential developers of new materials may also be reluctant to be involved with outside research organisations or to seek venture capital, as intellectual property is potentially more difficult to protect in these circumstances.

Morris-Suzuki (1994) reports that in the past, if not the present, there were examples of scientists not providing all the crucial details of a technological development in their publicly-released material. This was to frustrate other scientists who might attempt to replicate experiments. It can be noted — with some dismay — that this practice is contrary to the fundamental principle underpinning the scientific method. To the extent that the practice remains it illustrates the tensions which can arise when science and business ethics come face-to-face.

5.5 Technology adoption

With respect to new and advanced materials used in Australia, and the processes involved in their use as intermediate products, most research developments have been incremental improvements to products or processes originally developed overseas.

A number of factors can influence the rate at which new technology is adopted. Generally, the pattern of adoption over time follows an ‘S’ shaped curve. Initially the rate of adoption is slow, its adoption is then more rapid throughout the population of potential users, and finally tapers off as the technology becomes widely used.

Technology adoption is not simply a question of buying technology. In order to incorporate new processes and materials into Australian production, detailed knowledge of how the technology works is necessary. Inquiry participants who had purchased advanced processing techniques reported that often the technology had to be adapted to suit Australian conditions — and some simply did not perform to manufacturers' specifications. This means that the purchaser of technology has to either have these skills in-house or else acquire them.

5.6 Education, training and skills

Education and training are fundamental in the development of human capital and improving the economic performance of any technology-dependent industry. The role of education and training in the proper utilisation of materials is discussed in more detail in Appendix C1.

Training is provided at three different levels: University, TAFE, and in the workplace (including informal 'on-the-job' training). Continuing education is essential in keeping abreast of new and emerging trends in technology, particularly in areas where it is developing rapidly.

An appropriately educated and skilled workforce is required for cost-effective specification at the product design stage, and the subsequent incorporation of new materials in products.

Participants stressed the importance of certain core or generic skills. In particular, materials selection and compatibility within products, design requirements, and an understanding of processing technologies were raised as fundamental skills.

Participants also emphasised the importance of having a range of professional groups involved in the design and manufacture of new and advanced materials. The view was that this would increase the knowledge base, and provide the necessary inter-disciplinary approach for the utilisation of materials. It would also facilitate the networking for the pooling of resources and ideas.

One reason to facilitate networking is that in Australia manufacturing businesses tend to be small- to medium-sized enterprises (SMEs) with limited resources. Training of staff (so they are aware of new developments with respect to materials) and networking amongst academia and industry will enable greater awareness of materials. Participants claim that, generally, material producers and users are unaware of the properties of new and advanced materials:

> [These companies are] often technically underqualified. [They are] not capable of making use of what is currently available technically in the World, and they have great

> difficulty in recognising the steps which they should be taking to step from their current position into a World-competitive position (transcript, pp. 115–116).

There is a related and (as discussed below) inter-dependent issue. The materials content in science and technology courses — be they at university or trade level — depends to a large extent on the demand by industry for particular training. This highlights the importance of awareness and anticipation of need. Only when it is understood that a certain level of knowledge and skills is required (for product design and manufacture with new and advanced materials) will the demand for these skills (and the courses that provide them) increase.

As a general rule, awareness and demand for training in science and engineering is dependent on the size of a country's manufacturing sector, industry–government–research institutional relationships, and community attitudes to science and technology. Australia has a very small manufacturing sector relative to the major new and advanced material producer countries. Also, it does not have a 'culture' of interlocking business, government and education sectors. These factors inhibit the development and diffusion of advanced materials and associated technologies in Australia.

Improvements in the awareness of technological developments can be achieved by creating links between education, research institutions and industry. These links are increasingly being developed through attitudinal changes arising from new policy directions and funding mechanisms. Improved linkages will provide a feedback loop on the level of demand for training. That is, increasing skill levels through more materials related courses will lead to greater awareness and a subsequent increase in the use of new materials.

In addition to improved linkages, many participants argued that more resources should be allocated to materials training in engineering, industrial design, architecture and similar courses.

Awareness of the properties of new and advanced materials by both students and industry is the first step in fully exploiting the potential of these materials. Students (who ultimately become managers or technical workers) must be made aware of the range of materials available to design a particular product, and they must understand the relative merits (or otherwise) of incorporating new and advanced materials rather than traditional materials in these products. Manufacturers must also understand the potential benefits in using new and advanced materials, or these materials will not be fully utilised.

New and advanced material producers or users lacking the technical expertise to develop or alter a technology can engage research institutions to do this for them. For example, the University of South Australia has been working with General Motors Holden to improve a die coating process purchased from Japan.

Through collaboration with Holden and smaller firms, the University has improved the process to better suit local conditions and materials. For small firms such relationships with research institutions can also offer an avenue for gaining access to otherwise unobtainable technologies.

5.7 Collaboration

Collaboration involves sharing an activity and the risks and benefits arising from that activity, for example co-operation between two businesses to develop a new product. Both share the risks associated with research and development, both contribute resources to the project in the form of human capital and equipment, and both share in the benefits of accessing a new market if the commercialisation of the new product is successful.

Co-operation can encompass bulk purchasing, sharing the cost of equipment, research and development, training, market and technology monitoring and exchanging technical information.

Collaboration with overseas businesses, governments and research institutions allows firms to keep abreast of what is happening in terms of new developments and new applications.

Typically, collaboration is characterised by a long-term relationship that lies somewhere between vertical integration and arms length market transactions. It may involve equity links; be formal or informal; involve two businesses or more; be wholly domestic or international and cover a single or a range of joint activities and objectives (Centre for Technology and Social Change, 1990).

Businesses generally collaborate because in doing so they can access resources at a lower cost, or access knowledge and technology that they would be unable to develop on their own. The high cost and uncertainty of success in R&D can prohibit businesses (especially small ones) from undertaking this activity. Collaboration gives small businesses the opportunity to reduce R&D costs — through economies of scale, scope and massed resources. It can also reduce the time required to enter a new area of production.

Thus, collaboration can provide opportunities for small businesses to use their resources more effectively and to offset constraints arising from limited in-house resource capabilities.

Notwithstanding the advantages of collaboration, perceptions about the loss of proprietary information is frustrating the achievement of greater collaboration. In the Commission’s view, these perceptions can be misguided, particularly when generic technologies and skills are involved.

Many participants stressed the importance of technical support for the users of new materials. Collaboration between producers and users is one way of providing important insights into how new and advanced materials should be designed in order to facilitate their incorporation into products.

The technology and processes associated with using new materials are often subject to 'learning-by-doing'. Although technology associated with new materials may be easily transferred under licensing agreements, the knowledge required to use that technology effectively is not as easily transferred. Users unfamiliar with new materials require significant amounts of support from suppliers to ensure that they are used effectively. Taylor Ceramic Engineering note that:

> ... new materials due to their associated technical nature can be confusing to users of new materials and thereby require an education period to gain awareness of the advantages of these materials (sub. 28, p. 2).

It follows that close links between new material producers and users are required to ensure that the products being developed meet the latter's needs. This is particularly important in Australia where there seems to be an emphasis on producing new and advanced materials to individual user needs.

The new *AusIndustry* program to encourage and facilitate networking of organisations to meet specific objectives will assist in this area.

5.8 Availability of capital

As stated before, Australian producers of new and advanced materials tend to be SMEs operating in very new markets. To the extent that they can afford it, they are undertaking ongoing R&D to introduce newer products and processes.

Investment in research, design and development is quite costly. Furthermore, the returns on investment usually do not accrue until some time into the future, if at all.

The access to finance by SMEs — sometimes headed by one or two individuals with technical expertise and who have invested their savings and commenced at a very small scale — is largely restricted to external sources. It is not until their size and profitability increases considerably that they can begin to rely on retained earnings. Usually they have to raise equity finance because they have little collateral to secure debt. This poses difficulties if the owners are reluctant to lose proprietary control over their technology, and most are reluctant to do so.

Another issue raised by the SMEs operating in the new and advanced material field is the cost of debt finance. Banks generally charge higher interest on loans to SMEs relative to larger enterprises. This is because they consider that, in general, the risks of being paid back the loan and interest is higher for SMEs. The Reserve Bank of Australia (1994) has noted that the difference between the cost of debt for SMEs and larger enterprises does not appear to be disproportionate given the greater risks it states are involved. Another factor which can effect the financing of SMEs is that they tend to acquire more expensive forms of funding (such as fully secured overdrafts) rather than, for example, cheaper bill financing.

Similar issues have been raised in inquiries into the banking system over a number of years, and a definite conclusion as to whether these reasons for higher costs fully explain the premium in the cost of funds to SMEs has not been reached.

With respect to equity markets, venture and development capital (VDC) markets appear to be the most relevant equity sources for SMEs. While significant levels of funds for development capital are flowing into the VDC markets, the same is not true for venture capital (ADCAL, 1994). In particular, smaller enterprises requiring venture capital, under $1 million for example, may not be adequately served in the capital market.

Although the terms ‘venture’ and ‘development’ capital have been used synonymously, they can be used to define separate classes of investment. Venture capital is generally viewed as investment in businesses which are unlisted; have a new product, process or service; do not have any financial track record; cannot offer collateral or other security; and promise high rates of growth and above average returns.

However, venture capital is sometimes defined in a more restrictive sense, describing the injection of equity for the formation and start-up of small companies specialising in new ideas or technologies (OECD, 1985). This type of equity injection is also usually coupled with the input of specialist skills (such as management, marketing, administration) which assist in identifying, evaluating and piloting potentially high growth, high-technology companies.

Development capital, on the other hand, refers to investment in businesses that have proven track records, established markets and cash flows, and require an injection of capital to realise the businesses’ full potential. Typically, development capital involves larger amounts and the returns are expected sooner than is the case with venture capital.

There may be a gap in the market caused by the low level of venture capital funds being sourced from institutional investors. Recent government changes to the Pooled Development Fund (PDF) scheme, making it more attractive to institutional investors, should alleviate some of the problems experienced by SMEs operating in the new and advanced materials field.[1]

As businesses in the new and advanced materials area often are small and require venture capital, it is possible that there is under-investment in this sector when one takes account of both the private benefits (those that can be appropriated by the investor) and the external benefits (those that accrue to the economy more generally).

If external benefits from investment in new and advanced materials can be demonstrated, market failure would exist and there could be an argument for government intervention to improve the flow of equity capital to SMEs operating in this field.

A further concern relating to finance was raised by some participants in the inquiry. It is that potential equity providers lack sufficient information (about SMEs in general and ones in the materials field in particular) to make informed decisions on the potential viability of the firms in question. It would be a further example of market failure if a viable investment is left without finance, due solely to information constraints. To the extent that it is cost-effective to do so, this market failure should be addressed.

Recent government efforts to support the establishment of a Business Equity Information Service as part of the *AusIndustry* program, should improve the flow of information to potential investors. The Business Equity Information Service will attempt to match-up investors with small firms seeking equity finance. In addition, it represents an effort to increase capital mobility, raise the awareness of equity capital as an option, and assist in disseminating management best practice to small businesses.

5.9 Marketing

Marketing involves providing information to potential customers on product characteristics, qualities, uses and price. Although producers are aware of the advantages associated with their products, potential users may not be. There is often a significant perceived risk with the first use of a product, such that customers require information concerning a material’s performance and its advantages relative to substitute products.

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1 In 1993 the concessional tax rate for PDF investment in SMEs was reduced from 25 per cent to 15 per cent. The PDF scheme was designed to alleviate the problems experienced by SMEs in obtaining equity capital. It provides for companies qualifying as PDFs to receive a tax concession in return for providing long term patient equity for SMEs.

If products incorporating new and advanced materials are more expensive than substitutes made from traditional materials, but have improved qualities or result in a lower cost on a whole-of-life basis, these attributes will have to be promoted as part of a marketing strategy.

One of the products manufactured by the company Surface Technology Coatings is a titanium nitride coated drill bit. It is twice as expensive as uncoated drill bits, but lasts up to four times as long as a non-coated drill bit.

Effective marketing of new and advanced materials requires adequate technical knowledge. Rojan Advanced Ceramics comment that:

> The type of sales force required to promote, design and sell specialised ceramics products into the market place would need to be of high calibre in terms of their knowledge of Advanced Engineering Ceramics. Generally people of such a calibre are involved in engineering functions with large companies as opposed to a sales function (sub. 49, p. 3).

Large-scale producers of these materials (which in Australia generally means subsidiaries of large overseas firms) are likely to have this expertise in-house or have specialist agents available. This is not the case for the majority of SMEs operating in the new and advanced materials field. As mentioned previously, marketing is one facet of businesses which could benefit from a collaborative approach.

5.10 Influence of government regulation

Both Australian and international regulations have the potential to impact upon the supply of new and advanced materials.

Regulations may prohibit the use of a specific material. On the other hand, regulations (in terms of safety and the environment) may provide incentives to produce and use new materials.

Some laws have World wide impact (for example, those in dominant economies relating to common products) while others are country specific. Both types are discussed below. Some focus mainly on environmental impacts, others on health and safety issues.

Environmental regulations

Environmental regulations may operate to restrict the processing of new materials which generate pollution. This is the current situation with some rare earth minerals.

Until recently, Australia exported monazite, a rare earth bearing mineral, to be processed in countries such as France. However, a global trend has developed where nations are no longer willing to accept radioactive waste originating in other countries. This has meant that overseas processors have begun to move away from using monazite in favour of feedstocks that do not produce radioactive wastes, or else end-users overseas import rare earths which have already been partially processed to remove the radioactive components. In either case, this has halted Australian exports of monazite.

Australian producers and users are, or will be, affected by overseas environmental regulations aimed at reducing fuel use in motor vehicles. These regulations, although presently confined mainly to the US and Europe, will influence automotive design World wide. A consequence will be to increase the demand for many new materials in the quest for weight reduction.

One example is the Corporate Average Fuel Efficiency (CAFE) standards in the US. In 1975, the US Federal Government, through the *Energy Policy and Conservation Act Amendments*, enacted the CAFE laws as a response to the fuel price rises associated with the OPEC decisions of the early 1970s. The CAFE standards provide an incentive for automobile manufacturers to increase the fuel efficiency of their cars.

One way of improving fuel efficiency is by incorporating lighter materials to replace heavier traditional materials. Materials such as advanced aluminium alloys, magnesium alloys, polymers and ceramics, all offer opportunities for weight reduction in the manufacture of automobiles.

A particular Australian law has some impact on the use of materials in Australia. The *Industrial Chemicals (Notification and Assessment) Act 1989* established the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) which began operations on 17 July 1990. Under the scheme, new industrial chemicals are assessed with respect to occupational health and safety, public health, and environmental impact.

NICNAS is administered by Worksafe Australia within the portfolio of the Minister for Industrial Relations, but also involves the Health Department and the Environment Protection Authority in the assessment of chemicals. On 9 October 1994, the Assistant Minister for Industrial Relations announced a review of the NICNAS scheme and, accordingly, the discussion below does not go beyond the issues raised in submissions to this inquiry.

The Plastics and Chemicals Industry Association (PACIA) contend that the current NICNAS structure can act as an impediment to the development and introduction of new industrial chemicals. Furthermore, the slow introduction of new chemicals can mean that chemicals having greater potential dangers stay in use longer (sub. 14). During Public Hearings it was also stated that the cost recovery provisions for NICNAS are causing some concerns (transcript, p. 317).

On the information available to the Commission, the following principles are important considerations in the review of NICNAS:

1. NICNAS should encourage the use of safe chemicals;
2. Harmonisation with overseas standards should be achieved where practicable; and
3. The cost recovery regime should be based on the 'beneficiary pays' principle, recognising that there are likely to be public and private benefits and costs.

The issue of regulations for experimental aircraft was raised by one participant as a substantial impediment to the development of light aircraft in Australia and the consequent use of new and advanced materials.

Mr Ross Nolan stated that:

> We have a regulation in Australia... air navigation order 101.28... [that] includes things like experimental and developmental aircraft. It says... that an Australian designer has to meet a multimillion-dollar standard for his prototype. No other country in the World has such a barrier (transcript, p. 370).

The Commission was not able to fully inform itself on this issue in the time available and referred the matter to the relevant authority.

5.11 State government involvement

As a general rule, State governments are keen to have value-adding activities undertaken in their respective States. A variety of incentives are offered which can influence the development and use of new and advanced materials. The following is a description of approaches in three States, where there is some emphasis on adding value to mineral resources.

The Western Australian Department of Resources Development has a New Materials Processing Industry Strategy. The aim is to increase the level of value adding by encouraging the minerals sector to become further integrated and develop downstream processing of its raw materials resources. The government assists with investment and infrastructure development, market assessment, and training.

The NSW Department of Mineral Resources has called for expressions of interest in the development of an Electrometallurgical Industrial Park. If industry displays a sufficient level of interest, an inter-agency working group will be established to develop an action plan to oversee the planning and commencement of the industrial park. To encourage 'appropriate project developments', the NSW Department of Mineral Resources is considering incentive arrangements to assist with start-up costs.

> The Department is currently developing the concept of a dedicated Electrometallurgical Industrial Park (EMIP) in New South Wales as a means of encouraging investment in power intensive minerals processing projects. Many of the potential projects that could be located at such a park include new and advanced materials (eg specialty metals, advanced ceramics and special alloys) (sub. 5, p. 1).

The Queensland Government places emphasis on value adding activities. For example, the Queensland Department of Business, Industry and Regional Development has provided substantial assistance to the Australian Magnesium Research Development Project in Rockhampton, as well as assistance to downstream processing (such as die casting) and the establishment of an 'industrial park' at Pinjarra Hills.

6 WORLD WIDE DEMAND CONDITIONS AND TRENDS

Demand for new and advanced materials depends to a large extent on whether they are competitive as substitutes for traditional materials — taking into account any price premium they can attract because of superior performance or manufacturing cost savings associated with their use. The assessment of their competitiveness is also affected by uncertainty and risk — both real and imaginary.

New and advanced materials are attractive to users for their superior mechanical properties, or special electrical, optical or chemical properties. Because of their superior performance, they are selected for use in demanding environments, where traditional materials will not perform satisfactorily, if at all. New and advanced materials are often tailored or custom-made to meet specific requirements (US Bureau of Mines, 1991).

The US, Japan and Europe are the major producers and users of new and advanced materials. Demand in the US stems mainly from the military, aerospace, electronic and automotive industries. In Japan, demand is mainly derived from the electronic and automotive sectors. Demand in Europe is driven less by the military and more by the automotive and aerospace industries.

In Australia, demand exists in the automotive industry, biomedical applications, components for overseas aircraft manufacturers, mining, agriculture, boat and ship building.

Further details are contained in Appendices B1 to B12.

6.1 Substitutability and performance–price trade-offs

New and advanced materials can replace existing (traditional) materials. Where replacement occurs, a new material is substituted for another based on a trade-off between the material's price and its performance. Other factors in this trade-off or substitution decision include the ease of incorporating the new material into the production process, the skills required, and environmental factors such as fuel efficiency and recyclability.

By definition, new materials are not used widely when they are first discovered or formulated, production volumes are low, processing technologies are usually still being refined and therefore they are more costly to produce than traditional materials (OTA, 1988). For these reasons, prices tend to be high for new and advanced materials relative to traditional materials.

The higher cost of new materials can slow their uptake. Where the price of the material is higher than traditional materials, or it is more costly to incorporate into a product, the performance characteristics of a product must be valued by the final consumer if the new material is to be used in lieu of a traditional material.

Given the diversity of materials that are the subject of this inquiry, it is difficult to generalise about their price and performance characteristics. However, certain common themes emerged from the case studies.

Cost and performance requirements tend to be user-specific. The aerospace, military and biomedical industries are likely (within limits) to place greater emphasis on performance than price considerations, whereas the automotive industry, and to an even greater extent the building and construction industry, are more concerned with price. Regulations, in the US at least, are also considered to be a particular impediment to the use of advanced materials in the building and construction industry (OTA, 1988).

Within the US automotive industry, a recent survey examining materials selection ranked material prices and processing costs as the most important criteria, with performance considerations such as weight and corrosion-resistance being less important. Although environmental and safety issues were considered to be important, they were ranked below price and performance considerations (University of Michigan Transportation Research Institute, 1994).

Another factor affecting substitutability is the time frame involved. Planning lead-times for new products are typically four to six years in the automotive sector, and twelve to fifteen years in the aircraft industry. Once a new product has been selected and the manufacturing processes decided upon, advanced materials will not need to be purchased until the product goes into production. This can be some years after the original decision to use a particular material, because of the long-term planning involved.

6.2 User awareness

As discussed in Chapter 4, a common concern among new and advanced materials producers is that user industries are not sufficiently aware of the characteristics of the materials. This lack of awareness is considered to be a factor impeding demand for new and advanced materials.

Users are not always fully aware of the most up-to-date developments because materials are usually undergoing continual incremental improvements, and lags normally occur in the uptake of innovations.

Potential purchasers of materials need to take a whole-of-life (or life-cycle) approach to assessing the cost of new and advanced materials. Potential users might be unaware that a new material's superior performance can reduce failures and breakdowns of equipment and machinery and thereby reduce production costs. Although a new material may be more expensive to purchase than the competing traditional material, awareness of the lower whole-of-life cost of the material can lead to its selection as the preferred alternative. An example is the use of ceramic coatings, where increased wear-resistance can lengthen useable life, thereby reducing the overall cost of tooling equipment in industry.

Rojan Ceramics provided an example of the superior properties of a silicon carbide-based MMC over a alumina based ceramic:

> ... an Australian manufacturer was able to source from overseas a revolutionary metal matrix composite material (MMC) which is silicon carbide based. This MMC has extremely good wear resistance and found a niche market in the linings of hydrocyclones in the mining and mineral processing industry. Previous to the availability of this MMC the most 'superior' product used in this application was a alumina based material also sourced from overseas. Typical costs of using the alumina based material in a cyclone spigot were approximately A$400 per spigot with an associated lifetime of 400 hours. The MMC equivalent, although priced at A$1000 lasted closer to 4000 hours. The mining community adopted this MMC with optimism — their costs were reduced considerably (sub. 49, p. 2).

With the trend toward *concurrent engineering* in manufacturing, processes such as design, assembly, and a material's life-cycle cost should be considered simultaneously.

6.3 Demand trends

Because materials are inputs into the production process, demand for a particular material is a derived demand. In forecasting demand for a material, it is therefore usual to identify the industry sources from which this demand originates.

Demand growth for most of the new and advanced materials considered in the case studies is generally high. The high growth rate is partially an artefact of the low base from which it is measured. If a new and advanced material is going to replace an extensively used traditional material, growth in demand obviously will be substantial until the material changes its status to being an ‘old’ (traditional) one.

Most forecasts relate to international rather than Australian demand. With the benefit of hindsight, some have proved to be over-optimistic (University of Michigan Transportation Research Institute, 1992). The US Bureau of Mines (1994a) reports that failure to foresee the technical problems associated with incorporating the materials into product and the 1990–1992 recession were the main reasons why some forecasts have had to be drastically revised downward.

The following comments relate to World demand trends for those new and advanced materials that are the subject of case studies.

Aluminium alloys

Demand forecasts do not generally distinguish between primary aluminium and aluminium alloys.

World demand growth for primary aluminium plus aluminium alloys is expected to increase by 4 per cent a year from 1994 to 1999 (ABARE, 1994a).

Metal-matrix composites

Metal-matrix composites (MMCs) are mainly aluminium-based, although other matrices including magnesium and titanium are increasingly being used.

The US Bureau of Mines forecasts that World demand for MMCs is expected to grow to the year 2002 at an average annual rate of 9.2 per cent, but with World production reaching only 1132 tonnes. However, other forecasts suggest consumption could reach 15 000 to 20 000 tonnes by 2003 (sub. 67, p. 5). Demand is expected to be greatest in the US and Europe. Demand growth will come mainly from the automotive industry, particularly in the US, where demand is forecast to grow at 12 per cent a year between 1992 and 2002 (US Bureau of Mines, 1994a).

Advanced ceramics

World demand for advanced ceramics is expected to grow at an average annual rate of 4 per cent (US Bureau of Mines, 1994a). Growth is expected to be strongest for ceramic coatings. An area of significant growth — in terms of value-adding rather than volume — is the use of engineering ceramics for biomedical applications. Demand for electrical ceramics, the largest application of advanced ceramics, is expected to continue to grow, but at a lower rate than for engineering ceramics (US Department of Commerce, 1993).

Engineering polymers and advanced polymer composites

World demand for engineering polymers is projected to grow at an average annual rate of more than 7 per cent to the year 2002 (New Materials International, 1994c). Demand for advanced polymer composites (APCs) is expected to grow at a similar rate (US Bureau Mines, 1994a).

In North America, demand for engineering polymers such as nylon, polycarbonate (PC) and polyacetal (PA) is forecast to grow at an average annual rate of 5 per cent until 1998 (sub. 14, addendum). The appliance industry is expected to be the major source of demand growth. Considerable growth in demand is also anticipated in the electronics industry where the trend toward miniaturisation is expected to result in the replacement of commodity polymers by higher-performing engineering polymers (High Performance Plastics, 1994a).

The automotive sector is forecast to be a major source of demand growth for APCs, with an average annual growth rate of 27 per cent between 1992 and 2002. Significant growth in demand is expected from the military and the aircraft, construction and recreation industries (US Bureau Mines, 1994a).

Rare earths

World demand for rare earths is forecast to grow at 5.5 per cent a year until 2000. The main source of the projected growth in demand is from increased use of permanent magnets in the electronics and electrical industries and applications in catalysts (Kingsnorth, 1992).

Magnesium

World magnesium metal production is forecast to increase at an average annual rate of 12 per cent until 2002. Major current usage is as an alloying element in aluminium alloys but demand growth is expected to be strongest for magnesium components in the automotive industries which currently comprises 70 per cent of the World market for magnesium metal (Lewis, 1993).

Titanium

Future demand growth for titanium is dependent upon its major user, the aerospace industry, and on the rate of uptake of other advanced materials which may replace titanium in aerospace applications. However, demand for titanium by the military has declined in recent years, leading the US Bureau of Mines (1994a) to comment that, ‘the outlook for the titanium metal industry is unclear’.

Steel

ABARE estimates that World steel production will remain steady in 1995 but will increase to about 824 million tonnes by 2000. Most growth is expected to occur in China and other Asian economies.

While the demand for steel has remained fairly constant over the last decade, production has fallen in the US and in Eastern Europe (by 15 per cent and 40 per cent respectively since 1990) and also by a smaller degree in Japan. Output in China and other Asian countries has risen rapidly (both around 20 per cent). Greater use of high strength low alloy steels and improved processing technologies are expected to maintain the competitive position of steel.

Nickel

Demand for nickel is derived largely from the demand for stainless steel. The current long-term growth in production of austenitic stainless steel has been estimated at 4.5 per cent per annum (Hansen, 1994). Demand for stainless steel is expected to increase with the improving fortunes of the US economy, and in the longer term significant demand is expected from the newly industrialising countries in Asia (Manson, Gooday, Meek, 1994).

An area of potential growth for nickel is in battery applications for electric vehicles and stationary power. A number of nickel-based systems are under intense investigation for these applications (Rand, 1994).

One of the most promising is the nickel metal hydride system which has double the specific power of a lead acid battery. Problems exist however in the cost and self discharge propensity of the system.

7 COMPETITIVENESS OF AUSTRALIAN PRODUCERS

It is differences in national economic structures, values, cultures, institutions, and histories that contribute to competitive success. This chapter discusses a range of economic factors that influence the competitiveness of industries producing and using new and advanced materials.

There is, however, some difficulty in analysing competitiveness of activities as diverse and dynamic as the invention, production and use of new and advanced materials. Nevertheless, some messages emerge.

7.1 Sources of competitive advantage

There are a number of economic factors underlying the competitiveness of any industry and they also apply to new and advanced material producers and users. If an industry, or a nation, is in a situation where all these factors exist in an appropriate (mutually reinforcing) form, then it is very likely to have a competitive advantage. Porter (1990) has been influential in developing a framework for analysing competitive advantage. The factors identified by Porter and discussed in some detail below are:

- factor endowments and infrastructure;
- demand conditions; and
- related and supporting industries.

A key additional economic factor is the structure and strategies of firms. This is not discussed here due to the fact that there is such an enormous range associated with the businesses involved in producing or using new and advanced materials.

In addition to these economic factors, chance and government decisions can influence the competitive advantage of a nation or an industry. These factors are discussed briefly below.

Factor endowments and infrastructure

A nation can gain competitive advantage if it possesses, or creates where possible, low-cost or uniquely high quality factors — land, natural resources, physical capital and human resources. For example, it can be argued that one of the sources of competitiveness in the developing Asian countries is access to relatively inexpensive labour. A major reason for Australia's competitiveness in mineral resources is — obviously — their existence in Australia.

Competitive advantage also depends on how efficiently and effectively these factors are deployed. The mere availability of factors is not sufficient to explain competitive success. On the other hand, their unavailability goes a long way in explaining poor economic performance.

Porter (1990) makes a distinction between 'basic advantages' (which include natural resources, climate and unskilled and semi-skilled labour) and 'advanced advantages' (which include communications infrastructure, highly educated personnel, and university research institutes in key disciplines). He argues that basic factors are either inherited (and, therefore, beyond the control of humans) or can be created very easily. As such, they are increasingly unimportant to sustainable competitive advantage, and are only important in the shorter term. However, basic factors also remain important where skill requirements are modest, and technology is widely available. Porter argues that advanced factors have become the most significant ones for competitive advantage, yet they are more scarce, because their development requires large and often sustained investments in both physical and human capital.

Australian producers of new and advanced materials may have a *basic* competitive advantage in that the nation is endowed with considerable quantities of a large range of minerals, which can be further processed to become new materials. For example, Australia is a major producer of alumina and potentially new aluminium alloys because of natural endowments of bauxite.

That said, further processing will only take place if the commercial benefits of doing so outweigh the costs. The competitive advantage gained through access to minerals diminishes through the production chain if other factors are lacking. Professor Dunlop said that:

> Gains from the natural advantage of being a raw materials producer can be quickly lost at later stages in the manufacturing chain if best practice technologies are not implemented (sub. 23, p.1).

A number of participants in the inquiry suggested that Australia lacked the crucial elements needed to sustain this competitive advantage, for example the MTIA said:

> The advantages in raw and semi-processed materials due to cheap minerals and energy are only applicable at the low value added end of the product chain that relies on new materials. These early advantages can only be taken further if we develop the design/manufacturing technology skills needed to apply the materials to products (sub. 35, p. 12).

The argument here is that certain *advanced advantages* (technological skills) are lacking (see below).

Physical infrastructure

The physical infrastructure of an economy, such as transportation, the communications systems and power supplies, provides inputs to a wide range of industries. If quality infrastructure is provided efficiently, industries benefit from access to it at the lowest cost possible. If Australia's services are not provided and priced as efficiently as possible, industries incur a penalty when they compete with foreign suppliers at home or abroad.

In the case of new and advanced materials producers, Australia may have a competitive advantage compared with a number of countries, in the form of relatively inexpensive and reliable sources of electricity (which can be important, especially in the energy-intensive production of aluminium alloys, magnesium and titanium).

Social infrastructure

In addition to physical infrastructure, new and advanced materials development is also dependent upon an adequate skills and research 'infrastructure', which are components of so-called 'social infrastructure'. The quality of the nation's stock of scientific and technical knowledge in materials science and engineering is particularly important. All materials-related areas of research infrastructure need to be functioning effectively and efficiently, including that in universities, government research institutes, as well as private research facilities. Access to good research skills and know-how is important for innovation and product development. Having ready access to this knowledge at a reasonable cost is an important element of competitive advantage.

Australian science is recognised as World class. Professional and technical salary levels in Australia are such that R&D is relatively inexpensive compared with most other industrialised countries. Whether or not the nation produces enough scientists, and in the appropriate disciplines, are other matters.

A number of participants claimed that new and advanced material producers and users are disadvantaged by deficiencies in Australia's research infrastructure.

In commenting on Australian university research infrastructure, ANSTO made the following comment:

> The infrastructure of Australian University materials departments is poor by international standards. They are not equipped to carry out research on materials processing on modern equipment. A natural result is that the scientists and engineers

> graduating from Australian universities are not adequately trained in modern process technologies... (sub. 29, p. 1).

However, the situation varies between universities. There is also evidence that better use could be made of facilities and the expertise in universities and other institutions involved in materials-related research.

These shortfalls generally occur in areas of research infrastructure related to the *use* of materials. In the areas of mineral processing and mineral extraction needed for *production* of new and advanced materials the situation is different with well equipped laboratories and strong research teams in CSIRO and a number of universities.

Impediments may exist if Australian producers and users do not have access to the skills and training required to effectively produce and use new and advanced materials. Without these skills, Australian producers will incur higher production costs, and will be less able to compete with other nations which have access to these skills.

Professor Dunlop argues that there is a lack of awareness by industry as to the skills that are needed. He sees this as an impediment to Australian industry:

> However, I ... think that the greatest impediment to progress is ... getting well-trained, young engineers - managers - into these industries at a relatively young age in order to learn the industry and help the industry make the next step into the wider world, and that area, I think, is quite difficult. It is difficult to get the industry to realise that a university-trained materials engineer or manufacturing engineer is really what they need, and it is quite difficult telling somebody else what he needs when he doesn't recognise it himself (transcript, p. 119).

The importance of education and training and awareness in the context of new and advanced materials users and producers is discussed in Appendix C1.

Demand conditions

The nature of local demand can be a significant source of competitive advantage. Porter (1990) argues that the nature of demand in a country's local market shapes the way producers perceive and respond to buyer needs. The argument is that nations gain competitive advantage where local market demand gives producers an earlier picture of buyer needs, and where domestic buyers pressure local supply industries to be competitive and innovative.

At present certain industries play a crucial role in the take-up of new and advanced materials. These are the electronic, aerospace and automotive industries. In Australia, none of these industries are large on a World scale. Many are subsidiaries of overseas businesses or trans-national corporations and as a consequence their interest in, and demand for, advanced materials are not necessarily matters determined in Australia.

Accordingly, Australian producers of new and advanced materials do not face the same incentives as user industries in, say, the US, Germany and Japan. Professor Dunlop elaborated by stating:

> Australia's manufacturing industry has grown substantially in recent years in terms of its contribution to the national economy but this industry is often relatively unsophisticated when compared to its foreign counterparts. Australia has no large aerospace industry and its electronics industry cannot be compared with the large scale industries of Japan and USA. It is these two industries which are the prime drivers and consumers of new industrial materials in advanced countries (sub. 23, p. 1).

The size of local demand is not only important in that there is likely to be a correlation between the number of potential purchasers of a material and the degree of pressure placed on suppliers to be competitive, but it can have other positive effects on competitive advantage. Having a significant level of home demand reduces risk for suppliers, particularly if the local market is well established. Production for local consumption at levels close to the efficient scale of production also allows producers to be competitive in World markets. Even though for new and advanced materials efficient scale is likely to be continually changing, at any point in time demand in some countries is likely to be higher than in others. In countries with higher demand, it is likely that local producers will benefit from scale economies.

The relationship between Australian producers of new and advanced materials and user industries can be another important factor, particularly in terms of market power and its influence on competition.

The main user industries (aerospace, automotive, and electronic) can be expected to have considerable power in the factor markets. As a generalisation, these industries are dominated by a few firms. Accordingly, they have a degree of market power in dealing with material suppliers.

In summary, the evidence available to the Commission suggests that most Australian producers of new and advanced materials lack market power and hence will compete strongly to sell to a few user industries.

Another factor that determines market power is the availability of close substitutes. Traditional materials are often close substitutes for new and advanced materials, and hence the market power of producers of the latter materials is limited. Exceptions tend to occur where the new and advanced material is clearly superior to available substitutes, or where the material is tailor-made for specific end-products.

There are niche markets where some producers of new materials have a degree of market power, for example, tailor-made ceramics. However, these markets tend to be small, with often only room for one or two producers.

Supporting and related industries

Supporting industries can be industries either upstream or downstream from the industry in question. This means suppliers of new and advanced materials are supporting industries of the user industries, such as the automotive industry. Going back a further step, the suppliers of raw materials to those who process new and advanced materials are the latter's supporting industries. Research institutions can be considered in the same light.

The presence, or absence, of internationally competitive supplier or supporting industries can be a source of competitive advantage or disadvantage. They can create advantages in downstream industries via efficient, early, rapid, and sometimes preferential access to the most cost-effective inputs. Innovations made by suppliers can help users to become aware of opportunities to apply new materials technology, and gain quick access to information, new ideas and insights.

A particular feature of the demand for new and advanced materials suggests that close liaison — and possibly close physical proximity — is more important than in some other industries. The particular feature is that much of the process involves making incremental improvements to existing materials, rather than the development of completely new materials. Improvements often involve tailoring the materials to provide certain properties desired by the user, for example developing greater wear resistant ceramics, or fade resistant polymers.

The nature of these incremental improvements is such that close collaboration between users and suppliers can be crucial. If this is the case, producers located close to end-users will have a competitive advantage, because they can more easily tailor materials and provide technical support to suit those users.

It may also be necessary to gain a working knowledge of a customer's production processes, so that a material can be readily adjusted to meet changing needs. Because this is best accomplished on-site, local producers will be disadvantaged when users overseas require the producer to be readily available to provide effective and timely user support. It is easier to overcome local alliances and allegiances if new entrants are located close to customers and therefore able to develop the close relationships needed.

The existence of clusters of related and supporting industries is believed to facilitate collaboration that allows industry to take advantage of synergies that stimulate innovation. Clusters provide opportunities to take advantage of any economies of scale in physical infrastructure. They can also reduce communication and transport costs.

Chance

As noted earlier, chance plays a role in the discovery of new and advanced materials. Chance events can determine the country in which a discovery is made. However, it is argued that the other factors (discussed above) will determine where (in which country or countries) an industry will grow around a chance discovery:

> If a nation has only the invention, other nations' firms will be likely to appropriate it. Insulin [discovered in Canada] ... was turned into an international commercial success by companies based in Denmark and the United States, not in Canada. Both Denmark and the United States possessed favourable demand conditions, specialized factor pools, and other advantages (Porter, 1990).

Government decisions

What distinguishes the development of new and advanced materials from virtually every other economic activity is the influence of government funding which occurred for defence and strategic purposes. Much of this occurred in the US. The Cold War and the space race had a greater impact on development of materials than anything else. It is difficult to imagine what the extent and rate of materials development would have been had this expenditure not occurred.

With the end of the Cold War and the space race less funding is going to materials development for military purposes. This reduced funding will affect the rate of uptake of new materials by the commercial sector.

Governments can influence the rate of uptake of new and advanced materials. In terms of Australia's competitiveness in producing new and advanced materials, or products incorporating them, one area where Government has had a significant role is in education and science policy. The discoveries that have come out of CSIRO, ANSTO, DSTO and the universities are proof of that. For various reasons, discussed in Chapter 3 (on R&D) and Appendix C1 (on education, training and awareness), optimum competitive advantage is not being obtained from existing research, education and training structures. Optimising arrangements for greater economic gain from the production and use of new materials is discussed in Chapter 10.

8 VALUE ADDING AND ECONOMIC SIGNIFICANCE

Some participants stressed the desirability of adding further value to Australia's raw materials — a general point and not just confined to the production of new and advanced materials. Others suggested that Australia's raw material endowments are a source of competitive advantage in the production of new and advanced materials.

This raises some very important questions:

- In what circumstances (or for what raw materials) will value adding occur in production?
- Is the current level of value adding in production efficient?
- What is the economic significance of incorporating new and advanced materials into products?

8.1 Value adding

Before attempting to answer the above questions it is useful to define and discuss the concept of value adding.

What is value adding?

Taking a product (often a raw material, but it does not have to be) and further processing it is called adding value. The added value is measured by the sales value of the output less the purchase cost of materials that are used in production. The value added is equivalent to the value of the inputs — land, capital and labour — used in the process plus any profit.

Any processing (defined in the broadest possible sense) can lead to value adding, and it can occur anywhere along the production chain. A practical example of the processing stages involved in value adding is given in Table 8.1 — turning raw bauxite into aluminium and finally aluminium alloys.

In the case of new and advanced materials, value adding can be increased directly through their *production* or indirectly by enabling further production *using* new materials, producing intermediate and final products (that is, causing production to take place that otherwise would not have occurred).

Table 8.1 Stages in the production of aluminium based new and advanced materials

Primary commodity	*First stage value adding*	*Second stage value adding*	*Third stage value adding*	*Fourth stage value adding*	*'Enabled' production*
Bauxite straight from the mine.	Alumina is derived from bauxite using the Bayer method.	Aluminium is generated from alumina using the Hall–Heroult electrolytic reduction process.	Prefabrication into sheet and strip aluminium, extruded sections, powders and pellets, and ingot bars.	Manufacture into standard products. For example, welded structures, ships and boats, electrical and electronic components, and foil products.	Development of new and advanced materials. For example, aluminium based alloys, car components, and aircraft parts.

Source: Adapted from DITARD, 1993a.

In what circumstances will value adding occur?

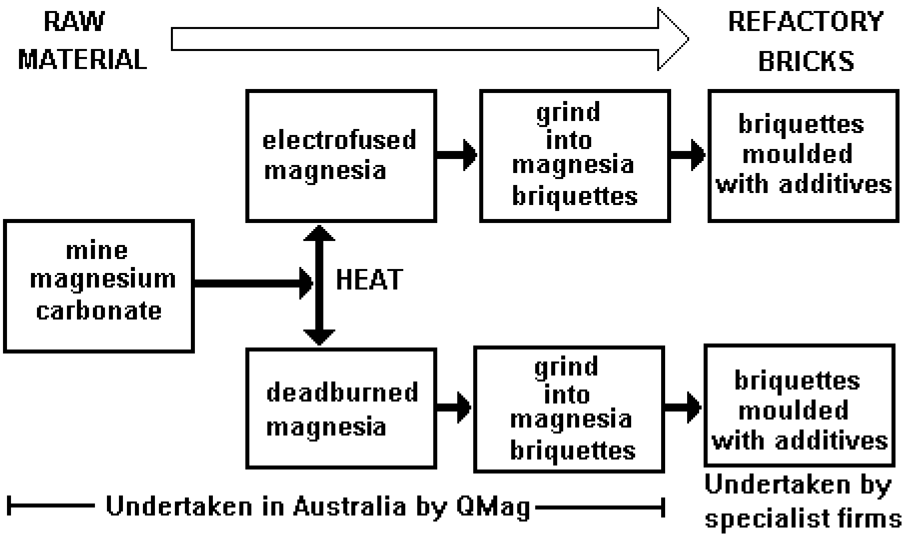
By and large, value adding occurs when it is commercially viable to do so. Australian producers of new and advanced materials are thought by some to have a competitive advantage, and hence opportunities exist to add value, because of their access to relatively cheap supplies of minerals. However, value adding to Australia's minerals to produce new and advanced materials will not occur unless prospective producers believe they can earn profits in doing so. They will make the appropriate economic decision (based on this principle) unless, as discussed below, there are spill-overs.

An example of a business going only so far in value adding is QMag, a successful Australian exporter. QMag produces, incorporating the latest production technologies, magnesia briquettes for use in the production of refractory bricks for lining steel furnaces. The steps in manufacturing refractory bricks are depicted in Box 8.1. After mining magnesium carbonate from a surface mine at Kunwarra, the raw material is transported to the QMag plant at Parkhurst, near Rockhampton. The magnesium carbonate is heated (using a high temperature furnace or electric arc furnace) to produce deadburned and electrofused magnesium. This is then crushed and moulded into magnesia briquettes. These briquettes are then sold to 25 regular customers in 20 different countries, including Australia. The refractory bricks are usually moulded in or near the foundry which uses them, with foundry specific inputs often added.

Why does QMag not fully process magnesium carbonate into refractory bricks, that is, complete all stages of production? QMag decided that because each buyer had specialised requirements, the extra earnings from the sale of refractory bricks would not be greater than the costs associated with trying to satisfy individual foundry needs. QMag is able to add most value to its activities by only completing three quarters of the final processing.

Of course, in a dynamic World economy, with continually changing relative prices, the appropriate stage in the value adding chain is not a fixture, and more or less value adding might be appropriate in the future.

Box 8.1: Further processing may not mean more value added



The QMag decision is based purely on the commercial factors which it faces. *Prima facie*, no significant social costs or benefits exist to suggest that in this case the commercial decision is not also the appropriate economic one. An economic evaluation would take into account any spill-over effects and tip the balance one way or the other.

An example of the problems involved in attempting to value add was the experience of ICI in trying to establish a zirconia powder production facility in WA (see Appendix B3). This operation was based on a raw material (zircon) in which Australia is a dominant World producer. However, this was an insufficient condition to make the operation viable. Markets (which are largely overseas) were more difficult to penetrate than had been anticipated, and market growth had been overestimated. The operation failed and was closed. The extent to which the recently announced purchase of the facility by Korean interests will result in re-establishment of production in Australia is not clear.

However, using imported raw materials, ICI Advanced Ceramics division has been successfully adding value by the manufacture and sale of zirconia-based products.

It should also be noted that often raw materials are a minor part of the cost of producing new materials or products incorporating them. The major component of value adding might be in the design (or conceptualisation) of a new product. Further, any competitive advantage gained through access to cheap minerals diminishes if other competitive advantages in the production chain are lacking — for example, access to the appropriate skills and technological support.

Is the current level of value adding efficient?

The foregoing discussion points out that what is commercially viable may not coincide with what is economically appropriate. This occurs when there are ‘externalities’ or spill-overs — where some costs are not borne or benefits captured by the buyers and sellers. Accordingly, resource use (including decisions on value adding) determined by the market place may diverge from a socially optimal use of resources. Whether or not there is a divergence between commercial (private) and economic (social) returns requires a case-by-case assessment, and if divergences exist government action may be warranted.

The Commission has no evidence to suggest that (properly informed) market-based commercial decisions, in the absence of environmental problems, will not lead to appropriate levels of value adding in the production of new and advanced materials. However, longer-term benefits could result from technological spin-offs resulting from developing the new technologies which are required to produce (and use) new materials.

8.2 Value adding in use

A feature of new materials is that the greatest value added can often result from the design of the product rather than the use of the particular material, which usually is only a small part of the total cost of the product (as mentioned above).

The experience of Telectronics in the development of a new and advanced polymer for use in heart pacemaker leads is typical of the case for many new materials in that, while only a small quantity of the polymer is used (a few grams per lead in the case of the pacemaker), without the material Telectronics would not be able to make a $5000 product. Similarly SOLA Optical has developed a highly successful World wide business in spectacle lenses using raw materials developed in Australia but produced overseas and imported.

9 POTENTIAL FOR PRODUCTION AND USE IN AUSTRALIA

As the previous chapters have illustrated, there are many factors that need to be considered when assessing the potential for further production and use of new and advanced materials. Supply and demand conditions, the nature of markets, and the likely competitiveness of both producers and users are relevant. Underpinning the variables is the science which can lead to a new material — or, alternatively, fail to produce a valuable one. The many unknowns and uncertainty about the role of these factors makes it difficult — if not impossible — to predict the prospects for greater production and use. According to Professor Gordon Dunlop:

> While it is possible to predict a general trend of increased use of new materials and suggest likely areas of application, it is not possible to say with certainty what technical developments will be achieved. Nor is it generally possible to predict whether particular developments in new materials technology will be achieved, when and how they will be commercially useable, or what their impact will be (sub. 24, p. 15).

Although it is impossible to predict the prospects, the influence of new and advanced materials will be significant. The globalisation of the Australian economy will require producers and users of these materials to respond to the challenge or become less competitive:

> We can say with certainty that Australian industry will be impacted by application of new materials. The effects are an unavoidable consequence of the exposure of Australian industry to the competitive pressures of global trade (sub. 24, p. 15).

Australian manufacturers that keep abreast of material developments can establish a competitive advantage, particularly by producing and using them at an early stage of their adoption World wide. However, to do this it is important that Australia has the research capability, research infrastructure, skills and training to capitalise on new materials developments.

The likelihood for further production and use of individual new and advanced materials is discussed below in terms of likely trends. The advantages and disadvantages faced by Australian producers, as well as the conditions necessary for success are identified.

9.1 Aluminium alloys

Much of the primary aluminium consumed in Australia in the packaging, building and automotive industries is used in the form of traditional aluminium alloys.

The potential for production of new and advanced aluminium alloys is limited even though demand is expected to grow strongly in the aerospace and automobile industries. Most of the demand for tailor-made alloys originates overseas. However, supplying overseas markets is likely to be difficult, despite Australia's ability to produce primary aluminium relatively cheaply.

The rate of overseas demand growth will be influenced by environmental regulations in the US and Europe, where the demand for lighter materials will closely follow tighter enforcement or newer regulations on emission standards.[1]

Although the development of some advanced aluminium alloys in Australia has moved past the research stage, there is no commercial production yet. Potential producers of new aluminium alloys in Australia would be likely to have two sources of competitive advantage. The first is access to excellent quality and abundant supplies of primary aluminium. The second is that the development of new aluminium alloys does not require significant investment of capital because different types of aluminium alloys can be produced using the same plant as used for traditional aluminium alloy production. Existing producers of aluminium in Australia are large and experienced and would therefore be advantaged because they already have the research and most of the production infrastructure in place.

Despite these advantages, the size of the domestic market for new and advanced aluminium alloys is never likely to be large enough to sustain a domestic industry, and therefore potential producers would have to target export markets.

Benefits to Australia from the local development of new aluminium alloys may best be gained by licensing to overseas suppliers who are in a better geographical position to service sophisticated overseas markets.

Some use of advanced aluminium alloys will occur in the automotive industry, in ship building and in aircraft maintenance. Opportunities exist for supply of aerospace components to overseas aircraft manufacturers under offset arrangements, as is occurring for example, with composite structures and titanium turbine blades.

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[1] The demand for lighter materials is also a function of consumer preferences for more economical (that is, fuel efficient) automobiles.

9.2 Metal-matrix composites

The potential for production of metal-matrix composites (MMCs) is limited despite the high expected growth rates emanating from the aerospace and automobile industries. MMCs are at the research stage in Australia, and there is very limited commercial production.

World wide there is strong competition in the supply of new MMCs, given the large number of producers and the high degree of substitutability between MMCs and other materials.

As with aluminium alloys, the rate of overseas demand growth will be influenced by environmental regulations.

However, despite the potential overseas market for MMCs, there is unlikely to be sufficient local demand to sustain a domestic production industry, at least in the foreseeable future, and therefore potential producers would have to seek export markets. This could be difficult because of barriers to trade (for example, US government assistance to US-based competitors), the preference of overseas users for using local suppliers and transportation costs.

Australian potential is linked to further research and the attainment of incremental improvements to the technologies used in the processing of MMCs, such as casting. This is because research to improve processes can reduce production costs, improve the physical properties of MMCs and make the final product more competitive, thereby offering the opportunity to enter overseas markets should the opportunity arise.

9.3 Advanced ceramics

Advanced ceramics are grouped into the following categories for the purpose of assessing potential production:

- advanced engineering ceramics and ceramic coatings; and
- advanced electrical ceramics.

Advanced engineering ceramics and ceramic coatings

Significant growth potential exists for World wide production of advanced engineering ceramics and ceramic coatings.

Australian producers of advanced engineering ceramics have already had some successes, mainly by focusing on niche markets (both locally and overseas) where the materials produced are custom-made for particular applications. ICI Advanced Ceramic’s (ICIAC) PSZ is a good example, where the ceramic performs better than other ceramics in given applications. Other Australian successes having further growth potential include biomedical and military applications. Beyond these markets, where the ceramics are less application-specific and more amenable to large production runs, Australian producers will have more difficulty in competing.

The existing Australian producers are forecasting very strong growth, largely through penetration of niche export markets. Although one enterprise has failed (conversion of zircon to high purity zirconia in Western Australia as detailed in Appendix B3), opportunities will develop for intermediate processing of Australian raw materials to provide feedstock for advanced ceramics production.

Advanced electrical ceramics

At present the World market for advanced electrical ceramics is largely linked to the growth in the electronics industries, where Japan and the US account for approximately 80 per cent of World production.

By World standards, the existing Australian market for advanced electrical ceramics is small. The one significant Australian producer is a subsidiary of an overseas trans-national producing mainly for the Australian military. Accordingly, growth potential in this area is minimal, being largely linked to demand by the military.

However, in other areas there may be some future potential, for example ceramic fuel cells and high-temperature superconductors, even though these are still essentially at the research stage.

Ceramic fuel cells

Fuel cells are a more technically efficient means of generating electricity than conventional methods. They are modular in nature and therefore equally suited to both large-scale and small-scale applications. There is potential for their costs to fall if they come to be widely adopted, although the extent to which this will occur once fuel cells are commercialised is unclear at this stage.

The existing Australian consortium developing solid oxide fuel cell technology is confident that significant potential exists for Australian production of ceramic fuel cells for electricity generation, both for local use and for export to South East Asia. Potential applications include on-site combined heat and electricity generation for hotels, apartment buildings and general applications in remote sites. In its submission, CSIRO summed up the potential benefits in the following way:

> [The] local market is estimated to exceed $200M in 10–15 years; [and it is believed that] considerable export potential exists (sub. 19, p. 12).

High-temperature superconductors

Superconductors are materials which conduct electricity without resistance or energy loss. There is extensive potential for future production and usage World wide of high-temperature superconductors (HTS).

The application with greatest potential impact is power transmission. Superconducting cables appear to be competitive at high power levels (in excess of 1000 MVA) and over long distances (more than 100 kilometres). They will greatly increase the current carrying capacity of underground transmission, possibly allowing a direct power match to overhead lines. Power generation and usage may benefit from various HTS devices and systems. For example, generators, transformers and motors using HTS will have advantages of reduced dimensions and lower losses compared with their conventional counterparts.

Other applications include magnetic sensors in medical applications, *maglev* transport (magnets for levitation, propulsion and guidance of high speed vehicles, such as high speed trains) and telecommunications, such as transmitting antennae (US Congress, 1990).

If the various applications mentioned above come to commercial fruition, this will mean a truly revolutionary change in some of the most common everyday activities.

HTS are still at the research stage, both in Australia and overseas. Most of the research into HTS is conducted in Japan and the US. Although relatively small in size, the Australian research is believed to be of World class. CSIRO is involved in research with MM Cables and BHP (sub. 19, p. 16). The University of Wollongong also has a significant program in collaboration with MM Cables. Nevertheless, commercialisation, if it occurs, is probably some years away. Apart from the potential in the fuel cell and HTS areas, the small size of the domestic market, and the relatively low levels of demand, make it highly unlikely that Australia will be a significant producer of electrical ceramics.

9.4 Advanced polymers and advanced polymer composites

The global polymer industry is characterised by a relatively limited number of large trans-national producers. Base resin or monomer production generally requires large plants to obtain economies of scale. With considerable installed capacity and existing infrastructure overseas, large scale base advanced polymer resin production in Australia is unlikely.

The potential for further production World wide of advanced polymers and advanced polymer composites is positive, reflected in the strong growth forecasts presented in Chapter 6. Much of the potential is expected to come from growth in the automobile industry. In Australia, Britax Rainsfords, a subsidiary of a UK trans-national firm, is a major producer and exporter of automotive components made from advanced polymers.

As with the light metals such as aluminium and magnesium, advanced polymers are expected to benefit from the demand for greater fuel economy and the use of light materials in cars.

On the other hand, government regulations which legislate for complete recyclability (as in Germany) may have an adverse effect on the potential for polymers and composites, unless technological developments to make these materials recyclable are successful. Technological advances which improve the performance characteristics of traditional materials such as steel, will also lessen the potential for further use of advanced polymers in automotive applications.

The main opportunities for raw materials production in Australia are in custom blending of polymers for specific local applications and in some cases for export. This will be done by both the large trans-nationals and perhaps, more importantly, by smaller firms servicing niche markets. The ability to work closely with end users provides significant opportunities in this area for import substitution.

Opportunities for use of advanced polymers and advanced polymer composites in manufacturing products are much more widespread. Increased demands from the automotive industry will be significant — in the supply of automotive components. This can result in significant export opportunities as has been demonstrated by Britax Rainsfords.

Opportunities will continue to arise for Australian manufacturers to develop viable export businesses using advanced polymers and advanced polymer composites, as has been demonstrated by SOLA Optical in spectacle lenses and Telectronics and Cochlear in the medical products area.

9.5 Rare earths

As mentioned in Chapter 2, the production of rare earths occurs mainly in the US, France, China and the CIS.

There appears to be limited scope for an Australian rare earth processing industry to develop. The World rare earths industry is dominated by a few producers, and although there appears to be some scope for new entrants into the market, the existing producers are believed to possess considerable reserve production capacity and this may deter new entrants.

However, the increasing dominance of China, both as a raw material source and supplier of refined products, could provide opportunities for Australian producers if importing countries seek to diversify their supply sources.

With technology innovation, significant use of rare earths will probably be in the manufacture of magnets.

9.6 Magnesium

About 31 000 tonnes of magnesium are used in the Western World each year in die casting processes. This accounts for around 13 per cent of the World's magnesium use. Most of this is used in automotive components.

Magnesium is not produced in Australia at present. Australia imports about 6000 tonnes of magnesium per year, 85 per cent of which is used as an alloying agent with aluminium. However, the potential for growth in magnesium use for this purpose is limited. Die casting is seen as the major potential market for magnesium in Australia.

Recent growth estimates for World consumption of magnesium for die casting range from 7.9 per cent a year to 20 per cent (Lewis, 1993). The forecast of 20 per cent growth is dependant upon the price of magnesium falling from $US1.40 a pound to $US1.00 a pound.

Any increased use of magnesium in Australia that may emerge will depend to a large degree on its use in the die casting industry to produce automotive components. The growth in magnesium production, like other lightweight advanced materials, will be contingent on environmental regulations and consumer tastes driving the use of lighter materials in automobiles.

The Australian Magnesium Research Development Project (AMRDP) may be well placed to take advantage of the expected increase in World wide demand. Early estimates suggest that it is possible for the project to yield a significant price advantage, which would enable it to gain a substantial share of the World market (refer to Appendix B6). This is contingent upon World demand for magnesium increasing sufficiently to absorb the current over-supply of the material and then continuing to grow.

9.7 Titanium metal and alloys

There are two distinct markets for titanium defined by disparate users — aerospace (military and civil) and the industrial market (chemical condensers and heat exchangers).

At present there is no production of titanium in Australia, and there is little evidence to suggest that titanium will be produced in the near future. With excess production capacity in the World, a potential Australian producer would need to have access to a cost-cutting technological breakthrough to allow it to gain market share. An impediment to be faced would be the need to overcome any US border protection measures designed to protect US producers of what the US government still regards as a strategic material.

Imported titanium will continue to be used in chemical plants, medical and selected aerospace applications.

9.8 Steel

With the continuing growth in Asian markets and the considerable investment by BHP in new technology and productivity improvement, steel production in Australia should continue to grow.

Greater use will be made of High Strength Low Alloy (HSLA) steels in order to maintain steel's market position in the automotive, construction and packaging industries.

Improvements in processing technology such as strip casting, and advances in joining and welding techniques will assist steel's competitive position.

Impacting on local steel production to some extent will be the establishment by BHP of additional minimills in overseas locations to service Asian and US markets.

Successful development and adoption of direct smelting processes to provide feed material for minimills will lead to additional local production.

9.9 Nickel metal and alloys

Australia has significant deposits of nickel which may be developed. The factors that will influence the establishment of new nickel mines in Australia include the success of developing new processing technologies, improvements in the price of nickel, and continued demand growth from stainless steel producers.

Some longer term potential could exist for increased use of nickel in batteries for electric vehicles or stand-by power applications, if current technical problems can be overcome.

9.10 Building on strengths

Although Australia (in line with other industrialised countries) consumes its share of new and advanced materials in final demand products, it is not a major user of the materials as intermediate inputs into the manufacture of final products. This is largely because Australia does not have significant new material-user businesses in the electronics, automotive, aerospace and defence industries.

At present, the greatest potential use in Australia lies in sectors where the country already has both a competitive advantage and a developed market on which to build. Dr Patrick Kelly stated:

> ... it is the materials 'user' not the materials 'producer' that is important. In areas, like mining equipment or engine component manufacture, where we do have a local industry, a technological base and an adequate market, a new or improved material can find immediate application and lead to benefits in productivity and/or competitiveness (sub. 21, p. 2).

An area not included in Dr Kelly's list, and where Australia may have a competitive advantage from which to build, is in the use of new and advanced materials in biomedical applications (refer to Appendix B10 for details).

The use of new and advanced materials can help to strengthen competitive advantage in manufacturing industries through the flow-on effects that come from access to new technologies and processes.

From whatever perspective, that of a final consumer, an input user or an existing or potential producer, Australians need to be better informed on the availability and qualities of new materials. As Professor Roger Horn stated:

> Even if Australia did nothing to develop new materials itself, but merely made use of new materials developed overseas, it would be necessary to know about the new materials available, and to know why, how and where to make use of them (sub. 9, p. 2).

As well as an awareness of the range of materials currently available, it is also important for Australian industry to be looking to the future so that we are prepared to take advantage of the technologies of tomorrow. The Australian Science and Technology Council (ASTEC) is currently developing a *foresight* program assessing how Australia can best look into the future.

According to ASTEC, foresight analysis recognises that although it is not possible to predict or pre-determine the future, it is possible to systematically capture the dynamics of change. This is achieved by developing an understanding of the forces and evolving trends that are driving change and shaping the future, and presenting alternative scenarios for future directions in science and society's priorities.

Although foresight analysis is not a prescriptive planning tool, more informed policy formulation and decision-making can be undertaken by considering alternative scenarios formulated by this approach.

As part of this program partnership studies are being undertaken with interest groups and three of these could have an impact on the materials area, namely the partnership studies on health, shipbuilding and urban water supply.

The National Materials Council is preparing a strategy for strengthening the discipline of materials engineering. It is intended that this exercise will provide an update on the review of research priorities undertaken by the Department of Science in 1985 (Department of Science, 1986). Again this exercise will provide a forecast on trends in the future use of materials in Australia.

10 MAKING THE MOST OF NEW AND ADVANCED MATERIALS

In Chapter 9, a number of areas were identified where new economic activity in the *production* of new and advanced materials could occur in the future. Normal market forces, particularly relating to raw material supply, technological change resulting from scientific discoveries and innovation, and the exploitation of niche markets, will be the determinants of change. Most of this activity will be undertaken by larger, established companies and, apart from continuing to support strategic R&D in this area, there is little influence that the Government can or should have.

However, the *use* of new and advanced materials to add value in manufactured products is a different matter. In this chapter, the shortfalls in this area are discussed and opportunities for Government to influence the situation are addressed.

This inquiry has established that, in common with many other aspects of Australian manufacturing industry, the utilisation of new and advanced materials is extremely variable across industry. The Commission found many firms utilising new materials in a very effective manner and in many cases they have developed highly profitable export businesses based on new and advanced materials.

However, numerous examples were brought to the attention of the Commission where the use of materials was far from optimal. This not only applied to the use of new and advanced materials, but also to the appropriate utilisation of more conventional (or traditional) materials.

From the point of view of developing internationally competitive manufacturing industries, it is the proper selection and use of the right material for the particular application that is most critical, whether the material be traditional or falling into one of the classes of new and advanced materials discussed in this report.

The Commission has identified three areas which contribute to the less than optimal use of materials:

- a lack of awareness amongst many firms, particularly small- to medium-sized firms (SMEs), as to the appropriate use of materials including new and advanced ones;
- shortcomings in the education system relating to training in materials, at both the technical and professional level; and

- problems in the research and development area, both in relation to the adequacy of facilities and the transfer of technology.

These issues are closely interrelated and they are all areas where Government can assist to improve the situation.

Recent overseas studies that have identified similar problems include a report to the UK Government by the Advisory Council on Science and Technology (1992), and a US study by the National Materials Advisory Board (1993).

10.1 Awareness raising

The first area contributing to less than optimal use of materials concerns awareness of developments in materials and their proper selection for use in manufactured products. This requires a knowledge of:

- the properties of materials relevant to their application;
- the processes required to fabricate the material; and
- an understanding of the costs and benefits (that is, net benefits) in whole-of-life assessments of the use of materials in various circumstances, given the initial cost may be higher than that of traditional materials.

Many participants indicated that there were significant shortfalls in one or more of these areas across many industries. This situation can only be corrected by raising the level of awareness within industry.

There seems to be a general concurrence that the expertise in use of new and advanced materials largely exists within Australia, but the problem is in linking this expertise to the needs of industry, particularly SMEs.

The primary responsibility for this raising of awareness must remain with the materials suppliers. Suppliers can collaborate in awareness raising through the formation of industry associations which promulgate information in various ways, and there is some evidence of this happening in Australia.

However, this approach is falling short of the optimal and there does appear to be a need to have in place other methods for awareness raising. The education system and the research community have important roles to play in this regard (discussed later in the Chapter).

Experience both overseas and in Australia demonstrates that an effective extension service activity is required. The *Materials Matter* program in the UK and the National Industry Extension Service (NIES) program in Australia are examples of this type of activity.

The Monash University Centre for Advanced Materials, the Queensland Manufacturing Institute (QMI) and the newly formed Materials Institute of Western Australia (MIWA) are other examples of Australian organisations with a potentially important role to play in awareness raising.

A successful model is to have a 'one-stop-shop' contact point staffed by as few as one or two materials engineers who have broad experience and a network of professional contacts. These staff would be able to answer queries directly but also have access to a wide variety of expertise within tertiary institutions, research organisations or private consultancies. The firm requiring specialist assistance could be put in direct contact with these experts.

Awareness raising is not dissimilar to basic education: one does not realise how beneficial it is until one has been subjected to it. For this reason, basic education is traditionally provided free of charge, and extension services to industry are, if not free to the recipients, at least subsidised. The net economic returns to society are found to outweigh the costs. Herein lies the justification for government involvement.

The *AusIndustry* program, incorporating NIES, plays a key role in augmenting the resources needed for awareness raising. However, some concerns were expressed about the relatively low profile that materials advice has in the programs in some states. Of course, appropriate material selection and usage is only one part of a successful enterprise, and effective general management and the use of total quality management systems are crucial ingredients. However, materials selection and use is such a pervading activity in industrial society that it cannot be given a low profile.

Where insufficient attention is given to materials, a solution is to replicate initiatives such as QMI and MIWA which combine and optimise resources from different sectors.

The Commission finds that *AusIndustry* should re-examine the emphasis on materials selection and materials use in its programs, to ensure that both these matters are receiving proper recognition.

The Commission also finds that to the extent that greater efforts need to be made in extension and technology transfer, encouragement should be given to state-based organisations which co-ordinate existing activities; and the infrastructure support funds of the *AusIndustry* Technology Access Program should be used to support initiatives in materials utilisation.

10.2 Education

The second shortcoming the Inquiry has identified is in the education system, and relates to training at both the professional and technical level. Deficiencies in training are impacting on the proper use of new and advanced materials.

Over the past two decades changes have occurred at the technical education level which have had undesirable effects. The Associate Diploma courses that used to be provided by Technical Colleges in the period up to the early seventies have not been replaced in the current system. Graduates from these courses played a major role in industry in that earlier period.

The TAFE system has started to address this gap with courses such as the Diploma of Applied Science (Materials Engineering) that has been developed in Victoria by Casey TAFE in conjunction with Monash University, and courses on materials which are being offered by Wembley TAFE in Western Australia.

In addressing this educational gap it is important that a national curriculum, rather than differing State-based ones, be developed. Demand is such that each State should have at least one TAFE college providing Associate Diploma courses. The National Materials Council and the Institute of Metals and Materials Australasia (IMMA) should be involved in accreditation of such courses.

At the tertiary education level, the training of engineers and architects in the proper use of materials is considered by many participants to have declined over recent years.

It is these professional staff who undertake the design function and thereby potentially have the most influence on materials selection and usage. If they do not have a proper understanding of the role of materials, then optimum utilisation will not be obtained. It is not necessary that all engineers (and architects or others who make decisions on materials selection) be specialists in materials science or engineering, but rather they need a broad, general knowledge and should be trained to know when specialist advice should be sought. It is this generalist competence in materials which is being lost.

Given that there is currently underway an Inquiry into Engineering Education (being undertaken by the Institute of Engineers Australia, the Australian Academy of Technology Science and Engineering (AATSE) and the Council of Engineering Deans), it would be appropriate for that inquiry to address this issue (in as much as it relates to engineers). Obviously, this would need to be done without adversely affecting the proper balance of issues investigated by the inquiry.

It would be appropriate for those reviewing engineering education to interact with those in other design professions who are responsible for course content, because the shortcoming is not just in engineering.

Just as important as the initial education one gets is life-long learning and maintaining up-to-date knowledge in the development of materials and related technology. Short courses are a powerful tool in achieving this objective. The initiatives of professional associations, such as IMMA, in developing programs of short courses in the materials area are to be commended.

A third problem in relation to education is that inadequate infrastructure is impeding student education in materials. A report by the National Board of Employment, Education and Training (NBEET, 1993) indicates that this a general problem across the tertiary system. It is particularly serious in the area of materials processing. Teaching students about materials processing on out-dated equipment is obviously undesirable. The same infrastructure inadequacy in materials processing also exists in the research area, and is addressed below.

One approach to partly alleviate the problem is better utilisation of existing resources by greater collaboration between the education sectors and Government institutions. QMI and the MIWA are excellent examples of this collaboration, with equipment and facilities from TAFEs, government laboratories and universities being brought together at one location and being available to all users including industry. However, this level of collaboration is the exception rather than the rule. The relevant organisations in each State or Territory should be encouraged to adopt similar collaborative models. The more general issue — of the allocation of resources for modern materials laboratories and equipment — is one for Government to address in the context of competing demands; however, the importance of adequate education and training in materials science cannot be over emphasised.

10.3 Research and development

The third area of deficiency identified pertains to the various shortcomings in R&D which are impeding the proper use of new and advanced materials.

A particularly important matter is the inadequacy of infrastructure supporting research into materials processing. This is not the situation in all aspects of materials research, for example, in materials characterisation there is not a shortfall in equipment. The high cost of certain types of equipment is one reason why this problem exists in other areas.

The standard of equipment impinges on education and training (as mentioned above) because certain pieces of equipment are used for both research and training, particularly at higher degree level.

A possible partial solution to this problem was suggested by CSIRO and has been endorsed by the National Materials Council. The suggestion is to form an organisation similar to the Australian Institute of Nuclear Science and Engineering (AINSE). AINSE is a co-operative venture between Australian universities and ANSTO to encourage and facilitate access to expensive facilities at the ANSTO Lucas Heights research establishment, particularly in the area of neutron diffraction.

An approach similar to the AINSE model has much to commend it. A possible source of funds to initiate such activity would be the ARC Research Initiatives program, which is specifically aimed at facilitating networking activities such as this. The proposed organisation would facilitate access to expensive items of equipment, particularly at ANSTO and CSIRO, required for materials research.

The AINSE concept is only a partial solution. It could be complemented by the creation of additional Centres of Excellence. The existing Centres are not able to adequately cover all the important areas of materials science and technology.

There has been some degree of concentrating related activities into centres such as that in casting at the University of Queensland (assisted by the formation of the CRC for Alloy and Solidification Technologies), ceramic processing at ANSTO, surface treatments at the University of South Australia, and the recent announcement by BHP of support for a Steel Institute at the University of Wollongong. More of this concentration of effort is required, as it is much easier to justify in cost-benefit terms the acquisition of expensive research infrastructure if the number of researchers is increased.

The CRC program has attempted to facilitate a concentration of research effort but without generally requiring the adherence to one of the original concepts enunciated by Professor Ralph Slatyer, namely the physical co-location of research activities with a common interest. The necessity of physical co-location has been challenged by the Department of Industry, Science and Technology, mainly on the basis that modern communication systems can overcome problems of distance and that the cost of forced co-location could be prohibitive.

However, given the weight of evidence supporting Slatyer’s prescription, much of it gathered from around the World, the Commission would expect that his original concept be taken into account in the current review of the CRC program.

Better links between industry and research

An important factor in technology transfer is making available to industry the skills available in research institutions and universities. The extension activities discussed in Section 10.1 above will partially facilitate this but other initiatives are required. A report by NBEET on research links between industry and universities in Australia identified direct personal linkages as the most effective way of optimising this knowledge transfer (NBEET, 1993). Any mechanisms which encourage this interaction should be encouraged. The *AusIndustry* networking proposals and the CSIRO proposal to attach staff to SMEs could both be beneficial in this regard.

Some participants recommended the formation of an Australian Mineral Industries Research Association (AMIRA) type organisation to facilitate research collaboration and technology transfer in the materials area. It is not evident that such an organisation would work in the area of new and advanced materials because of the diverse nature of the industries involved and the lack of incentive for firms to co-operate where there is not generic research activity.

AMIRA is atypical for a number of reasons. First, the research it does is highly focused on applications confined to the mining industry. Second, the activities of the member companies are commodity-specific, that is their businesses revolve around particular mineral commodities and they do not directly compete with one another. Further, much of AMIRA's research is directed at minerals extraction and processing techniques designed to reduce costs in the mining industry, so that all members of AMIRA have a common interest in this outcome. Few of these conditions exist in manufacturing industry. However, some form of collaboration in very specific and focused areas such as die casting may be appropriate.

A completely different, but significant, problem identified by a number of participants relates to difficulty of access to CRCs (and, most importantly, their research output) by firms (particularly, but not exclusively, SMEs) which are not formal members of a CRC. Clearly, there are difficulties involved in bringing existing or potential competitors together in what are 'joint venture' research arrangements.[1] However, there is a public good aspect of CRCs and the widest possible sharing of benefits is another issue which the present review of the CRC program could fruitfully consider.

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1 It can be noted that Morris-Suzuki (1994) claims that this issue was not a problem in collaborative R&D in Japan, where industry associations and government research agencies shared R&D, but individual firms in the area competed fiercely.

A CONDUCT OF THE INQUIRY

The terms of reference were received by the Industry Commission on 12 April 1994. They directed the Commission to report 12 months later.

An issues paper was distributed to parties with an interest in new and advanced materials. The paper defined the scope of the inquiry and raised issues of relevance to the inquiry.

During the inquiry the Commission conducted visits and meetings with businesses, organisations and government departments. Those who assisted the Commission are listed in Attachment A1.

Case studies were undertaken to collect information for an assessment of the potential for the further use of new and advanced materials. The studies were in the following areas:

- aluminium alloys;
- automotive industry;
- biomedical applications;
- engineering and electrical ceramics;
- magnesium;
- metal-matrix composites;
- nickel;
- polymers;
- rare earths;
- steel; and
- titanium.

The information obtained by the Commission from case study visits and from its own research, is presented in Attachment A2.

Initial public hearings for the inquiry were held in July and August 1994 in Melbourne, Brisbane and Sydney. Public hearings on the draft report were held in December 1994 and February 1995 in Melbourne, Sydney, Adelaide, Perth and Canberra.

A total of 67 submissions were received during the inquiry. Organisations and individuals who made submissions to the inquiry are listed in Attachment A3.

Attachment A1 Industry visits

The organisations who assisted the Industry Commission in the course of the inquiry are listed below. Organisations marked * participated in case studies.

New South Wales

Akzo Chemicals Limited*
American Cyanamid Company
Asahi Diamond Industrial Australia Pty Ltd*
Astra Engineering–Division of National Forge (Operations) Pty Ltd*
Australian Defence Industries Limited – Naval Engineering Division
Australian Graduate School of Engineering Innovation (AGSEI)
Australian Magnet Technology Pty Ltd (AMT)*
Australian Nuclear Science and Technology Organisation (ANSTO)
Australian Technology Group (ATG)
AWA Limited*
AWA Microelectronics Pty Ltd*
Bard Australia Pty Ltd
BHP Research Laboratories
BHP Steel
Bone Biomaterial Unit, University of New South Wales
BP Solar Australia Pty Ltd*
C-Ramic Australia Pty Ltd*
Centre for Advanced Materials Technology, University of Sydney
Centre for Photovoltaic Devices and Systems, University of New South Wales
Colby Engineering Pty Ltd
CRC for Cardiac Technology
CRC for Eye Research and Technology
Department of Mechanical Engineering, University of Sydney
Division of Radiophysics – GaAs IC Prototyping Facility, CSIRO
Du Pont (Australia) Ltd*
Ecogen Pty Ltd
Futuris Industrial Products Pty Ltd*
GEC Marconi Systems Pty Ltd
Hawker De Havilland Limited
Institute of Minerals, Energy and Construction, CSIRO
Instrument Engineering Pty Ltd*
Johnson & Johnson Research Pty Limited
Macnaught Medical Pty Limited
Materials Physics Laboratory, Macquarie University

Medical Industry Association of Australia (MIAA) Inc*
Pacific Power International*
Relativity Pty Ltd*
Semiconductor Science and Technology Labs
Silicon Technologies Australia Limited*
Taylor Ceramic Engineering
Telectronics Pacing Systems*
Thermal Ceramics Australia Pty Ltd*
Transform Composites*
Trimed Pty Ltd
UNASCO Pty Ltd*
VTOL Aircraft Pty Ltd*

Victoria

Aeronautical and Maritime Research Laboratory (AMRL), DSTO
AeroSpace Technologies of Australia (ASTA) Ltd
Aircar Industry
Automotive Industry Authority of Australia
BASF
BHP Research*
Bio Nova International Pty Ltd
Brenco Thermal Spray Pty Ltd*
Carborundum Resistant Materials Ltd*
Casey College of Technical and Further Education
Centre for Advanced Materials Technology, Monash University
Ceramic Fuel Cells Limited*
Ciba-Geigy Australia Limited
C M Whittington and Associates Pty Ltd
Comalco Limited
Comalco Research Centre
Composites Materials Engineering Pty Ltd*
CRA Limited
CRC for Aerospace Structures
CRC for Polymer Blends
Cyco International Pty Ltd
Department of Business and Employment
Department of Education
Division of Chemicals and Polymers, CSIRO
Division of Manufacturing Technology, CSIRO
Division of Materials Science and Technology, CSIRO

Dow Chemical (Australia) Limited
Ford Motor Company of Australia Limited
GE Plastics
ICI Advanced Ceramics
ICI Plastics
Industry Support Office, DSTO
Institute of Industrial Technologies, CSIRO
Institute of Metals and Materials Australasia Ltd (IMMA)
International Sintered Components Pty Ltd
Mineral Holdings Australia Pty Limited
MM Cables Communication Products*
National Forge Ltd*
National Key Centre for Advanced Materials Technology, Monash University
Olex Cables
Office of Training and Further Education
Plastics and Chemicals Industries Association Inc (PACIA)
Polymer Technology Centre, Royal Melbourne Institute of Technology
PolyPacific Pty Ltd*
Shorlube Industries*
SINTEC Australia Pty Ltd
Surface Technology Coatings (A Division of Sutton Tools Pty Ltd)
Technological Resources Pty Ltd (A Subsidiary of CRA Limited)
Thermal Bay Pty Ltd*
Townsend Chemicals Pty Ltd*
United Surface Technologies Pty Ltd*
Uniti Corporation Pty Ltd

Queensland

Aliteck Pty Ltd
Australian Stainless Steel Development Association (ASSDA)
Centre for Strategic Industrial and Resources Development
CRC for Alloy and Solidification Technology (CAST)
Department of Chemical Engineering, University of Queensland
Faculty of Science and Technology, Griffith University
Great Barrier Reef Marine Park Authority
North Queensland Engineering Agencies (NQEA) Australia Pty Ltd
Pratco Industries
School of Dentistry, University of Queensland
QMag (Queensland Magnesia)

Queensland Department of Business, Industry and Regional Development (DBIRD)
Queensland Metals Corporation (QMC)
Rare Earths Australia (REA)
Ticor Holdings Ltd*

Tasmania

ACL Bearing Company*
Comalco Aluminium (Bell Bay) Limited
Southern Aluminium Pty Limited*

Western Australia

Ashton Rare Earths Ltd (Mount Weld Rare Earth Project)
Australian Fused Materials Pty Ltd (AFM)
Materials and Manufacturing Application Centre, Central Metropolitan College of TAFE
Ceramco Pty Ltd
Department of Commerce and Trade
HiPerm Laboratory
HIsmelt Corporation Pty Limited
Imdex NL
Materials Institute of Western Australia
Newtech Woolharvesting Pty Ltd
Rojan Advanced Ceramics Pty Ltd
Western Australian Department of Commerce and Trade
Western Mining Corporation Limited*

South Australia

Britax Rainsfords Pty Ltd
Ferepac Consulting Pty Ltd
Gartrell School of Mining, Metallurgy and Applied Geology, University of South Australia
General Motors–Holden's Automotive Ltd
Land, Space and Optoelectronics Division, DSTO

Australian Capital Territory

ANUTECH
Australian Association of Aerospace Industries (AAAI)

Australian Bureau Agricultural and Research Economics (ABARE)
Department of Industry Science and Technology (DIST)
Department of Primary Industries and Energy (DPIE)
Energy Research and Development Corporation (ERDC)*
Plant Science Centre, Australian National University
Royal Australian Mint

Attachment A2 Case study information request

The following is a check list of the information sought for the case studies.

Part 1: All Businesses

1.1. Parent Company or Group.

1.2. Overseas affiliations.

1.3. Form and structure of business entity (e.g. private, listed, or subsidiary).

1.4. Total value of output in 1992–93.

1.5. Products produced by business (new materials and others).

1.6. Years business has operated in its current form.

1.7. Total number of employees (full time equivalent) as at 30 June 1993.

1.8. Level of profits in 1992–93.

1.9. Value of assets as at 30 June 1993.

Part 2: General Questions on New and Advanced Materials

2.1 New and advanced materials:

(i) produced in 1992–93

(ii) used in 1992–93

(iii) may potentially produce within the next 5 years

(iv) may potentially use within the next 5 years

2.2 Names of other companies you think the Commission should talk to.

Part 3: Producers of New and Advanced Materials

Production Information

3.1.1. Quantity and value of new and advanced material output between 1989–90 to 1992–93.

3.1.2. Full-time equivalent employment used to produce the new and advanced material (or obtain % of total company employment).

Output Assistance

3.1.3. Level of tariffs or bounties that apply to the new material.

Input Information

3.2.1. Raw materials, semi-processed goods, fuels and services used in production in 1992–93 and their total values.

3.2.2. Level of tariffs on inputs such as raw materials, semi-processed goods.

Market Information

3.3.1. Australian businesses that are the main users of new and advanced materials and what they do with them.

Market Expectations

3.3.2. Expected growth in demand over the next 5 years for the new and advanced material.

3.3.3. Main sources of this expected growth.

3.3.4. Australian companies that are not currently but are potential users of your new materials over the next 5 years.

3.3.5. Expected growth in demand for your new materials over the next five years.

3.3.6. Conditions necessary to ensure that growth expectations for your company are realised (e.g. skills availability, availability of process technology).

Exports

3.4.1. Level of exports between 1989–90 and 1992–93.

3.4.2. Countries to which your company exports.

3.4.3. Company's share of Australian and global markets for each new material.

3.4.4. Export price and price in overseas markets of each new material.

3.4.5. Forms and levels of government assistance available to overseas competitors.

3.4.6. Impacts, if any, of overseas assistance to competitors on your activities or market.

Competition

3.5.1. Main substitutes for each new material.

3.5.2. Strengths of your product relative to those of your competitors and major substitutes (e.g. price, quality, technology).

3.5.3. Company names of national and international competitors.

3.5.4. Your company's price setting principles (e.g. whether rebates are given to exporters or other customers, discounts, promotional prices, forward contracting, extent and reasons for price fluctuations).

3.5.5. Landed duty free price of imports of your new and advanced materials.

Innovation and Commercialisation

3.6.1. Process leading to the production of new and advanced materials.

3.6.2. Briefly describe the kind of technology used to produce the new materials.

3.6.3. Source of technology (e.g. developed 'in-house', purchased domestically or from overseas, franchised).

3.6.4. Difficulties of access to technology developed elsewhere (intellectual property rights).

3.6.5. Level of awareness of properties and applications of new materials amongst Australian user industries.

3.6.6. Difficulties, if any, in incorporating new and advanced materials into the production process (e.g. access to finance, skills, technology, information, changes to process technology and input costs such as transport and energy).

3.6.7. Critical commercialisation success factors.

Research and Development

3.7.1. R&D activities which have been undertaken in 1992–93 for each new and advanced material.

3.7.2. Level of R&D expenditure on the new and advanced material between 1989–90 and 1992–93.

3.7.3. Links, including assistance received from specialist research bodies and organisations such as CSIRO or universities, for the new and advanced material.

3.7.4. Involvement in a CRC:

(i) Name of CRC(s).

(ii) Contributions made by the business to the CRC(s) (e.g. finance, experience).

(iii) Arrangement with CRC on intellectual property rights.

(iv) Effectiveness of CRC.

Government Assistance

3.8.1. Awareness of government assistance programs that are available:

- 150 per cent tax concession on R&D
- Grants for Industry Research and Development (GIRD)
- National Industry Extension Service (NIES)
- Export Market Development Grants (EMDG)
- Export Finance Insurance Corporation (EFIC)

3.8.2. Type of assistance received from Commonwealth, State and local governments over 1992–93 for new and advanced materials. Forms of assistance received should also include government purchasing preferences, provision of land, energy, water and payroll tax concessions, relocation and training assistance.

Effectiveness of Assistance

3.8.3. Effectiveness of each form of assistance received.

3.8.4. Suggestions as to how government could assist more effectively.

3.8.5. Difficulties experienced in obtaining government assistance. (e.g. administrative difficulties in applying for assistance)

Government Regulation

3.9.1. Impacts (both negative or positive) on new and advanced material production of government regulations (such as environmental and planning approval processes, patent legislation, planning and trade waste permits).

Part 4: Users of New and Advanced Materials

Incorporating New and Industrial Materials in Production

4.1.1. Main reasons for using the new and advanced material.

4.1.2. Benefits, if any, that the use of new and advanced materials bring to products.

4.1.3. Difficulties, if any, in incorporating the new and advanced material into the production process (e.g. access to finance, skills, access to technology, access to inputs, transport, energy and other input costs, changes to the production processes).

Production Information

4.2.1. Quantity and value of final products produced between 1989–90 and 1992–93 which incorporated new and advanced materials.

4.2.2. Full-time equivalent employment used to produce each product using new and advanced materials (or % of total employment).

4.2.3. Quantity and value of exports of each product incorporating new and advanced materials between 1989–90 and 1992–93.

4.2.4. Countries to which your company exports.

New and Advanced Material Inputs

4.3.1. Quantities and costs of each new and advanced material used in each product in 1992–93.

4.3.2. New and advanced material suppliers used.

4.3.3. Substitutes for the new and advanced material in each of your products.

4.3.4. Proportion of the new and advanced material used in production that is imported.

4.3.5. Advantages or disadvantages of purchasing the new and advanced material from domestic suppliers, overseas suppliers and producing them ‘in-house’.

Market Expectations

4.4.1. Expected growth in your business’ demand for the new and advanced material over the next 5 years.

4.4.2. Conditions necessary to ensure these expectations are realised (e.g. skills availability, process technology).

Innovation and Commercialisation

4.5.1. Process leading to the production of new and advanced materials.

4.5.2. Briefly describe the kind of technology used to produce the new materials.

4.5.3. Source of technology (e.g. developed 'in-house', purchased domestically or from overseas, franchised).

4.5.4. Difficulties of access to technology developed elsewhere (intellectual property rights).

4.5.5. Level of awareness of properties and applications of new materials amongst Australian user industries.

4.5.6. Difficulties, if any, in incorporating new and advanced materials into the production process (e.g. access to finance, skills, technology, information, changes to process technology and input costs such as transport and energy).

4.5.7. Critical commercialisation success factors.

Research and Development

4.6.1. R&D activities that have been undertaken in 1992–93 for processes incorporating the new and advanced material.

4.6.2. R&D expenditure on new and advanced materials between 1989–90 and 1992–93.

4.6.3. Links, including assistance received from specialist research bodies and organisations such as CSIRO or universities, for new and advanced material R&D.

4.6.4. Involvement in a CRC:

(i) Name of CRC(s).

(ii) Contributions made by the business to the CRC(s) (e.g. finance, experience).

(iii) Arrangement with CRC on intellectual property rights.

(iv) Effectiveness of CRC.

Government Assistance

4.7.1. Awareness of government assistance programs that are available:

- 150 per cent tax concession on R&D
- Grants for Industry Research and Development (GIRD)
- National Industry Extension Service (NIES)
- Export Market Development Grants (EMDG)
- Export Finance Insurance Corporation (EFIC)

4.7.2. Type of assistance received from Commonwealth, State and local governments over 1992–93 for new and advanced materials. Forms of assistance received should also include government purchasing preferences, provision of land, energy, water and payroll tax concessions from State and local governments, relocation and training assistance from the Department of Employment, Education and Training and state governments.

Effectiveness of Assistance

4.7.3. Effectiveness of each type of assistance received.

4.7.4. Suggestions as to how government could assist more effectively.

4.7.5. Difficulties experienced in obtaining government assistance. (e.g. administrative difficulties in applying for assistance).

Government Regulation

4.8.1. Impacts (both negative or positive) on new and advanced material production of government regulations (such as environmental and planning approval processes, patent legislation, planning and trade waste permits).

Part 5: Potential Users and Producers of New and Advanced Materials

5.1. Likelihood of the new and advanced materials being used or produced within the next five years.

5.2. Substitutes for the new and advanced material in these products.

5.3. Anticipated benefits from the eventual use or production of the new and advanced materials (e.g. price, quality, technology).

5.4. R&D undertaken in 1992–93 into the use of the new and advanced materials.

5.5. Expected difficulties, if any, of incorporating the new and advanced materials into your production processes.

5.6. Government regulations such as environmental approval processes, patent legislation, tariffs and import restrictions, planning and trade waste permits that are expected to have either an adverse or beneficial impact on the use of new and advanced materials.

5.7. Reasons why new and advanced materials are not currently being used

5.8. Changes that will have to occur before the materials will be used.

Attachment A3 Submissions to the inquiry

Organisations and individuals who made submissions to the inquiry are listed below. Participants marked * presented submissions at public hearings. The remainder made written submissions only.

Submitter	*Submission number*
Advanced Materials Program, ANSTO*	29
Advanced Materials Program, ANSTO*	60
AeroSpace Technologies of Australia (ASTA) Ltd*	16
Ashton Mining Ltd*	44
Australian Composite Structures Society*	15
Australian Customs Service	2
Australian National Training Authority	48
Australian National University*	51
Burford, A/Prof R P	42
Centre for Advanced Materials Technology and The Warren Centre for Advanced Engineering, University of Sydney	33
Centre for Materials Technology, University of Technology Sydney*	10
Centre for Materials Technology, University of Technology Sydney*	46
Composites Institute of Australia Inc	20
Conran, Mr G W	11
Conran, Mr G W*	40
Conran, Mr G W	66
CSIRO Australia*	19
CSIRO Australia*	43
Defence Science & Technology Organisation*	25
Department of Industry Science and Technology	58
Department of Materials Engineering, Monash University	32
Department of Mechanical Engineering, University of Newcastle	36
Department of Resources Development, Western Australia	30
Department of Resources Development, Western Australia	54
Dunlop, Prof G L*	23
Horn, Prof R*	9
Horn, Prof R*	52
ICI Advanced Ceramics*	18

B1 ALUMINIUM AND ALUMINIUM ALLOYS

The discovery of aluminium is jointly attributed to a Danish scientist, Christian Oersted, and a German chemist, Friedrich Wohler in 1827. Aluminium remained a rarity and was more expensive than gold for some time. When the public was first introduced to aluminium in 1855, it was exhibited alongside the French crown jewels (Hendrick, 1991).

B1.1 Aluminium and new aluminium alloys

Although aluminium has only been produced in commercial quantities for just over 100 years, today the use of aluminium, measured either in quantity or value, exceeds that of any other metal except iron, and is important in virtually all segments of the World economy (US Bureau of Mines, 1993).

In the early 1950s, Australia was not considered to be well endowed with bauxite reserves and was a net importer of aluminium. Discoveries of World class bauxite reserves in Queensland and the Northern Territory in 1955 set the scene for Australia to emerge as a major World producer of aluminium. However, until the 1980s, Australia was a supplier of bauxite and alumina but only had a very small aluminium smelting industry (ABARE, 1992). Today Australia produces approximately 8 per cent of annual World aluminium production (ABARE, 1994c).

Material properties

Primary aluminium and, in particular, new aluminium alloys, offer a wide variety of characteristics which make them extremely popular materials for a large cross section of industries. Their characteristics include:

- low density;
- mechanical strength;
- ductility;
- electrical and thermal conductivity;
- good malleability;
- corrosion resistance; and
- good casting and forging characteristics.

These properties can be varied by alloying, by adopting various processing technologies and by forming composites in order to engineer aluminium-based materials that fit specific applications.

Classification of aluminium alloys

The classification of aluminium alloys according to the main alloying element is listed in Table B1.1. The convention is to list them in a series numbered 1000 to 8000. In addition to the 1000 to 8000 series, there is a 9000 group of aluminium alloys for the development of new alloys. None of these 9000 group are produced commercially within Australia at present.

Table B1.1: Classification of aluminium and its alloys

Series	*Main alloying elements*
1000	Aluminium of over 99 per cent purity
2000	Copper
3000	Manganese
4000	Silicon
5000	Magnesium
6000	Magnesium and silicon
7000	Zinc
8000	Lithium and miscellaneous added elements

Source: Street and Alexander, 1994.

Both traditional aluminium and its alloys (the 1000 to 8000 series in Table B1.1), and recently developed advanced aluminium alloys (the 9000 series), are of importance for this inquiry. This is because, to a certain degree, primary aluminium and its alloys are all competing for the same end-use markets.

For the purposes of this inquiry, primary aluminium is not regarded as a new material, neither are aluminium alloys that have been incorporated into production processes for a considerable period of time, such as Al 6061 (which consists of aluminium, silicon, magnesium and copper). However, the combination of new additives or alloying agents with pure aluminium, leading to incremental improvements in the properties of an aluminium alloy, is considered to fall within the definition of new and advanced materials.

More than 100 commercial alloys are currently available, and several new alloys are developed each year (US Bureau of Mines, 1993).

B1.2 International production and usage

Production

World production of primary aluminium is approximately 15.4 million tonnes per year. In addition to this, approximately 4 million tonnes is produced annually from recycled scrap (Street and Alexander, 1994). The aluminium industry is considerably larger than the copper, zinc, lead and magnesium industries which produce 8.05, 5.78, 2.35 and 0.25 million tonnes each year respectively, but substantially smaller than annual World production of steel (718 million tonnes).

Table B1.2: Summary and projections for World production 1992–1999

Mineral Production	*Unit*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*
Bauxite	Mtonnes	92.4	96.0	98.3	100.6	102.9	105.4	107.9	110.4
Alumina	Mtonnes	36.8	36.6	36.6	36.9	37.9	39.3	40.3	41.4
Primary Aluminium	Mtonnes	14.9	15.2	15.2	15.3	15.9	16.6	17.4	18.4

Source: ABARE, 1994b.

One of the merits of aluminium is its recyclability. The metal is recycled in large quantities. Around 25 per cent of annual World aluminium production is accounted for by recycling (Street and Alexander, 1994). This is reflected in the higher World production figure shown in Table B1.3 compared with Table B1.2, where the production figures in Table B1.3 include both primary and secondary (recycled) aluminium.

A major reason why recycling is practised is that energy is a major cost component in aluminium production and the production of recycled aluminium uses only 5 per cent of the energy required to produce primary aluminium (ABARE, 1992).

Table B1.3: Major World aluminium producers in 1993

Country	*Volume (kt)*	*Share of total (per cent)*
United States	3 697	19.1
CIS	2 850	14.7
(Russia)	(2 490)	(12.9)
Canada	2 303	11.9
European Union	2 099	10.8
Australia	1 400	7.2
Norway	873	4.5
Others	6 508	33.6
Total World production	19 370	100

Note: Production figures include both the production of primary and recycled aluminium.
Source: ABARE, 1994a.

Usage

Aluminium and its alloys, both traditional and new, are used widely in the automobile, aerospace, marine craft construction, building and mining industries, and in the production of sporting equipment.

In 1903, the famous aeroplane of the Wright brothers contained several parts made from aluminium. Today, although advanced military aircraft contain large amounts of titanium alloys, most commercial aircraft rely on aluminium alloys for up to 70 per cent of their weight (Street and Alexander, 1994).

The use of aluminium-based materials in the automotive industry has been growing steadily as a result of the Corporate Average Fuel Economy (CAFE) fuel efficiency regulations in the US (The CAFE regulations, discussed briefly in Chapter 5, create an incentive to reduce fuel consumption by way of weight reductions achieved through the use of light weight materials in the manufacture of automobiles).

International research activity

Internationally, there is considerable work currently focussed on the research and development of new aluminium alloys. Much of the work relates to the automotive, military and aerospace industries, but there are other prospective user industries as well.

An example of the type of R&D being carried out overseas is the French–Australian Industrial Research program (FAIR), which has approved a project involving the evaluation of an experimental high strength aluminium alloy for possible use in the fuselage of a new supersonic passenger aircraft, the Avion de Transport Supersonique Future (ATSF).[1] The ATSF is being planned as a successor to Concorde, however the aluminium alloys used in Concorde will not be suitable for the ATSF. The FAIR project is examining an experimental aluminium–copper–magnesium–silver alloy (Polymear, 1994).

Also important is the discovery of new applications for materials. In Japan, Kobe Steel and Furukawa are working with Toyota in the manufacture of aluminium panels and bonnets for automobile manufacture. Using aluminium instead of steel in the bonnet panels leads to a weight saving of eight kilograms.

In Europe, the Dutch metal company Hoogoven Groep has developed a material where a plastic sheet is sandwiched between two thin layers of aluminium. This material, known as Hylite, is designed to be used for automobile panels and bonnets (Materials Edge, 1992).

B1.3 Australian production and usage

Over the past three decades, Australia has developed an internationally competitive aluminium industry, and is now a large producer of bauxite, alumina and aluminium by World standards. Australia produces approximately 40 per cent of the World's bauxite, is the World's largest producer and exporter of alumina, and is the World's third largest exporter of aluminium after Canada and the CIS (ABARE, 1994c).

The growth of the Australian aluminium industry has been based on large and high quality reserves of bauxite and the availability of relatively inexpensive energy (ABARE, 1992).

Australian production of aluminium in 1993–94 was 1.39 million tonnes, and in 1994 export earnings from aluminium were valued at over $2 billion, compared with $62 million in 1980 (ABARE, 1994b). Aluminium exports account for approximately 4 per cent of Australia's total goods and services exports (ABARE, 1992).[2]

Table B1.4 shows Australia's production and export of aluminium from 1991 to 1993, and provides forecasts for the years 1994 to 1999.

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1 The FAIR program has no budgetary allocation but serves as a broker in helping to find partners from each country to participate in approved R&D projects (Polymear, 1994).

2 In many instances, aluminium is not exported directly, but as a component in a final product such as a car.

Table B1.4: Summary and projections for Australian production, and export volumes and values, 1991–99

	Unit	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*
Mineral production										
Bauxite	Mtonnes	41.76	39.85	41.17	41.50	42.63	43.40	44.00	46.00	46.75
Alumina	Mtonnes	11.40	11.82	12.22	12.30	12.65	12.70	12.70	13.30	13.50
Primary Aluminium	Mtonnes	1.24	1.23	1.30	1.39	1.41	1.41	1.45	1.61	1.61
Export Volume										
Bauxite	Mtonnes	na	na	na	na	na	na	na	na	na
Alumina	Mtonnes	9.19	9.45	9.67	9.59	9.90	9.95	9.87	10.16	10.36
Primary Aluminium	Mtonnes	0.92	0.93	0.98	1.05	1.06	1.06	1.09	1.24	1.23
Export Value										
Bauxite	$million	155	122	90	90	105	115	125	135	145
Alumina	$million	2 922	2 373	2 405	2 004	2 565	2 870	3 180	3 480	3 670
Primary Aluminium	$million	1 994	1 631	1 772	1 784	1 805	1 850	2 065	2 630	2 769

na not available.
Note: All figures in 1993–94 Australian dollars.
Source: ABARE, 1994b.

According to ABARE, the bauxite, alumina and aluminium industry chain is responsible for the direct employment of around 30 000 people at mines, refineries and smelters throughout Australia, and almost 100 000 people are indirectly employed in support areas (ABARE, 1992).

Growth in the Australian aluminium industry has continued into the 1990s and has been highlighted by a number of expansions to existing aluminium smelters and alumina refineries. For example, the Tomago smelter in NSW increased capacity by 140 000 tonnes in 1993 (ABARE, 1994b).

Nature of the Australian aluminium industry

Production of primary aluminium in Australia is dominated by a relatively small number of domestic producers. Comalco, which is 67 per cent owned by CRA, is Australia's largest primary aluminium producer with an annual output of 422 000 tonnes in 1992 (CRA, 1993). Alcoa of Australia produced 325 000 tonnes of primary aluminium in 1992 (WMC, 1993). Other Australian producers of primary aluminium are Portland Aluminium, Tomago Aluminium, and Alcan.

The main users of new aluminium alloys in Australia are the automobile, building construction, marine, and packaging industries.

Comalco, apart from being a large producer of primary aluminium, is the largest Australian company involved in the research and development of new aluminium alloys. An example of Comalco's efforts is the research on an aluminium–lithium alloy known as VACLITE™. Lithium is the lightest of all metals, but it is highly chemically reactive (Street and Alexander, 1994). The lower density and improved stiffness of aluminium–lithium alloys, relative to other aluminium alloys, allows weight savings of at least 10 per cent. The alloy also demonstrates excellent fatigue properties (DITAC, 1989). Aluminium–lithium alloys are produced under vacuum conditions.

Although aluminium–lithium alloys offer advantageous mechanical properties, they are much more expensive than other alloys. As a result, their use is only justified in aerospace and military projects (Street and Alexander, 1994).

Another example is Comalco's development of an aluminium alloy known as 3HA, developed for the manufacturer of cylinder heads and engine blocks. The alloy is comprised of aluminium, silicon, iron, copper, manganese, magnesium, chromium, nickel and titanium. However, Comalco's 3HA is not currently being used on a commercial basis by any car manufacturer.

B1.4 Supply conditions

Processing technologies

Incremental improvements to the technologies used in the processing of aluminium alloys — such as casting — are seen by both the producers and the users of aluminium alloys as at least as important as the development of new aluminium alloys themselves. Users of aluminium alloys such as Southern Aluminium — a manufacturer of alloy wheels in Bell Bay, Tasmania — place a higher priority on improving casting techniques than developing better alloys. Southern Aluminium considers the traditional Al 6061 to be suitable for their product, but see potential gains from refining their production processes.

Improvements to processing technologies can be important for two reasons. First, a reduction in the amount of time or waste material associated with the production process will reduce production costs, making the final product more competitive.

Second, if a new processing technology generates superior physical properties in the final product, such as a greater strength-to-weight ratio, or improved fluidity, the final product may be able to enter and compete in new markets against materials for which aluminium alloys were previously an inferior substitute.

Australia already possesses a significant casting industry with existing expertise and experience. High-pressure aluminium die casting technology has been actively developed by CSIRO over an extended period of time, and further developments have more recently been undertaken by the CRC for Alloy and Solidification Technology (CAST), directed by Professor Gordon Dunlop.

Comalco is joint owner of ICA Castings in the US, a company developing the ‘Improved Low Pressure’ (ILP) casting technology. The ILP casting technology uses traditional aluminium alloys to make components with traditional characteristics. However, the benefit of the ILP system is that it reduces the amount of time associated with production.

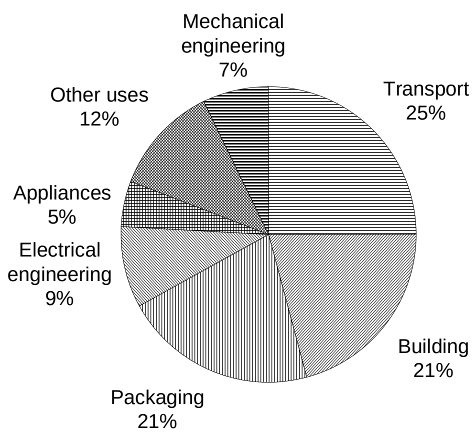
B1.5 Demand conditions

World consumption of primary and secondary aluminium in 1994 is estimated to be 22.7 million tonnes. The level of annual aluminium consumption is expected to increase to 28 million tonnes by 1999 (ABARE, 1994b).

The major end users of aluminium are the building and construction, packaging, electrical engineering and transport industries as shown in Figure B1.1. The transport sector is growing as a user of aluminium due to the increased use of aluminium in passenger motor vehicles (ABARE, 1994b).

In the US, motor vehicles currently contain an average of 87 kilograms of aluminium, 34 kilograms more than in 1983. In Japan, the average aluminium content of motor vehicles has doubled to 85 kilograms over the past four years. (ABARE, 1994b)

Figure B1.1: Aluminium end uses, 1993



Source: ABARE, 1994b.

The aluminium content in Australian built cars is closer to 70 kilograms (ABARE, 1992).

User awareness and preferences

The high cost of aluminium relative to traditional metals such as steel, and the short run costs associated with altering production processes, are seen as barriers to its increased use. In addition, aluminium does not stamp as well as steel, and is easier to dent.

The use of aluminium and aluminium alloys will be governed by the relationship between the up-front cost of a product such as a motor vehicle and the whole-of-life cost of operating it. For example, improving fuel efficiency by producing a car bonnet made out of aluminium as opposed to steel would more than double the initial production cost of the bonnet, with the technology presently available in Australia. However, the improved fuel efficiency using an aluminium bonnet would reduce the whole-of-life cost of running the car.

A force behind increasing demand for aluminium alloys by the automotive industry is the CAFE standards in the US, which were mentioned previously. Notwithstanding these standards, consumer preferences for fuel efficiency and concern with vehicle emissions are influencing demand for lighter vehicles. In Germany, the laws pertaining to recycling are also affecting the types of materials used in vehicles.

There is a considerable degree of competition between automobile manufacturers, which provides an incentive for them to search for, and incorporate, the best possible material in the construction of their cars.

B1.6 Markets

The World’s largest primary aluminium producers have strong lines of communication aimed at generating stability within the industry. Prices are able to be controlled through adjustments to production, because demand for primary aluminium is relatively inelastic, that is, there is limited opportunity for ready substitution between it and other metals. However, there is significant competition between new aluminium alloys via product differentiation.

Aluminium price volatility

As illustrated in Figure B1.2, the price of aluminium on World markets in the early 1990s was very low, causing major producers of aluminium to experience substantial operating losses. The figure also illustrates the volatility of prices over the last decade and a half.

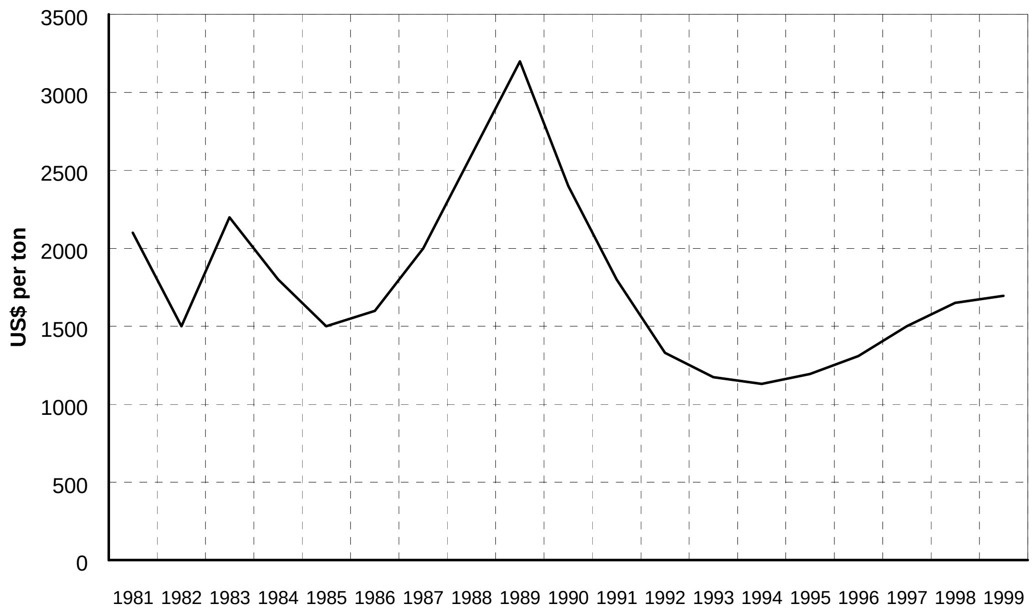
Since 1990, World stocks of aluminium have increased sharply and prices have fallen. Average prices in 1993 were at their lowest level since 1985 — and the lowest ever in real terms (ABARE, 1994b).

There were a number of factors contributing to the depressed World price of aluminium.

First, the break up of the former Soviet Union into the Commonwealth of Independent States (CIS) resulted in a large increase in the supply of aluminium onto the World market. In previous years, Eastern European countries, including the Soviet Union, shipped between 100 000 and 350 000 tonnes of aluminium to the Western World market. In 1990, the CIS exported 274 000 tonnes of aluminium. In 1991, however, shipments of aluminium from these countries exceeded 800 000 tonnes, and in 1993, exports had risen to 1.6 million tonnes, approximately 10 per cent of World production (US Bureau of Mines, 1993, and Australian Financial Review, 1994).

Second, the World recession experienced at this time led to a contraction of industrial activity in construction and aerospace industries. Reduced industrial activity World wide led to a decrease in the demand for, and consumption of, aluminium (US Bureau of Mines, 1993).

Figure B1.2: World aluminium price, 1981 to 1999



Note: All prices in 1994 dollars.
Source: ABARE, 1994b.

Third, the end of the Cold War and consequent cuts to the US Department of Defence (DOD) budget led to a significant fall in the demand for aluminium alloys, as well as many other new industrial materials (US Bureau of Mines, 1994a).

Finally, high prices for aluminium in the late 1980s encouraged firms to increase production capacity with much of this increased capacity coming on stream in the early 1990s (ABARE, 1994b).

These factors combined to place substantial downward pressure upon the World aluminium price.

The Brussels agreement

In late 1993 the implementation of aluminium import quotas by the Economic Union and the threat of anti-dumping actions in the US signalled the possibility of an aluminium trade war and prompted representatives of the governments of the larger aluminium-producing countries to meet to discuss the growing World oversupply of aluminium. The annual oversupply had reached 1.5 to 2 million tonnes in 1993 (ABARE, 1994b).

In January 1994, under the Brussels Agreement — a Memorandum of Understanding between the World's largest aluminium producers — it was agreed to reduce global production by 10 per cent in an effort to reduce oversupply, a cut of between 1.5 and 2 million tonnes.[3] This memorandum was confirmed at a subsequent meeting held in March 1994 in Ottawa.

Following this agreement, Russia cut annual aluminium production by 300 000 tonnes in 1994, and Western aluminium companies made cuts totalling more than 900 000 tonnes.

In Australia, the largest aluminium producers all reduced the level of production substantially:

- Comalco cut 36 000 tonnes from its annual production;
- Alcoa announced a 25 000 thousand tonne annual cut;
- Portland Aluminium announced a 30 000 tonne annual cut; and
- Tomago Aluminium announced a 38 000 tonne annual cut, and Alcan announced a 15 000 tonne annual cutback in aluminium production (ABARE, 1994b).

By January 1995, the price of aluminium had increased to US$2150 per tonne from a low of US$1040 per tonne in November 1993.

[3] The participating countries are Australia, the US, the CIS, Canada, Norway and the European Union (ABARE, 1994b).

B1.7 Competitiveness of Australian producers and users

Competitive advantages

There are two primary competitive advantages which the Australian aluminium industry possesses.

First, Australia has an abundance of excellent raw materials required for the production of aluminium. Our bauxite reserves are large and of high quality.

Second, Australia can generate relatively inexpensive electricity in power stations using abundant supplies of coal. In Australia, energy accounts for around 20 per cent of total production costs. Access to a cheap energy supply encouraged the development of the aluminium industry (ABARE, 1992).

The move to produce new aluminium alloys would complete the vertical integration of the aluminium industry.

Competitive disadvantages

It is likely that the level of demand within Australia is not large enough to sustain a domestic industry producing advanced aluminium alloys. By and large, advanced aluminium alloys are targeted at highly specialised end-uses such as the aerospace industry. Due to the limited size of the Australian aerospace and defence industries, Australian producers must break into overseas markets if they are to be successful.

Breaking into the US market may be difficult for a number of reasons. First, there are barriers to trade, such as tariffs. Second, various US based competitors receive support from the US government. It is known that the US government allocates considerable funds for R&D into advanced materials (in 1993, the Advanced Materials and Processing Program had US$1.8 billion for this purpose). However, it is not known to what extent this translates into direct support for aluminium alloy producers. Third, US customers may have a preference for US suppliers. Fourth, transportation costs would be greater for Australian suppliers than US suppliers.

B1.8 Economic significance

Table B1.5 illustrates the various stages of aluminium processing through to the fabrication of aluminium-based metal products. The latter stage does not occur to any extent within Australia because of the absence of major user industries.

Table B1.5: Stages in the production of aluminium-based new and advanced materials

Primary Commodity	*First stage value adding* [a]	*Second stage value adding* [b]	*Third stage value adding*	*Fourth Stage value adding*	*'Enabled' production*
Bauxite straight from the mine.	Alumina is derived from bauxite using the Bayer method.	Aluminium is generated from alumina using the Hall–Heroult electrolytic reduction process.	Prefabrication into sheet and strip aluminium, extruded sections, powders and pellets and ingot bars.	Manufacture into standard products. For example, welded structures, ships and boats, electrical and electronic components, and foil products.	Development of new and advanced materials. For example, aluminium based alloys, car components, and aircraft parts.

a About 2.5 tonnes of bauxite is required to produce one tonne of alumina. The Bayer method is used throughout the World for the production of alumina from bauxite. The Bayer method consists of four stages. First, the bauxite is treated with a hot sodium hydroxide solution in order to dissolve the aluminium hydroxides. Second, solid impurities are removed leaving a clear solution. Third, pure crystalline aluminium hydroxide is precipitated from the clarified solution. Finally, aluminium hydroxide crystals are heated to remove water and produce alumina.

b Aluminium is produced from alumina using the Hall–Heroult electrolytic reduction process. Alumina is added to a molten salt cryolite, and an intense electric current is passed through the solution. Pure molten aluminium is collected at the cathodes of the electrolytic cell. The molten metal is transferred to a holding furnace. The aluminium may then be alloyed by adding other metals to the holding furnace.

Source: Adapted from DITARD, 1993a.

B1.9 Potential for further production and use

Primary aluminium

World consumption of primary aluminium is projected to rise by 4 per cent per year on average, until 1999, at which time the annual World consumption of aluminium is expected to reach 19.2 million tonnes, 24 per cent higher than in 1993 (ABARE, 1994b). Taking into account recycled (secondary) aluminium the production is 28 million tonnes. The range of applications is extremely broad, and depends upon competitiveness in terms of both price and characteristics.

Asia is anticipated to become the World's largest consumer of aluminium by 1999. The rapid growth in consumption of aluminium in Asia reflects expected high rates of economic growth in the region (ABARE, 1994b).

New aluminium alloys

The primary advantage of new aluminium alloys is the ability to tailor properties for specific applications. The main potential for new aluminium alloys is in highly specialised markets, where material characteristics are more important than cost considerations. For this reason, it is high-technology applications within the aerospace, military and automobile industries which provide the greatest opportunity for new aluminium alloys in the foreseeable future.

To a large extent, the future of new aluminium alloys is dependent upon the level of demand for lighter materials emanating from automobile manufacturers. This in turn, is partly dependent upon the level, and rate of enforcement, of environmental regulations in the US and Europe, as well as changes in consumer tastes (such as desire for fuel efficiency and concern with emissions). Although there are forecasts which anticipate the demand for aluminium based products to increase dramatically as a result of tightening environmental regulations, particularly the CAFE standards in the US, it is very difficult, if not impossible, to predict what environmental regulations will exist in ten years time. Nevertheless, given the fact that the gestation period is considerable — the period of time a motor vehicle is on the drawing board — it is possible to make reasonably accurate forecasts for some years hence. Consequently, the CAFE standards and the German recycling laws provide useful guidance to the intermediate future.

Within this context, the further development and uptake of new aluminium alloys, both internationally and in Australia, is likely to be an evolutionary and steady process. This view was supported by Professor Dunlop, the Director of CAST, who stated that:

> ... more often than not it is the steady and <u>incremental improvement</u> of materials and processes that provide for increased profitability and improved market share (sub. 23, p. 1).[4]

Australia has an internationally competitive aluminium industry, with innovative researchers and companies in a strong position to continue the incremental development of new aluminium-based alloys and other materials. The pursuit of such developments will help to m aintain Australia's international competitiveness in the primary aluminium industry, even without revolutionary accomplishments in the areas of new and advanced aluminium alloys.

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4 Text underlined in the original.

B2 METAL-MATRIX COMPOSITES

Metal-matrix composites (MMCs) consist of a base alloy interspersed with particulates or fibres of a ceramic compound, such as silicon carbides, aluminium nitrides and oxides, boron carbides or graphite, which function as a reinforcement to the base alloy (Street and Alexander, 1994). The reinforcement is vital because it determines the mechanical properties of the composite. Aluminium alloys are predominant as the base metal in MMCs, followed by magnesium, copper, titanium and nickel-alloys (US Bureau of Mines, 1994a).

Aluminium MMCs fall into three main groups as outlined in the submission from Mr David Lewis:

> ① Fibre reinforced aluminium, where the reinforcing fibres are generally alumina, silica or carbon ... Long fibres provide the best physical properties ...
>
> ② Short fibre or whisker reinforcement, which uses shorter (and cheaper) fibres in the materials noted above ...
>
> ③ Particle reinforcement, commonly by silicon carbide or alumina ... Particle reinforcement is the cheapest form of MMC, with prices around two to three times those of regular aluminium alloys. However the potential to use low cost particulate reinforcing agents is under active investigation in Australia and Canada (sub. 67, p. 2).

B2.1 Material properties

MMCs provide producers with the ability to combine traditional metallic properties, such as ductility and toughness, with ceramic properties such as high temperature strength and stiffness, in order to provide a superior combination of properties (US Bureau of Mines, 1994a).

Compared with unreinforced metals, MMCs can provide superior mechanical properties tailor-made for specific applications. Tailoring specific mechanical properties for a particular application is achieved by the selection of the type and quantity of the ceramic reinforcing material added. In some applications, MMCs offer unique combinations of properties that cannot be found in other materials (OTA, 1988). The ability to tailor properties is the fundamental advantage that MMCs possess over traditional metals.

However, MMCs have some disadvantages relative to other materials. MMCs can be costly to produce, depending on the ceramic compound used for reinforcement, and often cost more to produce than comparable aluminium and magnesium alloys. This largely arises from the fact that MMCs can only be produced using a limited number of processes. The high cost of MMCs has led to their use being confined to high-performance applications, particularly in the military and aerospace industries, where the performance of the material is more important than its cost (OTA, 1988).

However, the price of many MMCs is falling due to the decreasing costs of some additives. For example, silicon carbide particulates used in many aluminium MMCs cost about US$5 per kilogram today, compared with US$25 per kilogram ten years ago (US Bureau of Mines, 1994a).

B2.2 Production and usage

Many commercial MMC applications have only just begun to be cost effective, usually due to their high-performance benefits (US Bureau of Mines, 1994a). In general, materials choice depends on both material properties and cost. For a material that offers acceptable performance characteristics, selection should be on the basis of life-cycle cost. The concept of life-cycle cost acknowledges that there are a number of elements to the cost of a material: raw material cost, fabrication cost, longevity, and disposal cost, and where this notion is recognised, MMCs are finding markets.

Table B2.1 outlines some of the MMCs currently used in the aerospace industry.

According to David Lewis significant applications could develop in the automotive industry:

> MMCs are likely to find niches for relatively simple items that can be die cast near nett shape and where normal alloys are either too weak and/or soft (sub. 67, p. 3).

What follows is a description of just a few of the potential applications for MMCs in the automotive industry.

Particle reinforced MMC brake rotors were first used on racing cars in the US and have subsequently been developed for regular vehicles by Ford. The main advantage of MMC brake rotors is the potential to halve the weight of the traditional cast iron rotors.

A second automotive application for MMCs is in cylinder blocks. While it is unlikely that complete cylinder blocks will be made from MMCs, there is significant potential for thin MMC cylinder liners to be used in conjunction with aluminium alloy blocks.

MMCs may also be used to stiffen extruded aluminium driveshafts, and reinforce the bowl rim of heavy duty diesel pistons.

Table B2.1: MMCs for aerospace applications

Base metal	*Added fibres*	*Applications*
Aluminium	Carbon Silicon carbide	Structural members. Mechanical connectors, satellite structures, wings and blades.
Magnesium	Alumina	Structural members.
Copper	Carbon Silicon carbide Tungsten	Combustion chambers. Rocket nozzles. Heat exchangers.
Nickel	Alumina Tungsten	Blades and discs.
Titanium	Silicon carbide Carbon Boron carbide	Housing and tubing. Shafts and honeycomb. Blades and discs.

Source: Mathews and Rawlings, 1994.

International production and use

Interest in MMCs has grown strongly since initial laboratory developments in the 1960s, however, the first commercial application of a MMC was not achieved until 1983, when Toyota introduced a MMC diesel engine piston (US Bureau of Mines, 1994a).

The wide variety of materials used in MMCs, and the fact that their production is largely at a developmental stage, means that there is no exact data measuring either the production or usage of MMCs. However, the US Bureau of Mines (1994) estimates that in 1992, the World market for MMCs was valued at US$56 million.

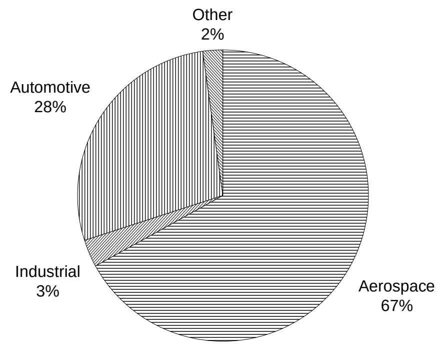
Although the automobile industry accounts for approximately 79 per cent of World demand when measured in volume, it only accounts for 28 per cent of the total sales value of MMCs. The aerospace industry, although accounting for a lower percentage of total usage than the automotive industry when measured in tonnage, accounts for approximately 67 per cent of sales value (US Bureau of Mines, 1994a).

This comparison reflects the superior mechanical qualities required and shorter production runs associated with MMCs used in the aerospace industry.

By far the greatest source of growth in the demand for MMCs is expected to come from the US automobile industry, which is projected to grow at a rate of 12 per cent per year until the year 2002 (US Bureau of Mines, 1994a). Some forecasts suggest consumption could reach 15 000 to 20 000 tonnes by 2003 (sub. 67, p. 5).

In the US, MMCs are included in the list of ‘critical materials’ targeted for joint partnerships between the government and industry (US Bureau of Mines, 1994a).

Figure B2.1 MMC applications (sales value), 1992



Source: US Bureau of Mines, 1994a.

These partnerships should ensure the development and growth of the MMC industry in the US.

In Japan, Sumitomo Electric Industries, in association with Honda, have developed a MMC which has begun to be used in the cylinder liners of the 1994 Honda RVF/RC45 (750cc) motorcycles. The new composite is described as a:

> ... heat resistant, rapid cooling and solidifying aluminium powder base metal ... to which alumina ceramic powder and graphite are added. The ceramic powder improves the MMC’s wear and thermal resistance, while the graphite prevents seizure due to its excellent sliding properties (Materials Edge ,1994a, p. 5).

In the US, Duralcan has secured an agreement with both Ford and Toyota to commercialise MMC brake components. Whereas aluminium alloys could not provide the necessary wear resistance, the MMC containing silicon carbide provides wear resistance as well as being light-weight. The MMC has already been used in US racing cars.

Australian production and use

There is currently no commercial production of MMCs in Australia. Cyco International, a privately owned Australian company, is involved in the research and development of a MMC using hollow flyash particles as an additive to aluminium. This MMC, known as ashalloy, uses flyash as the additive to an aluminium alloy base, which not only generates strength, but is also extremely light and cheap. Flyash is a tiny sphere which is generated as a by-product of coal combustion. In the US, a similar product is being developed by the Electric Power Research Institute (EPRI) in association with Ford.

B2.3 Potential for further production and use

The future of Australian activities in the production and usage of MMCs is somewhat uncertain. According to the joint submission from the Centre for Advanced Materials Technology and the Warren Centre for Advanced Engineering at the University of NSW:

> ... many of the new materials have either not met expectations leading to a decline in the current demand, or for various political and economic reasons, such as the scaling down or even closure of some defence programs in the USA and other countries due to the conclusion of the cold war ... In Australia the activities on the metal-matrix composites have somewhat waned (sub. 33, p. 2).

The potential for further production of MMCs is limited despite the expected moderate growth rates emanating from the automobile and aerospace industries.

World wide, there is strong competition in the supply of new MMCs, given the large number of producers and the high degree of substitutability between aluminium, magnesium, copper, titanium and nickel-based MMCs and other lightweight materials.

As with aluminium alloys, the rate of overseas growth in demand will be significantly influenced by the level, and rate of enforcement, of environmental regulations in the US and Europe, where for example, the demand for lighter materials generally will closely follow tighter enforcement or newer regulations on emission standards.[1]

Although there may be potential for the production of some MMCs in Australia, for most MMCs, there is unlikely to be sufficient local demand to sustain a domestic industry, at least in the foreseeable future, and therefore potential producers will have to target export markets. This could be difficult because of barriers to trade, assistance to US-based competitors from the US government, the preference of overseas users for using local suppliers, and transportation costs.

Australian potential is linked to further research and the attainment of incremental improvements to the technologies, such as casting, used in the

1 The demand for lighter materials is also a function of consumer preferences for more economical (that is, fuel efficient) automobiles.

processing of traditional alloys which serve as the base materials for MMCs. This is because research to improve processes can reduce production costs, improve the physical properties of traditional alloys and MMCs and make the final product more competitive, thereby providing opportunities to enter overseas markets.

Australian producers would need significant cost advantages from improved processing technologies or improved properties to be viable.

B3 ADVANCED CERAMICS

Ceramics are generally defined as 'inorganic non-metallic materials processed or consolidated at high temperatures' (US Bureau of Mines, 1993). They are traditionally based on naturally occurring clay materials (aluminosilicate compositions) and are handled by common processes such as grinding, mixing, forming, drying and firing. Traditional ceramics typically fall into one of the following major product categories: structural clay products (brick, terra cotta), whitewares, dinnerware, glass, porcelain enamels, refractories, cements, plasters and abrasives.

B3.1 Advanced ceramics

Advanced ceramics (ACs) differ from traditional ceramics in that they generally require a much more closely specified and higher purity feedstock. In addition, ACs involve more sophisticated (and more costly) fabrication and processing methods used in their production. It is these factors that have resulted in the production of AC materials possessing specialised properties enabling them to replace traditional materials in a number of applications.

ACs are usually categorised as advanced engineering ceramics (AECs) or advanced electrical ceramics. AECs are sometimes referred to as structural ceramics. AECs comprise two sub-categories, monolithic materials and AEC coatings.[1] AECs are used in those high performance applications requiring specialised engineering or mechanical properties, such as high temperature strength and wear resistance.

Advanced electrical ceramics fall into the class of *effect* materials (discussed in Chapter 1) and generally are utilised because of a unique physical property such as conductivity. They are used in those applications requiring superior electrical, electronic, optical or magnetic properties.

World production of ACs is increasing at relatively high levels, with the production of advanced electrical ceramics representing above 70 per cent of the total ACs produced. Table B3.1 highlights both the importance of electrical ceramics in total AC production, as well as the past and estimated production figures (in nominal value terms) for AEC monolithics, advanced electrical ceramics and other applications (which include ceramic coatings). Forecasts

1 AEC monolithic materials refer to components made up in the form of single blocks or shapes. They include AEC composite materials.

suggest that the value of advanced ceramics will increase by approximately 50 per cent between 1992 and 1997.

Table B3.1: World production of advanced ceramics, 1982, 1992 and 1997 (US$ million)

Year	*AEC monolithics*	*Electrical*	*Other applications*
1982	330	2 217	88
1992	1 945	10 250	1 255
1997	3 750	14 375	2 275

Source: Advanced Ceramics Report, 1994.

The major World wide producers of ACs are Japan, the US and Western Europe (refer to Table B3.2). Pacific Rim production essentially occurs in Japan, which accounts for about 60 per cent of World production (US Department of Commerce, 1993).

Table B3.2: World production of advanced ceramics by region, 1992

Region	*Quantity (kt)*	*Value (US$m)*
Pacific Rim[a]	353	7 926
North America	144	3 608
Western Europe	90	1 839
World wide[b]	583	13 373

a Source does not give a break-down of countries.
b Data may not add to totals shown because of rounding.
Source: Kline & Co. Inc, cited in US Bureau of Mines, 1994a.

Major corporations involved in the World advanced ceramics industry are listed in Table B3.3.

Table B3.3: World sales of advanced ceramics by the ten largest producers, 1992 (US$ billion)

Corporation	*Sales*
Kyocera Corporation, Japan	2.79
Murata Mfg, Japan	2.11
Compagnie de Saint–Gobain, France	1.39
Philips Electronics, Netherlands	1.15
Corning Incorporated, US	1.12
Sony Corporation, Japan	0.74
NGK Insulators, Japan	0.60
Cooper Industries, US	0.56
Noritake Company, Japan	0.37
General Motors Corporation, US	0.32

Source: US Bureau of Mines, 1994a.

In the following discussion, ACs will be separated into three main categories:

1. Advanced engineering ceramics — monolithics;
2. Advanced engineering ceramics — coatings; and
3. Advanced electrical ceramics.

Advanced engineering ceramic monolithic materials

AEC monolithics are defined here as the components for use in manufacturing rather than ceramic coating materials or the powders used as feedstocks. AEC monolithic materials utilise ultra fine and high purity feedstock powders and include the following ceramic categories: alumina, zirconia, silicon nitride, silicon carbide, boron carbide, sialons and aluminium titanate. Titanium carbide, titanium diboride and titanium nitride are also manufactured, although they are less common. In addition, additives (such as platelets and fibres) are used to impart reinforcement properties in AEC composite materials.

Properties

The specialised properties of AECs can include both high and low temperature strength, greater toughness, abrasion, erosion and corrosion resistance, exceptional hardness and controlled thermal conductivity. It is these properties that permit AECs to either replace traditional materials or to be used in some unique applications.

For example, boron carbide AECs exhibit superior hardness and therefore are used in applications requiring abrasion resistant qualities. Similarly, silicon carbide AECs are preferred for those applications requiring exceptional strength at high temperatures (such as in automotive engines); while silicon nitride AECs exhibit corrosion and oxidation resistant qualities, combined with high hardness, which make them ideal materials for use in components for gas turbine engines, cutting tools and ceramic armour.

Alumina AECs have properties which render them ideal for those applications requiring strength, hardness and wear resistance. These include components used in manufacturing, such as seal surfaces (for rotary pumps), nozzles, crucibles, cutting tools, and roller bearings. In addition, alumina ceramic composites can be used in defence applications (for example, ballistic armour) or prosthetics.

Zirconia AECs (including the Australian developed partially stabilised zirconia) can have a combination of intrinsic properties, such as hardness, strength, toughness, chemical inertness and biocompatibility, that makes them ideal for applications such as cutting tools, wear parts, seals, coatings, engine parts and composites for biomedical use.

Importantly, AECs are quite varied in both their physical properties and the manner in which they are processed to form any monolithic component or coating. Accordingly, the properties can vary, not only from one AEC material to the next, but also from within a given category of AEC materials (such as two types of zirconia AECs that exhibit different mechanical properties). This leads to AECs having quite disparate applications and they are generally manufactured for specific functions. For example, alumina AECs exhibit excellent hardness but they are prone to brittleness and are not very impact resistant. Some zirconia AECs, on the other hand, have excellent impact resistance but they are not very hard. Further, some zirconias exhibit poor thermal shock resistance and are therefore not amenable to high temperature applications, unlike silicon carbide which is a good thermal conductor.

Essentially, just like any material, the choice of any AEC depends on the application and the types of qualities the user requires in that application.

Despite the advantages of AECs, there exists a major impediment to their widespread adoption in certain engineering applications. This is their inherent brittleness, resulting in a high failure rate for ceramic components in certain applications. Essentially, there is a greater likelihood of material failures occurring with the use of AEC materials than is experienced with traditional metallic materials.

This is an important reason why some manufacturers (particularly in the automotive and aerospace industries) are cautious about the adoption of AEC materials in their manufacturing processes.

Although simplistic, the following example highlights the choice facing potential AEC users. An engine manufacturer purchasing one million tappets could choose between conventional metal tappets that typically have a failure rate of five out of one million, or a superior performing ceramic tappet that is characterised by a much higher failure rate for any given batch (Brockis, 1992). Clearly, for some major engineering applications, like engine manufacture, some advanced ceramic components will not be suitable unless techniques are developed to reduce the incidence of critical flaws, or engineering design is modified to accommodate the higher probability of failure.

A substantial amount of R&D is currently being undertaken to overcome the brittleness of AECs. This is particularly the case in those industries where the incidence of catastrophic failure could result in significant loss — such as in the aerospace industry.

Australian R&D into the properties of AECs commenced within CSIRO during the early 1970s. This research effort resulted in the production of one of the World's toughest AEC materials — partially stabilised zirconia (PSZ).[2] However, despite the ability of PSZ to counter the brittleness problem, it may not be suitable for some engineering ceramic applications because of its other thermo-mechanical characteristics.

Australian research into the PSZ ceramic has been scaled back since the mid 1980s. However, some work continues to be undertaken in an effort to increase toughness of non-zirconia based ceramics, by dispersing zirconia crystals within other ceramic materials to induce what is referred to as 'transformation' or 'micro-crack toughening'.

International production and usage

The AEC industry is still in its early stages of development, with some potential users being uncertain as to the feasibility of using AECs. World production statistics are scarce. One source of information is the US Bureau of Mines which regularly publishes data pertaining to both new material developments and the companies involved in the production of AECs. The Bureau relies heavily on the US Ceramic Industry Magazine Survey to draw conclusions on production information. It indicates that the production of AECs increased in nominal terms between 1990 and 1991, from US$1.4 billion to US$1.7 billion.

Available data are not consistent as can be seen from Table B3.4. This compares the US Bureau of Mines figures for 1992, with those detailed in the Advanced Ceramics Report (1994) and US Department of Commerce (1993).

2 Expenditure on research effort totalled approximately $15 million over a five year period.

The inconsistencies arise due to different definitions of what is a traditional ceramic and what is an AEC.

Table B3.4: Value of World production of advanced engineering ceramic materials, 1992 (US$ billion)

Source	*Value*
US Bureau of Mines	1.2
US Department of Commerce	1.8
Advanced Ceramics Report	1.9

Source: US Bureau of Mines, 1994a; US Department of Commerce, 1993; and Advanced Ceramics Report, 1994.

Although the estimates of recent production differ, there appears to be agreement that production of AECs will double by the year 2000. For example, the Advanced Ceramics Report forecasts 1997 production to be US$3.8 billion.

The major producers of AECs are Japan, the US, France and the Netherlands (US Bureau of Mines, 1994a). A breakdown of the types of AECs produced within each country is not possible. However, it is reasonable to expect that most of the AECs mentioned earlier are produced in each of the major AEC producing countries.

The companies involved in AEC production are either purely ceramic producers or trans-nationals with ceramics divisions. Smaller companies (with sales less than US$50 million) appear to be the major World wide producers (US Bureau of Mines, 1994a).

The major international AEC producers are Kyocera (Japan), Coors (US), Nortons (US), Carborundum (US), Feldmuhle (Germany), Hoechst Ceramtec (Germany) and Dianite Sintered Products (UK). These companies do not have a significant presence in Australia due to Australia’s small economy and the less developed state of our AEC industry. One company which does have a subsidiary in Australia is Carborundum (US).

The major uses of AECs can be summarised as:

- cutting and machining tools that exhibit excellent hardness and heat resistance qualities;
- bearings and drills that are highly abrasion resistant;
- components for automotive use (such as valves, seals, rods and piston rings, turbine blades for use in turbo chargers, and wear parts for use in reciprocating engines);

- biomedical components requiring materials with high biocompatibility (such as bioceramic dental implants); and
- a number of other components or products that are reliant on the properties offered by AECs (such as crucibles, knives, nozzles and ballistic armour) (US Bureau of Mines, 1992).

Australian production and usage

ICI operated a large scale powders and chemical plant in Western Australia between 1988 and 1992. The company became the largest production plant in the world for high purity zirconia, which was to be used as feedstock for the international advanced ceramics industry. However, the plant was decommissioned due to poor sales. It was sold in 1994 to a South Korean corporation, which intends to re-commission the plant (sub. 54).

In Australia, the main AECs manufactured are alumina ceramics, zirconia ceramics (in particular, PSZ) and to a lesser extent, silicon nitride and aluminium titanate.

The AEC industry in Australia producing monolithic materials is still in an early stage of development, being comprised of four small sized manufacturers producing components and parts for a wide range of industries, including the mining, power generation, refining and automotive industries. The companies, although small, exhibit high growth rates. There is a also a company in the pre-commercial development stage and another which is a domestic representative of a trans-national.

Total Australian output is approximately $10 million per annum (excluding production of refractory components), which compares to $263 million in the US (US Bureau of Mines, 1994a). Brief company profiles follow.

ICI Advanced Ceramics

ICI Advanced Ceramics (ICIAC) is a subsidiary of ICI Operations Pty Ltd and manufactures PSZ components for a broad range of applications across numerous industrial processes. The company originated from R&D undertaken by CSIRO and operates under a license from CSIRO. Typical ICIAC products include valve components, metal forming tools and can seaming rolls. The company exports approximately 60 per cent of its output (primarily to the US, Europe and the Asia–Pacific region) and it claims to have almost 100 per cent of the Australian market for applications requiring the toughness of PSZ. For applications demanding lower grade wear resistant ceramics, ICIAC’s market share is somewhat less.

Annual growth in ICIAC's output is expected to be about 15 to 20 per cent over the next five years, with valve manufacturers, and the mining and refining industries expected to be the main contributors. This growth will occur as PSZ becomes better known and more established as an engineering material.

ICIAC's large export share is largely derived from both its unique manufacturing expertise, as well as the technological advantage it enjoys by holding the rights to CSIRO's PSZ patent. There are two parts to the patent. The first covers the composition of PSZ and the second covers the manner in which the constituents are combined. Although the original patent expires in 1995, critical modifications to it have been made which will ensure that ICIAC's intellectual property is safeguarded for some time.

Taylor Ceramic Engineering

Taylor Ceramic Engineering (TCE) is a small, privately-owned company that has been in operation for 28 years producing alumina ceramic tools, parts and components for Australia's manufacturing and mining industries. Also produced are ceramic composites for defence (such as ballistic armour) and alumina ceramic–polymer (kevlar) composites for prosthetics use. Its annual output is approximately $1.5 million and 20 persons are employed. TCE's market share in Australia is difficult to determine given its unique processing technology and its high content of custom made products. Approximately 30 per cent of output is exported (in small job lots) to 27 countries, however, its World market share is not significant.

The business is based on innovative products and manufacturing techniques and spends approximately 20 per cent of turnover on R&D. This commitment has resulted in several breakthroughs in materials technology.

Annual growth in TCE's output over the next 5 years is expected to be about 15 to 20 per cent, with the major constraints to growth being capital funding. The company claims that a shortage of skilled personnel is a constraint on growth.

It is in the early stages of formulating an expansion plan, extending into the Wollongong region (close to its major client, BHP) where its long-term plan is to increase production, employment and exports.

Rojan Advanced Ceramics

Rojan Advanced Ceramics (RAC) is a private company producing a range of AECs, including high purity alumina materials, PSZ (a different grade to that produced by ICIAC) and alumina titanate materials for Australia's minerals processing, clay brick and general manufacturing industries. Typical applications of RAC products include cyclone liners and laboratory ware. Total annual turnover is approximately $650 000, 70 per cent of which is sold to the minerals processing industry, and it employs 12 persons. The company exports approximately 5 per cent of its output. Its products are tailored for particular applications.

Annual growth in RAC’s output has been in excess of 30 per cent over the most recent year and future growth is likely to come from the upgrading of manufacturing facilities, a larger domestic client base and increased opportunities for export, particularly to the Asia–Pacific region.

Ceramic Oxide Fabricators

Ceramic Oxide Fabricators (COF) is a small, private company producing alumina ceramic materials. Its output is comprised primarily of oxygen sensors made under licence from CSIRO, and oxygen probe assemblies. The remainder is in the form of tubes, crucibles, tiles, custom shapes, and other ceramic products. The company exports about 70 per cent of its oxygen equipment, primarily to the US (where it has above 90 per cent of the market for this class of equipment). However, its exports of other industrial and scientific products (crucibles and laboratory ware) are minimal. It is these latter products (only 25 per cent of COF’s business) that compete with those produced by the other AEC manufacturers in Australia.

COF anticipates a growth rate of approximately 25 per cent per year over the next five years. Its growth is expected to come from increased user awareness of the advantages conferred by the use of alumina ceramics, as well as increased product development. The company has recently developed a new way to use oxygen sensors to make an efficiency sensor in fuel combustion systems, which allows significant improvements in efficiency while reducing pollutants (when compared to standard oxygen sensors).

Carborundum

Carborundum is a subsidiary of Carborundum US (which is a subsidiary of British Petroleum). The Australian subsidiary’s total output is approximately $16 million per annum (70 employees) and it produces high temperature ceramic fibres for use in furnaces, as well as silicon nitride bonded silicon carbide refractories. However, both the refractory materials have been used extensively in the US for decades and do not fit into a definition of new and advanced materials.

In Australia, Carborundum sells a small quantity of imported new materials that have been produced by its parent in the US. They include pressureless sintered alpha silicon carbide, trademarked ‘Hexoloy’ (sales approximately $100 000 per year). This material can handle high temperatures and it retains its shape under extreme stress and heat.

Other advanced ceramics produced offshore by Carborundum are boron nitride and aluminium nitride. However, only boron nitride is sold in Australia (approximately $30 000 annually) and sales are expected to increase rapidly over the next two years.

Advanced Materials Enterprise

Advanced Materials Enterprise (AME), a subsidiary of Western Mining Corporation, is currently in the pre-commercial development stage. It contracted CSIRO to undertake research on a new process to produce silicon carbide components for the manufacturing industry — these are not currently being produced in Australia but are being imported by other companies. AME has already patented the technology, which is based on a pressureless sintering process, which is approaching the commercialisation stage.

While the silicon carbide components would not be in direct competition with either the alumina ceramic components produced by TCE, COF or RAC, nor with the PSZ produced by ICIAC, there would be some areas of overlap.

AME will be seeking volume markets and will produce primarily for export. Its strategy will be either to build a large scale production facility in Australia and export, or locate the production facility offshore. The location decision depends on a number of factors, such a international differences in taxation, labour market arrangements and infrastructure costs; but to a large extent, it depends on the size of the Australian market. It is therefore conceivable that, having identified a small Australian market, AME will locate their plant closer to the end users.[3]

Advanced engineering ceramic coatings

A ceramic coating (CC) is simply a thin film or layer of ceramic which is applied to a base material referred to as a substrate. The substrate can either be a metal, metal alloy, polymer, glass, or a composite of these materials.

Typically, CCs are used to protect a material against some form of deterioration, such as wear and corrosion, and they can be used as an alternative to the monolithic AECs discussed earlier. The advantages of using CCs over monolithic AECs are, first, the physical properties of both the substrate and the

[3] The major end users are expected to be companies operating in the Asian automotive industry.

CC can be optimised independently, yielding an end material with a combination of special properties.

Second, machining time and costs are reduced because the coating can be applied towards the end of the manufacturing process, after the substrate has been machined. With monolithic AECs, a final machining stage is usually required. Third, smaller quantities of expensive ceramic are used (relative to monolithics) for any given application. Fourth, there are cost savings involved in coating a component rather than replacing or substituting it for a monolithic AEC material. Finally, being thin films or layers, CCs can still be functional even in the presence of micro-cracks that could occur as a result of ceramic brittleness.

Despite these advantages, CCs are subject to spalling, chipping and porosity problems not encountered in monolithic AECs (US Bureau of Mines, 1992). In addition, they do not necessarily result in weight savings, particularly when working with a metal substrate, unlike monolithic AECs.

Ceramic coating properties

Depending on the coating used, CCs possess similar properties to those exhibited by monolithic AECs. In summary, they can exhibit a combination of the following properties:

- corrosion and erosion protection;
- hardness;
- wear resistance;
- friction control;
- thermal conductivity;
- electrical insulation; and
- optical selectivity.

It is these properties that enable CCs to significantly increase both product life and performance in numerous areas. For example, chemically bonded CCs are said to increase the life of some components by a factor of up to ten times, while titanium nitride coatings increase machine tool life by a factor of four. Further, CCs are sometimes used to enhance the aesthetic value of a product.[4]

[4] For example, Surface Technology's titanium nitride coated drill bits are said to be more marketable due to the nitride being a gold colour.

International production and usage

As for AEC monolithics, the CC industry is still in the infant stages of development. The World market for CC materials was estimated at approximately US$1 billion for 1992–93, and they are regarded as the fastest growing application of advanced ceramics.[5]

Information on the structure of offshore industries is difficult to obtain. However, firms applying CCs are not likely to be the same companies producing monolithic AECs. They are more likely to be small sized coating firms specialising in the application not only of ceramic coatings, but other materials as well, including metals, metal alloys and combinations of these materials. In addition, much application of CCs is done in-house by large manufacturing companies.

In terms of the potential uses of CCs, any existing material requiring special surface characteristics can usually have a ceramic coating applied that provides the solution. In particular, industries, such as mining, power generation, and refining, require surfaces that are hard and both corrosion and wear resistant. A CC could provide superior performance and extended longevity. Internationally, CCs are typically used in the following applications: jet engines, aerospace, industrial glass, printing, chemical, optical, electronic, textile, tool and die applications.

Australian production and usage

As with monolithic AECs, the CC industry in Australia is only just beginning to develop, being comprised of eight specialty firms applying CCs for a host of industries, including, mining, aerospace, refining, power generation, textiles, and pulp and paper. The products typically coated in Australia include aluminium alloy chutes, aircraft turbine blades, stainless steel crucibles, wire drawing dies, pump sleeves, valves, impellers, extruder barrels, drill bits, tools, bearings, glass and optical devices. Brief company profiles follow.

C-Ramic Australia (L & R Ashbolt Pty Ltd)

C-Ramic Australia is a small privately-owned company applying both metal and CCs to a vast variety of substrates for the mining, power generation and plastic extrusion industries. Its total output is approximately $4.5 million and it

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5 This figure should be treated with caution, for the US Bureau of Export Administration's estimates are based on the assertion that ceramic coatings markets represent 9 per cent of the total advanced ceramic market of US$11.3 billion. The US Bureau of Export Administration's estimates also suggest that World wide demand for advanced structural ceramics (monolithics) is 18 per cent of the total advanced ceramics market (US$2.1 billion).

employs 41 persons. Although it is difficult to gauge the exact proportion of total output represented by CCs, it is approximately 60 per cent. Accordingly, total output of CCs is approximately \$2.7 million, with about 24 persons devoted to this activity. Exports represent about 5 per cent of total sales.

C-Ramic has a coating referred to as a *chemically bonded ceramic coating*, which employs a unique patented technology and is used in a variety of applications, particularly in highly corrosive and abrasive environments. The coating is actually a composite of silica, alumina and chromia. This particular CC represents approximately 25 per cent of C-Ramic's CC output. It reputedly increases service life and imparts better corrosion and wear resistant properties relative to other ceramic and non-ceramic coatings.

C-Ramic expects a rapid growth rate in its CC business as user awareness of its new technology increases and industry becomes more proactive in its efforts to seek better performing materials. A doubling of output is expected each year for the next 5 years. Its major problems are the costs associated with component trials and difficulties with obtaining capital.

Brenco Thermal Spray

Brenco Thermal Spray (BTS) initially commenced business in 1946 as a tool maker servicing Australia's manufacturing industry. However, after recognising the changing needs of industry, it invested in new technology and now applies thermal spray ceramic, metal, and carbide coatings to substrates for various industries, including aerospace, automotive, chemical processing, petroleum and power generation. BTS's ceramic coatings include *cermet* coatings, which are composites of metals and ceramics. Its total output is approximately \$2 million per annum and it employs 15 persons. Exports represent about 10 per cent of total sales.

In terms of CCs, BTS's annual output is approximately \$200 000, with 90 per cent used for the maintenance of turbine engine components and the remaining 10 per cent used in the automotive and power generation industries. BTS's CCs provide thermal insulation to components used in high temperature environments.

BTS is on the verge of relocating, modernising and expanding its plant to take advantage of the high projected growth rates for its product. BTS report that its CC work is expected to double annually over the next 5 years as industries convert to coatings for those applications characterised by corrosion, wear or high temperature degradation.

United Surface Technologies

United Surface Technologies (UST) is also a privately-owned company specialising in the application of thermal spray coatings consisting of metal, carbides, ceramics or plastics. Its total output is approximately $2 million per annum with 25 per cent devoted to CCs. Total employees number 20 and it services numerous industries, from the food and beverage industry to petrochemical processing. Exports represent about 5 per cent of total sales.

UST uses *High Energy Arc Plasma* systems and a *High Velocity Oxygen Fuel* system of spraying coatings and it expects a 15 per cent annual growth rate over the next five years. Its major impediment is the lack of appropriately qualified personnel (particularly precision machinists and thermal spray applicators), which places constraints on potential output.

Surface Technology

Surface Technology (ST) is a subsidiary of Sutton Tools Pty Ltd, an Australian owned company in its 77th year of operation. ST applies titanium nitride coatings using the *Physical Vapour Deposition (PVD)* method for applications in the tool and die markets. In addition, titanium nitride has found many new innovative applications in such diverse areas as bearings, scissors, dog tags and medical prothesis. The coatings extend the life of the end product by providing friction and wear resistance. However, they can also be used for decorative purposes, as they have a shiny gold finish. For example, titanium nitride coatings are used on drill bits to both enhance longevity and to improve marketability (based on aesthetic appeal).

ST’s coatings have experienced a slow but steady growth in the six years that they have been on the market and the company continues to invest, and has ordered a state-of-the-art PVD machine which will be in operation in 1995. The investment will expand the service capabilities of ST with the provision of titanium carbonitride and chromium nitride coatings.

The provision of an even wider range of services in PVD coatings is anticipated by ST as the business looks to exploit its long standing association with CSIRO, Division of Applied Physics, and apply the Australian patented *Filtered Arc Technology* (see Appendix B8).

Silicon Technologies Australia

Silicon Technologies Australia (STA) is a public company employing approximately 80 persons (six in R&D) and its technology related sales were $400 000 in 1992–93. It has only recently commenced commercial operations for its range of coatings.

STA has been developing products which utilise the various properties of thin film ceramics. STA has demonstrated wear resistant coatings on metals, a unique flexible thin film acoustic sensor, and corrosion resistant coatings on aluminium and decorative finishes for a variety of metals. With support from GIRD funding, it has developed, in conjunction with university researchers, sol-gel coating techniques to an advanced stage and claims world leadership in this area. Sol-gel coating technology involves applying a solution to the surface which, when further processed, reacts to form a strong coherent film of a ceramic oxide.

However, its main product line will be coatings for energy efficient windows, which will result in reduced transmission of both heat and UV rays. It commenced glass coatings in 1991 and has recently had a capital raising on the Australian Stock Exchange to both finance the acquisition of Framex, a window manufacturer, and to finance growth. This recent venture reflects the company's philosophy that there is better commercial prospects in making products that incorporate new materials (for example, energy efficient windows) rather than the manufacture of new materials alone.

Internal company estimates suggest that growth within STA's Coated and Industrial Products Division will be approximately 50 per cent per annum from 1994–95 until 1998–99. This growth will occur largely as a result of the introduction of new products utilising the sol-gel ceramic coatings.

Other businesses applying ceramic coatings

There are three remaining companies that apply CCs to components for use in manufacturing. These are *A1 Metalising, Flame Coatings* and *RCL Phillips*. However, their prime activities centre on the application of coatings other than CCs. Accordingly, annual turnover of CCs for these companies is small.

Advanced electrical ceramics

The advanced electrical ceramics industry in Australia is diminutive, the major reason being that this industry is largely driven by the electronics industry and by World standards the electronics industry is very small in Australia. Japan and the US are the main producers of electronic equipment and advanced electrical ceramics. European countries are a distant third in production.

The domestic advanced electrical ceramics industry essentially comprises GEC Marconi Systems (GECMS) (formerly Plessey Australia), a subsidiary of GEC Marconi (UK), that produces piezoelectric ceramics primarily for acoustic detection devices. Areas in which local R&D is being undertaken in the advanced electrical ceramics field are in ceramic fuel cells and high temperature superconductors.

Piezoelectric ceramics

In order for a ceramic to exhibit the piezoelectric effect, the final stage of production involves the application of a high voltage to the ceramic to permanently polarise it. The preceding stages of production are as for advanced engineering ceramics, which is essentially the powder metallurgy process, namely oxide powder processing, dry pressing, slip casting and firing into final shapes. The piezoelectric effect involves the conversion of mechanical energy into an electrical signal (passive), or conversion of electrical signals into mechanical energy when acted upon by an electric field (active).

GECMS maintains and operates a manufacturing and test facility for the production of piezoelectric ceramics, using the powder oxide route. The facility was established by the Department of Defence and continues to be maintained with the significant support of this Department, as it is considered a strategic defence requirement.

The facility manufactures the primary sensing components for sonar systems for the Royal Australian Navy, such as the sonar sensors on the new Collins Class submarines, the sonars on the Oberon Class submarines, towed arrays (‘cables’ which are either towed by naval vessels or placed on the sea bed) for surface ships and submarines, as well as ‘Barra’ sonobuoys for the Royal Australian Air Force. GECMS also provides high level engineering support in development programs.

Although GECMS’s product line primarily services the needs of the Australian defence forces, it also pursues commercial applications and markets for acoustic devices, to reduce the costs of military components and to further develop its skills base. These markets include transducers for ultrasonic equipment and the music industry (guitar pick-ups).

ANSTO has developed piezoelectric ceramics both through a chemical process (sol-gel processing) and the industry standard powder process (which GECMS use). It has incorporated piezoelectric components in devices developed for mining and medical interests in Australia. For instance, ANSTO designed ultrasound transducers for Ausonics.

Ceramic fuel cells

Ceramic fuel cells, also known as solid oxide fuel cells, are solid state devices which convert a fuel’s chemical energy into electricity in an electrochemical reaction. Oxidation of the fuel is achieved by the passage of electrons through a ceramic layer (such as zirconia, which acts as an electrolyte) and thereby generates a flow of electricity.

Research and development on ceramic fuel cells is being undertaken by Ceramic Fuel Cells Limited (CFCL), with about $30 million to be spent over the five years to 1997. This consortium comprises CSIRO, BHP, Energy Research and Development Corporation, Strategic Research Foundation, Pacific Power, Generation Victoria, Electricity Trust of South Australia, Queensland Electricity Commission and the State Energy Commission of Western Australia.

Potential uses of fuel cells include remote area power and communications, central and large scale power generation, cogeneration (combined electricity and heat) at centres such as hospitals, apartment blocks, office buildings, restaurants, hotels, heavy transport, mining, military and drilling sites (sub. 19).

High temperature superconductors

Superconductors are materials which conduct electricity without resistance or energy loss. This occurs as the material is cooled below a certain temperature, which is known as the critical transition temperature. Low temperature superconductors (LTS), which are generally niobium-based materials, exhibit superconductivity at less than 20K.[6] To achieve and maintain these temperatures requires expensive and bulky cooling equipment.

High temperature superconductors (HTS) were first discovered in 1986–87. Several classes of HTS have been discovered, with transition temperatures between 93K–135K. The most widely studied HTS are mixed metal oxides containing barium, copper, rare earths and other metals.

HTS are still at the research stage, both in Australia and overseas. In Australia, CSIRO is involved in research with MM Cables and BHP (sub. 19, p. 16). The University of Wollongong has a significant program in collaboration with MM Cables which includes construction of a pilot production plant. However, most of the research into HTS is conducted in Japan and the US. Although relatively small in size, the Australian program is believed to be at the cutting edge of this type of research. However, significant commercialisation is probably some years away.

HTS are ceramics and thus brittle. They require innovative processing to fashion them into useful shapes such as long cables.

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6 ‘K’ refers to the absolute (temperature) scale, where zero K is equivalent to minus 270 degrees Celsius.

Proposed large scale applications of HTS embrace all aspects of electricity usage, with potential impact in electrical power generation, distribution and storage, transportation and medicine.

The total market for HTS is forecast to be US$150 billion to US$200 billion by the year 2020. The application of greatest impact is power transmission. Superconducting cables could be competitive at high power levels (in excess of 1000 MVA) and over long distances (more than 100 kilometres). They will greatly increase the current carrying capacity of underground transmission, possibly allowing a direct power match to overhead lines. Power generation and usage may benefit from various HTS devices and systems. For example, generators, transformers and motors using HTS will have advantages of reduced dimensions and lower losses compared with their conventional counterparts.

Other applications include magnetic sensors in medical applications, *maglev* transport (magnets for levitation, propulsion and guidance of high speed vehicles, such as high speed trains) and telecommunications, such as transmitting antennae.

Other electrical ceramics

Other advanced electrical ceramic materials include capacitors and ferrites, and packaging of semiconductors. No significant production of these materials occurs in Australia.

B3.2 Supply conditions

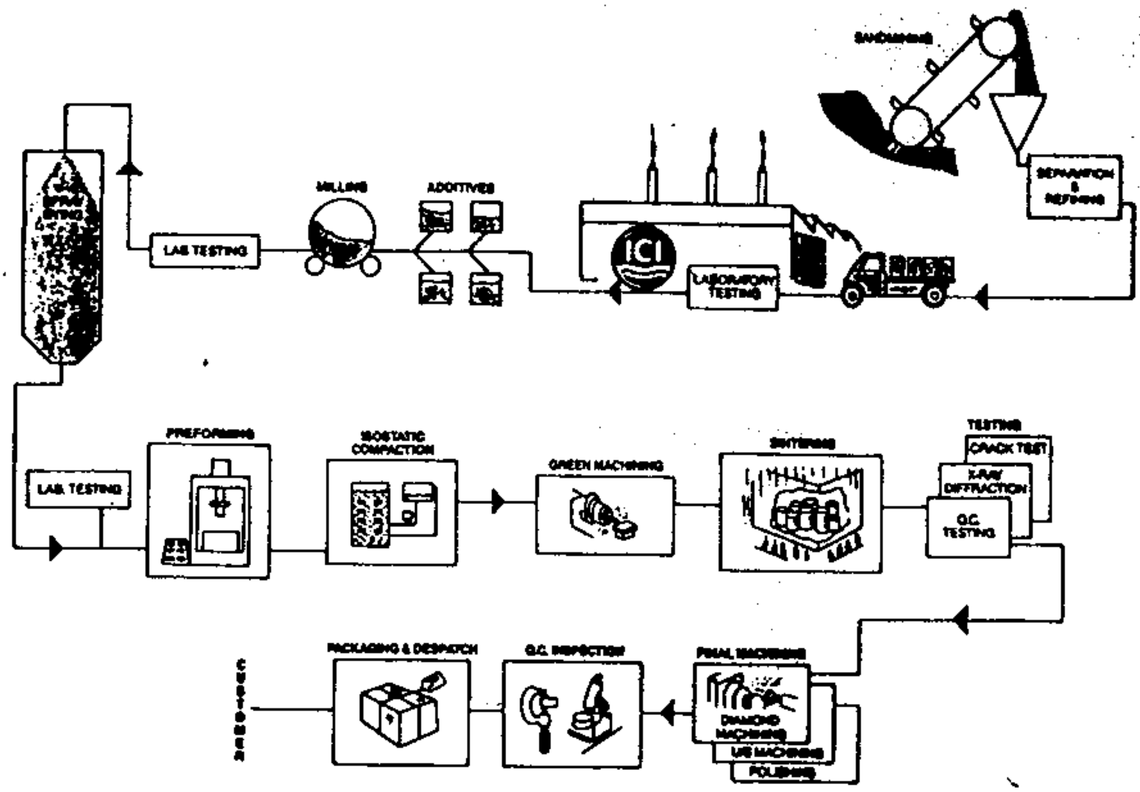
Most of the discussion in the remainder of this appendix covers advanced ceramics as a group. However, given that advanced electrical ceramics production only occurs to a minor extent in Australia, much of the information relates primarily to advanced engineering ceramics — monolithics and coatings.

Production technologies

The high temperature sintering with consequent shrinkage that is fundamental to almost all AC fabrication processes results in difficulties in controlling process parameters.

The production process is generally similar to traditional ceramic fabrication techniques, which involves dry pressing, slip casting and firing into final shapes. Hot pressing, sometimes isostatically, can also be an important process for some specialist ACs. However, over the years fabrication processes have improved as a result of the industry’s ability to produce ‘ultrapure’ and ‘ultrafine’ ceramic powders. A typical diagrammatic illustration of the processing technology used to produce PSZ at ICIAC’s plant appears in Figure B3.1.

Figure B3.1: Processing technology for PSZ



Source: Provided by ICI Advanced Ceramics.

The powder (in this case zirconia powder) is mixed with additives (these include stabilisers, sintering aids and powder binder systems) in a wet milling process. The powder is then pressed (isostatic compaction) and forms ‘green strength’. Green machining and shaping then occurs and the final details are added after firing via diamond machining.

Each manufacturer in Australia has a unique process which fits around the above scheme and is very much dependent on the application of its product. RAC adopts a more traditional slip casting method. It involves placing the alumina powder and water into a plaster mould, where the plaster sucks the water out (slipcasting), and the ceramic is then placed into a low temperature kiln. COF adopts a slightly different process. It extrudes (thrusts out a shape through a die), or slipcasts, or dry presses, or injection moulds, fires and diamond machines (where required).[7]

The processes used by TCE are claimed to be more advanced than the other three manufacturers, by virtue of its unique technology. This involves a high density forming capability which decreases machining time, thereby reducing production costs and minimising waste.

Internationally, efforts are continually made to further improve advanced ceramic processing technologies. These newer technologies can have the capacity to permit the prototyping and manufacture of advanced ceramics with superior technical reliability, product repeatability and cost effectiveness (US Bureau of Mines, 1994a).

Australian research institutions hold a well respected position in the international community. This was enhanced significantly in the mid 1970s when CSIRO, Division of Materials Science, developed PSZ, paving the way for toughened ceramics developments World wide. CSIRO continues to be active in ceramics R&D, with the current research areas of interest including zirconia, alumina ceramics, non-oxide ceramics and refractories.[8]

Other institutions active in advanced ceramics research include ANSTO, DSTO, the University of New South Wales, the University of Wollongong, Monash University, Curtin University and the University of Queensland.

With respect to Australian AEC manufacturers, each company devotes a considerable amount of resources to research and development of improved manufacturing technologies. For example, ICIAC are currently involved in a GIRD project (net shape forming), which seeks to form parts so that on firing they come closer to the final dimensions. Essentially, it involves the direct forming of a body from ceramic powder which will have the desired size and shape after sintering, with minimal need for manipulation either before or after firing. The project is designed to improve the speed and efficiency of processing for manufacture of advanced ceramics.

With respect to ceramic coatings, there are a number of processing technologies available to apply CCs to substrate materials with the most common comprising thermal spraying, chemical vapour deposition, physical vapour deposition and sol-gel processing (see Appendix B8 for a description of each technology).

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7 Injection moulding is a relatively inexpensive, high volume method for making near-net shapes (which reduces the need for machining), fine powder ceramic components.

8 According to CSIRO their ceramics program (incorporating zirconia, alumina ceramics and non-oxides) has the potential to contribute to import replacement to the value of approximately $30 million (sub. 19, p. 12).

Economies of scale and scope

The international experience of smaller private companies predominating in the manufacture of AC materials is mirrored in Australia. While this in part reflects the relative infancy of the industry both overseas and (particularly) in Australia, it is also indicative of the nature of the industry.

AC manufacturers produce components or coat products that are generally tailor-made for particular applications — where a close relationship between the supplier and client is usually established.

Scale economies are likely to become a more important factor for AC manufacturers as the market matures, that is, as demand increases resulting in greater capital investment and larger scale plants. Of course, if the market matures to the extent that ACs become common place materials, they move along the continuum from being new and advanced materials to traditional materials.

The production of ACs is often supply driven, with R&D efforts resulting in breakthroughs which are then introduced to potential users. However, the typical Australian experience is for a (potential) user to discover that a given material (whether it be a metal, polymer or even a ceramic) is performing poorly in a given environment. Contact is then made with the supplier and advice is sought on an appropriate replacement material. A relationship is then established and the supplier typically manufactures AC materials in small job lots and for specific applications, depending on the properties demanded.

It is the ability to produce componentry, or apply coatings of many different compositions and shapes, that dictates costs and benefits and economies of scope. Economies of scope are a more important factor (relative to scale economies) in improving the performance of AC manufacturers in Australia. This is because the AC industry is characterised by a large product range rather than volume, where manufacturers tailor-make a substantial proportion of their total output.

Given the stage of development (the relative immaturity of the market) of ACs, it is not possible to suggest how economies of scope will change.

Innovation and access to technology

Overall, there is a tendency for AC manufacturers to invest heavily in R&D activities and to establish close links with research organisations (in particular CSIRO and universities). R&D expenditure accounts for approximately 10 per cent of total turnover, which compares to less than 1 per cent for the manufacturing sector as a whole. This is supported by Government R&D via GIRD grants and the 150 per cent tax concession on R&D.

AC manufacturers' continual investment in R&D activities reflect their efforts to maintain or establish competitive advantage via one or more of the following avenues:

- develop better processing technologies;
- introduce products for new applications; and
- better solve the problems and needs of their client base.

While R&D activities have been scaled back somewhat at ICIAC, it maintains links with CSIRO, ANSTO, and universities. Its GIRD project on net shape forming is a joint partnership with Swinburne University of Technology, CSIRO and Monash University. In addition, it is involved in a joint project investigating the development of a composite titanium–ceramic orthopaedic knee replacement.

TCE injects a substantial amount of funds into R&D (about 20 per cent of total turnover). This could see it break into new markets by developing the capacity to produce non-oxide ceramics — which includes silicon nitride, silicon carbide, boron nitride, titanium diboride and titanium nitride. TCE claims to be on the verge of developing a foam ceramic material which could have significant potential in the industrial insulation industry via improvements in insulation properties and a higher thermal rating.

COF spends approximately 10 per cent of total revenue on R&D and it maintains strong links with the Australian National University and CSIRO. Its R&D could see the introduction of products such as a new diamond machining tool (diamond grit bonded by silicon carbide) used to machine advanced ceramics. In addition, it hopes to produce more ceramics for the biomedical industry.

RAC's expenditure on R&D is unknown, however, this business continues to be involved in a number of joint research programs (for example, a joint venture with Alcoa and Curtin University to develop alumina wear parts that are currently imported) and it maintains close contact with CSIRO, ANSTO and Curtin University.

With respect to CC companies, BTS has purchased its processing technologies primarily from the US. It spends approximately 5 per cent of total revenue on R&D and maintains informal links with research institutions, particularly CSIRO and Monash University. The bulk of BTS's R&D is into the identification of new applications rather than developing new processing technologies.

UST spends approximately 5 per cent of total revenue on R&D, with the bulk of this on ongoing development, and it is continually involved in joint programs with BHP to improve hard facings on steel mill rolls.

STA is extensively involved in R&D projects which are largely funded externally. Its 1989–90 involvement in a DITARD Generic Technology Grant resulted in the development of CCs by sol-gel processing and STA has developed expertise in this process. It has co-ownership and exclusive licence to commercialise the sol-gel materials and production technology.

For GECMS, application-specific technology is usually developed in-house. Individual users develop their own refinements to the technology to suit their specific product requirements and to embody some intrinsic quality that differentiates their product.

Many of the AC manufacturers have at some stage employed university students (including PhDs) as part of their ongoing R&D and training programs, further entrenching their links with universities.[9]

Control of intellectual property

Several AC manufacturers have either patented their own technology or purchased the rights to technology patented by research institutions. While there have been few (if any) incidences of an inability to protect technology via patents there has been some evidence of a lack of faith in the ability of patents to adequately protect intellectual property. Some manufacturers view patents as a signal to competitors of, first, one's competitive advantage(s) and, second, the direction in which superior technologies may be heading. To overcome this problem, some manufacturers have preferred to maintain secrecy over all or parts of their intellectual property by not filing patents or excluding crucial elements from a patent application.

Similarly, some companies prefer not to enter into joint venture R&D projects (such as through Co-operative Research Centres or less formal consortiums) because they fear losing control of their in-house developed intellectual property. It is also claimed that it is often difficult in joint venture R&D projects to have adequate mechanisms in place to ensure that an equitable sharing of property rights takes place.

9 These positions are usually part government funded.

Skill availability and development

Given the ‘high tech’ nature of the AC industry, manufacturers require highly skilled engineers, machinists, welders and tooling staff. While manufacturers feel that there is no problem with the supply of production engineers, there is some concern about the lack of materials engineering design skills. This is particularly important because there is typically a significant amount of design work involved in substituting a traditional material for an AC material.

While formal qualifications are not required for positions like skilled machinists, welders and tooling staff, participants suggest that some unskilled unemployed persons are reluctant to take up positions which involve up to two years on-the-job training. Further, some manufacturers note the declining number of apprenticeships as a reason why general industry skills are being lost.

Skill shortages are circumvented in part through overseas recruitment, as in the case of AWA Microelectronics (a user of advanced ceramics in electronic equipment). Substantive in-house training, as in the case of GECMS, also takes place.

Business links

Competitive pressures prevent the emergence of formal links between the various competing firms in the AC area. Each manufacturer closely guards the secrets to their respective processing technologies. However, some cross-referencing of new business occurs. For example, TCE may refer a potential new client to ICIAC if the performance requirements of the user are better suited to zirconia type ceramics, rather than alumina based ceramics.

Formal links by AC manufacturers are confined to joint research between manufacturers and research institutions. For example, the Advanced Ceramics Consortium was established in 1982 to identify and implement market driven collaborative R&D projects in the advanced ceramics area and introduce initiatives in ceramics education. Members of the consortium include TCE, GECMS, ANSTO and three NSW universities.

Marketing

Although some AC manufacturers rely heavily on being approached by potential users (either directly or through a consultancy such as a research institution), others are proactive in their efforts to increase sales by demonstrating the advantages of AC materials and highlighting their ability to tailor-make components for particular environments. ICIAC indicated that it spends up to

20 per cent of total turnover on marketing costs to demonstrate the properties of its PSZ material.

Government assistance

All AC manufacturers at some stage have taken advantage of some form of government assistance either to nurture their business' export assistance (EMDG grants), assist with R&D (GIRD, CRCs and the 150 per cent tax concession), or aid in the acquisition of accreditation (NIES Scheme). While some are dissatisfied with the assistance from governments in facilitating the provision of debt capital, there is general acceptance that existing Government programs are both well conceived and targeted. However, there is some dissatisfaction with the administrative burden associated with scheme compliance (particularly with respect to GIRD grants). There is also some skepticism directed at the CRC schemes because of the inherent difficulty in bringing (potential) competitors together in a joint venture arrangement.

B3.3 Demand conditions

Performance–price trade-offs

AC materials are generally more expensive than traditional materials. However, for any given application AC materials can provide superior performance and greater durability. For example, ICIAC's tooling wear and wear resistant parts can allegedly outlast and outperform traditional materials such as metals by as much as five to 20 times (sub. 18). Similarly, C-Ramic's chemically bonded ceramic coatings are said to increase the life of some components by a factor of up to six times, while titanium nitride coatings can increase tool life by a factor of four.

AC manufacturers note that the increased performance of the materials more than compensates for the increased cost. Rojan Advanced Ceramics provided an example of a silicon carbide based metal-matrix composite (MMC) material, used in the linings of hydrocyclones in the mining and mineral processing industry:

> Previous to the availability of this MMC the most 'superior' product used in this application was an alumina based ceramic ... Typical costs of using the alumina based material in a cyclone spigot were approximately A$400 per spigot with an associated lifetime of 400 hours. The MMC equivalent, although priced at A$1000, lasted closer to 4000 hours (sub. 49, p. 2).

Yet despite the significant life-cycle cost and performance savings offered by AC materials, there are widespread reports that industry is either too slow or reluctant to incorporate the AC materials into their production process. This is sometimes the result of a conservative bias towards the retention of traditional materials, but often it is the result of lack of awareness of both the properties of AC materials and the life-cycle advantages they confer.

User awareness and preferences

Although general industry awareness of AC materials is low, this is not unusual for an industry attempting to break into new markets. As the AC industry expands to both supply products more extensively to existing client industries and to increase the client base, awareness of AC potential will increase. Indeed, AC manufacturers report that their projected high growth rates are largely based on expectations of improved awareness.

It is likely that uptake could be accelerated by ensuring that potential purchasers are aware that the short term penalties involved with adopting AC materials (such as design costs and relatively high material cost) are likely to be more than offset by performance enhancements in the longer term.

Some companies point to the financial burden associated with the provision of field trials, where an AC material is trialed in a given environment for a certain time period at the manufacturer’s expense. The dilemma confronting manufacturers here is that awareness can be facilitated via the encouragement of greater field trials, yet the up-front costs incurred can be quite prohibitive for small firms. However, this will become less of a problem as the industry matures and cash flows become sufficient to absorb the up-front cost of field trials.

With respect to electrical ceramics, awareness of the properties and applications is low relative to the position in Japan and the US. However, suppliers of defence equipment generally have a high level of awareness of piezoelectric ceramics. There are several overseas producers that have established a presence in Australia in the production of sonar systems (such as the French-based producer, Thomson–Sintra, which uses piezoelectric ceramics).

Significance as inputs

Provided AC materials are used in appropriate applications, they can have significant impact on the performance of an enterprise. The potential benefits afforded to a manufacturer incorporating AC materials include the following:

- greater longevity;

- reduced maintenance costs;
- reduced down time;
- increased productivity; and
- enhanced competitiveness.

It follows that these factors can then have positive repercussions for other segments of the economy, boosting competitiveness and providing a further source for increased economic growth.

Substitutability

In many applications the use of monolithic ACs would not provide for a direct one-for-one substitution for a traditional material because design considerations need to be incorporated into the changeover. This is particularly the case for applications in the automotive and aerospace industries, where ACs offer better performance due to their ability to maintain their intrinsic properties at very high temperatures. To date, decision makers in the automotive and aerospace industries have adopted a ‘wait and see’ approach to the use of AC materials, resulting in only minimal substitution for other traditional materials or high temperature (super) alloys. Some examples include the introduction of silicon nitride glow plugs and turbocharger rotors in the early 1980s (Minerals Today, 1993).

As an example of the potential substitution value offered by ACs, Rolls Royce Industries of the United Kingdom conducted a study in 1992 to assess the feasibility of using advanced ceramics in their aircraft turbine engines. The use of advanced ceramic components (instead of traditional components) was shown to result in 10 per cent weight savings, 2.3 per cent thrust increase, 12.5 per cent increase in the thrust to weight ratio and a US$7 million reduction in the life-cycle costs for each aircraft (US Bureau of Mines, 1994a).

Monolithic ACs are having more success substituting for traditional materials where potential failure will not result in catastrophic loss, as might be the case for passenger aircraft. This includes applications in mining, power generation, refining and general manufacturing (such as, valve manufacturers, pulp and paper, earth moving, petrochemical, textiles, food, rubber and canneries). As mentioned earlier, typical substituted parts include valve seats, nozzles, crucibles, cutting tools and roller bearings.

Although Australian AC manufacturers are having success penetrating some markets via substitution, their ability to move into automotive and aerospace markets is limited for a number of reasons. First, Australian manufacturers are not yet producing AC materials that are conducive to automotive and aerospace use, such as silicon carbide and silicon nitride. Second, these user industries typically make input decisions in their home country, which is often the US. Finally, and perhaps most importantly, ceramic mechanical properties limit widespread use of AC materials in these industries.

With respect to coatings, their use in the automotive and aerospace industries is more widespread. This is because the crucial properties of the substrate materials are both maintained and combined with the properties of the CC. Unlike monolithic ACs, it is not a case of either substitution or replacement of one material for another. Rather, it is the performance enhancements of existing materials that characterise the importance of CCs to manufacturing.

Growth trends and prospects

During the 1980s several studies forecasted high international growth rates for the production and use of ACs. For example, World production of advanced structural ceramic parts was expected to grow rapidly, from US$3.8 billion in 1995 to US$9.6 billion in 2005 (US Bureau of Mines, 1993). Similarly, estimates reproduced in DITAC (1989) reveal that advanced ceramics were forecast to increase from US$11.3 billion in 1987 to US$32.4 billion by the year 2000.

However, recent forecasts have not been quite as optimistic in light of both the early 1990s World recession and the technical difficulties encountered with these materials (in particular, their brittleness). Recent forecasts appearing in the Advanced Ceramics Report (1994) are presented in Table B3.5. While the growth rate World wide is still very positive, it is not of the same magnitude as those produced previously.

Table B3.5: Value of World demand for advanced ceramic materials, actual (1992) and forecast (1997), (US$ million)

Year	*Value*
1992 (actual)	13 450
1997 (forecast)	20 400

Source: Advanced Ceramics Report, 1994.

Australian growth forecasts over the next five years are of the order of 15 per cent to 25 per cent per annum. This is based on an increasing industry awareness of the advantages conferred by the use of AC materials as well as R&D efforts to increase the range of AC materials produced in Australia. The growth is, however, from a small base.

B3.4 Markets

Nature and operation

In the market for monolithic ACs, manufacturers compete only in a limited range of products. This is because, first, quite specific compositions of ceramics are produced; second, differing processing methods are used in their production; and finally, each manufacturer has established its own niche market based both on location and on the particular qualities of the product it produces. This has resulted in a high proportion of AC output in Australia being custom-made for particular applications.

Despite the above factors, competition is intense in those markets where the applications are less specialised. This not only involves competition between AC manufacturers, but also between these manufacturers and producers of other advanced materials and more traditional materials which are substitutes.

In the CC market, unique compositions of CCs are applied and each company has primarily focused on particular niche areas. For example, C-Ramic concentrates on mining applications, BTS focuses on aerospace and STA has targeted the glass coatings market. Despite these narrow niches, limited competition does occur for some applications, particularly where companies are operating in the same local market (for example, the same State).

For advanced electrical ceramics, Japan and the US are the major markets. This is highlighted in Table B3.6, where for the selected devices, these two countries make up over 80 per cent of World wide demand.

Table B3.6: Demand by Japan and the US for major electrical ceramic devices (percentage of World demand), 1990

	Japan	*US*	*Other*
IC packaging	45	40	15
Substrates	45	40	15
Capacitors	45	40	15
Piezoelectrics	65	25	10

Source: US Department of Commerce, 1993.

The major application for piezoelectric ceramics which are produced in Australia by GECMS is for defence equipment. Major firms include GEC Marconi Systems (UK), Thomson–Sintra Pacific (French) and AWA.

Import competition

Of the major international AEC producers mentioned earlier, only Carborundum has any effective presence in Australia. Even so, its competition with local AEC manufacturers extends only to minimal importation of silicon carbide and boron nitride. These materials are not produced in Australia and, because of their unique qualities (particularly high temperature strength), they do not represent effective competition for existing Australian produced AEC materials. Imports of these materials will provide competition for those Australian companies planning to enter into the silicon carbide or silicon nitride area (for example TCE and potentially AME).

In the CC market, there is no evidence of import competition in those markets identified earlier. However, a significant amount of imported equipment embodies CCs (such as components for use in the mining industry), the exact magnitude of which is difficult to quantify.

Developers of defence systems in Australia either purchase piezoelectric ceramics from GECMS or from producers abroad. Selection of supplier is determined by both price and system performance.

Export opportunities

The major international AC producers (Coors, Corning, Nortons, Philips, Carborundum, Kyocera) have a good overall cover of the offshore markets for AC materials. Accordingly, the ability of Australian manufacturers to compete in international markets depends to a large extent on the type of ceramic involved and the applications required. In some cases, Australian manufacturers can, and do, compete successfully in niche Asian markets (particularly ICIAC and TCE), where the product is not of a generic nature and its qualities are unique.

Export opportunities in CC markets are limited largely because, like monolithic ACs, contracts are job specific. Exports into Asia will be maintained until Asian countries develop their own coating capabilities to the point of self sufficiency. Otherwise, CC manufacturers will only maintain or increase Asian market share by developing or using superior processing technology.

In the advanced electrical ceramics area, GECMS exports most of the systems it develops, rather than the ceramic components. Possible foreign markets for products are continuously being investigated. Some other foreign-owned assemblers of sonar systems export to Asian countries through their Australian base.

If Australia could successfully commercialise ceramic fuel cells and HTS in competition with major groups overseas, export opportunities would be considerable, even though the range of applications, and therefore demand, is difficult to predict accurately at this stage.

Barriers to entry

The nature of the AC industry (that is, a close relationship between suppliers and users, and the production of tailor-made products) effectively sets up a natural barrier against offshore companies. Likewise, Australian AC manufacturers are disadvantaged in their efforts to enter tailor-made product markets overseas. Locating production facilities offshore is the most effective means of countering this barrier, yet with the possible exception of AME, Australian companies have not ventured down this path.[10] Where AC materials are of a more generic nature, the relationship between supplier and user is less iterative, and distance therefore becomes less of a barrier. However, generic products usually imply larger production runs, lower costs and prices, and usually smaller profits per unit — and the product is tending to become a traditional material.

Technological factors prevent entry into those markets where patents are held or advanced processing technologies are closely guarded. However, patents do not prevent the production of materials which are close in character to the patented material. It is for this reason that some firms with technological advantages have demonstrated a preference for excluding important information from patent applications, or not filing patents at all.

With respect to advanced electrical ceramics in particular, the size of foreign producers poses a barrier to entry. Their ensuing scale economies enable them to produce at lower cost and so maintain a competitive edge. Relatively high levels of government assistance overseas also act as a barrier to entry.

Dr Patrick Kelly, of the University of Queensland, alleges that the small size of the domestic market, the relatively low level of technological sophistication in industries which serve it and a shortage of capital are all reasons why Australia is unlikely to become internationally competitive in the manufacture of electrical ceramics such as integrated circuit packages, integrated circuit boards, electronic components and piezoelectric filters (sub. 21).

[10] AME is not yet certain in which country it will locate its overseas production facilities.

B3.5 Competitiveness of Australian producers and users

Competitive advantages

In the AC field, Australia benefits from competitive advantages from two primary sources.

First, the World class expertise of our research institutions in advanced ceramics puts Australia in a competitive position when operating in global markets. Despite the small scale of Australian AC activities, this expertise has translated into very competitive technologies being developed, which have provided Australian AC manufacturers with an edge over international competitors. For example, CSIRO has an advanced ceramics laboratory that became internationally renowned following its development of the World's toughest ceramic (PSZ) in the early 1970s. Since then, it has maintained its international reputation via further developments in the AC field. This affords AC manufacturers with an invaluable resource.

Second, some Australian AC manufacturers are also provided with a competitive edge, owing to the nature of the materials produced. As mentioned earlier, many of the materials are custom-made, which makes collaboration between producer and user vital. This process is necessarily facilitated by the location of AC production facilities close to the end users.

The fact that many AC materials are custom-made, combined with Australia's proximity to the Asian region, may also provide Australian producers with a competitive advantage relative to the major international producers in the US, Europe and Japan.[11] This will become less a factor once the developing nations establish their own AC production facilities. Australian manufacturers will, however, be in a good position to establish a presence in Asia either by relocating part of their production facilities offshore, or by establishing a joint venture arrangement (or both).

Competitive disadvantages

On the face of it, Australia appears to be afforded the natural advantage of possessing abundant AC raw material supplies — in particular, zircon, bauxite and quartz. However, these ores need to be processed to high purity powders which are then used as feedstock for AC production. Australia does not currently have a large scale production facility for high purity powders and therefore the bulk of the country's inputs are sourced either from the US or

[11] In particular, countries such as Thailand, Indonesia and the Philippines.

Japan. These countries not only have the technical expertise, but they also have large domestic markets, both of which work to support large scale processing facilities.

Essentially, Australia is faced with a competitive disadvantage rather than an advantage by virtue of AC manufacturers being contingent on offshore companies for their feedstock (with the exception of TCE for some of its raw materials). This can translate into higher input prices and uncertainty with supply.[12]

The small size of both the Australian market and the individual companies also means that AC manufacturers cannot attract meaningful volume discounts on their inputs.[13] As the size of the Australian market expands, this will become less of a competitive disadvantage.

Impediments

Two potential impediments specific to AC manufacturers were identified by participants.

First, some firms claimed that they were unable to raise debt and equity capital for the purpose of funding expansion.

Second, Australian firms may be constrained in their export efforts by the imposition of seemingly anomalous harmonised tariff classification codes applied to engineering ceramic materials.

B3.6 Economic significance

Value adding in production

The AC materials produced in Australia are typically high value added, with raw material costs representing only a minor proportion of total output value (approximately 15 per cent). Labour input is the highest component of total costs.

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12 However, the impact on price is only marginal because of the relatively minor transport costs.

13 Indeed, this lack of market power has manifested in TCE manufacturing its own alumina powder.

Value adding in use

For many applications, the value of AC materials results in reduced whole-of-life input costs. In other words, the input cost of the AC itself may be relatively high, but its superior performance boosts the value added component for any given output.

B3.7 Potential for further production and use

The AC manufacturers will continue to have markets in Australia where the AC components produced are tailor-made for specific applications and when the quality of the components is advanced due to superior technology (for example, TCE). However, once the use of ACs becomes more widely adopted and more generic products are made, the potential for large scale production will increase and it is more likely that one of the large international companies will establish a more significant presence in Australia. The servicing of Australian or South East Asian markets may then become more difficult for specialist local firms, depending on the size of the market a new entrant targeted. However, as noted previously, if and when this occurs, AC materials will be approaching the category of traditional materials and the challenge will be to discover a yet more desirable material.

With respect to international markets, Australia's future in the US and Europe is restricted to those products which have a significant product advantage. ICIAC's PSZ is a good example, where it can perform better than alternative forms of PSZ in given applications. Similarly, COF's oxygen sensors will continue to dominate in some markets overseas. However, once ICIAC's and COF's patents expire, further technological breakthroughs will be required to ensure Australia retains its presence in these markets.

Essentially, Australia will find it difficult to increase exports in those markets where competitive advantage is derived from a large domestic user base and scale economies (conducive to generic product range). It will, however, have a role where competitive advantage is derived from superior technology, better technical know-how or a flexible output mix (conducive to shorter production runs and tailor-made products).

In terms of Australia's future in Asian markets, it will only be enhanced if producers maintain higher quality standards through advanced technology.

Fuel cells are a potentially more efficient means of electricity generation than conventional methods and are modular in nature. There is potential for their costs to fall, although the extent to which this will occur once fuel cells are commercialised is unclear at this stage.

There is extensive potential for initiating production and usage of HTS. The total World market for superconductivity materials is forecast to be US$150 billion to US$200 billion by the year 2020.

B4 ADVANCED POLYMERS AND COMPOSITES

Advanced polymers and advanced polymer composites (APCs) are new and advanced materials. They are manufactured by the plastics industry, which has been developing in Australia since the 1940s. They are used by a wide spectrum of the manufacturing industry.

B4.1 What are advanced polymers and advanced polymer composites?

In this inquiry, the term 'advanced polymer' refers to polymers that may have been developed up to several decades ago, but their use in industry is still fairly limited, despite their superior properties. Advanced polymers and APCs comprise only a small proportion of the range of polymers used in Australia (see Table B4.2).

Polymers are produced by a chemical reaction which bonds molecules of lower molecular weight, called monomers, into long chain molecules of higher molecular weight. Copolymers are polymers made from two or more different monomers. Polymer blends or alloys are mixtures of chemically compatible polymers. Resins are solidified polymers, usually supplied to fabricators as pellets for further processing. Plastics are compounds of polymers, plasticisers, stabilisers, fillers and other additives.

Polymers or resins can be classified as either thermoplastic or thermoset. In thermosets, the polymer chains are 'crosslinked' by heating giving high resistance to solvents and high temperatures. Thermosets include phenolics, polyurethane, epoxy and unsaturated polyesters. With thermoplastics, unlike thermosets, processing is reversible by simply reheating to the process temperature.

Polymers may be grouped into three categories: 'commodity', 'engineering' or 'high performance'. Engineering and high performance polymers are referred to as 'advanced polymers' in this report.

Commodity polymers, such as polyethylene, polyvinyl chloride, polystyrene and polypropylene, have been used widely by industry for many years. They do not perform well at high temperatures, but are very versatile and comprise the majority of all plastics used in Australia (see Table B4.2). Material developments using these polymers are occurring and will be discussed in this case study.

Engineering polymers are used in structural or functionally demanding applications, often replacing metals (PIA, 1992). Their properties include good resistance to heat and corrosion, strength and durability. Examples include acronylitrile-butadiene-styrene (ABS), polyamides (nylons), polyacetal (PA), polycarbonates (PC) and polybutylene terephthalate (PBT).

High performance polymers can be used in more demanding environments than engineering polymers. They are resistant to heat, have high strength to weight ratios, and possess fire retardant properties. Examples of high performance polymers include polyetheretherketones (PEEK), perfluroalkoxy (PFA), polyvinylidene fluoride (PVDF), polyvinyl fluoride (PVF) and fluropolyphenylene sulphide (PPS).

Polymer composites or ‘fibre reinforced plastics’ are comprised of a polymer reinforced by particles, whiskers, fibres or fabrics. The reinforcement provides strength and stiffness which is lacking in the polymer itself.

The reinforcing fibres can be either continuous or discontinuous (chopped). Polymer composites made of chopped fibres can be produced more cheaply but lack the strength of continuous fibre composites. Strength also varies with the direction of the fibres and the strength of the bond between the fibre and polymer. Most polymer composites are made of polyester, epoxy or vinyl ester resins reinforced with discontinuous, low-stiffness glass fibres, and are not classified as ‘advanced’. Fibreglass is neither new nor advanced and has been in use for about 40 years, primarily in boat hulls.

APCs are light-weight and have superior strength and stiffness. They have been in use for about 20 years, mostly in the aerospace industry, and usually contain a large proportion of high performance continuous fibres, such as graphite (carbon), aramid or boron fibres. Thermosetting polyesters and epoxies are generally used as the matrix material.

Other kinds of composites discussed in this case study, are light-weight structural sandwiches. These have aluminium or aramid honeycomb cores, with fibre-reinforced polymer or metal skins. Although the sandwich technology is not new, many honeycomb panel materials have been developed recently. These kinds of composites are mostly used as aircraft skins, but also have applications in the rail, marine and construction industries.

There is, therefore, a diverse range of materials which may be defined as advanced polymers and APCs. Each varies in terms of its strengths and weaknesses, and therefore its capacity to substitute for traditional and other advanced materials. Despite the large number of different materials in this case study, many common issues emerge.

Properties

The range of materials outlined in Table B4.1 is an indication of the variety of polymers and polymer composites available, their properties and uses. In general, engineering polymers have good strength to weight ratios, in many cases replacing secondary structures in cars, such as metal panels. Their major advantage relative to metal is that they are relatively light-weight, thereby increasing the fuel efficiency of cars. However, engineering plastics do not possess the strength or heat resistant properties, amongst others, of high performance polymers.

Composites such as boron and carbon fibre reinforced polymer resins, designed for military vehicles, have demonstrated little evidence of fatigue, corrosion, or loss of mechanical properties after 20 years use. Although as strong as metals such as aluminium, they are ultra light and lend themselves to large aircraft structures (Reinhart, 1992).

The variety of resins and characteristics available enables the manufacturer to selectively meet the specifications for end use application. Single resins can be varied by using different formulations or by using different additives or reinforcements. Manufacturers often provide many grades of each resin they produce and refinements are continually being made to many types of polymer to vary the properties of each. A user of engineering plastics noted that over the past ten years, there had been improvements in the processability, among other characteristics, of several polymers.

Advanced polymers and APCs can compete with each other and commodity polymers on the basis of both price and performance. For example, the low cost of commodity materials and their versatility has led to developments in these products such as high impact polystyrene (HIPS). HIPS is competing with a PC–ABS blend for application in the electronics industry, despite its lower impact strength and heat resistance (High Performance Plastics, 1994a).

High performance plastics are little used in Australia. These materials are very costly and are primarily developed for military applications and environments which are much more demanding than most commercial applications. It is unlikely that they will be widely used in Australia until their cost falls considerably. A similar situation exists in the case of carbon fibre ‘prepregs’,[1] as there is no production in Australia and currently limited demand for the material.

1 Semi-cured, reinforced materials impregnated with resins and pressed into a flat sheet.

Table B4.1: Examples of polymers and advanced polymer composites: characteristics and uses

Polymers	*Trademarks*	*Characteristics*	*Uses*
Commodity			
High density polyethylene (HDPE)		toughness, stiffness, stress-crack resistance	packaging
Liner and low density polyethylene (LLDPE and LDPE)		softer than HDPE, clarity, inertness and ease of processing	film, garbage bags
Polypropylene (PP)		light, resistance to corrosion, versatile	many uses, such as fresh food packaging
Polystyrene (PS)		good processability, optical properties, high rigidity, low temperature impact strength	many uses such as packaging, appliances, and medical
Polyvinyl chloride (PVC)		more difficult to process but able to blend with additives to give particular performance characteristics	construction, PVC pipe
Engineering			
ABS		impact, chemical and heat resistance, hardness, rigidity, surface gloss	packaging, automotive, appliances, plumbing, furniture
Polyamides (nylons)	Nylon 6, Nylon 6,6	absorb water, tough, high impact strength, good chemical, UV and abrasion resistance	automotive (bearings, gears, tubes), electrical components, automotive panels and other components
Polybutylene terephthalate (PBT)	Rynite (Dupont)	tough, good impact strength, UV resistance chemical resistance, low water absorption, high mechanical strength	electrical parts and connectors, appliances, automotive exterior parts

Table B4.1: Examples of polymers and advanced polymer composites: characteristics and uses, cont.

Polymers	*Trademarks*	*Characteristics*	*Uses*
Polyethylene terephthalate (PET)	Valox (General Electric) Ultradur (BASF)	melts at higher temperatures than PBT, rigid, thermal stability	films , packaging, microwave ovens, textile and machinery construction
Polycarbonate (PC)		transparent, good impact strength and toughness, creep resistant, fair UV resistance, electrical properties, poor chemical resistance	electrical switches and housings, appliances, medical instruments and goods, lighting
Modified polyphenylene oxide (PPO, PPE)	Noryl (General Electric)	good creep resistance, poor UV and chemical resistance, good impact strength	automotive instrument panels, pumps, electrical housings and connectors, appliance housings
Polyacetal (PA)	Delrin (Dupont)	superior to nylons in heat and creep resistance, fatigue and water resistant	telephone components, automotive and plumbing industries
Polytetrafluoroethylene (PTFE)	Teflon FEP(Dupont) Cortex	corrosion resistant, inert to chemicals, heat and abrasion resistant, non-adhesive	metal coatings, fabric impregnation, seals, gaskets, valve and pump parts.
High Performance			
Polyetheretherketones	Victrex PEEK (ICI)	low water absorption, chemical, abrasion and fatigue resistant, low flammability and more heat resistant than PPS	aerospace, military and computer industry
Aromatic Polyamides	Kevlar (Dupont)	high heat tolerance, outstanding strength.	ballistic vests, telecommunications industry, sailcloth
Polyphenylene sulfide (PPS)	Ryton (Phillips)	outstanding resistance to flame, heat and chemicals	electrical parts, automotive, sterilisable medical equipment

Table B4.1: Examples of polymers and advanced polymer composites: characteristics and uses, cont.

Polymers	*Trademarks*	*Characteristics*	*Uses*
Polyetherimides (PEI)	Ultem (General Electric)	high strength, heat and flame resistance	electronics, fibre-optic components
Polyamide-imide (PAI)	Torlon (Amoco Chemicals)	high strength, heat resistance, stiffness and excellent resistance to radiation	pumps, valves, electronic accessories
Advanced composites			
Graphite (carbon) fibre composites		Better strength to weight ratios than metals, chemically inert, high heat resistance	aerospace, sporting applications and yachts
Light-weight structural sandwiches		High stiffness, light-weight, fire retardant	rail, marine and construction industries

Source: PIA, 1992; US Bureau of Mines, 1990.

Given the relatively high cost of the more advanced materials, their application usually occurs where performance is a more important criterion than cost. In the automotive and most other commercial applications, cost is considered to be the most important criterion, given that existing safety and environmental standards are met. For example, in 1994, steel was considered to have a relative advantage over engineering plastics in terms of raw material cost, component processing, assembly and disposal in most automotive applications (University of Michigan Transportation Research Institute, 1994).

An indication of the relative cost of the different kinds of polymers may be made by comparing the average unit value of imports of commodity with engineering and high performance polymers. The average unit value is the value of total imports in the category divided by their weight. The average unit value reflects their cost and is indicative of the price at which they are sold to users. In 1992–93, the average unit value was highest for high performance polymer imports ($6 per kg), followed by engineering polymer imports ($3 per kg), and lowest for commodity polymer imports ($1.60 per kg).

International production and use

Between 1984 and 1992, it is estimated that the World market for engineering polymers and high performance polymers rose in nominal terms from US$700 million to US$3.2 billion (New Materials International, 1994c). In terms of weight, world production of engineering plastics in 1992 was estimated to be 14 million tonnes, having grown at an average annual rate of 4.8 per cent per annum over the previous ten years (Plastics News International, 1993).

For APCs, it is estimated that world production totalled US$4.3 billion in 1992, of which US$2.2 billion was produced in the US, US$1.2 billion in Europe and US$817 million in the Pacific Rim, mainly by Japan. By volume, the major end user industries in 1992 were aircraft, military and space, automotive and recreation applications (US Bureau of Mines, 1994a).

Most producers of engineering and high performance polymers are large trans-nationals such as ICI, Dupont, GE Plastics, BASF and Dow Chemicals, and production occurs mainly in the US, Japan and Europe. Most research and development also occurs in these regions.

The main market for high performance polymers and APCs is in military applications and this market has slowed considerably with the World wide recession and the end of the Cold War. Most major polymer manufacturers experienced falling sales and profits between 1991 and 1993 (High Performance Plastics, 1994b). For example, demand for ABS in the Japanese automotive and whitegoods industries continued to decrease over the past three years and Dupont Engineering Polymers recently closed a compounding unit in the US. These examples confirm comments made by ICI on recent reductions in international demand for these materials (New Materials International, 1994c). However, the World economic recovery has led to recent increases in demand and in resin prices (The Plastics Report, 1994).

Given the recent expansion of plant capacity for the production of engineering resins in the Pacific Rim (Japan, Republic of Korea and Taiwan), there are concerns of global over-supply of PC, acetal, PBT and ABS in 1995. Production capacity for carbon fibres is increasing in Japan, which is aiming to further improve advanced carbon fibre composites. However, recent demand forecasts for carbon fibre estimate that demand is expected to increase by 13 per cent a year to 1998 as the market shifts from military to commercial applications (Advanced Ceramics Report, 1994).

Major international producers of resins for processing into APCs include Dow Chemical, Shell and Ciba-Geigy. Major fibre suppliers include Hercules, Amoco and BASF. Major suppliers of prepregs include Fiberite, Hercules and Hexel (OTA, 1988).

In 1992, more than 90 per cent of the World production of APCs was produced by less than 30 businesses of which 12 were in the US, ten in Europe and several in Japan. A large number of SMEs are involved in fabrication of products from these materials (US Bureau of Mines, 1994a).

As the military is the main user of high performance polymers and APCs, there is a drive in the US to develop more commercial applications for these materials. While the Department of Defense is still the largest funder of US science and technology, the US Government now funds programs such as the Advanced Manufacturing Technology Program (AMTP) run by the Advanced Research Projects Agency (ARPA) and the Small Business Innovative Research Program (SBIR) to encourage the commercial use of these materials. This focus on small business is due to an awareness that advanced composites are not only used by a few large businesses but by a large number of smaller firms (US Bureau of Mines, 1994a). US government funding on materials research totalled US$478 million or 25 per cent of total Advanced Materials and Processing Program (AMPP) R&D funding in 1992. Of this, US$101 million was for polymer research and US$185 million for composites research (US Bureau of Mines, 1994a).

Australian production and use

Limited production of advanced polymers and APCs occurs in Australia. This is mainly because of low domestic demand. Given this, issues relating to the use of these materials is the main concern of this inquiry. Most producers of advanced polymers are trans-national chemical producers who undertake most of their product development overseas and import advanced polymers from their overseas facilities. Of the advanced polymers, only ABS is wholly manufactured in Australia. However, some compounding, where imported base resins are mixed with additives, fillers and reinforcements to produce advanced polymers, is undertaken in Australia. ABS, nylons, PBT, PA, PPE-PPO and PET are compounded locally (Sub. 14).

In addition, some smaller Australian producers are involved in the production of a range of polymer materials and composites for domestic and overseas markets. These smaller producers develop materials for particular customer needs which are mainly refinements of commodity polymers. These businesses perceive that while there are many opportunities in Australia, the need to develop new products will be accelerated by new opportunities arising in other countries.

The Australian manufacturing industry uses engineering plastics mainly in the automotive and automotive components industry and APCs are used mainly in the aerospace and military sectors. Some use is made of high performance polymers in telecommunications, for example, in sheathing materials of fibre optic cable (MM and Olex Cables). Aerospace Technologies of Australia (ASTA) uses about 11 container loads of prepreg per year at a cost of about $5 million in 1993–94. ASTA's demand is estimated to grow by 30 per cent over the next five years.

It is difficult to obtain production data which separates total plastics production from the production of advanced polymers. However, Table B4.2 below provides some indication of the use of advanced polymers. As most advanced polymers are imported and can be defined at a greater level of disaggregation than production statistics, import data provide a more reliable indication of the use of advanced polymers in Australia.

Table B4.2: Production and use of polymers in Australia, (kilotonnes)

	1987–88	*1992–93*
Production[a]		
Commodity Polymers	990	1 045
Imports		
Commodity Polymers	51	161
Advanced Polymers	8	70
Exports		
Commodity Polymers	25	108
Advanced Polymers	5	8
Estimated Total Use[b]		
Commodity Polymers	1 036	1 098
Advanced Polymers	3	62

a Total polymer production given limited production of advanced polymers in Australia.
b Production plus imports minus exports.
Source: ABS cat. numbers. 5464.0, 8362.0ı .

Producers either sell directly to the final manufacturer, or to fabricators, who mould or further process the advanced polymer or APC before selling the component to the final manufacturer. It is estimated that in Australia there are about 50 establishments using engineering plastics to manufacture components for the automotive, electronics, computer and sporting equipment industries. These establishments range in size from medium to large organisations (sub. 14).

B4.2 Australian producers, users and their activities

Given the large number of businesses involved to varying degrees in the production and use of advanced polymers and APCs, only a relatively small number were able to be interviewed for this case study. They are not necessarily representative of all enterprises using or producing these materials, but the case study has attempted to use data from firms using and producing both advanced polymers and APCs.

For many of the businesses who are involved in the production and use of advanced polymers and APCs, their production and use comprise only a small part of their overall activities whether in Australia, or internationally.

The main activities of the businesses interviewed are summarised below.

Producers — advanced polymers

Dupont (Australia) Pty Ltd

Dupont (Australia) Pty Ltd is a division of Dupont Ltd, which has operations in the US, parts of Europe and Asia. Both polymers and composites are produced by the company. Most of the materials which are the subject of this case study are not produced in Australia due to small domestic sales.

BASF

BASF is part of the BASF Group, a trans-national company which is based in Germany. BASF has a compounding operation in Australia to produce custom-made plastics which are not made in Germany. More than half of total Australian turnover is custom-made for domestic customers, particularly for the automotive industry. However, many of the advanced polymers are imported for sale direct to domestic users.

Dow Chemical (Australia) Ltd

Dow Chemical (Australia) Ltd is a wholly owned subsidiary of The Dow Chemical Company, which is US based. Australian activities consist of local manufacturing plus importing products and modifying these to meet local customer needs. Half of Dow’s sales are from imports and half from local manufacture, but the advanced materials are imported. Most development of new materials by Dow is driven by the needs of industry in the US and Japan.

ICI Plastics

ICI Australia is a subsidiary of ICI PLC, a UK based trans-national. In Australia, ICI Plastics produces 350 kilotonnes per year of the more common plastics: polyethylene, polypropylene and polyvinylchloride. The company also formulates and compounds some of these base resins to meet specific customer requirements.

Small quantities of acrylics, nylons, acetals, PEEK, PFTE and others are imported and traded to customers, or formulated and compounded to meet specific requirements. ICI's sales of engineering plastics are usually less than 10 kilotonnes a year, with the main markets being in automotive, telecommunications, cables and appliances. Local manufacture in Australia is not economic.

GE Plastics Australia

GE Plastics Australia is wholly owned by the General Electric company, a US-based trans-national.

The automotive industry is the largest user of advanced polymers produced by GE Plastics, closely followed by the telecommunications, electrical and construction industries. In 1992–93, advanced polymers compounded in Australia included Lexan Polycarbonate (PC), Noryl Modified PPO, Valox thermoplastic polyester (PBT), various grades of Xenoy PC-PBT alloy, Cycolac (ABS), Cycoloy (PC-ABS alloys) and Miron mineral and glass reinforced nylons. Key primary feedstocks of resins are fully imported. Other feedstocks are sourced locally. Products are tailored to customer specifications. Australian material requirements can be quite different due to different climatic conditions to other parts of the world. Product testing and development is undertaken in co-operation with technical facilities in Australia and overseas.

Ciba-Geigy Australia Ltd

Ciba-Geigy Australia Ltd is a subsidiary of a European based trans-national. Ciba-Geigy Australia produces advanced polymers and APCs as well as light-weight structural sandwich composites. Some of these are produced at Ciba-Geigy's plants in the US and Europe and imported. Product development in Australia consists of customising products to domestic clients' needs, particularly those which have to be altered to cope with Australia's climatic conditions as well as to adapt products to local regulations. Ciba-Geigy considers that it is not cost-effective to produce these materials in Australia given the small size of the local market and the lack of relevant engineering skills available in Australia. Ciba-Geigy provides an advisory and technical support service to its customers.

Akzo-Nobel Chemicals Ltd

Akzo-Nobel Chemicals Ltd, which recently merged with Nobel Industries Limited, is an international chemicals, fibres, coatings and pharmaceutical company with headquarters based in Germany and Holland. Local manufacture is limited to low technology commodity polymer products. Advanced polymers and APCs are imported from Akzo-Nobel's overseas facilities. Aramid fibre is their main 'exotic' product which is used in brake pads made by Allied Friction and Futuris. These fibres are also used to make ballistic vests and asbestos-free gaskets, fibre reinforced plastics and optical fibre cables. Other products sold include nylons, teflon and carbon fibres. Akzo-Nobel estimates that Australian sales of these imported products are around $8 million a year, about a quarter of the firm's turnover.

PolyPacific Pty Ltd

PolyPacific Pty Ltd is a specialist compounder working exclusively with polypropylene as its feedstock. Through processing and formulation technology, developed in-house, polypropylene compounds are formulated to meet customer specifications. Its current product range includes mineral reinforced polypropylene (to increase rigidity and heat resistance), glass reinforced polypropylene (for even greater impact strength and flexibility) and flame retardant polypropylene (to meet various electrical and safety standards for appliances).

PolyPacific continually develops new products to meet changing needs in the various end use industries, with the automotive industry being dominant. Other users are the appliance industry, packaging, houseware and industrial equipment. Its main competitors are local producers such as ICI Australia and Hoechst, along with imported Japanese compounds. About 15 per cent of turnover is exported to ASEAN countries and strong growth is anticipated in this region.

Townsend Chemicals Pty Ltd

Townsend Chemicals Pty Ltd is owned by Mirlex Australia Pty Ltd and has an annual turnover in excess of $10 million. Its main activity is in the local manufacture of specialty chemicals such as polymeric plasticisers, polyester polyols and thermoplastic polyurethanes. It has the ability to produce tailor-made specialty resins for its customers. New grades are constantly being developed for specific end use applications.

Townsend competes with large trans-nationals both within the domestic market and overseas. Its main competitors are Bayer, BASF, Morton and Dai Nippon Inc. About 40 per cent of its sales are exports to areas such as Asia, New Zealand, South America and South Africa. Townsend Chemicals considers that exports will be the main source of its future growth in demand.

Flexichem Pty Ltd

Flexichem Pty Ltd is a small producer of specialist polymer blends supplying the textile, paper, building materials and food industries. This small Australian company is able to compete with trans-national suppliers by providing specialist materials and service in relatively small quantities. Most of the polymer blends are silicone based.

Users — advanced polymers

Ford Motor Company of Australia Ltd - Plastics Plant

Ford Australia’s Plastic Plant at Broadmeadows (Victoria) produces bumper bars, consoles, instrument panels, fuel tanks and other automotive components. Advanced polymers used include ABS and modified PPO. It is the largest plastics fabrication plant in Australia, employing over 400 people and using a wide range of production technologies (see Appendix B9).

SOLA Optical

SOLA Optical, owned by AEA Investors Inc, has grown from a small Adelaide-based company into the World’s largest producer of plastic spectacle lenses. The SOLA Group, with sales in excess of $400 million per year, has manufacturing plants in eleven countries, and employs over 6000 people World wide, with 700 employed in Australia. In Australia, SOLA invests over $8 million into R&D each year.

Today, almost 60 per cent of spectacle lenses are made from plastic materials instead of the traditional mineral glass. The most common plastic is allyl di glycol carbonate (ADC) which is lighter, easier to tint, and exhibits greater impact resistance than glass.

In recent years there have been significant advances in both plastic lens materials and scratch resistant coatings. An example of this is the development of Spectralite® by SOLA. The Spectralite products combine a new lens material, a new manufacturing process, a new coating resin and new designs to produce a superior end-product. Since their first release in 1991, the Spectralite products have received four awards of excellence from the US Optical Laboratories Association.

The fact that over one-third of SOLA’s World wide sales revenue comes from products that did not exist five years ago is testimony to the importance of continual development of both materials and design technology.

Britax Rainsfords Pty Ltd

Britax Rainsfords Pty Ltd is owned by a UK company which has plants in the US and the UK. It is one of the largest users of engineering plastics in

Australia. Britax uses PA, PBT, PPE-PPO, PC and Polyamides and designs, moulds and casts mirrors for the automotive industry. It has 98 per cent of the Australian market and about 60 per cent of its sales are to automotive companies in Japan, Korea and the US. This share is expected to grow to 80 per cent in several years. Production is becoming increasingly automated to obtain consistency in the product.

MEMTEC

MEMTEC utilise hollow polypropylene fibre membranes to separate impurities from liquids. The hollow fibres filter extremely small impurities (rated at 0.2 micron) making them effective in removing bacteria, colloids, algae, suspended solids and some viruses. MEMTEC is one of the largest separation companies in the world.

Applications for MEMTEC's membrane separation technology include water purification and desalination, food and wine processing, and oil and water separation.

MM Cables Communications Products

MM Cables Communication Products is a division of Metal Manufactures Limited (MML). MML is part of the BICC Group of companies. BICC is a UK company which manufactures cables in the US and Canada, Asia, Europe and Russia. BICC is the World's second largest cable manufacturer. MML also has a joint venture with Corning Incorporated, called Optical Waveguides Australia (OWA). OWA is the largest manufacturer of optical fibre waveguides in the Southern Hemisphere and produces the majority of the optical fibres used in Australia.

MM Cables has the capacity to produce 400 000 kilometres of optical fibre cable each year, 1.2 million pair kilometres of twisted pair telephone cables and large volumes of LAN and related communication cables.

Kevlar and glass reinforced polyester along with the optical fibres are just some of the more exotic materials used in the manufacture of optical fibre cables.

Major customers are Telstra and Optus and 30 per cent of total turnover is from exports to the Asia Pacific region.

Olex Cables

Olex Cables is part of Pacific Dunlop Limited, an Australian company with factories in many countries of the World. It manufactures power cables for all the major Australian power authorities. Olex produces cable for the Australian telecommunication carriers and for the Asian market. High tensile steel, polyaramid, glass reinforced polyesters and various polymers are used as components in fibre optic cables. Optical fibre is produced at the Optix manufacturing facility at Tottenham, Melbourne using Sumitomo (Japan) technology. The materials used in the power cables include elastomers, crosslinked polyethylene, semiconductive polyolefines and other polymers. Olex provides customer support services and develops products in response to customer needs and its material developments are carried out in co-operation with the supplier and customer. International competition is from all the major European and Japanese cable manufacturers.

Telectronics Pacing Systems

Telectronics Pacing Systems, now a fully-owned subsidiary of Pacific Dunlop, commenced operating in the 1960s and now produces implantable defibrillators and pacemakers, and has managed to capture 18 per cent of the World market in pacemakers.

Telectronics' annual World turnover is approximately $300 million, with $10 million being earned in Australia. Telectronics spends more than $600 000 annually on research into new materials. In 1994, Telectronics discovered a malfunction in some lead wires casing giving rise to the possibility of litigation. This has arisen despite the completion of an extensive evaluation program and approval of the design by the US Food and Drug Administration.

Cardiac pacemakers are designed to provide controlled electrical stimulation to the heart in cases where irregular beating occurs. The pacemaker is largely an electronic device, battery driven and programmed at a sophisticated level to maintain heart function. Advanced polymers are used to provide electrical insulation and increase biocompatibility for the device (see Appendix B10).

UNASCO Pty Ltd

UNASCO Pty Ltd is a private company with an annual turnover of about $6 million. It uses advanced polymers to produce different kinds of teflon tapes to suit a variety of industrial applications. It maintains informal networks with overseas firms which assists with the product development process. Exports are estimated to comprise about a quarter of annual turnover. Of new products which are being developed, up to 90 per cent of production is likely to be exported.

Producers — advanced polymer composites

Composites Materials Engineering Pty Ltd (CME)

A privately owned Australian company, CME employs 45 people with an annual turnover of about $7 million. The business specialises in the manufacture of Sheet Moulding Compound (SMC) and Dough Moulding Compound (DMC) and claim to be the only company in Australia with the technology to make these composites. CME also has the largest compression moulding operation for composite materials in Australia. CME supplies the automotive, building, construction and sanitary industries, amongst others.

To support its customers, CME uses some overseas technology and maintains a technical and engineering support area which formulates materials specifically to meet customers' product specifications. For the past four years, CME has been exporting the materials into Asia, where the materials are moulded into a wide range of products.

Futuris Industrial Products Pty Ltd

Futuris Industrial Products Pty Ltd is wholly owned by Futuris Corporation Limited, an Australian owned company. Its main activity is the manufacture of non-asbestos railway brake blocks and disc pads for the rail, automotive and industrial markets. The non-asbestos friction brake formulations use fibres, fillers, friction modifiers and most of the technology is developed in-house.

The main users are railways, tramways and the automotive spare parts market. Futuris also exports its railway brake products to many parts of the world including Europe, Asia and the Americas.

Users — advanced polymer composites

Aerospace Technologies of Australia (ASTA) Pty Ltd

ASTA, formerly the Government Airforce Factory, is wholly owned by the Australian Government. ASTA Components, a unit of ASTA, supplies major aircraft manufacturers such as Boeing and Airbus with structural components. Composites used include resin impregnated carbon fibre, fibreglass fabric or tape as well as aluminium honeycomb core composites. Materials are sourced from overseas suppliers. ASTA considers that given the small size of the domestic market, such materials are unlikely to be produced within Australia. Over the past three years, ASTA estimates that sales of products using these new materials exceeded $100 million.

Transform Composites

Transform Composites is a private company with $12 million turnover annually which produces components for trains, buses and ferries. It supplies about 80 per cent of seats installed in trains in Australia. New materials are imported but modified to suit specific requirements. These include modified acrylic products and phenolics which are used for their high fire and safety performance, good mechanical properties and high strength to weight ratios. Transform has difficulties obtaining supplies of some materials from importers. For example, it is difficult to obtain small quantities for product development purposes. It also has difficulties obtaining up-to-date technical information on composite manufacturing techniques.

Thermal Bay Pty Ltd

Thermal Bay Pty Ltd is a privately owned business with annual turnover of about $5 million. The company is working with AMRL to develop materials and processes using phenolics which have excellent fire retardant properties, with applications in the defence industry and public transport. Composites are also used to produce seats for trains and buses owned by the NSW Government.

Thermal Bay has developed informal links with overseas firms, due to difficulties in obtaining the appropriate materials locally.

NQEA Australia Pty Ltd

NQEA Australia Pty Ltd is an engineering and shipbuilding company involved in the design and construction of boats and ships and other engineered products such as manufacturing equipment. It uses light-weight aluminium honeycomb panels with fire retardant properties in the construction of fast ferries. Other domestic competitors in the fast ferry market include Oceanfast, Austral, Wavemaster and Incat. A major factor influencing the development of fast and comfortable passenger ferries is the growing tourist demand to see the Great Barrier Reef, one of the most heavily visited off-shore tourist areas in the World. Australian manufacturers are exporting fast ferries into various markets.

NQEA has been using honeycomb panels for over eight years and over that time has experienced difficulties in obtaining supplies. For a short period it produced the composite materials in-house. Like many businesses, NQEA prefers to source materials within Australia due to the delays experienced with overseas suppliers.

The light-weight structural sandwiches are considerably more costly than traditional materials, due to the labour intensive processes required to join and finish the materials. They are only used where speed is a major criterion, for example, to travel two hours to a Great Barrier Reef tourist destination. In addition to their light weight, these materials have fire and safety advantages.

B4.3 Supply conditions

Production technologies

In Australia, there is limited production of advanced polymers and APCs. Domestic manufacturing is mainly in the use of these materials, that is, moulding them to fabricate final products or components of final products.

Processing technologies

In Australia, most base resins used in the production of advanced polymers are imported.

However, several trans-national companies in Australia modify engineering resins to tailor these to customer needs using compounding and extrusion technologies. Compounding mixes the polymer with various additives and fillers which can then be extruded and chopped into pellets and sold to plastic moulders and processors, who are described as fabricators.

Advanced polymers

Mould design and toolmaking are important skills which affect the quality and design of final polymer products. Methods to shape the advanced polymers include injection, compression and extrusion.

With injection moulding, the materials are melted and forced under pressure into a cavity and the finished part is ejected when the material has solidified. With compression moulding, the material is placed in a heated mould which is closed and pressure applied. With extrusion, the melted resin is forced through a nozzle or die that has the shape of the intermediate product, which may be tubes, pipes, sheet or film.

Computer Aided Design and Manufacturing (CAD–CAM) has been developed for the polymer industry by Moldflow, an Australian company. Moldflow is a World leader in developing software which simulates the plastic forming process and allows optimisation of die design and process parameters to improve the quality and cost-effectiveness of the manufacturing process. This business has over 80 per cent of the World market for plastic flow analysis, which is used at over 1000 plants World wide (Swinburne News, 1994).

Advanced polymer composites

Processing technologies for APCs involve three stages: (1) the impregnation of the fibre with resins; (2) the moulding of the materials; and (3) curing or 'crosslinking' to solidify the resin.

The processes used in Australia are similar to those used elsewhere in the World, but the volumes produced are much smaller. The main method used in Australia by most small plastic fabricators is open mould or hand lay-up, which accounts for 60 per cent of total output (sub. 14).

Laminating is also used and refers to reinforcing materials being impregnated with reins and pressed into a flat sheet (see Appendix B8).

APC manufacturers often use the labour intensive hand lay-up method of fabrication where automation has yet to be developed to speed up the process. Hand lay-up or open shell moulding is too slow to be appropriate for high volume low cost production methods. Consequently, the cost of processing these materials is the major barrier to their competing with metals in many applications, despite their superior performance characteristics.

Economies of scale

Although there is limited information on economies of scale in the production of advanced polymers and APCs, producers hold a general view that the size of the domestic market is too small in many cases to justify production in Australia. This seems to indicate that economies of scale are significant. Trans-nationals producing advanced polymer and APCs usually have several plants World wide, located near their major user industry markets.

Given the limited size of the Australian market and its varying demands, GE Plastics indicated that relative to its overseas facilities, the Australian plant had to be, and was, more flexible in terms of the variety of output it produces.

The small size of the Australian market has motivated many small to medium sized businesses, mostly users of advanced polymers and APCs to seek overseas markets, particularly in Asia, as the main source of future growth.

Access to technology

Major new product developments or improvements in resin processing technology generally occur offshore and are brought to Australia by the large, trans-nationals or by local firms purchasing overseas licences. Several businesses which participated in the case study obtained their technology by either of these two means. Product development in Australia is generally making refinements to existing products to adapt them to specific local conditions and demands.

Table B4.3 shows the source of technology for the businesses which participated in the case study. It points to most firms obtaining their innovations from their own research, but in most cases this is in adapting existing products rather than developing completely new polymers and composites.

Table B4.3: Source of technology of users and producers of advanced polymers, by firm size

	Parent Company	*Licence/ Purchase*	*Own Research*	*Joint Venture*
Large Firm[a]	7	3	6	1
Small Firm	-	1	5	-
Total	7	4	11	1

a Annual turnover of more than $15 million per year.
Source: Industry Commission.

A problem noted by some users of APCs, which indirectly relates to access to technology, was the difficulty they had experienced in obtaining advanced materials from overseas suppliers and the lack of information on recent technological developments. It was suggested that the agents of overseas companies were either unable or unwilling to fully inform Australian buyers.

A further problem was identified. It was that even if an Australian buyer was made aware of a technological development overseas, the Australian businesses would not necessarily have the expertise necessary to evaluate the development and make a decision on its applicability.

Research

Scientists interviewed for the case study indicated that the discovery of a new polymer in the near future was highly unlikely. Most research is likely to focus on the development of polymer alloys and APCs.

Most of the research and development which occurs in the Australian industry is directed at adapting overseas developments to local customer needs, although there are exceptions. Australians have been innovative in developing new applications for products, particularly the use of composites in the marine, sporting and recreation areas. Examples include the use of new polymer composites in surf boards and skis (sub. 14) and in fast ferries and catamarans.

While these were developed to meet Australian requirements (for example, fast trips to the Great Barrier Reef), the products have sales potential overseas.

Australia's particular climatic considerations have been the basis of many product developments. For example, BASF developed a weather-proof thermoplastic to cope with Australian climatic conditions when used for the plastic fuel tank in the Ford Falcon (Karpfen, 1988). Ciba-Geigy also developed a unique formulation of resins for the major power utilities in medium voltage, outdoor insulators.

The CRC for Polymer Blends focuses on the formation of polymer blends and alloys to meet pre-determined performance specifications. The aim is to identify and develop new compatibilising agents — chemicals used for mixing to produce materials with new properties. The project not only aims to develop new technologies for the design, manufacture and processing of polymer blends and alloys — but to also develop commercially attractive polymer blends and alloys (from olefin, styrene, vinyl and other polymeric base materials) and blends based upon recycled waste polymers.

As shown in Table B4.4, most case study participants had undertaken research and development activities, not necessarily all of which were on advanced polymers or APCs.

Table B4.4: Expenditure on R&D as a share of turnover of users and producers of advanced polymers, by firm size (per cent)

	0 to 5	*5 to 10*	*Over 10*	*Total*
Large Firm[a]	9	-	1	10
Small Firm	6	2	-	8
Total	15	2	1	18

a Annual turnover of more than $15 million per year.
Source: Industry Commission.

Somewhat surprisingly, Australian subsidiaries are not necessarily well informed of research developments in their parent or sister organisations overseas. This situation varies according to company policy. Several producers are aware of research developments in their overseas plants, whereas others are not.

Smaller businesses expressed a preference for relying on secrecy rather than patents to protect the results of their research and development activities, as illustrated in Table B4.5. This follows from a belief that if patented, innovations can be easily copied.

Table B4.5: Source of intellectual property of advanced polymer users and producers

	In-house Technology		*Purchased Patent*
	Patented	*Unpatented*	*or Licence*
Large Firms[a]	7	3	2
Small Firms	1	4	1
Total[b]	8	7	3

a Annual turnover of more than $15 million per year.
b Some firms have been counted more than once.
Source: Industry Commission.

The desire to maintain control of intellectual property is the main reason why some, mainly smaller businesses, do not involve themselves in co-operative research activities with outside organisations such as CSIRO and CRCs. SMEs who do not wish to become involved in CRC programs often have problems because intellectual property is tightly held by the original industry participants.

Basic research into the production and use of advanced polymers in Australia is mainly undertaken by government organisations such as CSIRO, universities and ANSTO. Development activities in advanced polymers include that of AMRL in using composites to repair and reinforce military aircraft structures, the work on packaging by CSIRO and that of the Intelligent Polymer Research Laboratory at the University of Wollongong.

AMRL has developed the use of fibre reinforced composites to repair or reinforce defective aircraft metallic structures. Special surface treatments have been developed to allow highly durable bonding of these repairs in situ on the aircraft. It is estimated that the development has saved the Department of Defence well over a $100 million, not including savings due to delaying the purchase of new aircraft. Because defence budgets overseas are being reduced and consequently defence forces are seeking cost savings to increase the service life of existing equipment, demand for this development may increase. Recent cuts in overseas military budgets may increase demand for this development as ways of reducing costs are sought. The development has been licensed to an Australian company, Helitech. This company has recently supplied the technology under contract to the US airforce to repair the wings of the Starlifter aircraft.

A research area of considerable interest is in what is known as ‘active packaging’. Active packaging absorbs, releases or selectively permeates gases to control the surrounding atmosphere. Most food products benefit from active packaging. An example is the development of a film for ANL to be used in packaging broccoli. An inert additive to alter the permeability of polyethylene was developed for this product.

Another innovative research area is in the development of compostible plastics. These are plastics formed from starch as opposed to petro-chemicals. The Department of Chemical Engineering, University of Queensland, is at the forefront of this work. The project has received a $1 million grant to develop the new starch-based plastics which could be used in packaging, utensils and containers in the food industry. Although these materials have been available for some time, the project aims to make starch-based plastics more competitive by improving their physical properties and substantially reducing their production costs.

At the theoretical end of polymer research is the work on so-called ‘intelligent polymers’. The goal of the work at the Intelligent Polymer Research Laboratory at the University of Wollongong is to develop materials that are able to monitor and respond to environmental stimuli. Possible applications include windows that change in response to changes in solar heat and ‘smart structures’ such as a crack-detecting helicopter rotor which ‘heals’ itself (sub. 17 and Brown, 1990). Research centres focussing on intelligent polymers have been established in the US, some of which are sponsored by ARPA (for aircraft applications). Research centres also operate in Japan and Scotland. Korea is also developing an interest in the area (sub. 17).

Business links

Where there is the necessity to tailor products to meet specific customer needs, good links exist between suppliers and the user industry. But there are not likely to be business links between producers. An exception is the automotive industry. Several smaller businesses have informal links with overseas contacts to keep abreast of international developments.

Larger businesses, particularly trans-nationals, are more likely to develop links with outside research organisations such as CSIRO, consider collaborative activities and are more willing to be involved with CRCs and universities. For example, ICI Australia is a member of the CRC for Polymer Blends where progress has been made in extending the range of use of the commodity polymers by novel alloying processes.

Because of the diversity of products and applications there is little vertical integration. However, given the number of intermediate processing steps between the material and final product it is not possible to generalise about the potential for vertical integration.

Government assistance

All businesses interviewed are aware of available government assistance and Table B4.6 below shows that advanced polymer and APC producers use most of the available forms of assistance. The R&D tax concession is used mostly by large firms, usually trans-national producers of advanced polymers and composites. Recipients of the R&D tax concession, GIRD and EMDG supported these programs.

Table B4.6: Types of Government assistance used by users and producers of advanced polymers

	R&D Tax Concession	*EMDG*	*NIES*	*GIRD*	*Other (PfD, EIIP, investment allowance)*
Large Firms[a]	6	4	-	1	3
Small Firms	2	3	2	5	3
Total[b]	8	7	2	6	6

a Annual turnover of more than $15 million per year.
b Some firms received several forms of assistance.
Source: Industry Commission.

B4.4 Demand conditions

Substitutability and performance–price trade-offs

Advanced polymers and APCs are able to be tailored in many different ways for a wide range of applications. To optimise cost and performance it is necessary to balance design and manufacturing considerations in addition to cost and performance issues. As environmental factors become more significant in materials selection, concepts such as design for the environment, disassembly, recycling and whole-of-life cost assessment are gaining acceptance, particularly in the US and Europe (University of Michigan Transportation Research Institute, 1994). It is likely that these concepts will flow through to the rest of the World.

In Australia, most engineering plastics are used in the automotive industry and have replaced steel over the past few decades in non-structural applications. The Ford Plastics Plant makes bumper bar facias and reinforcement beams, fuel tanks, instrument panels, crash pads, consoles, heater and air conditioning mouldings, and colour-keyed bodyside protection mouldings. The advantages are their light weight (which improves fuel efficiency) and corrosion resistance relative to steel. They also have improved thermal stability compared with commodity polymers.

User awareness and preferences

Lack of awareness by user industries and skills in materials selection are considered by material producers to be the major impediments to the uptake of advanced polymers and APCs. Many producers spend considerable time and other resources on educating users of the properties of advanced materials and appropriate materials selection.

On the other hand, user industries have their own reasons for the rate at which they adapt these materials. Some of the main user industries in Australia expressed concerns about potential failure of the material and consequent product recall. To the extent this is a concern, these industries would not use the new materials until they were satisfied with their performance.

In the case of the aerospace industry, the cost of obtaining material certification from Boeing or Airbus overseas is considered prohibitive given the size of businesses in Australia.

Clearly, the producer of a new material needs to demonstrate to potential purchasers its properties, and this can be an expensive exercise in its own right. To demonstrate the applications for advanced polymers and APCs in the building and construction industry, GE Plastics has spent US$10 million on a full-size demonstration house at Pittsfield, US. In this house the advanced materials are used for structural applications and fittings such as roofing, insulation, cladding and window frames (Murphy, 1994).

Significance as inputs

Among user industries in Australia, costs of materials do not tend to be a significant proportion of total costs, usually estimated to be between 10 per cent and 20 per cent of the costs of a final product. However, there is considerable variation depending on the end use. For example, in the biomedical field a highly priced product is likely to use a small amount of a relatively inexpensive material. Businesses such as Telectronics indicated that a greater proportion of value added is obtained from the design of the final product.

Growth trends and prospects

World demand for engineering polymers is forecast to increase to US$6.5 billion in the year 2002, up from an estimated US$3.2 billion in 1992 (New Materials International, 1994c).

In terms of weight, world consumption of engineering polymers is expected to increase by an average annual rate of 4.7 per cent per year to 17 million tonnes in 1997.

It is expected that the relative shares of thermoplastic and thermoset polymers will change, with the former's increasing due to advantages in processing, design freedom and recyclability.

The main growth markets for engineering plastics are expected to be electronics and the automotive industries. The appliance market is expected to increase its demand also. In the appliance sector, growth areas will be in compact discs and electronic components and housings which rely on the insulating properties of the advanced materials. The automotive sector will remain the largest user, with growth expected in bumpers, exterior body panels and interior components. Nylon and polycarbonate (PC) will be the major resins and advancements in nylon grades will occur. PC demand is expected to grow in the construction industry, particularly for glazing and skylights (Plastics News International, 1993).

Consumer preference for greater fuel economy and environmental concerns are expected to lead to an increase in the use of engineering plastics and composites in cars. However, given improvements in the strength to weight ratio of steel, current projections for substitution by polymers may be overstated, as have some past projections (University of Michigan Transportation Research Institute, 1994).

The consumer demand for miniaturisation in electronic devices, such as microcomputers and cellular phones, is expected to increase the demand for engineering polymers (High Performance Plastics, 1994a). Consumer products, such as cameras, are now expected to possess excellent mechanical properties and durability, resulting in increased demands for advanced polymers and APCs (Jackson, 1994). Hoechst is targeting blends of PC and ABS for the electronic and computer parts industries where their stiffness, impact resistance and dimensional stability makes them ideal for large, complex and structural components (Materials Edge, 1994a).

The reduction in global military tensions is expected to reduced the use of APCs (Reinhart, 1992). On the other hand, the building and construction industry is possibly a large future market for APCs given their corrosion resistance and high strength to weight ratios. The UK government is currently sponsoring a project known as ROBUST (stRengthening Of Bridges Using polymeric compoSite maTerials) to investigate the use of prepreg carbon and glass fibre APCs in bridge construction. These may replace steel plates which are bonded to the underside of concrete beams. This will also test a belief that replacing traditional steel and concrete with strong, light-weight APCs could cut construction costs dramatically (Peshkam, 1994). Maunsell Structural Plastics have constructed a bridge made of composites across the River Tay in Scotland (transcript, p. 90).

Influence of government regulation

Various types of government regulations influence the demand for advanced polymers and APCs.

Changes to environmental legislation, particularly related to fuel efficiency in automobiles, may increase the demand for advanced polymers. Automotive manufacturers will aim to reduce the weight of cars and use light-weight structural materials such as APCs and polymers to replace metal. However, environmental legislation aimed at increased recyclability may reduce the demand for these materials unless technological developments occur to increase their recyclability (High Performance Plastics, 1994a).

Building standards may also affect the use of advanced polymers and APCs. Standards are often established around the characteristics of traditional materials such as steel, timber and cement. They can be written in such as way as to make it difficult for plastics to meet these specifications, regardless of the performance requirements. Gaining approval for new polymer materials to be used in the building industry can be a lengthy and costly process. On the other hand, changes in building standards may accelerate the use of advanced materials. Several users noted that safely requirements regarding fire retardant materials are becoming more stringent and this should encourage the use of advanced polymers and APCs, despite their higher up front cost relative to traditional materials.

B4.5 Markets

Nature and operation

Given the diversity of available advanced polymers and APCs, not all producers supply all of them but rather specialise. Therefore, for any particular kind of material, the number of potential suppliers may be limited. Firms supplying these materials tend to be large, as most are subsidiaries of trans-nationals. Most of the products are imported with some refinement of these materials to meet specific customer needs.

Final users include the automotive, telecommunications, electronic, appliance, recreation and transport industries (marine, rail and bus manufacturers). The automotive, appliance and telecommunications sectors are characterised by a small number of relatively large firms in Australia. Government owned enterprises are also final users given their involvement in the transport and telecommunications sectors.

Import competition

All resins used in advanced polymers and APCs are imported with production in Australia being limited to compounding (mixing these resins with additives and fillers). All carbon fibre prepregs are imported. A few producers of APCs exist in Australia. A small number of small-scale producers who specialise in modifying commodity polymers to meet customer requirements exist. These firms continuously develop new grades of these polymers to meet market needs. It has been suggested that considerable potential exists for more import substitution in this area.

Imports of all categories of polymers have increased in terms of both volume and value over the last six years. In terms of value, commodity polymers experienced the greatest average annual increase in imports over the period (18.5 per cent), closely followed by engineering polymers (18 per cent) and high performance polymers (16.8 per cent). The average unit value of all categories declined over this period.

Table B4.7 presents information on value and volume of imports.

Table B4.7: Value and weight of imports, 1987–88, 1992–93

Polymer	*Value*		*Weight*	
	1987–88	1992–93 *($ million)*	*1987–88*	1992–93 *(kilotonnes)*
Commodity				
polyvinyl chloride (PVC)	15.5	25.1	19.8	26.8
linear low density polyethylene (LLDP)	17.7	47.1	14.8	45.4
high density polyethylene (HDPE)	15.8	31.8	11.1	29.8
polypropylene (PP)	2.6	10.3	1.4	9.2
polystyrene (PS)	4.4	11.6	1.0	7.8
epoxy	8.7	14.6	2.6	4.8
unsaturated polyesters	0	7.5	0	4.4
amino resins	1.2	4.4	0.7	1.5
acrylic	15.1	60.7	5.6	19.8
cellulosics	10.6	32.3	2.6	6.8
polymethylmethacrylate	2.3	11.0	0.6	4.4
phenolic	0	6.4	0	2.3
Total	94.4	260.9	51.3	161.4
Engineering				
acrylonitrile-butadiene-styrene (ABS)	4.7	8.5	1.9	4.7
polyacetal (PA)	2.9	7.4	0.6	2.4
polycarbonates (PC)	12.0	24.9	4.1	4.0
polyamides (nylons)	32.7	55.8	na	12.9
polyethylene terephthalate (PET)	6.9	59.5	na	32.4
polybutylene terephthalate (PBT)	5.2	8.4	na	2.1
polyether block amides	0	7.0	0	1.9
poly-(4-methylpent-1-ene) TPX	*2.5*	9.3	0.8	4.4
Total	66.8	180.7	6.4	62.7
High Performance				
PPS, polyamide, PEI, PEEK	5.6	17.8	1.0	4.2
polytetrafluroethylene (PTFE) (flouroplastic)	1.2	4.8	0.1	0.2
PFA, PVF, PVDF, ECTFE	.7	4.2	0.1	0.2
liquid crystal polymers (LCP)	9.5	18.5	na	4.2
Total	17.0	44.2	1.2	7.7
Composites				
urethane - glass filled	5.7	14.5	1.3	2.0
TOTAL	184.9	498.3	60.2	234.8

na: Not available.
Note: Totals may not add due to rounding.
Source: ABS cat. no. 5464.0.

Export opportunities

Exports comprise a larger proportion of total turnover for small businesses which participated in the case study than for larger participants (see Table B4.8). When large trans-nationals export it is usually because they are exporting as agreed with the parent company to meet a planned globalisation strategy. The producers and users surveyed are exporting mostly to Asia, India and New Zealand.

Table B4.8: Exports as a proportion of turnover, (per cent)

	0 to 10	*10 to 20*	*over 20*
Users	2	2	6
Producers	7	1	3
Total	9	3	9

Source: Industry Commission.

Pricing behaviour

Producers supplying the domestic market not only compete on price but also on quality and speed of delivery (particularly against imports). User industries prefer domestic suppliers, not only because of responsiveness in terms of delivery performance, but also because they found it easier to interact in the development of tailor-made materials.

B4.6 Competitiveness of Australian producer and user industries

Competitive advantages

The small size of the Australian market relative to the world market and its relatively large distance from major markets provide advantages for small producers or distributors who are able to compete in terms of speed and responsiveness to domestic market needs, as well as on price.

Among Australian producers of advanced polymers and APCs, local manufacturers sometimes have an advantage over imports in terms of their greater ability to quickly respond to changes in demand given the need to tailor-make the polymers. Sometimes a price premium is able to be charged for this service.

Australia is considered by some trans-national producers of advanced polymers to have a cost advantage in terms of skilled, technical labour relative to its Asian neighbours. Several trans-nationals have located their technical services for the Asia-Pacific Region in Australia for this reason.

Competitive disadvantages

Reasons for the limited production of these advanced polymers and APCs in Australia are the diseconomies of scale in producing for a relatively small market and the distance to major export markets. In addition, there is reported to be a limited skills base in Australia.

B4.7 Value adding

Value may be added to advanced materials by adapting these materials to local climatic conditions and other customer requirements. As these materials are costly relative to traditional materials, they are usually used if specified by the particular client, or if no substitute is available to produce the item (such as for biomedical equipment). Given the interdependence of design, manufacture and processing with materials selection, it is difficult to assign a measure of added value to the use of a particular material.

B4.8 Potential for further production and use

The potential for further production of APCs is likely to be limited to those which have a reasonable level of demand in Australia, that is, advanced polymers and APCs which are likely to be used by the automotive, appliance and telecommunications industries. Given the limited demand from the aircraft and military sectors in Australia relative to other countries, growth in Australian demand will therefore tend to be greater for engineering polymers than high performance polymers and APCs.

As the global market for producers is characterised by a relatively limited number of large trans-nationals, Australian production is likely to be limited to producers operating in small (niche) markets.

B5 RARE EARTHS

Rare earths is a collective term used to describe a group of seventeen chemically similar elements. The name rare earths is misleading as the elements are readily available. They include the lanthanides plus yttrium and scandium. They are generally classified into light, heavy and medium (see Table B5.1).

In metallic form, rare earths range from iron grey to silvery lustrous appearance; they are typically soft, malleable and ductile, and are usually reactive, especially at elevated temperatures or when finely divided. The elements do not occur naturally as metallic elements, but rather their strong affinity for oxygen causes them to form mainly as oxides. Their reactivity and chemical similarity makes it difficult to separate the rare earths to a pure form.

B5.1 History of use

The rare earths industry effectively began in 1883 with the development of the incandescent gas mantle incorporating 1 per cent ceria (CeO_2) and 99 per cent thoria (ThO_2). In the early 1900s, mischmetal, an alloy of rare earth elements, was the major ingredient in lighter flints, and by the late 1940s, rare earth elements were used in the production of ductile iron, to improve its rolling and physical properties (Jackson and Christiansen, 1993).

Developments in separation technology paved the way for new and more advanced applications of rare earths. In 1947, the first separation of adjacent trivalent rare earths was achieved using ion exchange.[1] This was followed in 1953 by the successful use of solvent extraction.[2]

Rare earth cracking catalysts were developed in 1962, and in 1964, europium was first used in colour televisions.[3] In 1966 and 1967, high strength rare earth

1 Ion exchange is a separation technique which involves the reversible interchange of ions between a solid and a liquid in which there is no permanent change in the structure of the solid.

2 Solvent extraction is a separation technique which takes advantage of the different affinities of the various rare earth elements for liquid solvents.

3 Catalysts are used mainly in the petroleum and auto industries. In oil refining, catalysts are used to increase the yield of gasoline extracted from heavier oil fractions by a process called cracking. Colour for television sets and computers is made possible through the use of a europium–yttrium compound for red, a terbium–fluoride–zinc–sulfide for green and a cerium–strontium–sulfide for blue.

permanent magnets made from yttrium or samarium combined with cobalt were developed.

Table B5.1: Rare earth elements

Type	*Element*	*Symbol*	*Atomic No.*
Light	Lanthanum	La	57
	Cerium	Ce	58
	Praseodymium	Pr	59
	Neodymium	Nd	60
	Promethiuma	Pm	61
Medium	Samarium	Sm	62
	Europium	Eu	63
	Gadolinium	Gd	64
Heavy	Terbium	Tb	65
	Dysprosium	Dy	66
	Holmium	Ho	67
	Erbium	Er	68
	Thulium	Tm	69
	Ytterbium	0	70
	Lutetium	Lu	71
	Yttrium	Y	39
	Scandium	Sc	21

Source: Periodic Table.

In 1970, unique hydrogen absorbing properties were discovered in a lanthanum nickel compound and the first amorphorous rare earth alloys were made. In 1972, rare earth phosphors were used in fluorescent lighting.[4] In 1976, French scientists developed lanthanum nickel hydride batteries. By 1991, Japan was producing 500 batteries a month, and now produces about 7 million per month. High strength permanent neodymium-iron-boron magnets were first made in 1981.

Prior to the 1960s, the chemical properties of the materials were exploited, with uses including lighter flints, alloy additives and in glass. Between the 1960s and 1980s, the unique physical behaviour of the rare earths were exploited in phosphors and magnets, these applications requiring high degrees of purity. Further developments in areas such as magnets and high efficiency electric lamps continue to be made.

4 A phosphor is a substance which is capable of storing energy and releasing it later as light.

B5.2 Rare earth extraction and contemporary uses

The rare earths are constituents in more than 100 minerals, but only a few are recovered for commercial production. Current known reserves of rare earths in the World are estimated to be between 60 million and 70 million tonnes (Kingsnorth, 1993). High purity rare earth metals are sold in the form of sponge, lump, ingot, crystal, rod, wire, chips, powder, sheet, foil, plate, custom cast and machined shapes. Alloys such as mischmetal, rare earth silicide, and ferrocerium, are available in a variety of shapes and sizes. Rare earth magnet alloys are produced to individual requirements and are sold in ingot form, as crushed ribbon, or as mixed oxides for powder metallurgical processes. Magnets are available in a variety of ingot shapes and sizes, in finished and semi-finished shapes, magnetised and unmagnetised.

Extraction

Bastnaesite, monazite, xenotime, and rare-earth bearing clay are the major sources of rare earths. Other mineral sources include loparite, uraniferous phoshorites, synchtisite and by-product solutions from processing uranium (US Bureau of Mines, 1992). Bastnaesite is the World's major source of rare earths, and accounts for 62 per cent of World output of rare earths (Gupta and Krishnamurthy, 1992).

Bastnaesite is typically rich in the light rare earth elements. It is predominantly mined in the US (California) and China. Monazite occurs as an accessory mineral in granitic and metamorphic rocks, pegmatites, vein deposits, in placer deposits and in carbonatites.[5]

Monazite and xenotime are mined as a by-product of ilmenite, rutile, zircon and tin mining. The joint-product nature of many of the rare earths explains the significant divergence between the quantities of rare earths produced and consumed (see section B5.3).

Also due to this jointness, the availability of placer monazite is linked to the demand for ilmenite and rutile. Significant placer deposits have been found in Australia, Brazil, Malaysia, Thailand and the United States. Considerable quantities of monazite have been produced as a by-product of beach sand mining in Australia since the Second World War.

Carbonatite monazite has been found in Brazil, China and Mount Weld in Western Australia. The minerals at the Western Mining Copper–Uranium mine

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5 A placer deposit is a superficial gravel or similar deposit. Pegmatites are rocks of well-crystallised minerals and ores.

at Roxby Downs also contain significant quantities of rare earths. Table B5.2 shows the major rare earth minerals and their theoretical rare earth content, and the major rare earth present.

Table B5.2: Rare earth minerals

Mineral	*Type*	*Major rare earth present*	*Rare earth oxide (max. percentage)*
Bastnaesite	Flourocarbonate	Cerium	74.81
Monazite	Phosphate	Balanced	69.73
Xenotime	Phosphate	Yttrium	61.40

Source: Based on US Bureau of Mines, 1992.

The relative proportions of light and heavy rare earth elements varies with the mineral type. For instance, bastnaesite has a higher proliferation of light elements, xenotime is high in the heavier elements but also contains a high proportion of yttrium, and monazite is more balanced.

The grade of purity of a particular rare earth is a factor in determining its price. The cost of separation increases as greater purity is sought. Low value rare earths are either unseparated or have been through only simple chemical separation.

Uses

The end uses for rare earths generally fall under two categories: those using mixed rare earths (either naturally occurring mixtures or mixtures enriched with respect to a particular rare earth with the needed properties), and those containing a rare earth in various levels of purity. Rare earth consumption in mixed form accounts for about 95 per cent of the total rare earths consumed on a volume basis, but only 50 per cent of total consumption in value terms. In contrast, the separated rare earths, which account for only 5 per cent in terms of volume, represent 50 per cent of the financial value of total rare earth consumption (Gupta and Krishnamurthy, 1992).

Rare earths are used in the petroleum refining industry (largely as catalysts), as alloying agents (used to enhance the oxidation resistance of alloys) in metallurgical processes, in glass, phosphors, optics, permanent magnets, polishing compounds and electronics.

Emerging and potential applications include using rare earths to absorb ultra violet light in automotive glass, corrosion protection, and metal coatings in corrosive and salt environments. These applications employ a range of products from mixed rare earth compounds and alloys to ultra high-purity individual metals and compounds. Table B5.3 provides an indication of the uses for individual rare earths.

Table B5.3: Applications of rare earths

Industry	*Technical application*	*Product*	*Rare earths used*
Optics	Phosphors	Colour television, fluorescent lamps and X-ray screens	Europium, Yttrium and Terbium
	High refractive glass	Video camera lens and photocopiers	
	Lasers	Medical technology	
Magnetics	Permanent magnets	Headphones, loudspeakers, computer disk drives, video recorders and electric motors	Neodymium, Samarium and Dysprosium
Electronics	Capacitors	Computers	Samarium, Europium, Gadolinium,
	Bubble memory systems	Computers	Terbium, Holmium, Dysprosium Erbium, Thulium,
	Magneto-optical recording	Data storage	Ytterbium, Lutetium, Yttrium and Scandium
Ceramics	Oxygen sensors	Auto emission control	Terbium, Holmium,
	Hard-wearing, temperature-resistant materials (zirconia, silicon nitride)	Piston linings, engine valve parts and machine tool cutting edges	Dysprosium, Erbium, Thulium, Ytterbium, Lutetium, Yttrium and Scandium
	High temperature conductivity (super conductors)	Computers	
Glass	Decolourising	High-quality glasses	Cerium
	Polishing	Television screen glass	Cerium
Metallurgy	Deoxidation, Desulphurisation	Steel	Lanthanum, Cerium, Praseodymium Neodymium,
	Pyrophoric properties	Flints	Promethium
	Alloys	Aircraft parts	
Catalysts	Oil refining catalysts	Petrol	Lanthanum, Cerium, Praseodymium Neodymium,
	Catalytic converters	Emission control systems	Promethium

Source: Adapted from Kingsnorth, 1991.

B5.3 Producers, users and their activities

World production

In 1989, total rare earth production was 67 000 tonnes; production capacity currently exceeds demand (Jackson and Christiansen, 1993).

There are about 66 rare earth processing plants in the World — 24 in China, 16 in Japan, 13 in the US, and several in the CIS (Jackson and Christiansen, 1993). However, the World market is dominated by the French company Rhone Poulenc, Molycorp in the United States, CIS producers, and a number of small size producers in China.

Europe

Rhone Poulenc is a major producer of highly processed, purified and therefore high value rare earth products. The firm has to import all its raw materials as it has no local source of rare earth minerals. In the past, Rhone Poulenc relied heavily upon by-product monazite from the Australian mineral sands industry as its major source of raw material. Due to the relatively high level of thorium oxide in this feedstock, which results in radioactivity, the company is now importing its raw materials in the form of rare earth chlorides from China and India. These materials have been processed to be free of the radioactive wastes. The company has two plants, La Rochelle on the French Atlantic coast and Freeport in Texas. The company was involved in a joint venture with Sumitomo Metal Mining Company (called Nippon Rare Earths) to operate a small processing plant in Japan. The joint venture recently ended, but Rhone Poulenc will continue to have a presence in Japan.

Other significant European producers include Megan of Norway producing ultra high purity yttrium oxide, Treibacher of Austria producing mainly mischmetal, and London & Scandinavian Metallurgical Co Ltd of the United Kingdom, producing mainly polishing powders. The CIS is also a major producer.

United States

Molycorp is the only major fully integrated rare earths producer in the Western World. Molycorp produces and markets bastnaesite concentrates, intermediate rare earth products (low value, bulk mixed rare earths) and a range of high purity rare earth compounds. It extracts a selection of rare earths from bastnaesite mined at Mountain Pass in California. Molycorp is the largest producer by volume in the World.

China

China has devoted significant resources to becoming a major rare earth producer, currently supplying 60 per cent of the World's rare earths in the form of concentrates and rare earth chemicals.

There are over 20 separate deposits in China, the major resource being the bastnaesite deposit at Baotou which is a source of light, medium, and heavy rare earths. In the 1980s, China developed its ionic clay deposits. These deposits are characterised by a low cerium content and a high yttrium content. The comparatively low grade of the ores is offset by easier mining and processability. The presence of radioactive elements in the ionic clays is also very low. China has become the major supplier to Rhone Poulenc of rare earth concentrates, replacing the previous main source of monazite which was Australia.

Australia

Throughout the 1980s, Australia was one of the World's largest producers of monazite. Monazite exports are being phased out primarily because environmental regulations overseas no longer make it viable to export unprocessed monazite without first having extracted the radioactive waste associated with its processing. Although Australia has been a large producer of the primary mineral, there has been limited involvement in the processing of rare earths. Recently, there have been attempts to establish a rare earths processing industry in Australia.

Ashton Mining has for a number of years been working to develop its Mt Weld (WA) rare earth deposit. The project has the potential to supply 10 per cent of the World's demand for rare earths for more than 30 years. The project is based on a monazite deposit, which is fairly high in cerium, neodymium, and europium, but low in thorium and uranium.

The technology for its primary processing has been developed in conjunction with AMDEL Ltd and ANSTO, with the latter helping to develop its secondary processing technology and with the construction of a pilot plant at Lucas Heights. In November 1992, Ashton Mining received environmental approval from the WA Minister of the Environment. Since receiving this approval, Ashton Mining has decided to concentrate on processing cerium from the Mt Weld site instead of processing a range of rare earths. The project has been suspended and Ashton Mining has contracted CSIRO to redesign its primary processing stage with the objective of reducing some of its production costs. Ashton Mining expects that if it is successful in going into production, it will export at least 95 per cent of its cerium output. Ashton Mining aims to eventually expand the project to produce a wider range of the rare earths.

The company SX Holdings has received approval to establish a rare earth processing facility at Port Pirie in South Australia. It plans to be involved in areas of downstream manufacturing in which rare earths are utilised; for example permanent magnets, magnetostrictive alloys and corrosion protection. The project has received approval from the South Australian Minister for the Environment, and SX Holdings is currently attempting to raise finance in order to allow the project to move to the next stage, which is the construction of a processing plant.

In the past there have been other attempts at establishing a rare earths processing industry in Australia. In 1988, Rhone Poulenc wanted to establish a rare earth and gallium plant at Pinjarra in WA to treat 15 000 metric tonnes of monazite per year. The WA government did not approve the company's plan for disposal of ammonium nitrate, thorium and radium waste products.

Currumbin minerals attempted to develop a rare earths processing plant at Lismore, Northern NSW in the 1980s. The initial feed to the plant was to be from stockpiled monazite. The NSW Government required that the project be subject to a Commission of Inquiry and subsequently the project was not approved primarily because of the adverse environmental consequences associated with the disposal of radioactive byproducts.

A rare earth processing facility operated at Port Pirie in South Australia in the early 1970s. A range of mixed and purified rare earths were produced. Production and marketing problems caused the operation to be placed into receivership and then closed in 1975.

Users

Total World demand for rare earths in 1990 is estimated at 35 000 tonnes with an approximate value of US$400 million (Kingsnorth, 1992). The US, China and Japan are the major consumers of rare earths (refer to Table B5.4).

The difference between the 67 000 tonnes of rare earths produced and the 35 000 tonnes sold, is that some is lost in the process of refining and not all production of rare earths is sold, some is stockpiled (sub. 44).

China

In 1990, consumption in China represented about 19 per cent of World demand. The pattern of consumption in China differs from the rest of the World. The major use in China is in metallurgical applications, which accounts for about 51 per cent, compared with about 19 per cent in the Western World. Catalysts are the second largest use, accounting for about 29 per cent (24 per cent in the

Western World). In comparison, rare earth use in the glass industry, which is one of the largest users in the Western World (about 26 per cent) accounts for only 5 per cent of Chinese consumption. Chinese applications include using rare earths as desulphurising agents in foundries, in fertilisers for the agricultural industry and in the textile industry, where rare earth compounds are used in dye chemicals, accounting for the high value under the category 'other' in Table B5.4.

Table B5.4: World rare earth usage by country, 1990 (tonnes)

Application	*North America*	*China*	*Europe*	*Japan*	*Others*	*Total*
Catalysts	3 800	1 900	3 120	490	905	10 215
Glass	2 050	300	2 020	2 690	2 370	9 430
Metallurgical	1 100	3 380	660	210	4 630	9 980
Magnets	400	120	190	950	100	1 760
Ceramics	310	100	420	850	70	1 750
Phosphors	150	250	290	270	140	1 100
Other	70	550	70	50	25	765
Total	7 880	6 600	6 770	5 510	8 240	35 000

Source: Kingsnorth, 1992.

Western World

The major user of rare earths in 1990 was the US consuming a total of 7880 tonnes of rare earths. The major users of rare earths in the US were in the catalyst (48.2 per cent of total consumption) and glass (26 per cent) sectors. In 1990, Europe consumed a total of 6770 tonnes of rare earths, with the major areas of consumption again being in the catalyst (46.1 per cent) and glass (30 per cent) sectors. Japan consumed a total of 5510 tonnes of rare earths in 1990, with the major areas of consumption being in the glass (49 per cent) and the magnet (17.2 per cent) sectors.

Australia

Australia does not have a significant rare earths user industry, because Australia is not a significant producer of the types of products incorporating rare earths, for example televisions and permanent magnets. However, some use is made of rare earths. For example, Australian Magnet Technology (AMT), located near Newcastle, is currently producing permanent rare earth magnets under licence from General Motors. SEMCOR, a research and development consortium located in Sydney, has been successful in developing new-generation electric motors incorporating rare earth permanent magnets. Motors have been developed for Bardark Solar Power Pty Ltd and Filmlab Engineering Pty Ltd.

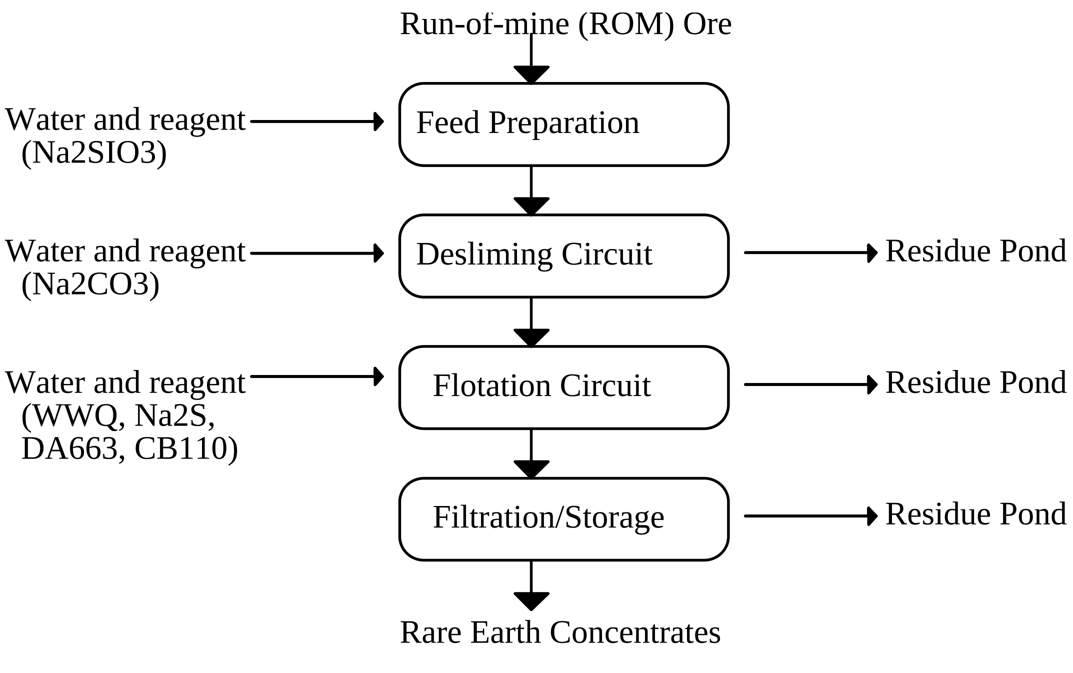
B5.4 Supply conditions

Production technologies

The ores containing the rare earth elements go through two stages of processing — beneficiation and refinement. Generally, beneficiation involves the crushing and grinding of ore, followed by desliming, conditioning, flotation and filtration. The resulting concentrates are then sold directly to processors or, to a lesser extent, are sold to brokers for resale.

Figure B5.1 provides an example of a beneficiation process flowsheet for monazite.

Figure B5.1: Beneficiation process flowsheet



Notes: Na_2SiO_3 represents sodium silicate.
Na_2CO_3 represents sodium carbonate, also known as soda ash.
Na_2S represents sodium sulphide.
WWQ is a high quality wheat starch.
DA663 is an acrylic polymer.
CB110 is a blended type of collector.

Source: Kinhill Engineers, 1992.

Rare earth concentrates undergo extensive processing to produce mixed or separated compounds. The major processes used in separating rare earths are precipitation, solvent extraction and ion exchange.

Figure B5.2 represents the processing options for the major mineral concentrates. In the case of bastnaesite, Molycorp roasts the concentrate to remove carbon dioxide and hydrogen fluoride. The Batou process relies on sulphuric acid digestion to remove fluoride and carbon dioxide. In both processes purification occurs in a chloride solution. In the Molycorp process, cerium is separated from the other rare earths during hydrochloric acid leaching (HCL).

The phosphates in monazite and xenotime minerals are resistant to mild chemical attack but can be dissolved in strong hot acids and alkalis. In the acid route, the rare earths are separated by precipitating the double sulphate. The rare earth sulphates are then converted to hydroxide form prior to further treatment. In the alkali route the concentrate is treated with caustic soda and this keeps the rare earths in the solid phase as hydroxides. The rare earth hydroxides can then be leached with acid, either HCL or nitric acid (HNO_3), and separated by solvent extraction.

The higher-value rare earth products are those made of well-separated and purer forms of rare earth elements. The purity required increases the cost, but it also allows the special physical properties to be used. Low value rare earth products are either unseparated, or have been through simple chemical separation only.

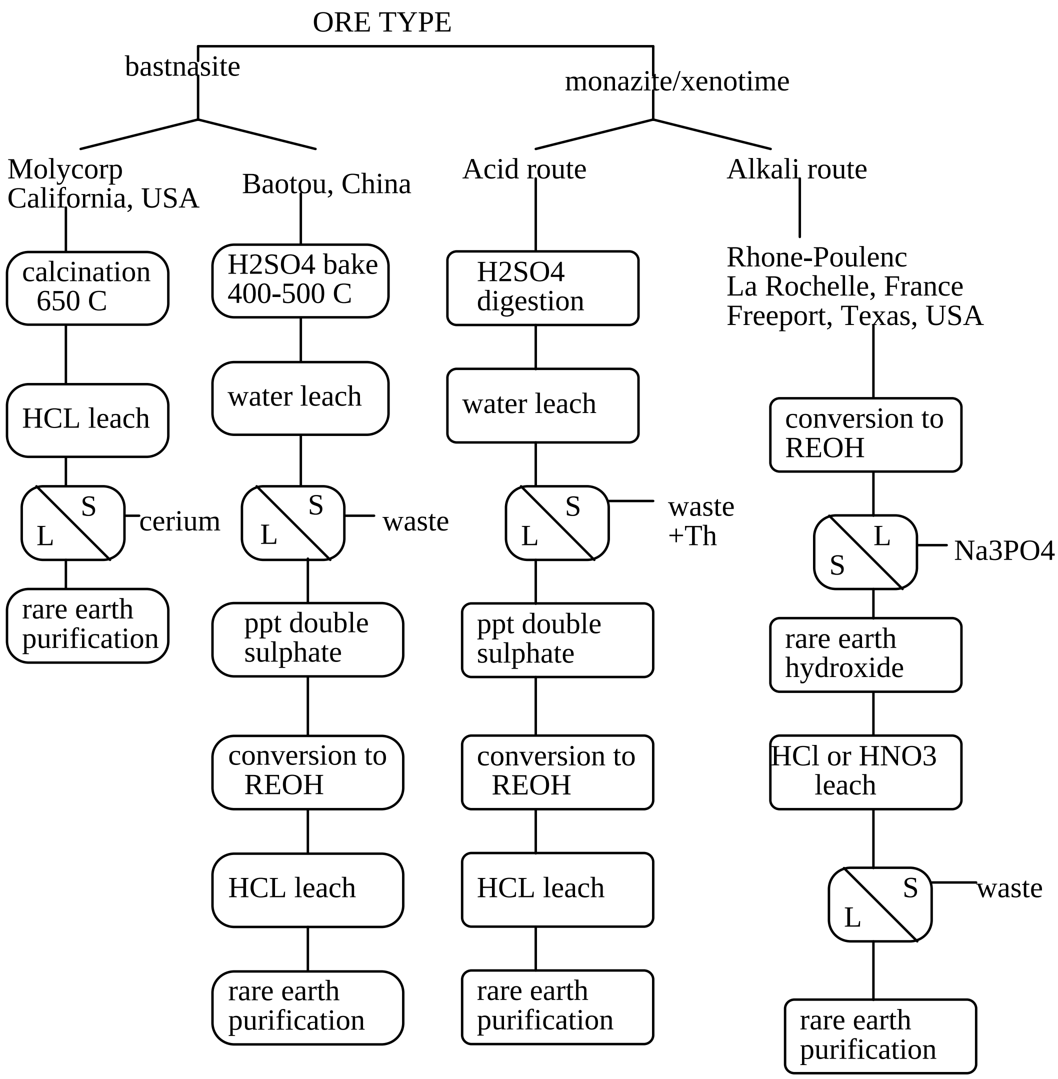
It is necessary for rare earth processors to strike a balance between the production of a particular element or compound to meet demand and the minimisation of stockpiles of rare earth elements not in high demand. Stockpiling can impose a cost particularly if it is required for a considerable time.

The nature of wastes from rare earth processing depends on the ore mineralogy and the process used. The most important distinction between processing monazite and bastnaesite is that the monazite contains thorium and uranium whereas bastnaesite does not. The other chemical wastes generated by rare earth processing are similar to those from other small chemical plants and are not of the same level of concern.

Australian monazite usually contains about 4 to 8 per cent by weight thorium and 0.1 to 0.3 per cent by weight uranium (Hart and Levins 1988). The main solid waste from monazite processing is a sludge which contains the same quantities of uranium and thorium as the monazite, but in about one-tenth of the mass. These must either be disposed of, or stored, indefinitely. Australia does not currently have a long-term radioactive waste repository. There are plans to develop a site for a national repository for the disposal of low level radioactive wastes.

The Mt Weld ore has relatively low levels of both thorium and uranium (approximately one fiftieth lower than beach sand monazite), and consequently does not face the same waste storage or disposal problems. The level of radioactive waste associated with the project is sufficiently low that it can be returned to the mine site.

Figure B5.2: Processing options for major concentrates



Notes: HCL represents hydrochloric acid.
H_2SO_4 represents hydrogen sulphate.
NA_3PO_4 represents sodium phosphate.

Source: Ring et al, 1993.

Access to technology

Different separation methods are used depending on the feedstock mineral concentrate being used. Although the general process may be the same, the choice of solvents, for example, can differ from mineral to mineral (refer to Figure B5.2).

In the past, access to the appropriate processing know-how has been important, and was well guarded by established rare earth processors. For example, Hart and Levins state that:

> Details of the solvent extraction flowsheets and even the solvents themselves are usually regarded as proprietary information by rare earth processors (1988).

On the other hand, it would be possible for new entrants to purchase technology from China and the CIS.

B5.5 Demand conditions

The demand for rare earth elements is a derived demand; it depends on there being some downstream use or application requiring the rare earths as inputs. Increases in the demand for rare earths are therefore driven by the range of factors that increases the demand for end use goods (such as television sets, radios and computers) and these include population growth, increases in income and the prices of the goods in question. Furthermore, new products and new applications using rare earths will increase the demand for the materials.

The amount of rare earths used in every day products is very small. For example:

- only 2 to 3 grams of rare earth powders are used in a 20 watt phosphor lamp;
- the average consumption of cerium oxide per autocatalyst in Europe and Asia is 70 to 80 grams and 80 to 100 grams in the US; and
- a 48 cm television screen contains 5 grams of yttrium oxide and 0.5 grams of europium oxide.

Although used in small amounts some of the rare earths can be a quite costly input, especially at high levels of purity (refer to Table B5.5). The price of rare earths can vary significantly with purity. For example, neodymium at 96 per cent purity is worth US$6.75 per pound whereas that of 99.99 per cent purity is worth US$40 per pound.

Table B5.5: Molycorp rare earth prices, June 1992

Product (oxide)	*Purity (per cent)*	*Price (US$ per pound)*
Cerium	99.00	10.50
Dysprosium	96.00	60.00
Erbium	98.00	65.00
Europium	99.99	450.00
Gadolinium	99.99	65.00
Lanthanum	99.99	8.75
Neodymium	96.00	6.75
Neodymium	99.90	40.00
Praseodymium	96.00	16.80
Samarium	96.00	30.00
Terbium	99.90	375.00
Yttrium	99.99	52.50

Source: US Bureau of Mines, 1992.

A significant area of growth in the demand for rare earths has come from the permanent magnet market. Rare earth permanent magnets (such as neodymium-boron-iron and samarium-cobalt magnets) have begun to displace conventional permanent magnets (such as those based on aluminium-nickel-cobalt ores). The high performance exhibited by rare earth permanent magnets has allowed the production of smaller and hence lighter and more efficient motors, used in such products as video recorders and personal computers. For a more detailed discussion of rare earth permanent magnets refer, to Attachment B5.1.

As new applications are developed, there is increasing scope for rare earth products to substitute for other materials. For example, there is scope for increased substitution of rare earths for toxic materials, such as chromates, zinc, cadmium and nitrates in corrosion protection coatings. The corrosion resistance of rare earth coatings approaches that of chromates in some applications.

Growth trends and prospects

World demand for rare earths is forecast to grow at a rate of 5.5 per cent per annum to between 50 000 and 70 000 tonnes per annum by the year 2000 with a total value of between US$1 and US$1.2 billion. The demand for high purity rare earths is expected to increase by 15 per cent per annum, while the demand for low purity rare earths is expected to grow between 2 and 4 per cent per year (Kingsnorth, 1992).

The environmental impact statement for the Mt Weld project (1992), identified a number of applications of rare earths that are expected to experience rapid growth:

- The development of cerium-doped solar protection glass (which reduces the transmission of ultra-violet rays, and which in turn reduces the need for air-conditioning and ultra-violet plastic stabilisers) is expected to increase the demand for cerium by 400 per cent before the year 2000. This has the potential to double again if it is applied to architectural glass.
- The demand for consumer electronic goods, computer applications, and light weight electric motors is expected to maintain the increasing demand for neodymium, samarium and dysprosium used in rare earth permanent magnets. Production of Neodymium used in Nd-Fe-B magnets is forecast to increase by 20 to 30 per cent per annum over the remainder of this decade.
- The demand for trichromatic phosphors used in fluorescent lamps, containing yttrium, europium, and terbium, is forecast to grow by more than 10 per cent in the short- to medium-term.
- The development of a new rechargeable battery based on the hydrogen storage capacity of lanthanum-nickel-hydride is forecast to absorb much of the current surplus lanthanum production.

The catalyst industry is a major outlet for the cheaper light rare earths and low purity rare earth compounds. The amounts of rare earths used in petroleum processing catalysts is decreasing, but the demand for pollution control catalysts has increased substantially.

At present, some of the rare earths are in oversupply, while others are under supplied or in balance. Users are showing an increasing preference for the higher purity rare earth compounds over the more common mixed compounds (US Bureau of Mines, 1993) and, consequently, the market for unseparated impure low value rare earths is not growing.

Kingsnorth (1993) provides forecasts in the growth of World demand and supply of rare earths (refer to Table B5.6). Kingsnorth has the Australian producer, Ashton Mining (Mt Weld) entering the market in 1996. He believes this opportunity exists as demand is forecast to increase. As noted before, Ashton Mining has plans to concentrate on producing cerium, mainly for export. This firm does not believe that the Chinese, who are major producers of cerium, will be in a strong position to take advantage of growing World demand, rather the Chinese will need to meet the demands of their own growing cathode ray tube market. Ashton Mining believe that the dominance of Chinese producers may open the door for other producers, even though the market is in a state of oversupply, as users may want to ensure a diversity of supply.

Table B5.6: Forecast growth in World production of rare earths

	1992 (tonnes)	1992 (per cent)	1996 (tonnes)	1996 (per cent)	2000 (tonnes)	2000 (per cent)
Total Demand	38 500		48 000		60 000	
Total Production						
Rhone Poulenc	8 500	(22)	9 000	(19)	10 000	(17)
Molycorp	8 000	(21)	9 000	(19)	10 000	(17)
Japanese Producers	5 000	(13)	4 500	(9)	4 000	(7)
China (domestic)	9 000	(23)	13 000	(27)	19 000	(31)
China (export)	2 000	(5)	4 000	(8)	7 000	(11)
Others	6 000	(16)	5 500	(12	4 000	(7)
Mt Weld	Nil	Nil	3 000	(6)	6 000	(10)

Note: Figures in parentheses show production for each producer as a percentage of total production.
Source: Kingsnorth, 1993.

Influence of government regulation

Environmental regulation can indirectly generate demands for rare earths, in new applications or equipment designed to help comply with such regulations. Vehicle exhaust catalytic converters, for example, were introduced in the United States in 1975, as a measure aimed at reducing emission levels. In 1981, the regulations were further tightened, leading to the development of three-way catalytic converters.

The Corporate Average Fuel Efficiency (CAFE) requirements in the US are also generating increased demand for rare earths. The move towards producing lighter, more efficient cars has increased the demand for rare earth permanent magnets, which can be used in small electric motors in a number of areas within a car.

Regulation prohibiting the use of toxic materials such as chromates may also provide an opportunity for increased use of rare earths in the area of corrosion protection.

B5.6 Markets

Import competition

Presently Australian manufacturers using rare earths in their products have to import these materials. If an Australian producer such as Ashton Mining was going to enter the market it would have to compete on price, quality and other grounds (for example, timeliness of delivery). It would appear that this firm can meet these criteria, and it should be noted that the plan is to put no more than 5 per cent of its production into the domestic market.

Barriers to entry

There do not appear to be significant barriers to entry in the rare earths processing industry. The significant cost associated with developing the appropriate technology may pose an initial barrier to firms without access to financial capital. The existence of over-capacity and sunk costs for those presently in the business could make it difficult for potential entrants. However, it should be noted that there is not one market for rare earths but a number of separate markets for the specific rare earths and the level of purity. Hence, it is difficult to generalise. Prices tend to be established via long term contracts, thereby locking users into one supplier. This could also make it difficult for new entrants in trying to break into markets.

B5.7 Competitiveness of Australian producers and users

Competitive advantages

As noted already, Australia does not currently have any rare earth processors. However, a competitive advantage that potential entrants may have is secure access to rare earths minerals.

Competitive disadvantage

The lack of a significant domestic user industry may be a possible source of competitive disadvantage for potential processors. The small size of the local market for rare earths would make it necessary for potential processors to seek export markets.

Value adding in production

There is such a wide range of rare earth compounds, alloys, mixtures and forms, that estimating the value added by further processing is difficult. Clearly, it depends on the particular rare earth, the level of processing required and its end use. The value added by processing monazite into a more refined form is depicted in Table B5.7. Value added calculates the residual return to labour and capital after subtracting the increasingly higher material input costs incurred at each step along the processing chain.

Table B5.7: Value added by processing monazite

Processed mineral	*Value added ratio*[a]
Monazite	1
Separated light rare earths	5
Separated heavy rare earth oxides	10
Refined rare earth metals	150

a The proportion by which the value of unprocessed mineral consumed is increased by processing to the stage indicated.

Note: Value added refers to the gross value added to the unprocessed mineral by processing to the stage indicated (value of processed output minus value of material inputs consumed).

Source: ABARE, 1987.

The high value adding potential for rare earths is partly reflected in the high prices obtained for some of the purer forms of rare earths shown previously in Table B5.5.

B5.8 Potential for further production and use

Producers

Potential Australian processors may have the opportunity to supply three markets. The first will be a market for rare earth hydroxides or chlorides, which have been processed to remove the radioactive waste, and can therefore be marketed as a feedstock for further separation by other processors. The second market is for the low-value, mixed rare earths, which have been produced through simple chemical separation.

The third market is for the high value rare earths, which have been produced through complex separation, allowing users to take advantage of the individual properties of the pure elements. It is this area of the rare earths market that is experiencing the greatest amount of growth. The demand forecasts presented in section B5.5 are for separated rare earths elements.

There appears to be some potential for an Australian rare earth processing industry to develop. There are no significant barriers to entry, however the dominance of Rhone Poulenc and Molycorp combined with excess capacity may make it difficult for potential entrants. However, as mentioned earlier, Ashton Mining felt that the dominance of Chinese producers may open the door for other producers, even though the market is in a state of oversupply, as users may want to ensure diversity of supply.

Users

It is unlikely that Australia will become a significant user of rare earths. Australia has had limited involvement in the manufacture of products incorporating rare earths to date, because important industries utilising rare earths are under-represented in Australia.

The demand for rare earth permanent magnets is expected to show significant growth before the end of the decade (refer to Attachment B5.1). Australia appears to be in a position to take advantage of this growth in demand. The research being undertaken by the Research Centre for Advanced Mineral and Materials Processing (RCAMMP) is currently aimed at reducing costs of production. AMT is already producing rare earth permanent magnets under licence from General Motors (although this is on small scale), and SEMCOR has had some success incorporating permanent magnets into small electric motors. These factors would indicate that there is some scope for Australia to develop its rare earth permanent magnet capabilities.

Attachment B5.1 Permanent Magnets

Any material placed in a magnetic field will exhibit magnetic properties. For the majority of materials the magnetisation disappears when the magnetising field is removed. However, there is a class of materials, which are known as ferromagnetic, that retain their magnetisation when the magnetising field is reduced to zero. A number of materials containing rare earths exhibit this ferromagnetic behaviour. Rare earth permanent magnets offer larger maximum energy properties than other permanent magnets such as, aluminium-nickel-cobalt (Al-Ni-Co) and the ferrites.[6] This means that rare earth permanent magnets produce more power than traditional permanent magnets. This has allowed the replacement of more traditional permanent magnets to produce smaller, lighter and hence more efficient magnets.

Permanent magnets have a wide range of applications in the aerospace, automotive, medical and electronic industries. For example, in the automotive industry, permanent magnets are used in starter motors, speedometers, anti-skid brakes and alternators. In the electronics industry examples of applications include, video recorders, electric clocks, hearing aids, electric shavers and personal computers.

The most common rare earth permanent magnets are composed of neodymium, iron and boron (Nd-Fe-B). The process of manufacturing permanent magnets is summarised by Figure B5.3.

There are two commercially available methods for producing Nd-Fe-B magnets, developed at about the same time. The Sumitomo process involves the jet milling of ingots of the alloy to produce fine powders of a critical size, which are then sintered. The General Motors process involves molten alloy being sprayed onto a revolving copper disc (melt spinning). The resulting ribbons are then broken into flakes and hot pressed into blocks from which permanent magnets can be made. The magnets are then ground to achieve the desired shapes.

RCAMMP has developed a procedure using mechanical alloying, which eliminates the need for a high temperature melting stage. The component elements are milled in a high energy ball mill, where the particles are fractured and mixed. The resulting alloys are heat treated to develop optimum magnet properties. Street (1993) states that processing costs represent a significant proportion of the final cost of a magnet. Reducing the number of processing stages offers potential for reduction in production costs and hence the price of Nd-Fe-B magnets, offering scope for increased use. Further reductions in

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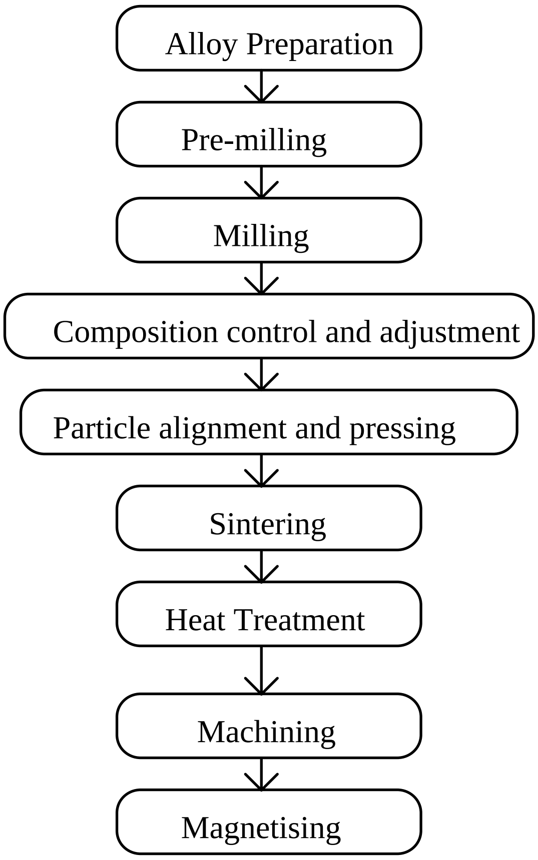
6 A class of magnetic compounds containing iron oxide as a major component.

processing costs may be possible through the development of remanence enhanced materials.[7]

RCAMMP has developed exchange-coupled-remanence-enhanced (ECRE) materials which offer a number of potential benefits over more conventional magnetic materials. These include:

- smaller amounts of rare earth to form the alloy;
- higher energy properties than other isotropic materials (which eliminates the need for an aligning process to produce a high energy product);[8]
- smaller magnetising fields are required for magnetisation or ECRE materials; and
- fewer processing steps are needed. ECRE materials can be produced from powder using near net shape processing methods such as plastic injection moulding and extrusion.

Figure B5.3: Summary of process for manufacturing permanent magnets



Source: Street, 1993.

The total value of permanent magnet production (including rare earth permanent magnets, Al-Ni-Co and the ferrites) World wide is estimated to be over US$1 billion annually, and the market has been growing steadily for the past 20 years in terms of tonnage (US Bureau of Mines, 1990). By the year 2000, the Nd-Fe-B magnet market is expected to be US$1.1 billion (sub 19). Table B5.8 presents the market for all permanent magnets as a

7 The properties of these materials depends on the bringing together of two different magnetic phases. One of these phases is chosen to increase the intensity of magnetisation. The other phase, usually a conventional rare earth permanent magnet material, offers resistance to demagnetisation.

8 The material exhibits the same magnetic properties in all directions of measurement.

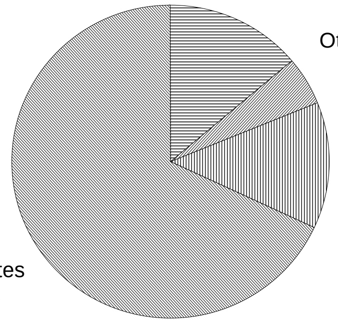
percentage of total magnet sales. Figure B5.4 shows the share of the market held by the different type of permanent magnets.

Table B5.8: Use of permanent magnets, 1990

Applications	*Percentage of total magnet sales*
Motor and generator applications	35
Telecommunications, information technology, data processing and instrumentation control	25
Acoustic transducers, loudspeakers, headphones and microphones	20
Mechanical applications, – torque drives and vehicle levitation	20

Source: US Bureau of Mines, 1990.

Figure B5.4: Market for permanent magnets by magnet type, 1990 (per cent)



Source: US Bureau of Mines, 1990.

The price of Nd-Fe-B magnets, is only 70 per cent to 90 per cent that of samarium cobalt (Sm-Co) magnets, also a rare earth permanent magnet. This is primarily because of the low cost and abundance of neodymium relative to the scarcity and high cost of samarium. Nd-Fe-B magnets are increasingly being used although they are still more costly than the ferrites or Al-Ni-Co magnets. However, the superior properties of Nd-Fe-B magnets compared with any other commercially available permanent magnet mean that they have the capacity to replace such magnets in certain existing devices. They also have the potential for new applications, such as in medical body scanners.

There are nevertheless two disadvantages in using Nd-Fe-B magnets. First, they are limited by their low Curie temperature in applications above temperatures of 120°C.[9] Second, they are highly susceptible to corrosion and oxidation compared with Sm-Co magnets. Current research is aimed at minimising these disadvantages. On balance, there is significant scope for neodymium magnets to substitute for Sm-Co magnets except in high temperature applications.

Nd-Fe-B magnets have already found widespread commercial application, particularly in automobiles. General Motors uses Nd-Fe-B magnets in starter motors, windshield wiper motors, and ventilation motors. Nd-Fe-B magnets have allowed General Motors to cut in half the size and weight of its starter motors without sacrificing power (US Bureau of Mines, 1990). This weight saving is important in terms of meeting CAFE requirements in the US.

9 Curie temperature is the temperature above which a compound loses its magnetism. Therefore in high temperature applications Nd-Fe-B magnets lose there magnetism relatively easily.

B6 MAGNESIUM

Magnesium is the eighth most abundant element and its compounds were mentioned as early as 400 years BC, when Hippocrates referred to the properties of magnesite and its use as a laxative. In 1883, magnesium was being produced by the electrolytic reduction of magnesium chloride, and by the turn of this century, World production was about ten tonnes per year.

The focus of this case study will be on new processing technologies, and new uses for an 'old' material. Although magnesium is used in the desulphurisation of steel and electrochemical applications, this case study will focus on the 'newer' uses for magnesium — as magnesium metal and aluminium–magnesium alloys.

> Magnesium and its alloys melt at about the same range of temperatures as aluminium (around 650ºC) and is one third less dense, making it the lightest of the commonly used metals. Although magnesium is relatively soft as a pure metal, its properties can be substantially enhanced by alloying (addition of other elements) or by heat treatment and working (CSIRO, 1993).

Although there is no production of magnesium metal in Australia at present, there is considerable interest and research being undertaken. This level of activity results from the presence of World-class magnesite deposits in Australia, an existing die casting industry, and World wide interest shown in the metal by the automotive industry because of its lightness and the possibility of associated fuel savings. These factors could result in very significant increases in magnesium metal consumption over the next decade.

B6.1 The World market for magnesium

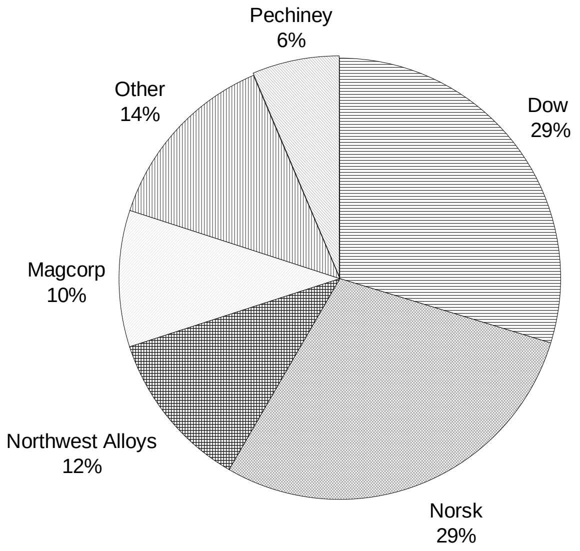
World production

Western World magnesium production is about 250 000 tonnes per year.

Two companies, Dow and Norsk Hydro, dominate, producing about 60 per cent of the World's magnesium (as shown in Figures B6.1 and B6.2).

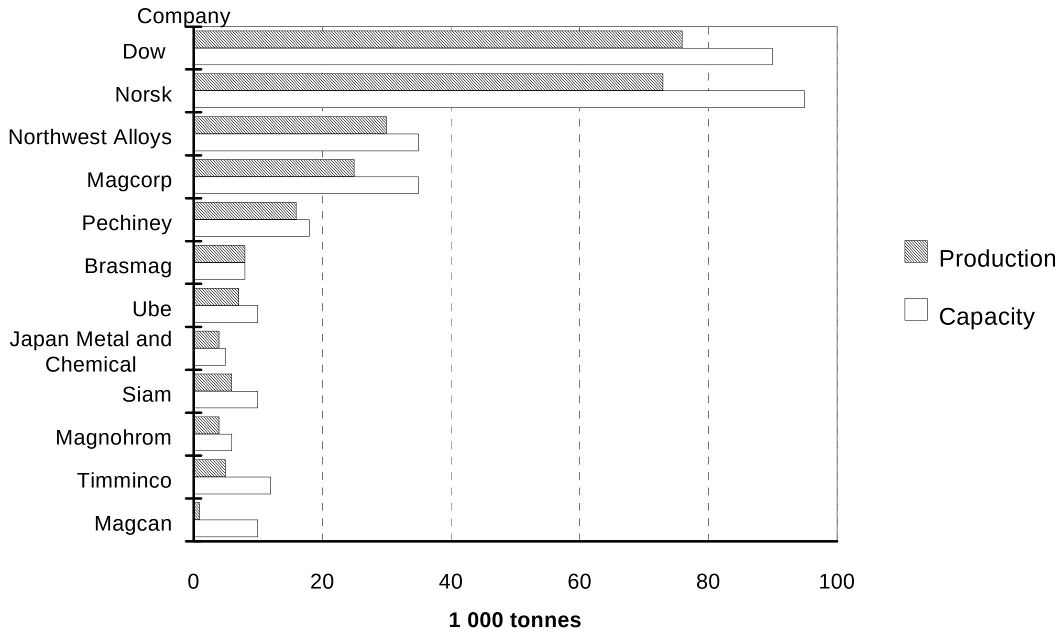
The magnesium industry is currently in a state of oversupply, with capacity utilisation only around 76 per cent (see Figure B6.2).

Figure B6.1: World magnesium production by producer, 1992



Source: Metal Bulletin & IMA, quoted in Lewis, 1993.

Figure B6.2: World magnesium production by volume, 1992



Source: Metal Bulletin & IMA, quoted in Lewis, 1993.

World consumption

The four principal uses for magnesium are:

- structural metal;
- alloying with aluminium;
- iron and steel processing; and
- electrochemical and other applications.

Use as a structural metal (magnesium casting)

Structural uses for magnesium include metal components manufactured using die casting and sand casting techniques.

Die casting is seen as the major potential growth market for magnesium use. About 31 000 tonnes of magnesium are used each year in die casting processes. This accounts for around 13 per cent of the World's magnesium use (see Figure B6.3). Most of this is used in automotive components:

> Around 70 per cent of the high pressure diecasting market is for automotive components, which is also the highest growth area. The remaining 30 per cent is roughly equally split between computers/electronics/office equipment/communications equipment, hand held appliances and sporting goods/other equipment (Lewis, 1993).

Use in aluminium alloys

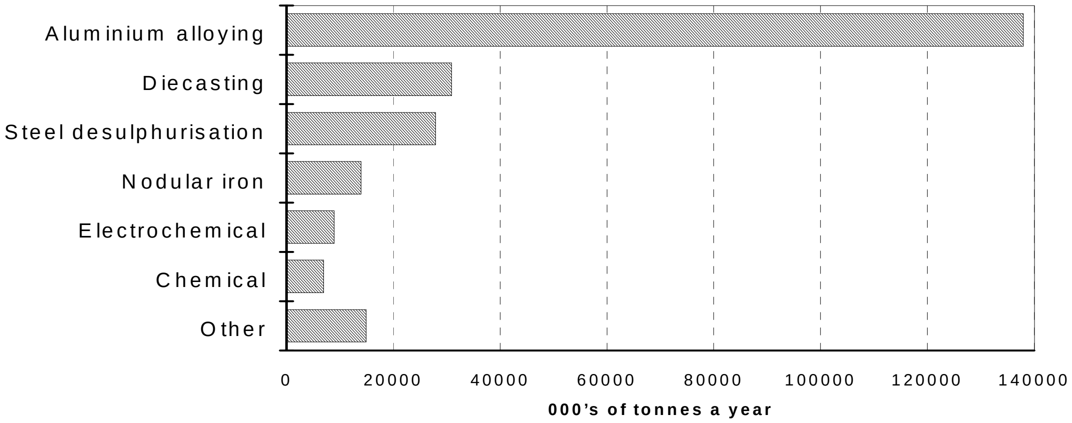
Magnesium is used as an alloying agent in a large proportion of aluminium alloys. This use accounts for about 138 000 tonnes of magnesium each year, which is about 56 per cent of World production (see Figure B6.3). The International Magnesium Association state:

> This is the largest single application for magnesium, accounting for about one half of total consumption. Relatively small amounts of magnesium added to aluminium will improve its strength and corrosion resistance. Many aluminium alloys contain some magnesium. The 5,000 series, frequently called marine alloys because of their excellent corrosion resistance, may contain up to 6.5 per cent magnesium (1991).

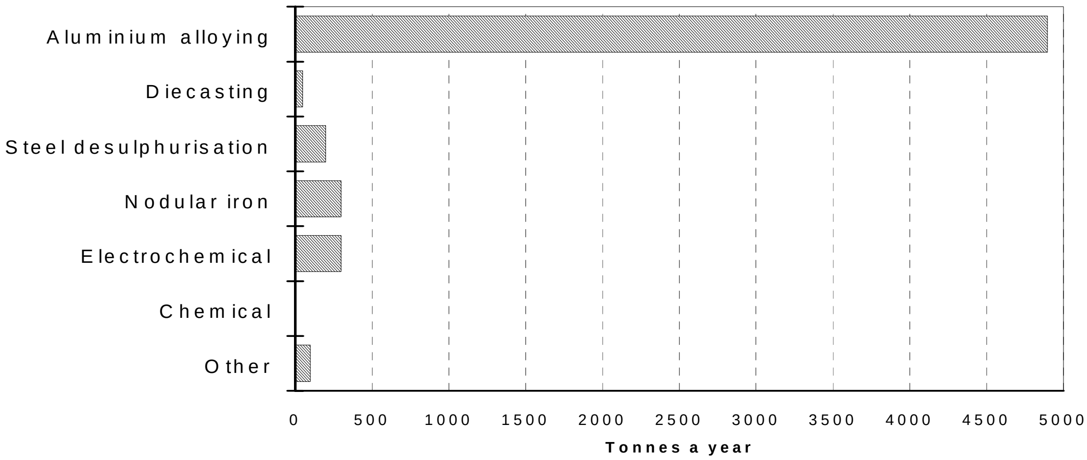
Other uses

Magnesium used in the desulphurisation of steel and in electrochemical applications accounts for considerable amounts of magnesium, but the processes involved are not new, and simply use magnesium as a basic input.

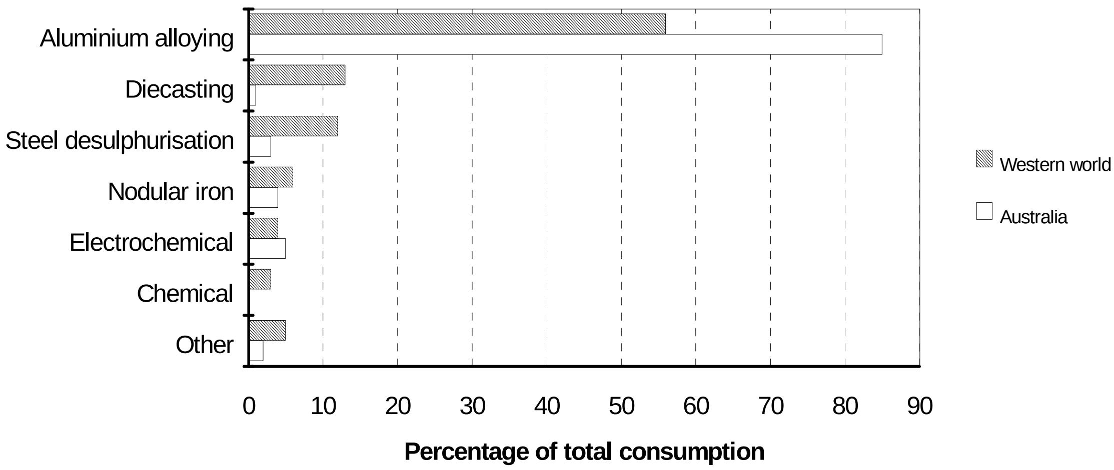
Figure B6.3: Magnesium consumption by use
(a) Western World



(b) Australia



(c) Total production



Source: Lewis, 1993.

B6.2 Australian production and usage

Australia consumes about 6000 tonnes of magnesium each year — 85 per cent of this is used producing aluminium alloys. With no local production, this 6000 tonnes is all imported at a cost of about $27 million annually. In comparison to the rest of the Western World, a relatively high proportion of the magnesium consumed in Australia is in the production of aluminium–magnesium alloys (see Figure B6.3(c)).

In the 1970s, CSIRO was at the forefront of the development of diecasting technology. Some participants in this inquiry who have relevant experience viewed sections of the Australian diecasting industry as world class, and the industry has ready access to this diecasting expertise which has been built up over many years.

In 1993, Australian producers diecast about 300 tonnes of magnesium, most of which is used in anode production (in comparison with the 43 000 tonnes of aluminium alloys diecast in Australia in the same year).

Australia has a considerable R&D base in both diecasting and the production of magnesium. Diecasting research, such as the work being done by the CRC for Alloy and Solidification Technologies (CAST), and age-hardening techniques being developed by CSIRO in Melbourne, is keeping Australia equal to the world's best in magnesium diecasting technology. CSIRO had 12 years experience in magnesium research before joining the Queensland Metals Corporation (QMC) based Australian Magnesium Research Development Project (AMRDP). Professor Dunlop claimed that:

> While relatively small by international standards, the Australian light alloy casting industry comprises a very important sector of Australia's manufacturing industry. It is a substantial exporter and has considerable potential for growth (sub. 23, p. 1).

Australia has excellent magnesite resource endowments, the deposit in Queensland and another deposit in Northern Tasmania being two of the largest known deposits in the World. The Queensland deposit is currently being mined at a level of 2.5 million tonnes of ore per year. This production is currently being entirely used for refractory applications.

B6.3 Supply conditions

Production technologies

Magnesium can be produced by two different methods:

- electrolysis of molten magnesium chloride; and

- thermal reduction of magnesium oxide.

Both processes are used to produce significant quantities of magnesium, although currently the majority of magnesium produced is by the electrolytic method.

Electrolytic production

The majority of the World's magnesium production is processed using the electrolytic reduction of magnesium chloride — known as the electrolytic process. Dow, Norsk Hydro, Magcorp and Magcan all use this process. The Unites States Bureau of Mines report that:

> Electrolytic recovery of magnesium requires a magnesium chloride feedstock that is normally prepared from seawater or brines. Two types of magnesium chloride can be made — hydrous and anhydrous. ..... Electrolytic cells used to recover magnesium from either hydrous or anhydrous magnesium chloride differ from company to company, and most information about cell design and operating conditions is not disclosed (1992).

Thermal reduction

All other producers use the silicothermic process. This involves the reduction of calcined dolomite with ferrosilicon in a vacuum furnace. Lewis described the process thus:

> The magnesium vapour produced is then condensed in cooled vessels. There are several variations to this theme used by different producers. Despite usually higher operating costs the size of the individual silicothermic units (around 4,000 tonnes a year) can suit small local markets (1993).

B6.4 Demand conditions

Performance price trade-offs

The renewed interest in magnesium is driven by the automobile manufacturing industry's interest in producing lighter vehicles, and the material's suitability in new casting techniques. Magnesium is lighter and easier to machine than most other metals. It is 50 per cent lighter than aluminium, and only one quarter the weight of steel. The following forecast illustrates the potential demand for weight savings in the automobile industry:

> Automakers will place a value of (US)$1.75 or (US)$2 per pound by 1998, (US)$3 per pound by the year 2003 on weight savings in domestic cars and light trucks (New Materials International, 1994c, p. 3).

With regard to advantages in casting, the thixotropic properties of the metal (that is, a gel or putty like form when stable but adopting a liquid form when shaken) allow it to be used in net-shape, thin wall and squeeze casting. This allows magnesium to be cast into a single component, replacing alternate designs made from several parts. It also offers the ability to cast complex parts that reduce labour costs.

Cost savings

Molten magnesium does not react with die steels, providing longer die life and increased productivity. Also, magnesium cools more quickly after casting than aluminium and steel, allowing casting rates to increase. The International Magnesium Association described these advantages as follows:

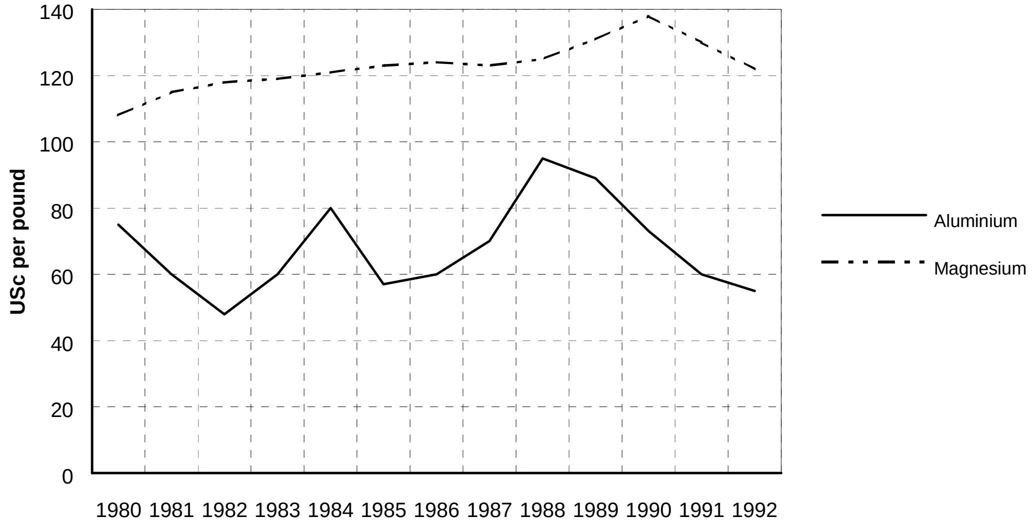
> Magnesium has a substantially lower heat content per unit volume than aluminium, which means that alloys solidify more quickly in the die and higher casting rates are possible. In some cases it is possible to get twice as many castings per hour, although the normal increase over aluminium is usually from 40 to 50 per cent (1993).

Queensland Metals Corporation estimated the typical die casting production cost to be three quarters of the cost of aluminium — taking into account the relative prices of the two metals, waste involved and stamps per die (Queensland Metals Corporation, 1993).

Because the metal is easier and faster to machine than aluminium, speed of production brings with it cost savings.

Although magnesium offers these advantages over other metals, it is still viewed as too costly by some potential users. A magnesium price of one and a half times the price of aluminium is seen as the threshold price at which magnesium can be directly substituted for aluminium. In recent years, the price of both magnesium and aluminium have both fallen. Magnesium, however, still remains about double the price of aluminium (see Figure B6. 4).

Figure B6.4: Aluminium and magnesium prices: 1980-1992



Source: Lewis, 1993.

Substitutability

If the focus of potential for increased demand of magnesium is on the automobile industry, substituting magnesium parts is not the only means of achieving lighter and more fuel efficient cars. Further discussion of substitutability of materials within the automotive industry occurs in Appendix B9.

Notwithstanding the factors which might retard the substitution of magnesium for other materials, it is making inroads into the automobile materials market.

> ... by 1996, Ford would have 30 auto parts in magnesium, Chrysler would have 20, and General Motors would have 46. That is a 100% increase over the 1992 use of magnesium by the same automakers (Light Metal Age, 1994).

Demand growth

The future demand for magnesium will be largely determined by its use in the aluminium alloy and diecasting industries. The question arises how fast will these two industries grow?

Demand for aluminium alloy is expected to grow by two per cent a year (Lewis, 1993). Most of this increase is likely to come from use in aluminium alloys in beverage cans and the automotive industry. The average percentage of magnesium in aluminium alloys produced in Australia is low by World standards, at about 0.4 per cent.

Aluminium alloys used in the production of beverage cans consist of about two per cent magnesium. When talking about the potential for aluminium beverage can production in Australia, Lewis said:

> The biggest potential boost could come from a proposed new 100 000 tonne a year beverage can sheet rolling mill at Bendigo, which would consume approximately 2 000 tonnes per year (Lewis, 1993).

As larger proportions of magnesium are being used in new alloys, the growth in demand for magnesium will be more than proportional to the growth in demand for aluminium alloys. New alloys being used in the aerospace and automotive applications, such as alloy 7093, use a larger percentage of magnesium (2.2 per cent compared to the standard alloy mix of 1 per cent) (New Materials International, 1993). That said, the quantities involved are relatively small.

Recent growth estimates for world consumption of magnesium for diecasting range from 7.9 per cent a year to 20 per cent (Lewis, 1993). The forecast of 20 per cent growth is dependant upon the price of magnesium falling from $US1.40 a pound to $US1.00 a pound.

The University of Michigan Transportation Research Institute report predicts magnesium use to increase from 4.5 pounds per car in 1990 for the average American car, to 15 pounds per car in 2003.

General Motors in the United States has just placed an order with Meridian Technologies of Canada for the manufacture of complex brake and clutch pedal boxes in magnesium alloy. This development has been referred to as follows:

> It is also thought to be the largest single magnesium parts contract ever awarded to a supplier in North America... North American auto builders such as Chrysler and Ford Motor will be watching the development with close interest. Neither has attempted to use magnesium on this scale before. In this case GM expects to build one million vehicles with these parts (New Materials International, 1994a, p. 1).

Lewis sums up the hopes of magnesium producers and diecasters in the publication *Magnesium - Opportunities for Australian Industry*, saying:

> Western world magnesium diecasting growth is forecast at approximately 12 per cent per year in the period to 2002, from the current base of 34 000 tonnes. The automotive sector, comprising 70 per cent of the market, has the highest predicted growth at 15 per cent per year. If magnesium prices fall relative to aluminium prices from typical levels of 2 to 1 to a floor of 1.5 to 1, the automotive area growth rate will rise to an estimated average of 20 per cent per year (Lewis, 1993).

B6.5 Potential for further production

Potential

A range of reports, mentioned above, have estimated that the demand for magnesium, particularly for diecasting, will increase rapidly to the year 2000 and beyond. Estimated growth rates for magnesium diecasting range from 7.9 per cent to 20 per cent per year (Lewis, 1993).

If, as predicted, the World wide demand for magnesium increases at 7.9 per cent a year, by around 1997 there will no longer be an oversupply of magnesium. Demand will be a function of the demand for magnesium in all its uses, with the biggest increase expected in the diecasting area. How is Australia placed to take advantage of any possible increase in demand?

Australian production

The project closest to fruition is the Australian Magnesium Research Development Project (AMRDP). It is planned to have a pilot plant operating in Gladstone by the 1997. The history behind the AMRDP project is presented in Box B6.1.

There has also been a magnesium production pilot plant at BHP’s Shortland laboratory in New South Wales. The pilot plant used the Ilolaire process to demonstrate a new low cost way of producing magnesium. The developer of the process, Mr Jim Heggie said:

> The Ilolaire technology involves the use of a direct current, transferred plasma arc within a furnace chamber operating at atmospheric pressure. This innovative manufacturing process has established that a low cost structure will apply for both the production of magnesium metal and high purity alloy (The AusIMM Bulletin, 1994).

Government’s role

Both Federal and State governments have been involved in the funding research and development projects related to magnesium and downstream processing technologies. The Commonwealth Government partly funds the CRC for Alloy and Solidification Technologies (CAST) — which receives $2 million a year

Box B6.1: Australian Magnesium Research Development Project (AMRDP)

The AMRDP is a consortium including the Queensland Metals Corporation (QMC) and CSIRO. The consortium intends to utilise the Kunwarra magnesite deposit in central Queensland, discovered by QMC in 1985, which is the largest known micro-crypto crystalline magnesite deposit in the World.

The AMRDP consortium was created as an entity to attract funds from private and public interests. Both State and Commonwealth governments have agreed to provide $25 million, contingent upon equivalent funding from the private sector.

In the early stages of the project QMC paid CSIRO to investigate possibilities for producing magnesium metal. Once CSIRO validated the quality and magnitude of the Kunwarra resource, it agreed to forfeit payment for contract work in return for shares in QMC. In 1993, CSIRO undertook a $1.5 million feasibility study into alternative technologies for producing magnesium metal. The study concluded that the process CSIRO developed, which uses low temperature processing technology, standard chemical engineering equipment and incorporates an innovative dehydration process, will produce a high quality magnesium at lower than present market cost. Precise details of the technology are confidential.

With the creation of the consortium, partners were sought for the construction of a one thousand tonne pilot plant at Gladstone. Ube and MIM both joined the project agreeing to contribute 90 per cent of funding on an ongoing basis. After contributing $8 million both firms withdrew from the consortium in April 1994. QMC have stated that the withdrawal was due to internal business reorientation within those companies (MIM returning to ‘core’ businesses and Ube because of the downturn in the Japanese economy).

Plans for the pilot plant have been approved, gas and electricity are connected to the site at Gladstone, and QMC has recently provided an additional $2 million to finance further research until March 1996. It is now a question of attracting new partners. To aid this process, the AMRDP had BHP Engineering and ICIA Engineering conduct a technical and cost audit. They concluded that the technical processes were sound and that the costings were also correct. The audit demonstrated that on the basis of the R&D done to date, the consortium can produce a better quality magnesium metal than is currently available globally, and at a cheaper cost.

If finance is forthcoming, the pilot plant will be completed by 1997, at a cost of $35 million. If the pilot plant is proven commercially viable, a full-scale production plant will be established with a final capacity of 60 000 tonnes, or about 25 per cent of the current world market. This capacity will be increased incrementally from a starting point of 20 000 tonnes.

over a seven year period. The Commonwealth Government has been involved in a more indirect sense through CSIRO's contribution to the AMRDP (see Box 6.1) and other related research efforts, such as the formulation of the Light Metals Industry Development Strategy (outlined in Box B6.2).

Box B6.2: Light Metals Industry Development Strategy

The Light Metals Industry Development Strategy is an initiative of the Department of Industry, Science and Technology (DIST). The strategy is being formulated in collaboration with industry, the research community and other relevant agencies. Its goal is to ensure that local producers are equipped to meet any increased demand for lightweight automotive components.

The Commonwealth has funded a number of studies under this strategy, including:

- a study by the Australian Automotive Technology Centre which identifies those components most suitable for manufacture in magnesium (jointly funded by DIST and CSIRO); and
- a CSIRO conducted study into ways of handling magnesium process scrap, which was funded by DIST, CSIRO and the Queensland Department of Business, Industry and Regional Development.

Source: DIST, 1994b.

In 1987, Queensland Metals Corporation (QMC) approached the Queensland State Government to 'come up the magnesite learning curve with the company' (QMC, 1993). The Government established a Magnesite Working Group which included representatives from various Departments (Premier's, Treasury, Business Industry and Regional Development) and the Electricity Commission. QMC outlined the Government support program in the following way:

> Initiatives of the Working Group, and the State Government, have included the construction of a spur gas pipeline to Rockhampton from Gladstone... reservation of industrial land... granting of significant loan funds for magnesium metal research and development; and other measures of support and project facilitation (1993).

Governments have also supported downstream processing. The Queensland Government purchased a Ube squeeze-casting machine for use at the CSIRO facility in Pinjarra Hills (details of the diecasting industry are given in Appendix B8).

Magnesium metal

When considering the future of the magnesium metal production in Australia, the near future lies with the viability of the AMRDP project. For the project to progress to the next stage, the consortium needs to attract more funding from the private sector. If this occurs and the pilot plant proves to be commercially successful, with quality and costs as predicted, the viability of the operation will then depend on the predicted increases in demand for magnesium.

If 20 000 tonnes of magnesium from the first stage of the AMRDP project is produced at a lower price than its competitors, it should be possible to secure a share of the World market without undue difficulty. There will be an added bonus if the quality of the Australian product is of superior quality. However, due to the current state of World oversupply of magnesium, demand growth will nevertheless be important to ensure the viability of the project.

The further planned expansions of the AMRDP project will be dependent upon World demand growth, increases or decreases in competitors' capacity, the price of magnesium, and AMRDP's industry linkages and marketing ability.

Further value adding

The use of magnesium in local production need not depend on producing it in Australia. Magnesium may be imported and then included as an intermediate input. Although magnesium may be used for other purposes (cathodic protection of underground pipe and water tanks), the greatest potential for magnesium use is as an intermediate input in the diecasting industry, and in which demand by automotive manufactures will have the largest impact.

Demand growth in the diecasting industry depends in turn on the need for lighter, more fuel efficient cars, and the availability and price of other light weight material substitutes.

Australia's has considerable diecasting expertise, which has been built upon since the early 1970s. Along with the current levels of diecasting exports, the local industry is in a good position to utilise established overseas links to meet any increased World wide demand for diecast magnesium products. It should be noted that a successful magnesium diecasting industry in Australia is not dependent on the local production of magnesium metal.

B7 TITANIUM METAL AND ALLOYS

Titanium is a commonly used metal in military and aerospace applications. It is as strong as steel, but 45 per cent lighter. Eighty per cent of titanium metals and alloys produced are used in jet engines and airframes of civil and military aircraft, and in space and missile applications.

As well as being strong and light, titanium is also corrosion resistant and consequently is used in applications requiring this property. Uses include:

- condensers, tanks, reactor vessels and heat exchanger pipes and tubing in the power, oil and gas and chemical processing industries;
- electrodes in sodium chloride and sodium chlorate production;
- storage and piping equipment in environments of wet chlorine gas and bleaching solutions in the chlor-alkali and pulp and paper industries; and
- biomedical applications.

Some uses of titanium depend on both its high strength to weight ratio and corrosion resistance properties. Such uses include:

- the hull and other structural parts of submarines; and
- high pressure drilling riser for offshore oil drilling platforms.[1]

Titanium also is used in leisure and sporting goods, such as bicycles and golf clubs, in spectacle frames, and in architectural applications (Nishimura, 1991). The ability to produce a wide variety of permanent colours by anodising leads to some of these applications.

Titanium metal is produced from rutile or ilmenite that has been processed into synthetic rutile. Both are commonly occurring mineral sands in Australia. In 1993, Australia accounted for approximately 38 per cent of total World rutile production (ABARE, 1994e). ABARE (1987) estimated that only 3 per cent of the minerals rutile and ilmenite are processed into titanium metal.

The production of titanium metal from these mineral sands includes the production of the intermediate product titanium sponge.[2] The sponge

1 The riser extends from the platform to the ocean floor, and is the main support and containment column for the drilling casing.

2 Titanium sponge is a porous, incompletely fused mass of metal crystals, which is formed as a result of an ore reduction process.

subsequently undergoes further processing to become titanium metal ingot, which is then milled into specific forms (including sheet, strip, plate, bar, billet, wire, foil or tubing) for final use. Titanium metal may also be processed into powder for various applications, including prosthetics.

The properties of titanium metal can be altered through the creation of titanium alloys. The specific application of the material will influence the alloy created. The titanium alloy Ti-6Al-4V, which is used in aircraft, is the most commonly used titanium alloy, and accounts for approximately 50 per cent of all titanium-based alloys (Donachie, 1988).[3]

The production of titanium ingot and mill products and their use in manufacturing produces wastage, or scrap. The amount of scrap can be as high as 75 per cent in processing ingots into final products. In certain circumstances, this scrap can be processed and remelted into ingot.

Generally, corrosion resistant applications will use ‘unalloyed’ titanium, while applications requiring high strength to weight will use a titanium alloy.

Australia has a small number of users of titanium metal, but no producers.

B7.1 International production and usage

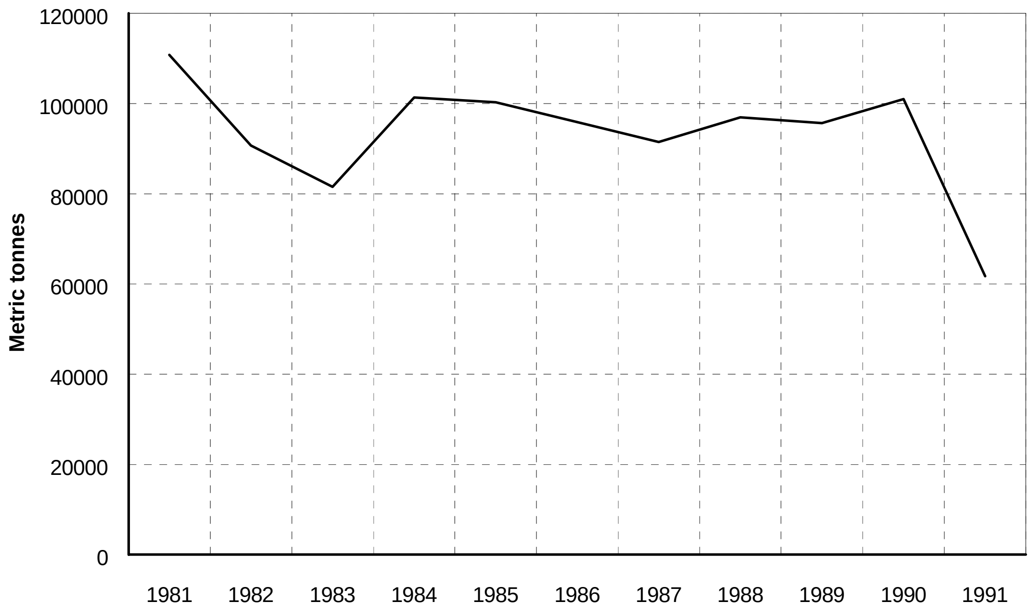
Production

Production of titanium sponge and titanium metal is concentrated in the CIS, the US, and Japan. Figure B7.1 shows World production of titanium sponge over the period 1981 to 1991.

In 1992, three countries, the US, Japan and the CIS, accounted for 95 per cent of world capacity in titanium sponge production. Excluding producers in the CIS and China, there are only six businesses in the World producing titanium sponge and seventeen producing titanium metal (Metals Bulletin Monthly, 1993). Table B7.1 provides estimates of the maximum titanium sponge and metal capacity in the main producing countries.

3 This alloy contains 6 per cent aluminium and 4 per cent vanadium.

Figure B7.1: World titanium sponge production, 1981 to 1991



Note: The figures for 1990 and 1991 are both estimates only.
Source: CRB, 1993.

Table B7.1: Estimated production capacity of titanium sponge and metal, 1992

Country	*titanium sponge capacity (kilotonnes)*	*titanium ingot capacity (kilotonnes)*[a]
CIS	90.7[b]	56.7
US	21.3	58.2
Japan	29.1	22.8
Europe	5.0[c]	8.2
China	2.7	3.6
Total	148.8	149.5

a Includes vacuum arc, electron beam and plasma processes.
b Gambogi (1992) estimated titanium sponge capacity in the CIS to be only 52 000 tonnes.
c Towner and McAllister (1994) report that late in 1993 this capacity ceased to exist.
Source: Metals Bulletin Monthly, July 1993.

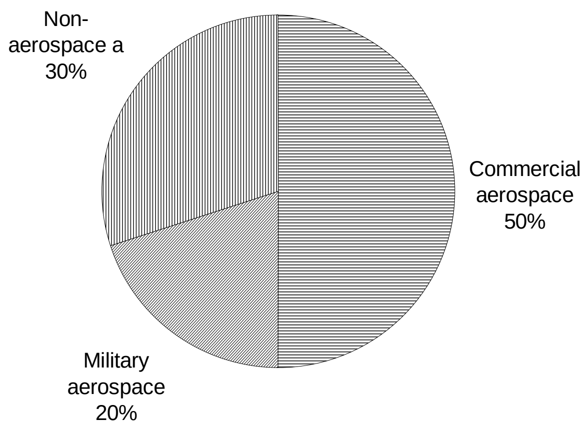
In 1993, it is estimated that there was approximately 50 per cent excess production capacity for titanium sponge (Towner and McAllister, 1994). Excess production capacity in the industry has been attributed to reduced demand from military aircraft manufacturers and the recent entry of stocks of titanium sponge and scrap from the CIS onto the world market, as well as recessionary conditions in the early 1990s (Metal Bulletin Monthly, 1993).

Use

The US and Japan are the major producers and consumers of titanium products in the Western World. Figure B7.2 shows the use of titanium mill products, such as sheet, bar and billet in the US 1993. It is evident that commercial aircraft and military aerospace industries are the dominant users, accounting for 70 per cent of total usage. It is estimated that approximately 16 500 tons of titanium mill products were consumed in the US in 1993 (Gambogi, 1994).

Specific applications in the military and civil aerospace applications include: rotor heads, blade attachments, anti-vibration mountings and weapon carriers in helicopters, and landing gear brackets in the European Airbus. Military aircraft such as the Tornado and the Lockheed Blackbird have 25 per cent and 85 per cent, respectively, of their structural weight in titanium alloys (Street and Alexander, 1994).

Figure B7.2: Use of titanium mill products in US, 1993



a Includes uses in specialty chemical, pulp and paper, oil and gas, marine and medical industries.
Source: Gambogi, 1994.

The pattern of usage of titanium in Japan varies significantly from the US pattern described above. For example in 1991, only 3 per cent of titanium was used in aircraft applications. Industrial applications, such as in the electricity and chemical industry and plate heat exchangers, are the dominant users of titanium in Japan. Other areas of use include building and civil work, consumer products and electrolysis (Department of Oceania and South East Asia, MITI).

B7.2 Australian production and usage

Production

At present, there is no production of titanium metal in Australia.

Use

In the 12 months to June 1994, Australia imported 184 tonnes of titanium metal for use in the manufacture of products for the domestic market. These materials were valued at approximately $7.7 million. The US and UK were the largest suppliers of titanium metal to Australia (ABS, 1994).

National Forge, based in Melbourne, is the largest user of titanium metal in Australia. It imports titanium from the US and the UK, and uses it to forge titanium metal blades for aircraft engines. There are only a small number of manufacturers of this type of blade in the World.

National Forge began forging titanium blades in the 1960s with assistance under the Offsets Program. The titanium blades produced by this business are exported to the US, the UK, France and Korea, and in 1992–93 this represented approximately $5 million worth of business.

There are many other smaller Australian users of titanium products in manufacturing processes. For example, products made from titanium are used in Australian chemical processing and power plants; in the biomedical industry titanium is widely used in dentistry and for replacement hip, knee and finger joints, and Nowra Motorcycles is investigating the viability of producing titanium connecting rods for use in racing motorcycles.

B7.3 Markets

As evident from Figure B7.2, demand for titanium is from two separate markets: military and civil aerospace users, and industrial users. The military and civil aircraft industry demands high strength-to-weight alloys such as Ti-6Al-4V. The ‘industrial’ market for titanium generally uses lower strength, unalloyed titanium.

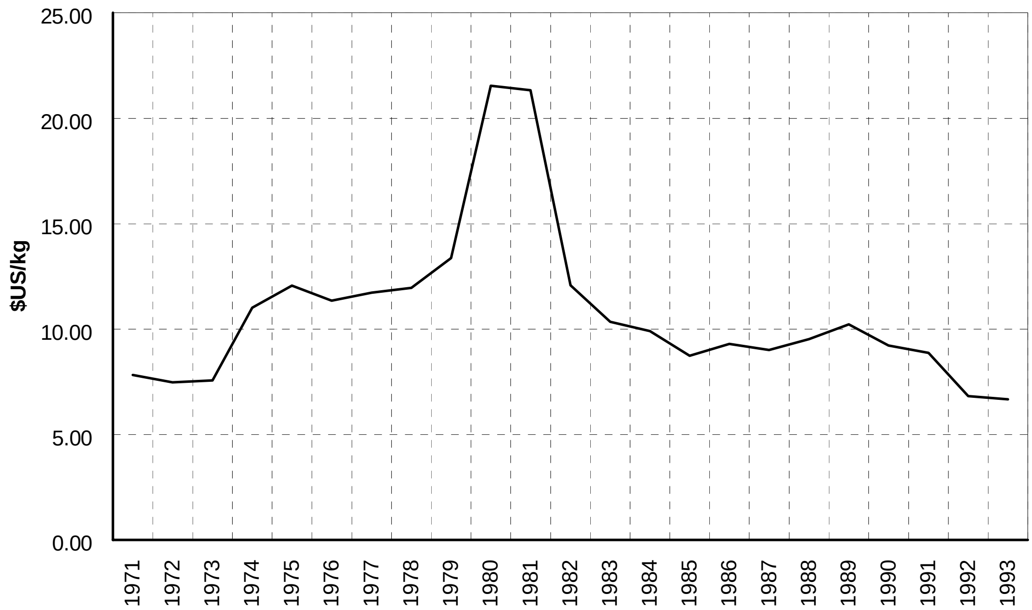
The pricing practices of titanium producers have been influenced by the volatility in demand. Donachie states:

> The industry has been cyclical in nature and has operated at peak capacity only a few times in the nearly four decades since titanium was introduced as a commercial material. Consequently, producers have been aggressive in their pricing policy because of the less-than-full utilization of capacity (1988, p. 16).

The price of individual titanium mill products (billet, sheet, strip, bar and plate) differ, reflecting the cost associated with producing the particular item. For example, in the US in 1993, the published price of titanium billet was between US$13.20 and US$16.50 per kilogram while titanium plate was between US$18.70 and US$20.90 per kilogram (Gambogi, 1994).

Figure B7.3 shows the volatility in the price of titanium sponge and its decline since 1981. This decline reflects the decrease in demand.

Figure B7.3: Price of titanium sponge, 1971 to 1993



Note: Prices are in constant US 1987 dollars.
Implicit price deflator from US Dept of Commerce, Bureau of Economic Analysis.

Source: Gambogi, 1992 and 1994.

B7.4 Supply conditions

Production

There are three stages to the production of titanium metal:

1. Ilmenite, rutile or synthetic rutile is processed either directly into titanium tetrachloride or to titanium dioxide, then into titanium tetrachloride;
2. Titanium tetrachloride undergoes a reduction process to produce titanium sponge; and
3. Titanium sponge is melted and further processed to titanium metal ingots.

There are two existing processes used to produce titanium metal: the Kroll process and the Hunter process. In the second step (the reduction process) titanium tetrachloride is reacted with molten magnesium if the Kroll process is used or molten sodium in the Hunter process. Both are batch processes and energy intensive.[4]

According to the US Bureau of Mines (1992), only China and the CIS produce titanium sponge in a vertically integrated mine-to-metal process.

Access to technology

The two standard technological processes used to produce titanium metal, the Hunter and Kroll processes, are proven and available for potential processors with the financial means to build a plant. However, there is a significant capital cost involved in establishing a titanium metal plant. DITAC (1990) estimated that to establish a titanium sponge plant in Australia with an annual capacity of 10 000 tonnes would have cost US$260 million in 1988.

Substitution

Titanium metal and alloys have the best strength-to-weight ratio of all commercially available metals in the 500°C–600°C temperature range, thus, their use in blades, casings and discs in jet aircraft engines. However, titanium is reaching its technical limits in various applications, including jet engines. As the performance required of engines is increased, the performance of materials used in them must also increase. Given the ongoing refinement in these applications, titanium could be replaced by metal-matrix composites or inter-metallic alloys (US Bureau of Mines, 1991).

4 A batch process is one where the material is produced by one operation.

However, metal-matrix composites and inter-metallic alloys can be titanium based. Titanium aluminides (30 per cent aluminium, 70 per cent titanium) are one type of inter-metallic alloy.

One example of research into inter-metallic titanium alloys is that being conducted in Japan. The National Research Institute for Metals has developed a nickel-titanium-aluminium alloy which maintains its properties up to a temperature of 1000 °C. This alloy could be used in jet engines and turbine blades, rockets and supersonic craft (New Materials Japan, 1994c). The company, NKK Corporation, has developed a superplastic titanium alloy containing titanium, aluminium, vanadium, iron and molybdenum. The properties which make it attractive include its superplasticity, mechanical properties and cold formability. This material has the potential to be used in airframes (New Materials Japan, 1994a).

A US Government organisation, Advanced Research Projects Agency (ARPA), is attempting to develop titanium reinforced with continuous fibres of silicon carbide. This product is intended for use in both military and civil aircraft turbine parts (Materials Edge, 1994b).

B7.5 Demand conditions

Factors inhibiting the use of titanium

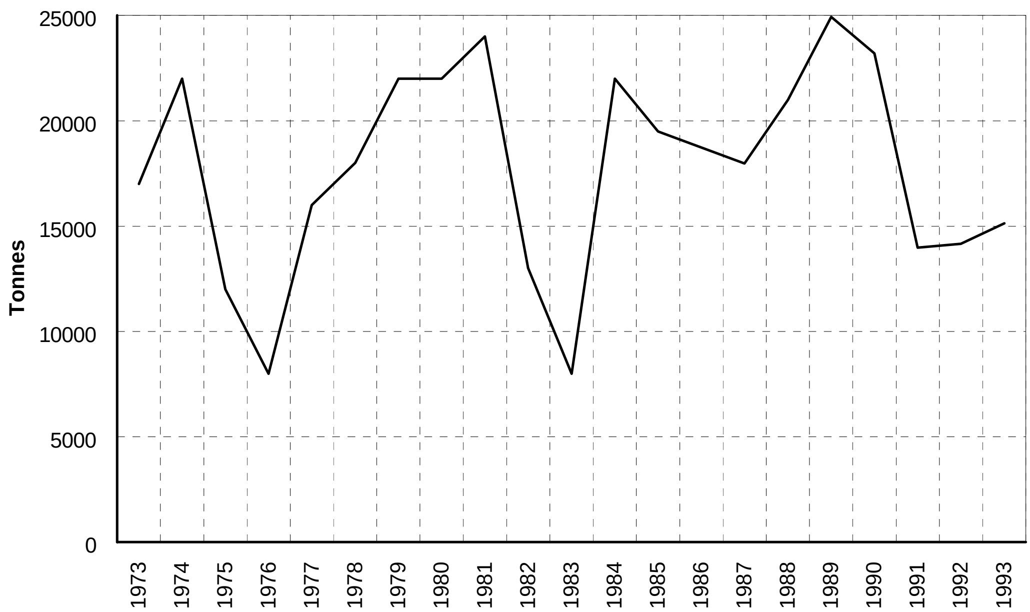
Apart from its high cost, titanium has properties which make it difficult and expensive to work. While military and aerospace users are familiar with the characteristics of titanium and the techniques required to work with it, others are not. For example, it is a reactive metal, which makes machining difficult. Welding must occur in an inert atmosphere. Cutting tools can bond to a hot working surface and the machined surface is easily damaged (US Bureau of Mines, 1990).

Growth trends and prospects

Data on production and consumption trends in the CIS are not readily available. It was believed that until the end of the Cold War, the USSR consumed more titanium than the US. While the current situation in the CIS is unclear, it is widely believed that the CIS has significant over capacity for both titanium sponge and metal production and large stockpiles of the materials. The price of titanium exported from the CIS has been up to 75 per cent lower than prices prevailing before the CIS entered the world market (Department of Resources Development (WA), 1994).

As noted earlier, the US is a major user of titanium. Data on US use is presented as illustrative of trends in consumption. Figure B7.4 shows titanium consumption in the US from 1973 to 1993.

Figure B7.4: Estimated titanium consumption in the US 1973 to 1993



Note: The figures in the graph have been derived from the three sources below for the time periods 1973 to 1985, 1987 to 1991, and 1992 and 1993. The figure for the missing 1986 year has been interpolated as being mid-way between the figure for 1985 and that for 1987.

Sources: Department of State Development, 1988; and Gambogi 1992, 1994.

The volatile nature of demand has been attributed to the fluctuating demand of the major titanium users, military aerospace and commercial aircraft. As explained earlier, the recent decline in the demand for titanium metal, and the resultant excess production capacity, has been attributed to the end of the Cold War and the associated decline in demand from military users, the slow growth in the global economy, and reductions in demand from the commercial aircraft users (Metals Bulletin, 1993 and Gambogi, 1992). In 1993, production of titanium metal and sponge was approximately 50 per cent below maximum capacity because of these factors (Towner and McAllister, 1994).

Some scope may still exist to increase the usage of titanium in traditional applications. Gambogi (1992) reports that the new Boeing 777 is expected to have approximately nine per cent titanium in ‘empty aircraft weight’ which is an increase from approximately 6 per cent in current aircraft.

Demand for titanium could increase as new high volume applications of titanium become apparent. Gambogi (1992) makes the point that non-aerospace industrial uses are generally those requiring resistance to corrosion. Consequently, these applications could present opportunities to increase the use of titanium. A recent example is the use of titanium in a high pressure drilling riser located in the North Sea. Use in other undersea drilling applications and in the construction of submarine hulls may lead to increased demand.

As previously noted, demand for titanium in Japan is mainly for industrial and consumer applications. The decreasing price of titanium metal and increased availability to non-military users has meant easier access to the metal for use in consumer products. Consequently, use of titanium in consumer applications is expanding rapidly. In 1991, 3 per cent of total titanium use in Japan was in consumer products (Department of Oceania and South East Asia MITI). By 1993, this had increased to be 11 per cent. Consumer products being produced in Japan include titanium golf clubs that were first produced in 1990 and in 1993, in excess of 200 000 were sold (Asahi Newspaper, 1994).

The range of alloys using titanium could increase in applications such as the titanium aluminides. CSIRO is currently undertaking research in this field and comments that titanium aluminides could be used:

> ... for aircraft structures and engine components and for static power generation, [they could] provide value added product opportunities for the Australian aluminium and titanium industries [with a] potential world market of $1.5 – 2 billion by 2010 (sub. 19, p. 13).

B7.6 Competitiveness of Australian producers and users

Production prospects for Australia

There is no evidence that titanium metal will be produced in Australia in the near future. The prospect was considered some time ago and is discussed in section B7.8.

Australian uses of titanium metal and alloys

As noted above, National Forge is one of only a small number of producers in the World of forged titanium metal blades for aircraft engines. All titanium metal and alloys used in Australia have to be imported. Most users of titanium metal and alloys in Australia require only small quantities of the material and this precludes obtaining any quantity discounts on price.

B7.7 Economic significance

Table B7.2 shows the price increases associated with further processing of titanium mill products. The table indicates that in 1993, Australian rutile was purchased for between US$365 and US$390 per tonne, with approximately 2.2 tonnes of rutile required to produce one tonne of titanium metal (Fraser, 1991). The average price of sponge metal was US$8250 per tonne.

Table B7.2: Published prices of titanium concentrates and products, 1993

Concentrates and products	*Price per kilogram (US $)*	*Price per kilogram (US $)*
Concentrates		
Ilmenite fob[a] Australian ports	0.061 - 0.064	
Rutile bulk fob Australian ports	0.365 -0.390	
Metal		
Sponge		7.70 - 8.80
Mill Products		
Billet		13.20 - 16.50
Sheet		16.50 - 17.60
Bar		16.50 - 19.80
Plate		18.70 - 20.90

a Free on board - the value of the goods at the point they are loaded on the vessel of export.
Source: Gambogi, 1994.

The level of value-added is likely to be particularly high in biomedical applications, where titanium often represents a critical enabling material for biocompatibility. In these types of applications, the notional value-added attributable to the material far exceeds the value of the titanium as a metal commodity.

Although titanium is an expensive material and accounts for 6 per cent of empty plane weight, as noted previously, it is only a small part of the total value of the aircraft. This situation would be typical of most applications of titanium; that is, titanium is a critical and expensive component and a key element in value-adding, but only a small part in the overall end product cost.

B7.8 Potential for further production and use

Production

The excess production capacity in major producing countries would suggest a new producer would only enter the market if a cost-saving technological breakthrough in production occurred, and only if the new entrant could compete with selling prices which did not have to cover ‘sunk’ costs. The other difficulty facing a potential new entrant is the existing import duties levied by major manufacturing countries. For example, the US applies ad valorem duties at 25 per cent on unwrought titanium metal, including sponge (Gambogi, 1994).

In the late 1980s, an Australian firm, Ticor (previously Minproc Holdings Limited), had planned to establish a titanium metal plant at Gladstone. The firm obtained a license to use a new production technology called the Ginatta Electrolytic Process. It was a continuous, rather than batch process and so was expected to lead to reduced production costs, estimated at $4.40 per kilogram of titanium sponge (DITAC, 1990).

A draft Environmental Impact Assessment for the Gladstone location was completed in which it was argued that the project had two significant cost advantages (Ellis, 1991). First, Ticor was involved in a joint venture sand mining operation in Western Australia and thus would have had a ready supply of the raw material feedstock for titanium metal — ilmenite and synthetic rutile (even though actual and potential alternative sources of feedstocks were available in Queensland and New South Wales). Second, Gladstone, offered significant locational advantages including reliable and relatively inexpensive electricity — energy costs are between 40 per cent and 50 per cent of total operating costs in titanium production. Over two years the firm invested $15 million before discovering that the Ginatta production process, which appeared to be successful in the laboratory, is flawed and cannot produce titanium metal in a commercial facility at the present stage of its development. Thus, the proposal to produce titanium metal in Australia has been temporarily abandoned by Ticor.

Unless there was a significant reduction in the costs of titanium production, and this would most likely be as a result of a major technological breakthrough, there would appear to be little likelihood of a titanium metal production plant in Australia in the foreseeable future.

The Western Australian Department of Resources Development (1994) maintains that it may be feasible to establish a titanium metal ingot plant in Western Australia. However it notes that a number of (somewhat demanding) conditions would have to be met before a plant could be successfully established. These conditions are:

- an upturn in the civilian aerospace market;
- growth of industrial markets for titanium;
- sustained price increases for titanium ingot;
- decommissioning of existing inefficient titanium metal plants; and
- use of the most efficient processing technology in the proposed plant.

Use

The increasing importance of industrial uses of titanium has been noted. It could be expected that Australian use of titanium in such applications would increase in concert with global trends.

Australia has developed considerable expertise in the use of titanium implants in biomedical applications. The Alfred Hospital in Melbourne is one of only two hospitals in the world involved in using titanium as replacement finger joints. Titanium alloy powders can also be used in prosthetic devices such as artificial hips, knees and shoulders. The powder is used to form a porous surface which allows new bone tissue to grow into it (Biomedical Materials, 1994a). Although the value of these products is very high, the quantity of titanium demanded for biomedical applications is small.

There are some impediments to increasing the use of titanium metal and alloys in Australian industry.

First, Australian firms wanting to develop export markets for titanium products face the costs associated with having to import all titanium used in production then export the final product. Barriers to trade may also be an impediment to developing titanium products for export. For example, producers of export for the US would be subject to import duties of 45 per cent duty on wrought titanium metal (Gambogi, 1994).[5]

Second, the limited use of the metal in Australia means new users may have limited access to or be unaware of any existing technical support. These difficulties are reflected in the experience of an Australian manufacturer who established a dental laboratory to cast titanium. The manufacturer required both equipment and training from overseas. In discussing the experience, it was noted that:

5 Shaped by working with tools.

When the casting machine arrived in Australia we assembled it with no technical assistance...

If something went wrong with the equipment or if a casting had faults in porosity, there was no one that we could approach for help or advice here in Australia. ... Many hours were spend in assessing each step of the procedure to analyse where we had gone wrong so that success could be achieved (Haldezos, 1991, p. 81).

B8 PRODUCTION TECHNOLOGIES

The development and use of production technologies is significant for both the manufacture of a new and advanced material and its subsequent use. A new production technology can decrease the cost of using a material and thus increase its attractiveness relative to other materials. Material properties will also be influenced by the production technology used in its manufacture or application.

For example, new production technologies based on near-net shaped forming result in decreased scrap material and often fewer steps in the production process. Consequently, final product costs will generally be lower for a product made using a near-net shape forming technology than for similar products manufactured using traditional technologies.

However, it is not always the case that materials and appropriate processing technology are developed concurrently. Thus, it may be the case that the use of a material is limited because an appropriate production technology has not been developed. On the other hand, the development of a new production technology may be the impetus to expand the uses of a material. For example, magnesium metal has been produced and used for over 100 years, although it is evident that the further development of casting production technologies will encourage increased use of the material (see Appendix B6).

The importance of processing technologies is evidenced by the fact that the US International Trade Commission (ITC) is conducting investigations into processes which influence the adoption of new manufacturing processes. These processes are considered to be critical for the development of the advanced materials industry and for the future competitiveness of the US manufacturing industry. Some of the processes that the ITC is investigating are listed in Box B8.1.

This appendix describes a range of production technologies that are associated with the production and use of new and advanced materials. Some of the processes are currently being used by Australian industry, and others are not.

The appendix does not purport to identify all the production technologies associated with the production and use of new and advanced materials. It includes those technologies which were identified by inquiry participants.

Box B8.1 Processes being investigated by the US International Trade Commission

The following matters are being reviewed by the US International Trade Commission (ITC). The results will be published in a series of articles in the journal *Industry Trade and Technology Review*.

- Government policies and programs and new manufacturing processes for materials;
- Trends in materials use and processing;
- Direct ironmaking — highlighting multiple company co-operation, industry-government co-operation and environmental factors affecting commercialisation;
- Stir casting — highlighting environmental factors affecting commercialisation and absence of government involvement;
- Sol-gel process — highlighting government-industry partnership in commercialising new processes;
- Spray deposition — illustrating government-industry co-operation and co-operation among end user industries and manufacturers;
- Gas-assist injection moulding — illustrating impact of intellectual property rights on commercialisation; and
- Electron beam curing — highlighting government-industry co-operation and environmental factors driving technology.

B8.1 Metal forming processes

Casting

Casting is fabricating an item by pouring molten metal into a shaped cavity and permitting that metal to solidify.

High pressure die casting is the process in which molten metal is injected at high pressure into a steel die to produce high accuracy, intricately shaped metal components. Metals commonly used in this process include aluminium, zinc, brass and magnesium. There are a number of possible variations to the process. For example, either a hot or cold chamber may be used, depending on the type of metal being cast.

Due to long term research by CSIRO and more recent research work at the CRC for Alloy and Solidification Technologies (CAST), Australia holds a leading position in high pressure die casting technology. This is particularly an area of optimisation of die design aimed at minimising wastage and increasing production rates.

Low pressure die casting refers to the process when the pressure at which the metal is forced into the cavity is slightly above atmospheric pressure.

Comalco and a US based company, Intermet, are involved in a joint venture to develop 'Improved Low Pressure' (ILP) technology. The ILP casting technology uses traditional aluminium alloys to make components with standard characteristics. The benefit of the ILP system is that it reduces the amount of time associated with production. A US patent for ILP was approved in 1993 (Comalco, 1993).

CSIRO's Preston facility, has two pilot plants for casting, one for low pressure and one for high pressure die casting.

Squeeze casting is used to form near-net shape components in materials such as aluminium, magnesium and metal-matrix composites. It is a process for casting metals reinforced with continuous fibres. Fibre bundles are infiltrated with molten metal and a high pressure is applied. This increases the degree of infiltration of the molten metal. This technique has been designed to overcome problems of porosity. Squeeze castings are able to be heat treated. This process is used in the automotive industry.

Australian research work on squeeze casting is currently being conducted by CAST at the University of Queensland. A pilot plant for squeeze casting has been established at Pinjara Hills, in Queensland, in association with CSIRO, CAST and the Queensland Centre for Advanced Technology.

Rapid solidification processing (RSP) is the process of rapidly cooling metals or metal alloys from molten state to room temperature. It enables control of the microstructures properties of a material. The process can be used to improve the strength, corrosion resistance, and electrical and magnetic properties of a material. The materials are usually formed as a wire or strip. CSIRO is undertaking work on this process.

Powder metallurgy

Powder metallurgy (PM) is the process of transforming powdered metals into components. These components are mainly used in the automotive, mining and white goods industries.

The four steps to make a PM component are:

- manufacture of powders;
- blending of powders;

- compaction of powders in a press; and
- sintering the product (this process is discussed in section B8.3).

The advantage of the PM process is the ability to produce near net shape components, that is, the process produces components of the desired final dimensions. This involves minimum wastage of material. The process provides an alternative route to the production of components which avoids the traditional steps of forging or casting hot metal followed by machining to achieve the desired shapes, and can thus be a less expensive method of production. The PM process also produces in large volumes products of consistent size and shape. Different combinations of powders can be used to achieve different component properties. PM components are lighter than components made from a solid material.

These advantages have led to the wide and increasing use of PM components by automotive manufacturers.

PM parts remain porous, even after sintering, which can be either an advantage or a disadvantage, depending on the application. A porous part will never be able to achieve the strength of a non-porous component.

Research work on the sintering process and the consolidation and flow of metal powders is currently being conducted at the University of Queensland in the Department of Mechanical Engineering and the Department of Mining and Metallurgical Engineering. The researchers at the University of Queensland are also involved in a collaborative ARC project with Comalco and ACL Bearings on the processing and sintering of aluminium powders.

Heat treatment

Heat treatment consists of various processes used to give properties of strength, toughness, ductility and wear resistance to products.

In Australia, heat treatment is used in activities such as engineering, forging and foundry. Cavallaro, *et al* (1993) report that the heat treatment processes most frequently used in Australian industry are: stress relieving, normalising, annealing, quenching, tempering and austempering. New heat treatment processes include plasma nitriding and carburising, laser and electron beam hardening. These processes (described below) are not widely used by Australian industry.

Stress relieving is the process of heating to a suitable temperature, then holding this long enough to reduce residual stresses (that is, the stress remaining in a structure) and then cooling slowly to minimise the development of new residual stresses.

Normalising is applied to steels and involves heating to a suitable temperature above the critical range, followed by cooling to below that range in still air. Normalising promotes uniformity of structure and produces beneficial end-properties.

Annealing is the process of heating to, and holding at, a suitable temperature and then cooling at a suitable rate for such purposes as reducing hardness, improving machinability, facilitating cold working, producing a desired microstructure, or obtaining desired mechanical, physical, or other properties.

Quenching is rapid cooling. There are a number of quenching techniques which may be used. They include direct quenching, fog quenching, hot quenching, interrupted quenching, selective quenching, spray quenching and time quenching.

Tempering is reheating to a temperature below the critical range to secure the desired combination of strength and ductility.

Austempering is an isothermal heat treatment for steel. Cast metal is heated to a temperature in the austenite phase region (between 815°C and 925°C) then holding for the length of time required to saturate the austenite with carbon. The metal is then quenched. Austempering is used to obtain strength and ductility in a material.

Induction hardening is a selective hardening process in which the localised heat is produced by electromagnetic induction.

Nitriding depends on the diffusion of nitrogen into the surface of a steel article. The processing temperature range is 500-600°C and no subsequent quenching is necessary.

Carburising involves the diffusion of carbon into the surface of a steel article and transformation to martensite. The processing temperature range is 860 – 980°C.

Electron beam (surface) hardening is a selective surface hardening process that rapidly heats a surface by direct bombardment with an accelerated stream of electrons.

Plasma nitriding is the process in which the article becomes the cathode in the plasma of a high-current glow discharge in an atmosphere which contains nitrogen. The process occurs at low pressure and relatively low temperatures (350°C).

Other metal fabrication techniques

Forging is the process of plastically deforming (usually hot) metal, into desired shapes with compressive force, with or without dies. It can involve reshaping a billet or ingot by hammering.

Rolling involves passing the material between two rolls revolving at the same peripheral speed, but in opposite directions. The rolls have smooth or grooved surfaces and the gap between them is smaller than the height of the material at entry. During its path through the rolls, there is a reduction in the cross-sectional area with corresponding increase in length. This process may occur more than once and on different sets of rolls before the desired shape is achieved.

Extrusion is the process where a heated piece of metal is placed in a chamber. High pressure is applied from one end by means of a hydraulically operated ram. This causes the metal to flow through a restricted orifice at the other end to produce various shapes.

Drawing is the process of gradually reducing the diameter of a metal rod (or plastic cylinder) by pulling it through perforations of successively diminishing size in a series of plates. This production technology can be used to produce wire and specialty filaments.

B8.2 Welding and joining processes

Welding and joining production technologies are essential for the development of many manufactured products. Joining processes include welding, brazing, soldering, and using adhesives and fasteners.

Welding refers to the process in which the localised coalescence of materials is achieved through application of heat or pressure either jointly or individually.[1] There are many specific welding technologies including a range of arc welding processes, electron beam welding and laser beam welding.

A CRC for Materials Welding and Joining has been established. Organisations involved in this CRC include the Universities of Wollongong and Adelaide, ANSTO, BHP, CSIRO and the Welding Technology Institute of Australia.

Arc welding processes achieve coalescence by the heat of an electric arc being established between the base metal and an electrode. There are various methods of arc welding which are determined by the way the arc is shielded from the atmosphere. For example, in the gas-tungsten arc welding process (or TIG

1 Coalescence involves coming together to form one whole.

process) the shield is provided by the flow of inert gas, often argon or helium, through the welding torch nozzle.

Electron beam welding achieves the heat of coalescence by bombarding the base metals with a concentrated stream of electrons. This process allows welding of thick sections with a narrow zone of molten metal and often occurs in a vacuum.

Laser beam welding produces the heat of coalescence by focusing a beam of light from a high power laser on the base metal. Laser welding is a high energy welding process and allows a deep penetration of the base metal.

Solid state welding processes are those that produce coalescence of the surfaces at temperatures below the melting point of the base metal being joined without the addition of brazing or solder filler metal. Pressure may or may not be applied. The process can be used to produce high quality joints between both similar and dissimilar materials. Diffusion bonding used in fabrication of titanium components is an important solid state welding process.

Brazing is a process for joining solid metals in close proximity by introducing a liquid metal that melts above 450°C. The introduction of automation has brought brazing processes to the forefront in large scale production.

Soldering refers to the process of joining materials at a temperature less than 450°C. The solder acts as an adhesive and, unlike welding, does not form an inter-metallic solution with the materials being joined.

Adhesives are simply substances capable of holding materials together by surface attachment. Adhesives are widely used in household appliances, industrial applications (especially in the automotive industry), and the medical and dental fields.

The development of polymers has resulted in the development of adhesive resins which are strong and tough under thermal stress. These resins have been used in the construction of concrete bridges, and are used in critical applications in aircraft and aerospace systems and electronic equipment.

B8.3 Ceramic forming processes

Sol-gel technology is the process of reacting liquid state precursors to form a porous unfired ceramic shape. The most common case involves the reaction of a metal alkoxide with water to form an oxide.

Preparation of a ceramic by a sol-gel technique usually involves three stages:

1. hydrolysis and condensation to form individual particles or polymers;

2. linking of these to form a high viscosity gel; and
3. aging and drying to remove all or part of the solvent and form a shrunken and porous ceramic precursor. The precursor is then heated to a temperature which depends upon the degree of consolidation desired.

The sol-gel process is used to produce bulk ceramic articles, thin films and coatings.

An Australian company, Silicon Technologies Australia, is involved in research and development of commercial applications of this technology. It is working to produce ceramic coatings which may be applied to windows to minimise heat transfer, to sensors for surveillance, and to glass for protection against corrosion and scratching (sub. 63). A more detailed description of this firm’s activities is presented in Appendix B3.

Cold pressing involves compacting a powder between two plungers in a die cavity. It is used to manufacture products of uniform thickness and symmetric shape.

Cold isostatic pressing usually involves room-temperature pressing of a powder-filled flexible container, using water or oil as the pressure medium.

Sintering is the welding together and growth of contact area between two or more initially distinct particles at temperatures below the melting point. The rate of sintering is increased by the use of increasingly smaller, rather than coarse, powders. Generally powders are compacted at room temperature either by pressing in a die or by isostatic pressing, then sintered at a higher temperature, but without the application of pressure. The density of a compact will increase with sintering.

Hot pressing is the process of compressing a powder in a heated die between two forming rams. The process is similar to cold pressing, except that the pressing is conducted at sintering temperature and sintering occurs simultaneously with compaction. Hot pressing can only be used to form simple shapes.

Hot isostatic pressing (HIP) involves placing powder or moulded articles in a gas-tight capsule, which is then placed in a furnace. The simultaneous application of temperature and pressure eliminates microvoids. This process can be used to produce various shapes from ceramic materials with superior properties, for example, density, uniformity and rupture strength.

Developments of HIP at ANSTO have contributed significantly to the Synroc program for nuclear waste disposal. Chapter 3 provides more detail on the development of the Synroc process.

B8.4 Polymer forming

Processing techniques

Advanced polymers

Compounding is the process of mixing polymers with various additives and fillers which can then be extruded and chopped into pellets to be sold to plastic moulders and processors.

Extrusion involves forming melted resin which is forced through a nozzle or die that has the shape of the intermediate product, which may be tubes, pipes, sheet or film.

Injection moulding involves forming melted material under pressure into a cavity and ejecting the finished part when the material has solidified. This technique can be used to produce both thermoset and thermoplastic products.[2]

Blow moulding involves placing a parison of heated thermoplastic between two halves of an open split mould.[3] The mould is closed and the parison expanded against the sides of the closed mould by air pressure. The mould is then opened, the part ejected and the scrap is trimmed and reused. Blow moulding may be either an intermittent or continuous process.

Compression moulding is mainly used for thermosets. With compression moulding, the material is placed in a heated mould which is closed and pressure applied. Wiring devices, closures and sheets are produced by this technique.

Advanced reinforced plastics

Pultrusion is a process that produces long extruded shapes with various constant profiles (extrusions). Continuous reinforcement filaments are pulled through a thermosetting polymer bath and then through a long heated steel die. The product is cured in this process. The most common material for pultrusion is polyester with glass reinforcement. Pultrusion fabrication is also used for thermosets.

Filament winding is used to produce axi-symmetric parts, such as tubes and storage tanks, in a rotating mandrel. The reinforcing filament is wrapped continuously around the form. The reinforcements may be prepregs, or they

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2 A thermoset is a plastic in which the polymers become cross-linked in processing and thus cannot be reheated to be reused. A plastic which can be reheated is a thermoplastic.

3 A parison is a molten hollow plastic tube or a preliminary shape.

may be impregnated by passing them through a polymer bath.[4] Final products are strong due to a highly reinforced structure.

Filament winding is used in the production of high integrity structural composites (tanks, bars, pipes, rocket casings and bolts). This process can be automated. Applications include aerospace, mining, chemical and petrochemical storage and construction.

Resin transfer moulding (RTM) occurs when the material is heated in a transfer chamber, then forced into a closed mould, heated and ejected when solid. RTM is usually quicker than compression moulding and is mainly used for thermosets and composites.

Open moulding involves forming reinforced shapes. Approximately 60 per cent of total output in the Australian plastics industry is produced by open mould methods (sub. 14). Methods include:

- *The hand lay-up process* (also called open shell moulding) — resin is brushed, poured or sprayed onto reinforcing material placed in the mould. The quality of the final product depends on the skill of the operator. This method is used for thermosets in boats, automotive bodies and structural sections;
- *The spray up method* — resins and chopped fibres are sprayed into the mould. This method is used to produce furniture, boats and automotive components;
- *The reinforced vacuum formed sheet method* — the material is vacuum formed and reinforced resin is applied to back the surface; and
- *Continuous laminating* — the reinforcement is covered with cellophane and has resin dipped or sprayed onto it and a second sheet of cellophane added. The process is completed by passing the product through a heat zone.

Resin injection moulding (RIM) involves forming, under high pressure, a mixture of two or more reactive fluids, into a mould cavity. Very rapid chemical reactions take place in the mould and the polymer solidifies. Various reinforcements, such as fibre glass, may be added. It is similar to hot-chamber die casting (using a piston to trap material and force it into a die cavity at high pressure). Pellets or granules are heated and forced into a split-mould chamber (using a hydraulic or screw system) at pressures exceeding 20 000 psi (140 MPa).

[4] A prepreg is reinforced material containing, or combined with, the full complement of resins before moulding.

B8.5 Surface coating treatments

The special properties of ceramic, metal and polymer coatings lead to a wide and diverse range of applications including tribological, electronic and optical protection at high temperatures, and large-scale architectural and automotive use.[5]

A specific coating technology is not restricted to producing one type of coating. For example, the physical vapour deposition process (described below) can be used to produce metal, alloy, semiconductor, superconductor and polymer coatings.

Chemical Vapour Deposition (CVD) is the deposition of a solid material from the vapour phase onto a (usually) heated substrate as a result of many chemical reactions. It is an established surface coating technology. The process occurs at relatively high temperatures in the range of 1000°C to 2000°C.

Hard CVD coatings are widely used in industry. For example, about 70 per cent of all metal cutting inserts in the US and Europe are now coated by the CVD process. CVD coatings are also used in brick making, textile machinery and glass making, microelectronic applications, extrusion and die casting of aluminium and the hot forging of steel (sub. 38). CVD coatings can be used to protect against the effects of wear, erosion and high-temperature oxidation.

The main advantages of CVD coatings are high adhesion, good throwing power resulting in good coating uniformity and ability to deposit multi-layer coatings. CVD processes are also attractive because of their ability to deposit a wide range of coatings on various types of materials. The main disadvantage of CVD is the high deposition temperature which can cause problems of distortion and microstructural modification of substrate.

Physical Vapour Deposition (PVD) involves creating material vapours by evaporation, sputtering or laser ablation, and then condensing them onto a substrate to form a film. This technique has the fundamental characteristic that one or more of the constituents undergoes a change in state from the solid to the vapour phase within the confines of a vacuum chamber. The PVD processes fall into two general categories: sputter deposition and evaporative coatings. PVD achieves a high level of adhesion and enables deposition of ceramic coatings at relatively low temperatures, 150°C–500ºC.

The advantages of the process include generally good adhesion between coatings and substrates, thickness uniformity, usually no need for post-coating finishing operations, high resistance to corrosion and good chemical stability at

5 Tribological refers to friction and wear.

high temperatures. The process is versatile, being able to deposit many materials, including metals, alloys and polymers and produce different types of composites — particulate, fibrous or laminate. There are disadvantages of PVD technology, namely, limited throwing power (which requires manipulation of components during deposition to achieve uniform coating coverage), high costs associated with equipment, and high energy requirements (Cavallaro *et al.*, 1993).

CSIRO, in conjunction with the Royal Australian Mint and Dynavac Engineering Pty Ltd, has used the PVD process to develop the filtered arc deposition system (FADS 3000). This is the first PVD based surface coating technology which provides a coating smooth enough to meet the coating standards for proof coin dies. A FADS 3000 unit is currently undergoing final trials at the Royal Australian Mint and will be marketed by the Mint and Dynavac.

Thermal spraying is a generic term denoting a group of commonly used processes for depositing metallic and non-metallic coatings. There are two basic types of thermal spraying processes, combustion processes and electric power processes. The combustion process relies on the combustion of a hydrocarbon fuel (acetylene, propane, kerosene) and oxygen to plasticise and propel the powder particles onto the substrate. In the second process, the electric power (wire, arc or thermal plasma) is the source of energy used to spray the powder particles. A variety of technologies, such as flame spraying, arc plasma spraying, electric arc spraying and various high velocity oxygen fuel spraying techniques are involved. Some of the specific thermal spraying processes are described next.

Plasma spraying (both low and high pressure) is where a molten refractory metal is atomised and then sprayed onto a preform where it solidifies. The solidified shape may be further consolidated and shaped by forging. Alternatively, metal may be sprayed as micro-droplets from a plasma device onto reinforcement fibres on a preform. It may also involve the sequential deposition of plasma-sprayed metal and particulate or chopped fibre reinforcements.

Arc-plasma spraying occurs when uniformly sized particles are fed into the jet that emerges through the nozzle of a high pressure direct current arc. The particles are melted and ejected.

Sputtering is the process where small particles are ejected in short bursts to deposit a thin metallic film on glass, plastic, or metal in a vacuum.

Laser coating is where laser power is applied to produce sprays of powdered material for coating purposes. Powder particles can be accelerated in the laser beam and melted before striking the substrate material where rapid solidification takes place.

Electroplating is the coating of an electrically conducing surface by application of an electrical potential in a suitable solution that contains the ions of the metals to be deposited. The electrode to be coated is the cathode. The most common use of electroplated coatings is to provide corrosion resistance to the substrate on which they are applied. The coatings are also used in applications which require resistance to wear and toughness.

Hard facing is any process that produces a hard surface on a metal which remains relatively soft.

Pratco Industries Limited is an Australian company which has developed a hard facing based process. The process is used mainly on high wear areas of machine parts and blades used in the agricultural and mining industries. The process is called Tuff-Tung hard facing. A powdered metal-matrix composite of steel and tungsten-carbide is distributed via an electric arc process onto the surface of the metal substrate. The result of this process is the controlled introduction of tungsten-carbide particles into a molten pool of parent material. This produces a highly wear resistant and thin hardfacing system.

B9 THE AUTOMOTIVE INDUSTRY

This case study focuses on the current and potential use of advanced materials and new processing technologies in the automotive industry, both overseas and in Australia, and considers in some detail impediments to their uptake.

B9.1 The automotive industry and new and advanced materials

The automotive industry is the World's largest manufacturing activity. This means the uptake of new materials by the automotive industry, even if relatively small compared to the current use of traditional materials, could determine to a large extent future use of new materials.

Most new materials and advanced processing technologies covered in this report have applications in the automotive industry. These include:

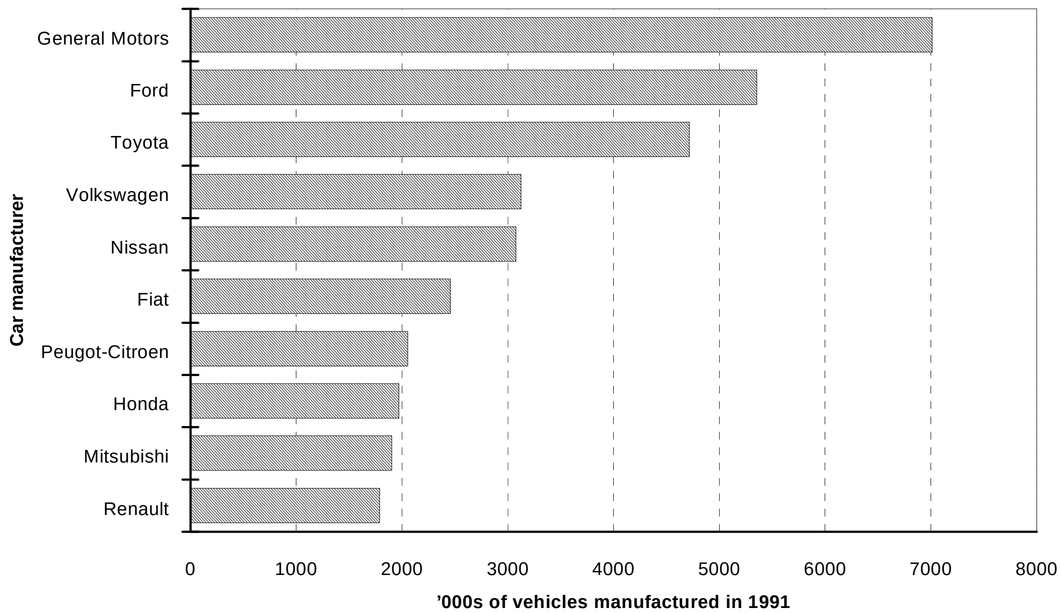
- aluminium and magnesium alloys — which bring with them many of the properties of steel and iron, but weigh less and have processing advantages;
- new processing technologies — new casting, welding, surface coating and die stamping technologies have applications in the automotive industry; aimed at optimising the use of 'traditional' materials such as iron and steel, and adapting existing processes to cope with new materials;
- powder metallurgy — for use in engine components such as camshafts, connecting rods and pistons;
- ceramics — for specific non-structural applications such as exhaust manifold liners, piston crowns, wear resistant seals and turbocharger turbines;
- plastics and polymers — currently used in many non-structural applications including interior and exterior trim, as well as the potential for much wider use in applications such as bumpers, hang-on body panels, and a variety of engine-accessory components. These materials bring with them a range of properties including lighter weight, ease of forming and quality finishes; and
- iron and steel — although by no means 'new materials', the need not to neglect these two inputs was stressed by several participants involved in the automotive industry. Iron and steel play such a large role in the automotive industry that optimising their use, and the development of new high strength and microalloy steels, could overshadow other new material developments.

B9.2 The World automotive industry

International production and usage

There were around 580 million passenger motor vehicles in use in 1991, with 160 car manufactures in operation (Lethbridge, 1992). A breakdown of production is given in Figure B9.1. About 48 million vehicles were produced in 1993, with around 36 million of these being cars (Australian Automotive Industry Authority, 1993).

Figure B9.1: Output of the World's top ten automotive producers



Source: Letherbridge, 1992.

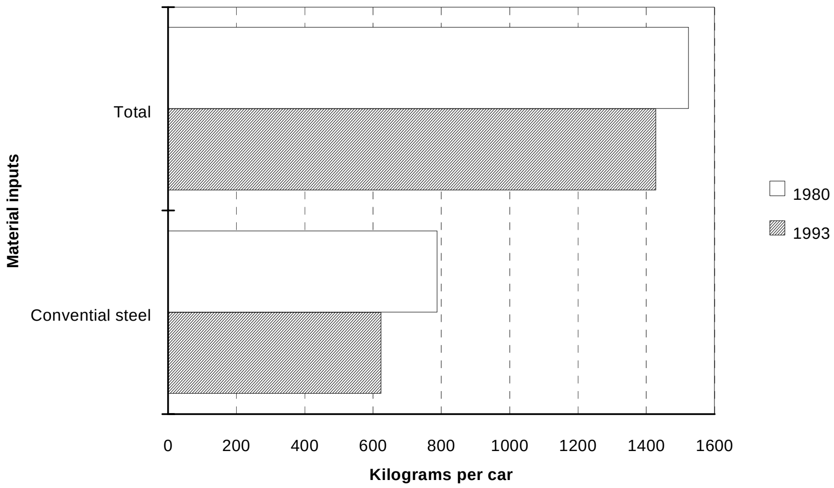
This production is dominated by the United States, Japan and Germany. But other industrialised and some developing nations are starting to make inroads into their markets. As stated in the *Delphi VII Forecast and Analysis of the North American Automotive Industry*:

> The 'Big Three' auto-producing nations — Japan, the United States and Germany — will continue to dominate world production. But second tier producers — led by France and Spain — could represent as much as 5 million units of output annually as Canada, South Korea, the United Kingdom and Mexico join this group (*University of Michigan Transportation Research Institute*, 1994).

Current material usage

The average car weight in the US has dropped by six per cent since 1980. This is reflected in the change of material inputs. Conventional steel still accounts for the greatest input, 43 per cent of material weight, but this is 20 per cent less than in 1980 (see Figure B9.2).

Figure B9.2: Average US car weight and steel use, 1980 and 1993



Source: (American Metal Market, 1993) as quoted in Winter, 1993.

Over this period, there has been a general fall in the level of use of cast iron (14 per cent decrease) while glass and rubber stayed about the same. However, the demand for other materials that are regarded by some to be traditional materials increased. For example, the use of high strength steels increased by 245 per cent, and the use of magnesium increased around 300 per cent (see Figure B9.3).

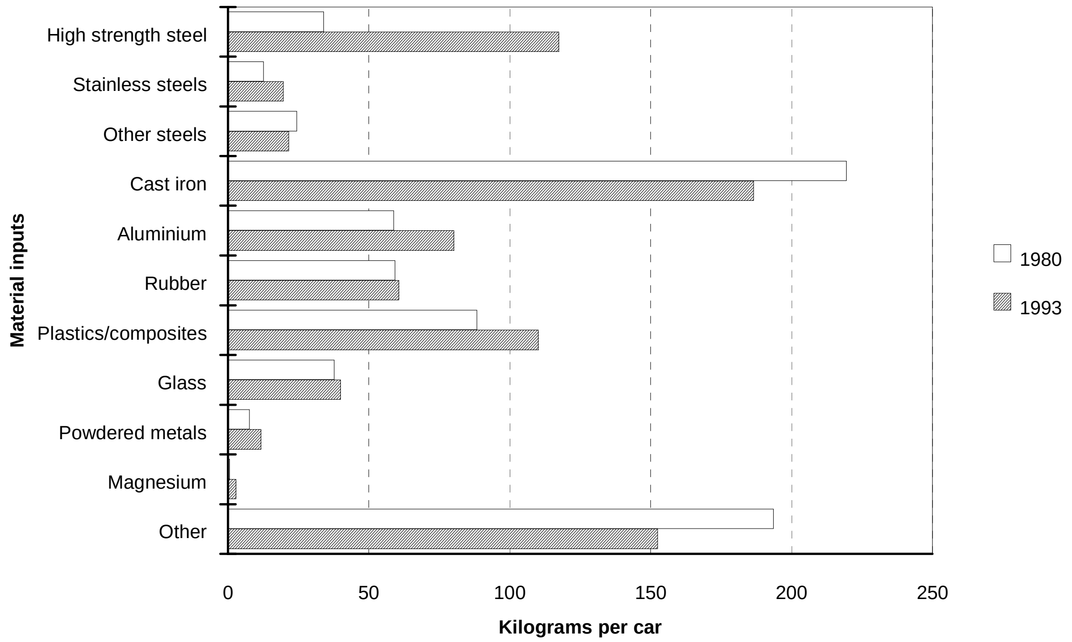
Other materials which benefited from increased use during the 1980s included:

- aluminium — 36 per cent increase;
- plastics and composites — 24 per cent more use; and
- powdered metal parts — about 50 per cent rise.

Australian production and usage

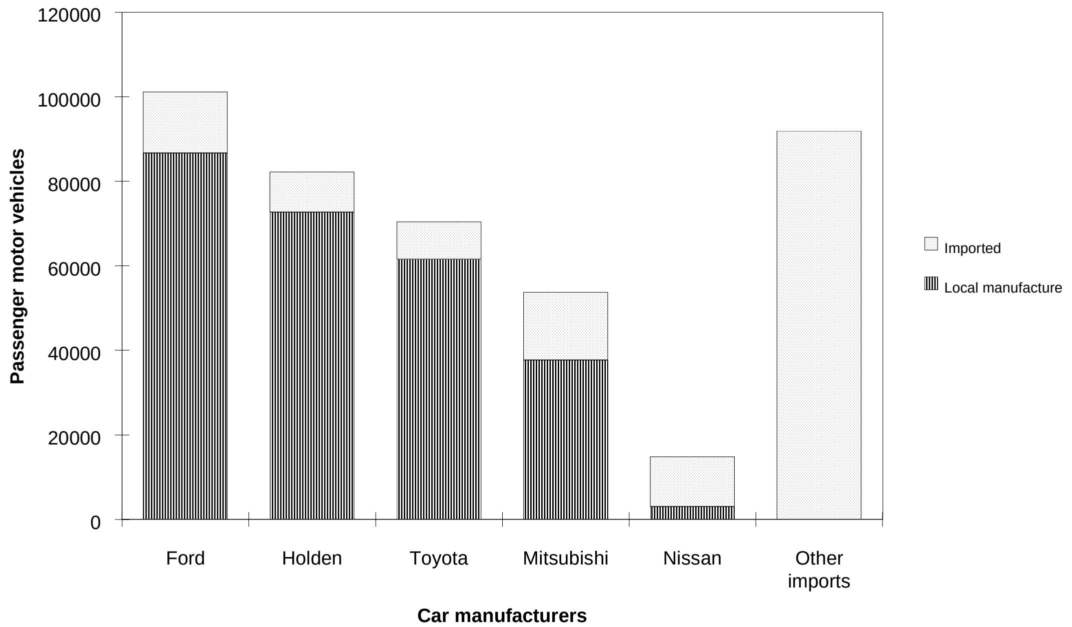
Toyota, Ford, Holden and Mitsubishi all manufacture passenger motor vehicles in Australia, with Nissan withdrawing its car assembly activities from Australia in 1992. There are about 200 automotive component manufacturers. Figure B9.4 and Box B9.1 give a snapshot of the Australian car industry.

Figure B9.3: Material consumption per car in the United States, 1980 and 1993



Source: (American Metal Market, 1993) as quoted in Winter,1993.

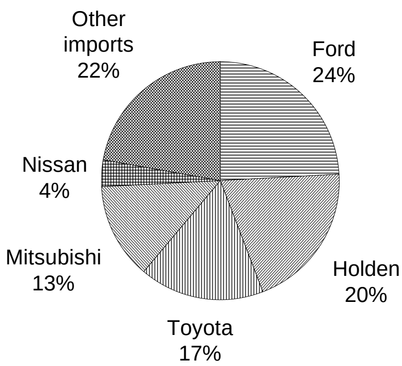
Figure B9.4: Car production and imports in Australia, 1992–93



1 Note: Nissan ceased to be a manufacturer after 1992. Sales in 1993 are out of 1992 production.
Source: VFACTS, *Vehicle Retail Sales*, 1992-93 as quoted in the Automotive Industry Authority, *1993*.

Box B9.1: A snapshot of the Australian automotive industry: 1992

Market share



Domestic sales of new vehicles rose 2.4 per cent to 553 306. Passenger motor vehicle sales increased two per cent to 414 425, with a slight weakening in sales to private buyers being more than offset by a rise in sales to corporate fleet owners. Despite the withdrawal of Nissan from local production at the end of 1992, sales of locally produced cars increased slightly by 0.2 per cent to 261 541.

Production of cars rose 5.9 per cent to 294 070, underpinned by a 15.6 per cent rise in production of large cars. The value of car production increased by 22.4 per cent to $6 490 million.

Exports of automotive products (vehicles and components) totalled $1 465 million, an increase of 17.5 per cent for the year. From 1984 to 1992 the average annual growth of exports was 16 per cent. The United States was Australia's largest market for automotive exports, accounting for 24.3 per cent of the total.

Imports increased by 5.1 per cent, their share of the new car market rising slightly from 35.8 per cent to 36.9 per cent. South Korea's import share increased from 11.5 per cent to 17 per cent, largely at the expense of Japanese sourced vehicles which were down from 77.2 per cent of the total imports to 73 per cent, following the appreciation of the yen.

Source: Automotive Industry Authority, 1993.

B9.3 Supply conditions

As mentioned earlier, many new materials and processes have applications and potential use in the automotive industry. A brief description of some of these applications is outlined below.

Material properties

Aluminium

The characteristics of primary aluminium and, in particular, new aluminium alloys offer a wide range of uses for the automotive industry. Aluminium's low density and mechanical strength make it particularly suitable for car manufacturers interested in reducing the weight of their vehicles.

These characteristics can be altered, via alloying, in order to engineer aluminium alloys or composites to fit specific applications.

However, the relatively high cost of aluminium and the costs associated with altering production processes are seen as barriers to its use. In addition aluminium does not stamp as well as steel, and is easier to dent. However, stronger alloys have now been developed that meet automotive manufacturers requirements for press formability.

> Some automakers have discovered that aluminium, unlike plastics, can be handled and formed using the existing plant infrastructure originally installed to process steel sheet (Advanced Materials and Processes, 1994).

The potential use of aluminium will be governed by a price quality trade-off. For example, to produce a car bonnet made out of aluminium as opposed to steel would more than double production costs. But the new bonnet would be only one third of the original weight. The question facing users is whether the weight reduction is worth the extra cost.

The use of aluminium has increased in automotive production during the 1980s (see Figure B9.3), and this trend seems likely to continue. As Winter said:

> This may be a banner year for aluminium, but even steeper future growth is predicted, particularly in the area of body panels and structural components. Ford is by far the most aggressive US automaker in its plans for aluminium usage, especially iron body-panel applications. It already uses about 350 000 aluminium hoods per year... The automaker predicts Ford cars will have an average of [143 kilograms] of aluminium just in body panels by 2005. Ford's aluminium-intensive Synthesis concept car is the latest example of the automaker' s increasing interest in the light metal (1993).

Magnesium

Like aluminium, the interest in magnesium is driven by the manufacturers' response to customers' interest in lighter automotives, as well as its suitability to new casting techniques. The relative weight of magnesium, 50 per cent lighter than aluminium, and the ease in which it can be processed are seen as making it suitable for use in the automotive industry. Advanced Materials and Processes said:

> Magnesium, at two-thirds the density of aluminium, has always competed with cast aluminium. Due to increased pressures for weight reduction, the use of magnesium in passenger cars will increase significantly in the coming decade. However, the cost penalty per pound saved of magnesium relative to aluminium remains a deterrent (1994).

The use of magnesium by the automotive industry has increased three hundred per cent in the United States over the last decade. This was from a very low base of only 1.5 kilograms per car (see Figure B9.3), but Winter predicts this to increase:

> But those small numbers belie much bigger realities in low volume vehicles. The entire seat frame of the Mercedes 500SL and 300SL 2-seat coupe is made of magnesium, as is the bi-instrument-panel support bracket on the Audi V8 (1993).

Automotive parts currently being made, or likely to be made in the near future, from magnesium include housings, brackets, seat frames, wheels, valve and transmission side covers, steering wheel components, oil pans, door frames and trim, intake manifolds, and brakes and brake pedals.

Engineering plastics

The engineering plastics being used by Australian automotive manufacturers are, on average, about a decade old. The processes involved with the use of these plastics are relatively new. Changes in both materials and processes have been evolutionary. New ‘high performance’ plastics (that is plastics capable of withstanding extreme temperatures and stress mainly used for advanced aerospace and defence purposes) are viewed as far too expensive to use in private motor vehicles, and their superior performance is not needed for this market.

One area where evolution is continuing to take place is the ‘blending’ of engineering plastics and alloys. By blending, producers can get the benefits of both materials without losing any preferred qualities. Improvements to materials properties attributable to blending that have been achieved over the past nine years include lower shrinkage, improved surface appearance, wear and heat capability. Further discussion on engineering plastics can be found in Appendix B4.

Another area manufacturers are putting considerable effort into is the forming of plastics. They are undertaking developments to make plastics flow more readily into the moulds, casting thinner walls, reducing cooling times and the amount of plastic required for production.

Production technologies

Die casting

Magnesium and aluminium are particularly suited to die casting technologies. The continuing development of these technologies could lead to an increased use of aluminium and magnesium in the automotive industry. Growth will be largely influenced by the relative prices of aluminium and magnesium, and the demand for lighter car parts. Aluminium and magnesium are replacing die cast zinc products in many automotive applications.

Advantages of improved casting technologies include:

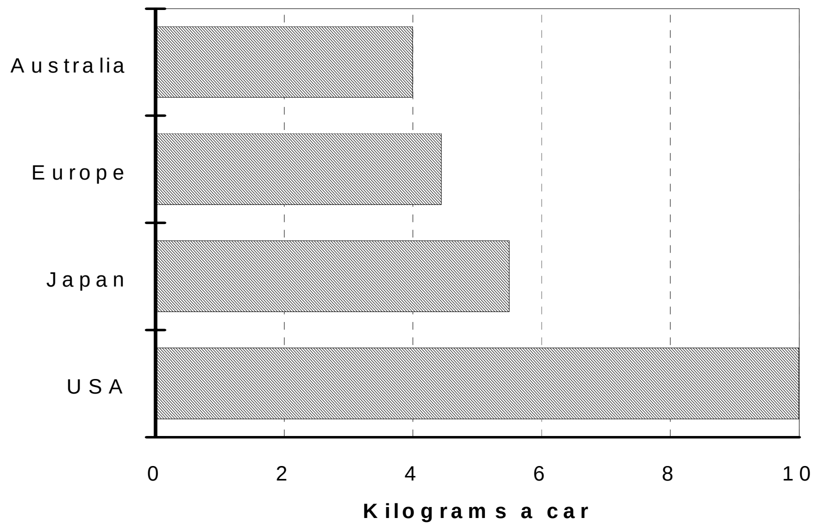
- 'thinner' casting — that is the ability to cast relatively thin sections which use less material and cool more quickly than traditional moulds;
- less wastage; and
- the ability to cast more complex parts.

Powder metallurgy

The largest user of powder metallurgy products in Australia is the automotive industry, which accounts for 45 per cent of domestic demand. Parts made by powder metallurgy are used in such components as oil pump gears, valve guards, door hinge brushes and shock absorber parts.

There is perhaps scope for further use of powder metal parts in the Australian automotive sector. The automotive industry is the largest consumer of these metals World wide. It accounts for 70 per cent to 75 per cent of all powder used in the powered metal industry World wide — while in Australia the automotive industry accounts for only 45 per cent of powder metals use. On average, Australian cars have less powder metal parts per car than in passenger cars throughout the World although it is only in the US that a significant amount is used (outlined in Figure B9.5).

Figure B9.5: Powder metal use by the auto industry



Source: Materials Australia, 1993.

B9.4 Demand conditions

Substitutability

Much of the focus on applying new materials to the automotive industry lies in the demand for lighter, more fuel efficient cars.

Car weight can be reduced in a number of ways utilising new materials. These include:

- aluminium body parts replacing steel;
- aluminium and magnesium alloys replacing engine and structural support parts;
- the greater use of powder metal parts for specific engine component applications;
- replacing steel panels with engineered plastics and polymers;
- advances in aluminium and magnesium casting techniques, enabling parts to be cast faster, more efficiently and, perhaps most importantly, cast more ‘thinly’;
- replacing glass with clear plastics; and
- using higher strength steels.

However reducing the weight of cars is not the only way to save fuel and reduce emissions. Greater fuel efficiency can be achieved through improvements in engine efficiency and improving aerodynamics. Designing smaller automotives powered by alternative fuels are also possibilities that may limit the future demand for new materials.

Substituting between new materials and traditional materials

Although considerable focus has been placed on new materials replacing traditional materials, steel manufacturers have been conducting research to remain competitive. The development of high strength and microalloy steels will compete directly with new materials, as they are stronger and lighter than traditional steels.

An advantage steel has over new materials is that it does not have to overcome the costs associated with changes in manufacturing. For new materials to be implemented into a production process, new capital must be purchased (or existing equipment adapted) and manufacturers must learn to use any new technology involved.

European steel manufacturers are currently working with Porsche to continue to develop high strength steels, while microalloy steels using boron as an alloying element have now been developed by BHP.

Developments in alloy steels are progressing quite rapidly.

> More than half the alloy steels now regularly used in automobiles were not available as recently as 1986. Since the early 1970s, micro-alloyed steels have been widely used for crankshafts, connecting rods, gear shift forks and levers. Volvo are using 25 000 tonnes of micro-alloyed steel a year. The Rover Group in Britain claimed an annual saving of £500 000 by replacing a heat treated manganese-molybdenum alloy steel crankshaft with a micro-alloyed steel forging (Street and Alexander, 1994).

Growth trends and prosects

New materials utilisation is very much dependent upon fuel economy legislation and changes in consumer demand (which can be independent of legislation). The *Delphi VII Forecast and Analysis of the North American Automotive Industry* placed estimates on material inputs under a given set of fuel economy standards (University of Michigan Transportation Research Institute, 1994).

It estimates that if the Corporate Average Fuel Efficiency (CAFE) standard (see following) was set at 35 miles a gallon by 2003, steel and cast iron use would fall by 20 and 30 per cent respectively. The use of aluminium would increased by 50 per cent, while magnesium inputs would increase by over 300 per cent. However, this 300 per cent increase is from a very low starting point of 4.5 pounds (2 kilos) a car to 15 pounds (6.8 kilos), in 13 years.

The estimated material use outlined in the Delphi VII report are presented in Box B9.2 and Figure B9.6.

Box B9.2: Estimates of car inputs in the year 2003

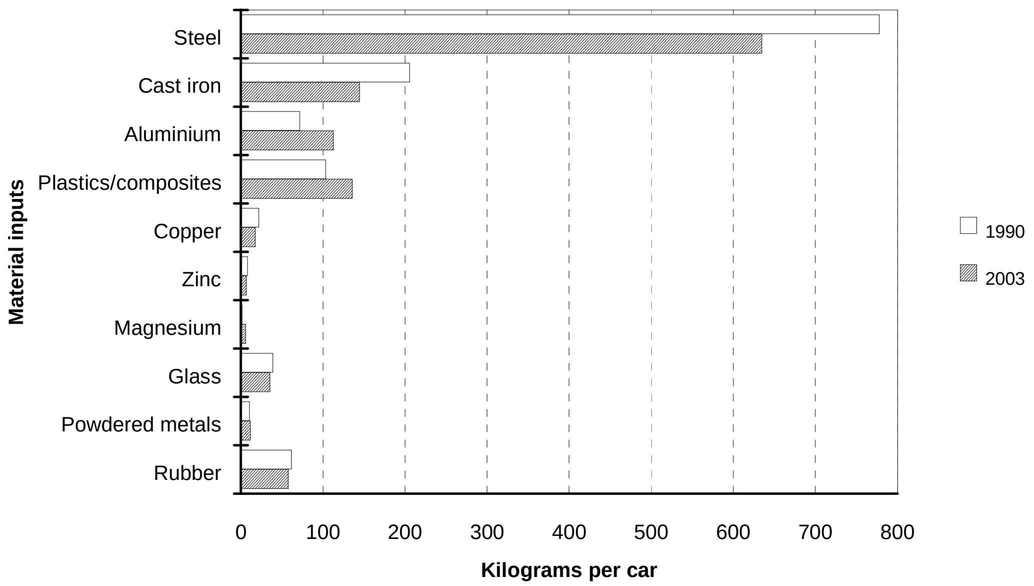
A 15 per cent increase over the next decade is forecast for plastic usage in passenger cars. Polymers that are expected to experience increased use include polypropylene, polyethylene and nylon. Concurrently, polyvinyl chloride use is forecast to decrease.

Other lightweight materials are also expected to increase substantially. Aluminium and magnesium will likely see increased application. Aluminium will likely see gains in several strategic areas. It is expected to be used in 70 per cent of cylinder heads and 40 per cent of cylinder blocks by 2003. Aluminium is also forecast to be used in nine per cent of car frames and 89 per cent of styled wheels by 2003. Magnesium is forecast to see use in a wide variety of applications including various housings, instrument panel components and seat frames.

Powdered metals, metal matrix composites and other materials are expected to experience increased application in engine components such as camshafts, crankshafts, connecting rods and pistons.

Source: University of Michigan Transportation Research Institute, 1994.

Figure B9.6: Material usage in US automotive production, 1990 and 2003



Source: University of Michigan Transportation Research Institute, 1994.

Influence of government regulation

Government legislation can play a large role in influencing the direction of materials use in the automotive industry. Regulation affects all aspects of manufacturing, including fuel economy, safety and recycling requirements.

Fuel efficiency

Corporate Average Fuel Efficiency (CAFE) standards

In an effort to reduce fuel consumption, the CAFE standards, as enforced by the US Environmental Protection Authority (EPA), place each vehicle within the automotive manufacturers' fleet in a 'weight class'. The EPA tests the engine's fuel economy with consideration given to the weight class in which the engine is categorised. The average weight of each manufacturer's fleet must be under certain levels (which will decrease over time). The notion is to reduce average car weight so that fuel consumption and emissions are reduced.

Reducing vehicle emissions

Materials can play a role in reducing environmentally harmful vehicle emissions in a number of ways. For example, the role of materials in improved batteries for electric-powered motor vehicles is discussed in Box B9.3. In conventional petroleum-powered motor vehicles, new and advanced materials are already used in catalytic converters that play an important role in reducing automotive exhaust emissions.

Safety and operational requirements

Although much of the focus of government regulation has been on increased fuel efficiency, safety and operational requirements still play an integral role in determining automotive design and inputs.

It is very difficult to determine the effect that safety regulation will have on new material inputs. Making a car safer could mean increasing its weight. Measures such as anti-skid brakes and airbags add marginally to the overall weight of the car. There might be a weight-safety trade-off — that is, the heavier the car the safer you are in an accident. Steel is still viewed as the best shock absorber for frame and panel use. Therefore safety requirements may force car producers to use traditional materials in structural parts.

Box B9.3: Batteries for electric vehicles

Research into batteries has been stimulated by the need to find a product capable of powering an electric car. This work is largely in response to the California Clean Air Act. The Act requires that by 1998, 2 per cent of all new vehicles sold in California will produce zero emissions, and 10 per cent of vehicles by 2003. It has been estimated that the World market for electric vehicle batteries is will exceed $US5 billion by the year 2004 (R&D Review, 1994).

The battery which will power an electric vehicle must have:

- a long driving range;
- be economic in its use of input electricity;
- minimal energy loss on standing;
- fast recharge for rapid refuelling;
- a long service life for low depreciation cost;
- a low cost to gain customer acceptance; and
- zero or low maintenance so that little routine attention is required (Rand, 1994).

As of yet, no battery has been produced which is capable of meeting all of these requirements, however, many are currently being developed in anticipation of filling these goals. Rand (1994) suggests that the lead-acid battery is the battery most likely to be developed and used in the near term to power electric vehicles. However, a number of other systems are under active development.

B9.5 Impediments facing Australian producers

Impediments may exist to the application of new materials in the Australian car industry.

Design times and overseas influences

The length of time taken between the planning process and production has an effect on the incorporation of new materials into automotives. If car manufacturers are designing cars four years in advance, they are only able to utilise technology and materials that are currently available. Therefore, there could be a lag between the development of new materials and their uptake by the automotive industry. In 1994, it was been claimed that: ‘For 1997 to 1998, the basic architecture of the car is defined. There will be little change in content' (University of Michigan Transportation Research Institute, 1994).

For example, the design for the 1997 Commodore has already been completed — therefore there is little opportunity for the application of very recently developed new materials in its design, presuming some were appropriate.

The Ford Falcon is the only car completely designed and manufactured in Australia. All other makes and models are, to some degree, designed (or manufactured) overseas. Although local car manufacturers adopt designs and components to suit local conditions and preferences, this degree of overseas influence will impact on the use of new and advanced materials in Australia. In addition, Australian automotive exports are reliant on meeting overseas preferences and design specifications, and Australian vehicle purchasers make comparisons of the local product with overseas ones.

Market size

Some see the relatively small output of the Australian car industry as an impediment to the quick uptake of new materials. By World standards, Australia has very small automotive production runs. This means that between models there are 'carryover' parts. That is, parts which were designed for the last model but, to make the most out of materials and capital equipment, are still used in the current model. This is likely to happen even if better materials and designs have become available. The notion is that machinery needs to 'pay for itself' before it is scrapped and with small production runs this is likely to take longer.

Outsourcing, modularisation and the 'Mexican hat dance'

Car manufacturers worldwide are increasingly having parts of their production process completed outside their factory walls by other companies — which is often referred to as outsourcing.

As more outsourcing occurs, another trend is emerging — the modularisation of components. For example, instead of buying the various parts for a gear box from several component suppliers and assembling them in-house, car makers buy the entire gear box, ready-to-fit, from the one manufacturer.

The 'Mexican hat dance' is a term used to describe dealings between automotive manufacturers and component makers. Often automotive manufactures are keen for component makers to adopt and develop the latest materials and processing technologies, ahead of furnishing them with contracts. At the same time component manufacturers complain that they cannot afford to make the investment in new technology if they do not have a guaranteed income in the form of contracts. The process has been described in *New Materials International* thus:

> The industry is seeing a typical ‘Mexican hat dance’ of the type already witnessed in North America. For example, automakers have said to the stamping companies: ‘If you make an investment in laser welding equipment we will furnish the contracts.’
>
> The stamping firms and the steel service sector have said the same: ‘If you furnish the contracts we will make the investment in equipment’ (1994).

Purchasing technology

One way to incorporate new technology and materials into Australian production is simply buy it from overseas. However automotive manufacturers suggest it is impossible to just buy a ‘turn-key’ operation from overseas. An understanding of the technology and training is essential to successfully use technology developed elsewhere.

Because Australia has not been involved in the development of these technologies, it takes some time before a full understanding of the technical processes involved can be fully understood — a task which often has to be undertaken by researchers outside the company.

On a positive note, quite often the process can be improved by learning-by-doing. For example the University of South Australia has been working with Holden to improve a die coating process purchased from Japan. Through collaboration with Holden and other smaller firms the University has improved the process to better suit local conditions and materials.

B9.6 Potential for further production and use

Further use of new materials by the Australian car industry will depend on:

- fuel efficiency standards — how much will CAFE change and how will this effect Australian production?;
- recycling requirements;
- relative prices of traditional and new materials;
- the future of the Australian car industry in general; and
- downstream processing — will the changes in the casting industry be successful and if so how will this effect new material uptake?

The development of the aluminium and magnesium industries, and further innovative use of plastics and polymers by local producers, should see the level of new and advanced material use in Australia’s automotive industry increase. However, the importance of steel and iron to the automotive industry should not be overlooked.

B10 BIOMEDICAL APPLICATIONS FOR NEW AND ADVANCED MATERIALS

The idea of using materials to replace or supplement human biological functions is not a recent phenomenon. Sutures were first used in about 4000 BC, and the implantation of gold plates for skull repair is documented back to 1000 BC.

More recent developments in the use of biomedical products containing biomaterials have radically transformed the ability of medicine to increase the length and improve the quality of human life. For example, heart pacemakers and artificial heart valves were first developed in the early 1950s, and in 1969 an artificial heart was implanted for the first time in a human patient.

This appendix describes the development and incorporation of new materials within the biomedical industry. Finally, the potential use of new materials in the biomedical industry is discussed.

B10.1 Biomedical materials

According to the European Conference on Biomaterials, a biomedical material, or *biomaterial* is:

> ... a material intended to interface with biological systems to evaluate, treat, augment or replace any tissue, organ or function of the body (1992, p. 528).

Biomedical materials cover a wide range of materials that are increasingly being used in medical, dental, veterinary and pharmaceutical applications.

In many cases a wide variety of materials are used in a single product. For example, a defibrillator contains titanium, platinum, polyurethane, silicon, rare earth batteries and components based on ceramics.

Implantable medical devices incorporating new and advanced materials are being used increasingly in many branches of medicine. The success of implants, such as heart pacemakers and valves, hip joints, and vascular conduits, depends heavily upon the right choice of materials. Sophisticated biological systems, like the human body, are well equipped to reject intruding objects, thus the materials used for biomedical applications must be selected carefully .

The evolution of biomaterials is directly linked to developments in materials science and technology. Research, development and commercialisation of new and advanced materials can act as a driving force for innovation in the use of biomedical materials, as new developments widen the choice of materials available to medical researchers.

The search for biomaterials has increasingly taken on a 'life-of-its-own' as the biomedical industry matures and the importance of materials in medical science is realised. Although Australia is a leader in the biomedical field, many of the materials used in biomedical products are currently imported.

However, growth in the value of the market for biomedical products, and increasing development of materials specifically for biomedical applications, provides an opportunity for Australian firms to provide biomaterials and manufacture biomedical products.

Polymers

Polymers represent the largest and most diverse group of biomedical materials. According to Marchant and Wang:

> The overwhelming majority of biomaterials used in humans are synthetic polymers... rather than polymers of biologic origin (1994).

Medical uses account for only a small proportion (approximately 3 per cent in 1991) of usage in the general polymer market (DITAC, 1991). The use of polymers in medical applications is growing and in the US alone is expected to be worth US$3.3 billion in 1998 (Biomedical Materials, 1994d).

In the early 1940s, synthetic polymers were introduced in surgical aids. Polymers have since been adapted to replace skull bone, hip joints and other hard tissue. Over the last 30 years polymers have also been used for surgical grafts, and their use continues to grow (DITAC, 1991).

Polymers are available in a wide variety of compositions and can be readily fabricated into complex shapes as solids, gels or liquids. The properties of synthetic polymers vary widely from soft, delicate hydrogels used for contact lenses, to resilient elastomers used in cardiovascular devices, to tough plastics used in orthopaedic and dental applications (Marchant and Wang, 1994). They can be made permeable or impermeable, and in certain circumstances can fulfil the role of either hard or soft tissue. Polymers can also be combined with other materials to form composites with enhanced properties, and can be used as components in artificial organs, devices, and instruments for therapy and diagnosis (DITAC, 1991).

Metals

Stainless steel has been the most commonly used metal for biomedical applications due to its low cost, availability and workability (DITAC, 1991).

More recently, titanium has become a very popular metal for biomedical applications, and is often joined with carbon, aluminium and vanadium or niobium in alloys for surgical implants. Its discovery as a metal suitable for human implantation is outlined in Box B10.1.

Box B10.1: The discovery of titanium as a biomaterial

The biocompatible properties of titanium were largely discovered by accident about 40 years ago. A Swedish scientist, Per-Ingvar Branemark, was studying the function of blood and marrow and wanted to be able to see inside the fibula bone in a rabbit's leg. He made a viewing chamber by screwing a cylinder of titanium into the fibula. On completion of his study, Branemark found that bone had grown into the threads of the titanium cylinder and it could not be removed.

A few years later, Branemark was studying the effects of eating, drinking and smoking on blood cells, and developed a small titanium viewing chamber which he inserted into the upper arm of volunteer medical students. The chambers were left in place for months but caused no adverse reaction.

Only then did it occur to Branemark that a metal which could form such a strong bond with bone without triggering a reaction from the body's immune system could be extremely useful in surgery. In 1965 Branemark inserted titanium screws into a human jaw for the first time.

Source: Saul, 1994.

A further potential development in biomedical materials relates to bone growth and adhesion to pure titanium implants. Medical-grade titanium powders can be applied to the surface of implants to create a porous surface into which bone tissue can grow (Biomedical Materials, 1994a). This process is known as osiointegration.

The biocompatability of titanium is attributed to the immediate formation of stable oxides on exposure to air, which generates a tough surface coating on the implant (DITAC, 1991).

Titanium has also been used widely in dentistry in recent years — in oral surgery, orthodontics and restorative work. For applications in oral surgery, finished products of titanium such as mini-plates and clips are commercially available (DITAC, 1991). Titanium is also being used for dental prostheses such as crowns and inlays.

One benefit of titanium for dental applications is that it does not suffer from discolouration. However, titanium takes more time to finish and polish than traditional dental alloys (DITAC, 1991).

Although titanium has long been known to be highly biocompatible, its use in dental prosthetic materials has been limited because of difficulties in establishing reliable casting techniques (DITAC, 1991). However, as casting technologies continue to develop, the potential for using titanium in dental applications increases.

Ceramics

Ceramic materials are used in biomedical applications because they can offer desirable properties such as biocompatability, hardness and wear resistance. The principal biomedical applications for ceramics is in orthopaedics, dentistry and heart valves. In 1994, the sales of bioceramics in the US alone is expected to reach $20 million. A summary of the discovery of bioceramics is presented in Box B10.2.

Box B10.2: The discovery of bioceramics

In 1967, a young ceramics engineer, Larry Hench, a scientist at the University of Florida, was designing semiconductor switches for nuclear weapons. On a bus ride to a materials conference in the US, a Colonel just back from Vietnam, told Hench that thousands of soldiers were having limbs amputated because of faulty implants.

In 1969, under a grant from the US Army, Hench designed a glass that bonded so well to the bones and tissues of rats that it could not be removed.

What Hench discovered in 1969 was the first bioceramic.

Source: Coxeter, 1994.

Bioceramics have recently been used to replace the ossicle (a small bone in the middle ear) that helps restore hearing in patients who have sustained damage to this part of the body. The bioceramic (known as Bioglass) enables a physical and chemical bonding with body tissue. It is the result of many years of research into bioceramics and could potentially be used for other bone replacement implants.

Ceramics are also used as a surface coating to improve the performance of implants where a positive tissue reaction with the implant is desirable. Some bioceramics are particularly conducive to the development of interfacial reactions as the ion exchange between the ceramic surface and body fluids generates a gel-like calcium-phosphorous-rich bond. The use of ceramics in this way has been growing steadily in the dental area, with developments emanating particularly from Japan. For example, Nippon Kogaku has combined the advantages of high strength metal with the biocompatibility of ceramics in a metal ceramic tooth root. The root is composed of a metal core surrounded by bioglass.

B10.2 Essential properties of biomedical materials

Biomedical materials must meet higher performance requirements than materials used in many other applications. The use of materials which impact directly upon human health, particularly those which are implanted within the body for long periods of time, rightly demand stringent criteria.

Although each biomedical application possesses its own specific set of requirements, there is one requirement which all biomedical materials must fulfil, namely, *biocompatibility*. Biocompatibility, combined with application-specific characteristics, ensures compatibility between the biomedical material and its host, irrespective of whether the material is to be used internally or externally.

Biocompatibility implies that there is either no adverse reaction or else an appropriate interaction. It is required to ensure that the potential for rejection or other hostile interaction between the implant and the host is limited. Indeed in many instances a positive interaction of material with the biological surrounds is desirable. As noted above, medical-grade titanium powders can be applied to the surface of implants to create a porous surface, into which bone tissue can grow.

In many cases, it is relatively easy to find materials that possess the physical properties required for a specific application, such as strength, elasticity, or optical transparency. The difficulty, however, is in selecting materials that react appropriately, or not at all, with the host environment while maintaining these physical properties. It is necessary to ensure that the material itself is not damaged, via corrosion for example.

B10.3 Producers, users and their activities

In 1988, Worldwide sales of biomaterials amounted to approximately $13 billion per year (CSIRO, 1994b).

Current research into biomedical applications for new materials is largely centred in the US, Europe and Japan. Most of the World's medical technology products (88 per cent) are sold in these parts of the World (HIMA, 1994).

Overseas

The US market for medical technology products — of which biomedical products containing biomaterials is part — is the largest in the World and valued at approximately US$38.2 billion per annum (HIMA, 1994).

It has been estimated by CSIRO that in the US, the level of R&D in this industry as a percentage of market turnover is between 5 and 6 per cent per annum (CSIRO, 1994b).

The US, apart from being the World's largest single market for biomedical products, is also a large supplier to the rest of World. For example, US companies supply approximately 55 per cent of the biomedical products used in Australia (HIMA, 1994).

Western Europe is the second largest market for medical technology products, and is valued at approximately US$26.6 billion (HIMA, 1994).

Japan's involvement in the biomedical industry is more recent than that of the other industrialised countries. The history of Japanese involvement is outlined in Box B10.3.

Figure B10.1 presents data on the medical technology products market.

Box B10.3: Japan's involvement in the World biomedical industry

Traditionally Japanese firms in the biomedical field have not been particularly active outside Japan. Of the World's 20 largest medical device manufacturers, only one is Japanese, whereas 13 are American and six are European.

Japan only began to realise the potential for biomedical materials towards the end of the 1970s. Interest from government and industry reached a peak in the early 1980s. At that time it was estimated that there was a technology gap of at least five years between Japan and the US. However, by 1985, after considerable technology transfer, joint R&D ventures and licensing, Japan had virtually closed the gap.

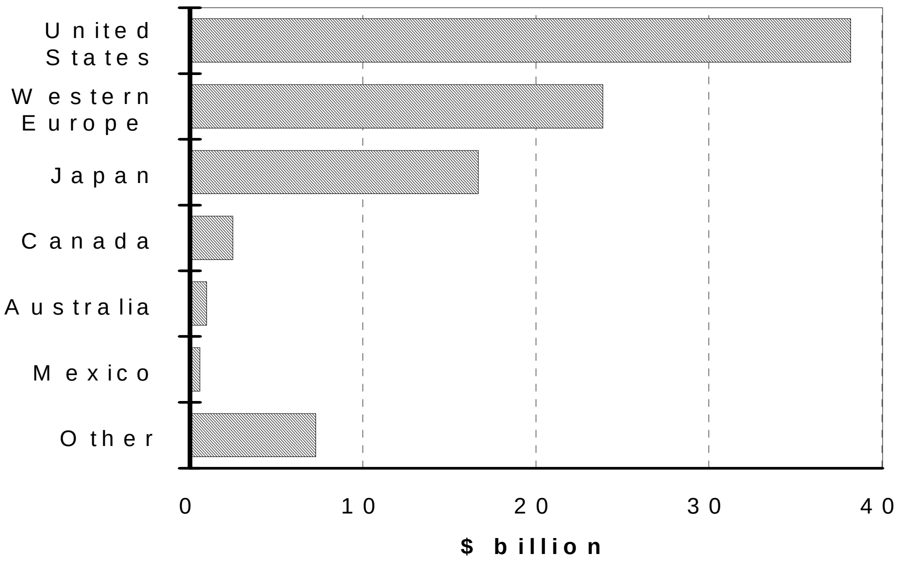
In 1993, the Japanese market for medical technology products — of which biomedical products containing biomaterials is part — was valued at US$16.7 billion and R&D has continued at approximately 5 to 6 per cent as a proportion of sales.

A key to Japan's success appears to be the emphasis placed upon the transfer of technology and expertise. For example, companies that were previously heavily involved in chemicals and basic polymer research got involved in research into biomaterials.According to DITAC:

> The Japanese strengths in biomaterial research lie in their ability to make high quality products innovatively from existing technology... intelligent and highly motivated researchers, and an educational atmosphere... that is directed towards industrial application (1991, pp. 71 and 72).

Source: CSIRO 1994b; DITAC, 1991; HIMA, 1994.

Figure B10.1: Market for medical technology products



Source: HIMA, 1994.

Australia

Australian medical research has achieved an international reputation for excellence. The pre-eminence of Australian inventiveness in general, and medical research specifically, has generated growth in biomedical activity in Australia. The establishment of the Australian Society for Biomaterials (ASB), founded in 1988, is illustrative of the increasing activity in the biomedical field by Australian researchers, medical practitioners and industry. The ASB is leading the campaign to create an international implant tracking and data system, a proposition endorsed by the Commission.

In Australia, the market for biomaterials is approximately $300 million, and the level of R&D into biomaterials represents approximately 2 per cent of market turnover. Approximately 85 per cent of this R&D is undertaken in-house by businesses (CSIRO, 1994b).

Although there are a number of firms in Australia producing biomedical products, the materials used are often imported rather than supplied by domestic firms. The main companies currently engaged in biomaterial research, material production or material use are listed by activity in Table B10.1.

Table B10.1: Biomaterial activities in Australia, 1994

Category	*Organisations*	*Products*
Cardiovascular	Telectronics	Pacemakers Defibrillators
	CRC Cardiac Technology	
	Bio Nova	Vascular prostheses
Drug delivery	ICI Australia	Drug delivery
	FH Faulding	Slow release drug delivery
	Auspharm International	Drug delivery and wound management
Equipment and devices	Rescare	Respiratory equipment
	Domedica	Renal dialysis
Maxillofacial	Tuta Labs	Blood Bank equipment
	Cochlear	Implanted bionic ears
	CRC Cochlear Implant, Speech and Hearing Research	Speech processing prostheses
	Southern Dental	Dental consumables
	Biodental Research	Dental composites
Ophthalmology	CRC Eye Research and Technology	Contact lenses
Wound management	Johnson & Johnson	Wound management
	Cyanamide Australia	Sutures
	Smith & Nephew	Dressings

Source: CSIRO, 1994b.

A brief discussion of five Australian-based organisations follows. The discussion aims to illustrate the vital role that a very small quantity of a material plays in the manufacture and sale of a relatively expensive product. The cost of the new material might only be a very small part of the total cost, but often the device would not function without it.

Telectronics Pacing Systems

Telectronics Pacing Systems, a fully-owned subsidiary of Pacific Dunlop, commenced operating in the 1960s and now produces implantable defibrillators and pacemakers. It has managed to capture 18 per cent of the World market in pacemakers, and controls 60 per cent of the biomedical implant market in Australia.

Telectronics annual turnover is approximately $300 million, with $10 million being earned in Australia.

Cardiac pacemakers are designed to provide controlled electrical stimulation to the heart in cases of irregular heart beat. The pacemaker is largely an electronic device, battery driven and programmed for synchronous operation between heart and lungs. Polymers are used to provide electrical insulation and increase biocompatibility for the device. In general, the electronic componentry is implanted in the upper right of the chest with leads which feed across the chest cavity to attach to the appropriate sites in the ventricular wall of the heart. In 1994, Telectronics discovered a malfunction in some lead wires casing giving rise to the possibility of litigation. This has arisen despite the completion of an extensive evaluation program and approval of the design by the US Food and Drug Administration (FDA).

Telectronics is a core participant in the CRC for Cardiac Technology. It has been working closely with CSIRO Division of Chemicals and Polymers to develop a new polymer to act as an insulator for pacemaker and defibrillator leads. Telectronics spends more than $600 000 annually on research into new materials.

The experience of Telectronics is typical in the biomedical industry, in that only a small quantity of the polymer is used (a few grams per lead), but without the material, Telectronics would not be able to make a $5000 device.

CRC for Eye Research and Technology (CRCERT)

Ocular research is one of the many areas of medical research in which Australia has achieved an international reputation, and to which the CRCERT has contributed strongly (Newton-Howes and Fagan, 1991).

The concept of contact lenses is thought to have first been developed by Leonardo da Vinci who described glass contact lenses (DITAC, 1991). However, it was not until the 1940s that polymers were used in contact lenses.

Most of the materials currently used for the production of contact lenses are not new and advanced materials, but traditional polymers which have been approved for usage as medical devices since the 1960s.

CRCERT, amongst other work, is undertaking a research program into biomaterials involving four interrelated projects. These projects are aimed at understanding the relationship between material properties and device performance, and identifying factors which influence device biocompatability (Newton-Howes and Fagan, 1991). The projects are in materials testing, development of new materials and surfaces, development of an artificial cornea, and investigation of tear ocular surface and biomaterial interactions.

The critical properties of polymers used in contact lenses are not only their optical transparency and long-term stability, but also gas membrane characteristics that permit permeability of oxygen. This is an essential property. As there is no blood supply to the cornea, the only source of oxygen is from the surrounding air.

CRCERT is also working on a project developing a contact lens especially for the Asian eye, which has a different shape to the Western eye (for which contact lenses have traditionally been designed). The Asian market for such a device could be substantial, with approximately 1.3 billion people requiring some form of vision correction (Newton-Howes and Fagan, 1991). At present only a very small proportion of these people (between 0.06 per cent and 5 per cent, depending on the country) are wearing contact lenses (Holden, *et al* 1991).

The cost of the polymer, or where it is produced, are not the crucial issues — rather it is the fact that it is an Australian-developed concept with potentially significant economic benefits.

Bio Nova International

Bio Nova is the producer of a unique vascular prosthesis which combines the advantages of biological and synthetic prostheses. This has been achieved by the development of a bio-synthetic material.

Studies involving the growth of biocomposite vascular grafts in sheep began in 1973. After five years of *in vitro* (within the laboratory) and *in vivo* (within a living organism) evaluation, the first human implantation of this new vascular prosthesis occurred in 1978. It was called Omniflow and is a tube of mature ovine collagen which is deposited around a polyester mesh template while implanted in a sheep's back. The tube is implanted in the sheep for three months. Once removed, the collagen is trimmed and the tube is ready for testing and human implantation.

The creation of a collagen–polyester composite mesh design stimulates tissue. Collagen alone would be too elastic and would bulge under blood pressure. The polyester mesh reinforcement is similar to the reinforcement in garden hoses and pressurised gas lines. In such structures the vascular tube has an internal mesh skeleton which strengthens the pipe and spreads the forces evenly along its length. The collagen coating provides a biocompatible contact surface and the polyester mesh enhances durability.

Although Omniflow is in many ways a superior product to traditional man-made vascular prostheses, it is considerably more expensive. The end product costs approximately $1000. In 1994, the World market for vascular prostheses was estimated to be approximately $1.2 billion, and is predicted to grow at 6 to 8 per cent every year. Bio Nova currently exports to Italy, Austria, Switzerland and France, as well as selling Omniflow in Australia.

It is the concept and design of Omniflow, rather than the particular materials used, which makes it a unique product.

Cochlear Pty Ltd

Cochlear, a fully-owned subsidiary of Pacific Dunlop, developed the Mini System 22, an implant system designed for the spiral section of the internal ear known as the cochlea. The concept originated in the 1970s from the pioneering work of Professor Graeme Clark and colleagues at the University of Melbourne. In 1985, it was approved by the US FDA for use in profoundly deafened adults, and in 1990 it was approved for use in profoundly deafened children.

Today, there are over 12 000 people with various types of Cochlear implants World wide, over 4000 of whom are children.

The Mini System 22 retails for approximately $20 000, and in 1994 Cochlear achieved World sales of approximately $55 million.

In a normally functioning ear, sound waves travel from the environment to the outer ear. The sound waves then move on to the middle ear where they cause the eardrum and three tiny bones to vibrate. These vibrations move through the fluid in the snail-shaped inner ear (cochlea). Thousands of tiny hair cells in the cochlea convert the vibrations into electrical energy. This electrical energy stimulates the hearing nerve which sends sound signals to the brain.

People with sensorineural hearing loss, or nerve deafness, have hair cells or nerve fibres that are undeveloped, damaged or destroyed. The Mini System 22

Cochlear implant by-passes the damaged hair cells to stimulate the intact nerve fibres, which then send auditory signals to the brain.

The Cochlear implant system has 22 channels and consists of internal and external components. The internal component consists of an implanted magnet and a receiver. The external component consists of an externally worn speech processor and cable attached to the external directional microphone and transmitter. The system incorporates rare earths, silicon rubber and platinum in its construction. All manufacturing for the World market is completed in Australia.

Cochlear has a substantial research and development program. Of the 200 people employed by Cochlear Australia, approximately 60 are involved in research. Total expenditure on research and development accounts for approximately 15 per cent of annual turnover. Cochlear is also a core participant in the CRC for Cochlear Implant, Speech and Hearing Research, along with the Australian Bionic Ear and Hearing Research Institute, Australian Hearing Services, University of Melbourne, Department of Otolaryngology.

B10.4 Demand conditions

A growing market

In 1993, the demand for medical technology products — of which biomedical products containing biomaterials is part — increased by 7 per cent (HIMA, 1994).

Demand for biomedical products continues to grow rapidly for a number of reasons. First, World population growth increases the number of potential recipients of medical treatment.

Second, increasing affluence in Asia, and to some extent Africa and Latin America, increases the number of people that can afford state-of-the-art medical treatment.

Third, growing affluence in some developing countries is associated with the adoption of high fat ‘Western’ diets which have been linked to heart disease and other ailments which require medical treatment.

Fourth, improved diet, medicines and living conditions have led to increased life expectancy in industrialised countries — and have the potential to effect developing countries in the same way in the future. This increases demand for medical treatment later in life.

Demand for biomaterials is likely to increase in concert with all these changes.

Asia is by far the fastest growing market. Between 1991 and 1993 the Asian medical devices market grew at the rate of 18 per cent per year. This growth rate is expected to increase to 22 per cent per year for 1994 and 1995 (HIMA, 1994).

World demand for heart valves alone was valued at US$490 million in 1993 (Biomedical Materials, 1994a). World demand for ophthalmic diagnostic and surgical products was estimated to be worth US$1.35 billion in 1992. Growth in demand for these same products over the next ten years is expected to average around 2 per cent per year, with growth largely emanating from Asia (Biomedical Materials, 1994b).

The World market for selected biomedical products is summarised in Table B10.2.

Table B10.2: Market value and growth for selected products, 1994

Category	*Product*	*Value ($m)*	*Annual growth rate (per cent)*
Cardiovascular	Pacemaker leads	144	5
	Vascular grafts	132	5
	Cardiac valves	162	5
Disposables	Catheters	1 725	5
Drug delivery	Time release polymers	106	60
Ophthalmology	Intraocular lenses	850	6
	Contact lenses	4 533	6
Orthopaedics	Knees and hips	700	5
Wound management	Traditional dressings	1 466	-2
	Synthetic dressings	352	16
	Biological dressings	37	25
	Sutures	1 018	5
Total		*11 225*	

Source: CSIRO, 1994b.

The Australian biomedical industry is relatively small, and has been estimated by CSIRO at $300 million (CSIRO, 1994b). However, the size of the industry is determined by what products are included.

B10.5 Product liability

The legal liability issues associated with incorporation of new and advanced materials in biomedical products may militate against their use.

Recent events in the US have been met with concern by some in the Australian biomedical industry. According to Gould *et al*:

> The cost of testing, qualification, regulatory compliance, and product liability insurance to manufacturers of basic materials used in medical devices has steadily increased over the past decade (1993, p. 355).

The well publicised problems with silicone breast implants is indicative of the legal liability faced by firms in the biomedical industry.

However, the situation in Australia and most other countries is not analogous to the US.

As is the case with most professionals, medical practitioners face potential common law actions and remedies if they are negligent. Due to the nature of their work, medical practitioners (and hospitals) seek the consent of patients before using certain procedures. For this process to be beyond legal challenge it has to be (in Australia, at least) 'informed consent'. This means that the patient is supplied with certain information, such as the probability of something going wrong. The use of biomaterials could be, where necessary, dealt with in this way.

There are statutes that apply to the manufacture or importation of biomaterials, for example, Part VA of the *Trade Practices Act* sets a condition of strict liability on the manufacturer or importer of a product for harm caused by defective goods.

B10.6 Competitiveness of Australian producers and users

Competitive advantages and disadvantages

Australian research in medicine, dentistry and related technologies is World class, consisting of highly skilled medical and scientific researchers and practitioners. As a general rule, Australian scientists are not as highly paid as potential competitors from other industrialised countries.

Australia's main competitive advantage is the standard of its medical related sciences.

The World-class work undertaken in Australia by companies such as Telectronics has been supported by Australian universities, and in recent years by the creation of the two CRCs. The CRC for Eye Research and Technology has not only developed a successful final product, but has produced original equipment in the process, and has sold the designs around the World. The CRC for Cardiac Technology has been instrumental in enabling Telectronics to design and manufacture an internationally competitive product. The CRC format appears to have been effective in bringing together business and researchers resulting in research that has a potential commercial market.

Australia may have a competitive advantage in supplying the Asian market — which is growing at a rapid pace — due to our geographical proximity, our relatively inexpensive scientists and a developing understanding of the Asian business culture. Australia's close proximity may enable it to work co-operatively with Asian organisations so that our products best suit the Asian market.

Australia's existing or potential competitive advantage is in the development of biomedical products, not necessarily in the manufacture of a material *per se*, for example, a new polymer.

B10.7 Potential for further production and use

The major factor in potential for biomaterials is the high actual and projected growth rates in the biomedical industry as outlined in section B10.4.

Another source of potential growth for Australian suppliers of biomedical materials may stem from the withdrawal of major international suppliers from the market, following legal losses. For example, Dow Corning has withdrawn supply of various grades of silicon from the World market, leaving a gap which has mainly been filled by numerous smaller suppliers.

A large portion of value added in the production of biomaterials can be attributed to the design of the product, and this is what Australia has been good at doing.

According to US Health Industry Manufacturers Association (HIMA):

> Despite numerous claims to the contrary, today there are more market opportunities around the world for enterprising medical technology firms than ever before ...
>
> Moreover, medical device markets in nearly a dozen countries grew in excess of 15 percent in 1993, and similar rates of growth are expected again in 1994 (1994, p. 1).

Australia has both the research skills and the technical expertise to be a successful player in the international biomedical industry, as has been shown by the World wide success of Telectronics. As long as the scientific base is not eroded and markets are researched and monitored, Australia has the potential to play an important role in the future of biomaterials and biomedical product development and sales.

B11 THE STEEL INDUSTRY

Before the Industrial Revolution steel was an expensive material, used in small quantities in articles such as swords and springs. However, things soon began to change.

> In August 1856 Henry Bessemer announced his invention of a process which made it possible to produce steel cheaply and in a large quantity (Street and Alexander, 1994).

After several unsuccessful commercialisation attempts with various partners, Bessemer went into mass production on his own, and several years later was producing nearly one million tonnes of steel each year. Steel went on to become one of the fundamental building blocks of modern industry.

Today the steel industry plays an integral role in the World and Australian economies.

Production of steel in Australia represents about 1 per cent of total World production. Steel exports are about $1.5 billion which represents around 4.5 per cent of total merchandise exports.

Recent developments in steelmaking technology and advances in steel alloys could have major impacts on Australia's economic performance. Changes to the steel industry could have a far greater impact in the short to medium term, at least, than many of the new and advanced materials mentioned elsewhere in this report.

> [Steel and iron] are the basic metals of an industrial society. Although there are many acceptable substitutes for many of their uses, in the short term there are no practical substitutes on a large scale because of the cost and lack of availability of alternative materials (Houck, 1992).

There are several areas in which advances are occurring in steel making technology — direct smelting, electric arc furnace technology and the adoption of continuous casting technology. These advances in steel making technology (such as BHP's strip casting developments) allow more efficient production of steel.

Innovation is also occurring in alloy steels. This innovation is aimed at counteracting recent inroads made into traditional steel markets by substitute materials, such as aluminium and plastics. There is also product innovation to more accurately match properties to increasingly differentiated uses. Steel grades in use today were not commercially available twenty years ago. The new grades have allowed the thickness and weight of steel used in many products to be reduced.

Box B11.1: What is steel?

Steel refers to an alloy of iron that is malleable at some temperature and contains manganese, carbon and often other alloying elements. Steel containing only carbon and manganese is called *carbon* or *mild steel*. Steel containing metallic elements such as nickel, chromium, or molybdenum is termed *alloy steel*. Steel containing sufficient chromium to confer a superior corrosion resistance is called *stainless steel*.

Hundreds of individual alloy specifications have been developed to produce different combinations of strength, ductility, hardness, toughness, magnetic permeability, and corrosion resistance to meet the needs of modern consumers. These alloy specifications are called *grades*.

Source: Houck, 1992.

B11.1 Steel production

Steel production facilities are of two types — integrated mills and non-integrated facilities (or minimills) (see Box B11.2).

Integrated steel mills smelt iron ores to crude liquid iron in blast furnaces and refine the iron, with some scrap, in basic oxygen furnaces, producing liquid steel. The liquid steel is mostly cast into semi-finished products in continuous casting processes.

Non-integrated (or minimill) steel producers melt low cost raw materials, primarily steel scrap, in electric arc furnaces. They incorporate the most recent production technologies such as continuous casting. Because minimills are a recent development they utilise state-of-the-art technology. Although integrated mills would also like to use the most recent technology, there are costs involved in replacing existing equipment if it is not at the end of its economic life and hence there is a lag in the introduction of new technology in integrated mills.

The development of electric arc furnace technology has had a large impact on production. Minimills now produce about one third of the World’s steel, and 75 per cent of the increase in World steel production from 1970 to 1990 was from minimill production (ABARE, 1994a).

Box B11.2: The steelmaking process

Steel is produced at either an integrated steelworks or a non-integrated (minimill) facility. An integrated steelworks produces steel from raw materials — iron ore, coke and limestone. The integrated steelmaking process can be simplified into three major areas — ironmaking, steelmaking and shaping.

The production of coke from coal is carried out in the coke ovens. The coke is used in the blast furnace to reduce iron ore to liquid iron. Iron ore, coke and limestone are fed into the top of the furnace while a hot air blast (1200ºC) is blown into the bottom of the furnace. The liquid iron is drained from the furnace along with slag.

The basic oxygen steelmaking process takes the liquid iron and alloying metals, and combines it with scrap steel to produce liquid steel.

Electric arc furnace minimills use scrap steel to produce new steel products. Scrap steel is fed into the electric arc furnace and melted.

After both processes, when the steel has reached the required temperature and chemistry it is poured into a ladle, for transfer to the ladle furnace area, where it is refined further. Molten steel is converted to solid semi-finished product by casting, either into ingots, or the more modern and efficient continuous casting process.

Source: BHP, 1992.

B11.2 International production and usage

World steel production has trebled from around 200 million tonnes in 1950 to around 700 million tonnes in the 1980s (see Figure B11.1). This increase was mainly the result of increased use in industrialised nations.

More recently, world steel production in 1993 and 1994 was around 720 million tonnes, well below the 786 tonnes produced in 1989 (see Figure B11.1).

ABARE estimates that World steel production will remain steady in 1995 but will increase to about 824 million tonnes by 2000. Most growth is expected to occur in China and other Asian economies.

Figure B11.1: World steel production, 1950 to 1994

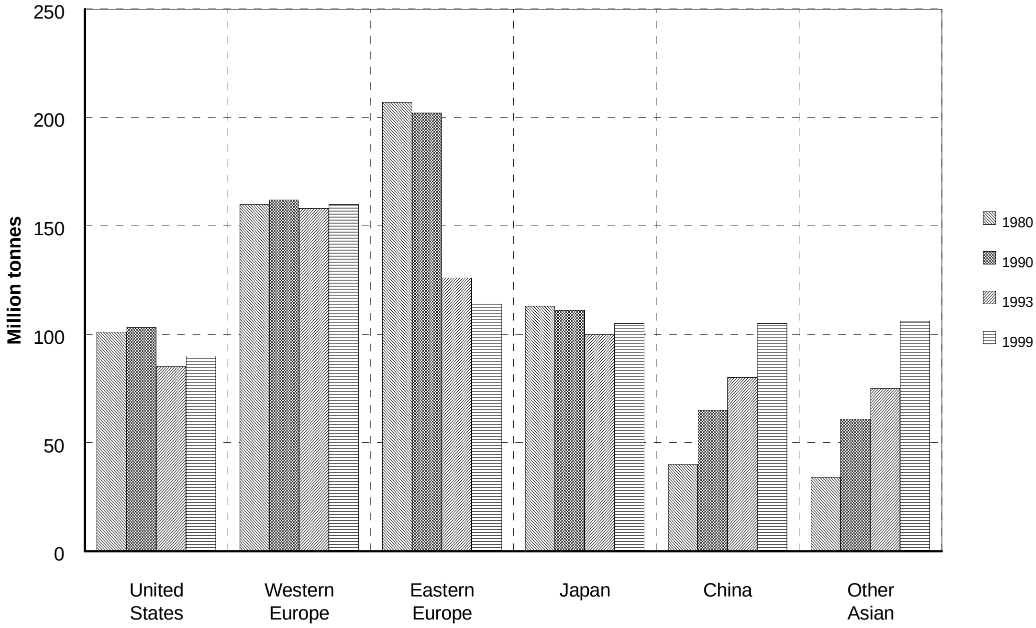
Source; ABARE, 1995.

While the demand for steel has remained fairly constant over the last decade, production has fallen in the US and in Eastern Europe (by 15 per cent and 40 per cent respectively since 1990) and also by a smaller degree in Japan. Output in China and other Asian countries has risen rapidly (both around 20 per cent) (see Figure B11.2).

This can be explained by several factors. Economic growth in China and other developing Asian countries has meant the demand for steel is increasing — steel is essential for the development of basic infrastructure. However, in more developed countries steel use is gradually declining, as it is slowly being replaced by other materials; and the slow down in economic growth over recent years has had an impact. The fall in use in Eastern Europe is attributed to the ongoing political and economic upheaval.

Figure B11.2 presents data on production in recent years as well as forecasts for 1999.

Figure B11.2: World steel production by region, 1980 to 1999



Source: ABARE, 1994d.

B11.3 Australian production and usage

Only two companies produce steel in Australia.

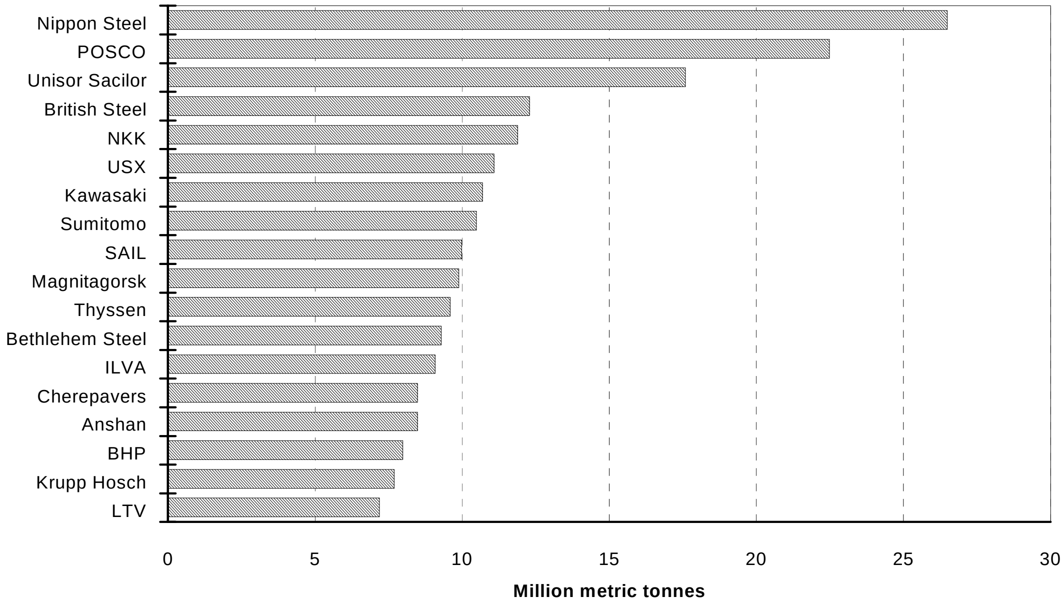
The majority of steel production in Australia is carried out by BHP's Steel Group — around seven million tonnes each year. BHP sells about $5.5 billion worth of steel products annually, and is in the top 18 steel producing companies in the World (see Figure B11.3).

The other is Smorgon Steel which produces steel products using a scrap-based minimill at Laverton near Melbourne.

BHP spends about $60 million a year on steel research (see Box B11.3). The money spent on steel research at BHP represents about one per cent of all R&D in Australia, or two per cent of private R&D funding.

BHP Steel group's activities are summarised in Box B11.3.

Figure B11.3: Top 18 Steel companies, 1993



Source: International Iron and Steel Institute, 1994.

Box B11.3: A snapshot of BHP Steel

BHP Steel returned a profit of $537 million in 1994, with a total revenue of nearly $7 000 million, while employing about 27 500 people.

Spending on research and development totalled $60.1 million, up 15.3 per cent from the previous year, and focussed particularly upon product development and market applications. Significant research expenditure is also spent to maximise the asset life and operational efficiency of existing integrated production facilities, particularly in the area of blast furnaces and coke ovens, as well as into new production processes, including research into direct casting of flat products.

BHP steel production has increased by 6.5 per cent from 6.8 million tonnes in 1992–93 to 7.25 million tonnes in 1993–94. Assumed stronger economic growth of around 3.8 per cent is forecast to lead to a further increase in Australian steel production to 7.35 million tonnes in 1994–95. At around 3 million tonnes, exports represented 42.5 per cent of total Australian production and surpassed the 1992 record levels.

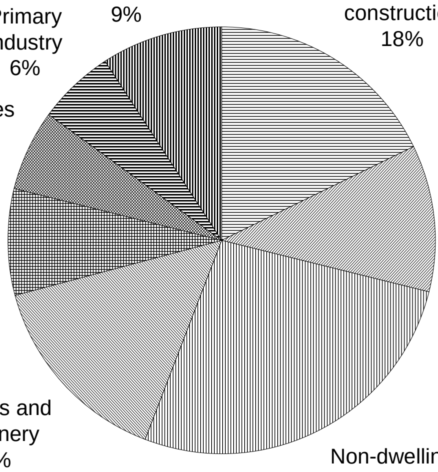
The commissioning of the 250 000 tonne capacity Rooty Hill minimill by BHP in September 1992 contributed significantly to recent production growth. However, the bulk of increased steel production is coming from existing facilities, and through installation of new equipment such as the $150 million caster at BHP's Whyalla steel works.

Source: ABARE, 1994a.

Steel consumption

In Australia, the construction industry dominates the use of steel (see Figure B11.4). Within the construction industry, steel used in non-dwelling construction represents 27 per cent of all use.

Figure B11.4: Steel use in Australia by market



Source: BHP, 1994.

Stainless steel

Stainless steel is created by the addition of chromium and, generally, nickel to steel. On exposure to water or air, a thin film of chromium oxide is formed on the surface of the steel, which becomes corrosion resistant. The addition of alloying metals in stainless steel makes them stronger than most carbon grade steels (see Box B11.4).

> All stainless steels have a high resistance to corrosion due to their chromium content. This remarkable resistance to attack is due to the chromium rich oxide film which is always present on the surface of the steel. Although extremely thin, this invisible, inert film is tightly adherent to the metal and extremely protective in a wide range of corrosion media. The film is rapidly self repairing in the presence of oxygen and damage by abrasion, cutting or machining is instantly repaired (Australian Stainless Steel Association, 1994).

BHP ceased production of stainless steel in 1987 due to the high costs associated with its production in outdated facilities. BHP now imports slabs of stainless steel and rolls it into sheet and other products.

Box B11.4: Types of stainless steel

There are several types of stainless steel — ferritic, martensitic, austenitic and duplex.

The ferritic steels are magnetic and have a low carbon content and contain chromium as the main element (around 13 to 17 per cent).

The martensitic steels are magnetic containing around 12 per cent chromium and a moderate carbon content. They are hardenable by quenching and tempering (as are plain carbon steels) and are mainly used in cutlery manufacture, aerospace and general engineering.

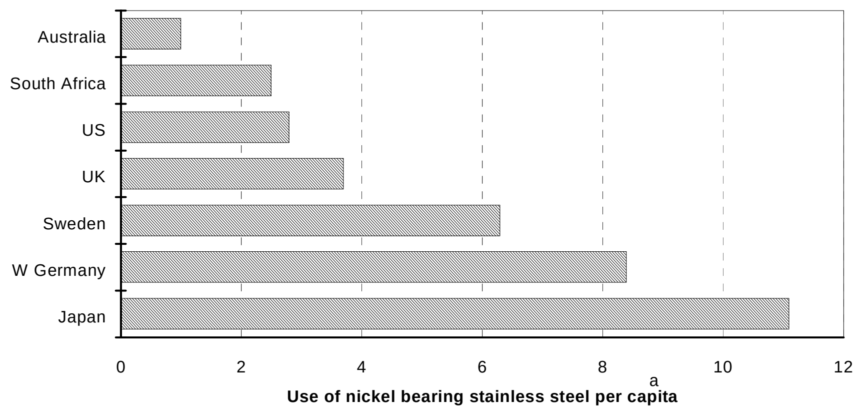
The austenitic steels are the most widely used group of stainless steels. They are non-magnetic and in addition to chromium (about 18 per cent) they contain nickel which increases their corrosion resistance. They are the most widely used stainless steels.

Duplex steels contain a mixture of austenite and ferrite. They are usually higher in strength than either ferritic or austenitic steels and some types can have a better resistance to chloride exposure. Duplex stainless steels are used extensively in chemical plant and marine applications.

Source: Australian Stainless Steel Association, 1994.

Several participants stated that Australia's use of stainless steel was less than optimal. Mr Noel Herbst in his submission to this inquiry argued that this was due to insufficient training in the use of stainless steels and the fact that there was no producer in Australia strongly advocating its development and use. He cited the use of stainless steel per head in Australia as being far less than many other industrialised countries (see Figure B11.5)

B11.5: World wide use of stainless steel, 1991



a: use of nickel bearing stainless steel per capita in 1991 taking Australia to be 1.
Source: Sub. 8, p. 2.

B11.4 Supply conditions

Innovations in the supply of steel can be separated into the development of new steel alloys (such as high-strength low-alloy steels) and the adaptation of new production techniques (such as electric arc furnaces and strip casting).

New steel alloys

High-strength low-alloy steels

High-strength low-alloy (HSLA) steels contain a relatively small amount of alloying agents, usually less than one per cent. Alloying agents include niobium, vanadium, titanium, copper and nickel. The superior strength of HSLA steels enabled users to use less material.

HSLA steels are quite commonly used in the automotive and construction industries (see Box B11.5).

> **Box B11.5: High strength steel and super-skyscrapers**
>
> Nippon Steel has successfully developed a high-strength steel that will allow the economical construction of super-highrise buildings 400 to 1000 metres high. The new steel provides superior tensile strength and weldability as a structural steel, and will significantly cut the amount of steel needed in constructing building frames.
>
> The new steel contains less carbon, but more copper and nickel. It contains no boron because steel containing that element requires a high preheating temperature for welding. Nippon Steel foresees the steel as contributing to building construction mainly in the role of box section columns. The steel will allow buildings of the future to employ slender columns and be more earthquake resistant.
>
> Source: Nippon Steel News, 1994.

A new development of a more exotic material is amorphous metals (and in particular glassy steels) with applications in power transformers (see Box B11.6).

Box B11.6: Amorphous materials

Amorphous materials are made by the rapid cooling of liquid metals using the rapid solidification technique, which causes the metals' atoms to be locked in a random, liquid-like arrangement similar to glass. The materials used for this process are usually iron, nickel or cobalt based, with additives such as boron, silicon and carbon. The resulting metallic glass is exceptionally hard, some four to five times harder than silicon-steel.

Over the past 30 years amorphous materials have evolved from being a scientific curiosity to the centre of an important engineering application, namely, as the core material for electricity transformers. These materials are referred to as 'glassy steels'.

The first large-scale evaluation of transformers with amorphous cores took place in the US in 1985 to 1987. The success of these tests lead to over 120 000 amorphous transformers being in use by 1991. It is estimated that in 1994 approximately 400 000 amorphous transformers were in operation around the World.

Professor Nafalski of the University of South Australia has undertaken a study examining the potential use of amorphous materials for transformers in Australia. Professor Nafalski states:

> Study carried out for Western Australian conditions has shown that the application of metallic glass transformers in Australia is economically sensible. There are virtually no metallic glass core transformers in Australia, but there is a great potential for their production and application (sub. 39, p. 2).

Although the up-front cost of transformers with amorphous cores is between 30 per cent and 50 per cent more than traditional transformers made from crystalline silicon-iron, their superior performance in preventing core losses means that when whole-of-life costing is used, they are often cheaper than traditional transformers.

Source: sub. 39.

New production techniques

Direct smelting, electric arc furnace technology and the adoption of continuous casting technology have been identified as advances that will have major impacts on the Australian steelmaking industry.

Direct smelting

One type of innovation in ironmaking is direct smelting. This process is yet to be proven commercially viable but research is proceeding in Japan, Australia and the US.

Direct smelting creates feedstock for use in electric arc furnaces (as an alternative to scrap) or integrated mills. The WA Department of Resources Development said:

> The increasing scarcity of quality scrap and the move into higher quality steel products by electric arc furnace producers, presents an opportunity for Australian ore to be processed into suitable electric arc furnace feedstocks such as direct reduced iron , hot briquetted iron and iron carbide (Department of Resources Development (WA), 1994).

The advantages of this process over conventional blast furnace operations are numerous. As most of the oxygen reduction is carried out in the molten state at a high temperature, it proceeds much more quickly than reduction in the solid state. Equipment can be scaled to suit production needs without affecting operating economies. As coal is charged directly into the smelting reduction furnace no coke is required thus eliminating coking ovens. Low grade thermal coal, char or powdered coke can be used, which cuts costs by removing the need for more expensive coking coal. The smelting reduction process can be stopped and started with relative freedom, allowing greater flexibility in operation than with a blast furnace. The process offers opportunities for removal of impurities such as phosphorus, alumina and silica at the hot metal stage, and surplus process gases have a high utility value as energy or as a chemical feedstock.

Two companies are developing direct smelting technologies within Australia, BHP and HIsmelt.

BHP

BHP is developing hot briquetted iron for use as feedstock in electric arc furnaces. BHP said:

> BHP is seeking to gain a technological advantage over the world's best steelmakers with its commitment to a $750 million iron-ore processing plant in Western Australia. The hot briquetted iron plant, planned to produce two million tonnes of high iron content feedstock a year, would be able to supply a series of electric-arc furnaces (mini-steel mills) BHP intends building throughout Asia, as well as supplying Asia's rapidly expanding steel industry (BHP, 1994).

HIsmelt

A process of direct smelting is currently being developed in Australia called HIsmelt. The HIsmelt is a joint venture project between CRA and the Midrex Corporation of the US.

The HIsmelt process developed by the CRA uses only one reduction vessel with only preheating of the iron ore being necessary. The final product can be further refined and processed in an integrated mill or shipped off to a minimill facility.

Under development for about 12 years, the HIsmelt project is now in its third phase of development, with a $150 million, 100 000 tonne a year research facility underway in Western Australia.

A technical description of the HIsmelt process is outlined in Box B11.6.

Box B11.6: The HIsmelt process

HIsmelt is a second generation direct smelting process which has common characteristics with other direct smelting processes, namely:

- reduction of the iron oxide occurs in a molten metal bath at much higher temperatures than in a conventional blast furnace; and
- heat released by the combustion of carbon and other hydrocarbons is utilised in the smelting process.

The main distinguishing features of the HIsmelt process are:

- all processes occur in one reduction vessel;
- the injection of coal and preheated air (rather than oxygen) into the bottom of a molten metal bath;
- the creation of a gas zone above the molten metal bath which contains a high density of metal droplets ejected from the bath by the hot air blast. These droplets perform a very important function in causing heat transfer between the gas zone, where heat is being produced by combustion of carbon and hydro carbons, and a molten metal bath; and
- combustion heat not captured by this process is used to preheat and prereduce iron ore in a fluidised bed above the reduction vessel.

The advantages of the HIsmelt process are:

- the ability to accept a wide range of both iron ore and coal feed materials;
- high thermal efficiency;
- simple to start, stop or adjust production rates; and
- it is more evironmentally friendly than traditional processes.

Source: HIsmelt Corporation Limited, 1992.

Electric arc furnaces

To increase production without outlaying the high capital cost associated with integrated steelmaking operations, BHP will to look to minimills in order to expand its operations. ABARE said:

> [An] advantage minimills have over integrated plants is that because they are economic at a much smaller scale, the startup cost of a minimill plant is considerably less than that of an integrated plant. A modern integrated plant with a capacity of 3 million tonnes a year requires and investment of around US$4.5 billion (Cusack, 1992), whereas BHP's Sydney minimill with a capacity of 250 000 tonnes a year required investment of around $A300 million (US$220 million using 1992 average exchange rates) (ABARE, 1994d).

Integrated producers cannot compete with the lower operating costs associated with minimill production, but to date production from minimills has generally been of a lower quality. ABARE added:

> Minimills appear to have the advantage over integrated mills in that they can produce long products at lower per unit costs than integrated plants... Barnett and Crandall (1986) calculated that at 1985 operating costs a representative US integrated mill could produce wire rod at a cost of US$339 a tonne whereas a representative US minimill could produce the same product for US$244 a tonne (ABARE, 1994a).

However, the cost of raw materials has an impact on the economies of the competing methods. The commercialisation of direct smelting processes could result in less reliance on scrap as a source of feedstock.

Minimills are considered to be more environmentally friendly than traditional integrated steel mills.

> Electric arc furnaces also tend to have an advantage over integrated plants in that they tend to have less impact on the environment. The electric arc furnace consumes scrap steel which would be difficult and costly to dispose of otherwise and does not produce any of the undesirable byproducts which integrated steel plants can produce. The coke ovens, blast furnace and basic oxygen furnace produce significant amounts of carbon dioxide, carbon monoxide and other undesirable emissions. Apart from noise pollution, which can be controlled, the electric arc furnace process does not produce any more pollution than most manufacturing processes. As a result, electric arc furnace operations have been located in suburban areas with minimal impact (ABARE, 1994a).

Continuous casting

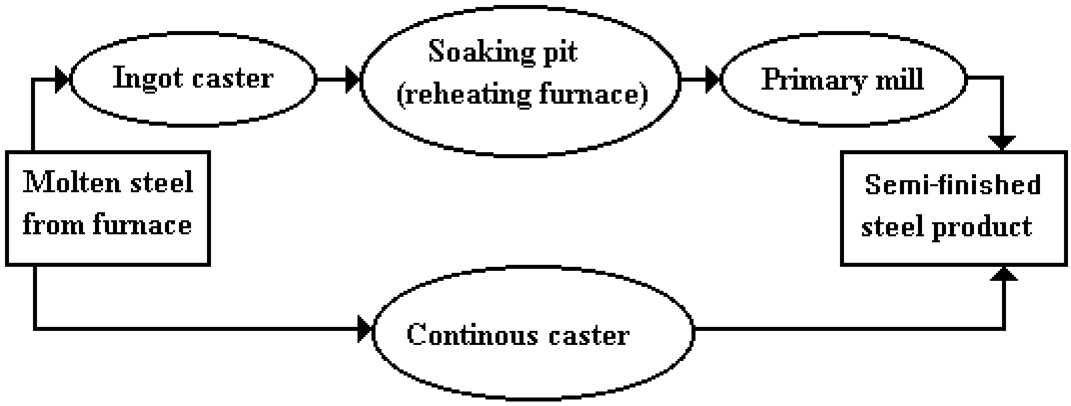
Developed in the 1950s, continuous casting techniques have greatly improved the productive efficiency of steelmaking. As ABARE said:

> Continuous casting technologies have been around for about 40 years and have greatly improved the productive efficiency of those companies that have utilised this technology. However, some steelmaking companies have been slow to adopt this

> technology, including the United States, China and Eastern Europe. The competitive performance of a steelmaker is directly related to the use of continuous casting. In addition, recent developments in casting technology have the potential to further increase the competitiveness of electric arc furnaces. Innovation in slab casting techniques will allow electric arc furnaces to move into the production of certain flat steel products (ABARE, 1994b).

With continuous casting technology, molten steel is directly cast into semi-finished products and hence the forming of ingots, subsequent cooling, reheating and primary rolling of ingots is eliminated (see Figure B11.6).

Figure B11.6: Ingot and continuous casting methods



Source: ABARE, 1994d.

ABARE identified several advantages derived from the use of continuous casting, including:

- energy savings of up to 15 per cent;
- a reduction of scrap of up to 50 per cent;
- faster production; and
- lower capital costs.

Strip casting

Recent developments in casting technology, such as strip casting, have the potential to further increase the competitiveness of the electric arc furnaces.

BHP is a World leader in strip casting technology, which is a refinement of continuous casting technology. BHP has unveiled a new sheet-steel process at its Port Kembla operations.

The operation, called Project M, has been described by BHP as the world's biggest single R&D project in the steel industry.

The new strip casting process makes it possible for sheet steel to be produced as thin as one millimetre from the casting process. BHP described the process:

> The strip casting process involves liquid steel being poured between twin cooling rolls to produce coils of sheet steel. The process is being researched by many steel and equipment companies and has the potential to become the low capital cost route for producing steel capacities of up to 500 000 tonnes. Built by IHI, the development casting machine at Port Kembla will cast more than 60 tonne heats, melted from scrap, to produce 25 tonne coils up to 1.9 metres wide (BHP, 1994).

The Chief Executive of BHP Steel, Mr Ron McNeily said:

> It is very exciting. It will be a whole new generation of steel industry technology. It means you are virtually going from molten scrap, molten metal, to the finished product in the one process and then out the door to the customer (Haigh, 1995).

A smaller pilot plant, producing five tonne coils, has been successfully trialled and a new plant will produce 25 tonne coils. If successful, output will increase to simulate production levels of a full-scale steel plant.

Coating technology

BHP is at the forefront of steel coating technologies. Recent developments in coating technologies and other processing technologies may eliminate the advantage aluminium has over steel in beverage cans.

BHP described some of its developments in steel coatings thus:

> Metallic coating research and development is directed towards improving process and product technology, and the development of new coatings with improved properties. Procedures include the theoretical analysis and practical studies of the fundamentals of corrosion, electrochemical phenomena, the chemistry surfaces, the mechanical properties of metal coatings and metallurgical reactions between the coating material and steel base (BHP, 1990).

B11.5 Demand conditions

Besides trying to meet the demand for steel markets through improving technologies at integrated steelworks and expanding production via new technologies (such as electric arc furnaces), many steel producers are looking at ways to compete with substitutes (such as aluminium and plastics).

Steel makers have fought back against substitute materials in a variety of ways. These include making use of HSLA steels, better designs for existing steel products and the development of better coating and joining techniques (see Box B11.7).

For example, new lightweight steel cans are poised to return to the beverage industry. Companies such as Foster's Brewing Group, Lion Nathan and Coca Cola Amatil have undertaken feasibility studies on the cost differential between steel and aluminium cans and are expected to make a decision in the near future about whether or not to switch back to steel cans. They are considering the move because of the recent rise in aluminium prices and the development of ultra-thin steel sheeting by BHP (see Box B11.7).

Box B11.7: Steel versus other materials

The beverage can market

BHP's steelworks is upgrading its tinplate manufacturing operations in an effort to shore up support for steel as a food container against strong challenges from 'newer' materials, such as aluminium and plastics. The upgrade will increase output from BHP's Packaging Product Division by 40 per cent.

Products generated by BHP include tin plate for cans, steel strip binding and black strip for uncoated plate steel. In a bid to expand its range, BHP plans to introduce a new can sheet product dubbed 'tin free plate'. The steel will be electrolytically chrome-plated, offering food producers a wide range of final coatings while also being cheaper than traditional tin plate.

BHP will install facilities to allow for the production of wider and thinner steel sheet. These innovations, as well as decreasing the thickness of steel coatings, will allow end-users of can sheet greater flexibility in can production.

By the time the expansion of the tinplate and chrome-plate facilities is complete, BHP hopes to increase exports from a present rate of 25 per cent of output to about 50 per cent.

The automotive market

BHP has joined 24 other steel companies World wide in a study aimed at protecting the world steel industry's annual 35 million tonnes automobile market against aluminium. The 25 producers are funding a $1.5 million study by Porsche Engineering which will examine ways of producing the lightest possible steel-bodied car in the most cost-effective way.

Source: Howarth 1994.

As with other materials discussed in this report, changes in legislation are also influencing the demand for certain steels (for example, stainless steel):

> The [US] 1990 Clean Air Act Amendments and Energy Policy Act of 1992 have led to increases in demand for stainless steel in the automotive industry. For automotive emission control, stainless steel is the only material that provides ten years of leak-proof exhaust system operation. Other examples either in use or under development include commercial hot water heaters and photovoltaic substrates (Advanced Materials and Processing, 1994).

B11.6 Potential for further production and use

There are several factors expected to determine the potential for the further production and use of steel in Australia. They include:

- the demand for speciality steels;
- the emergence of Asia, in particular China, as a source of demand for steel, steel-making technology and raw material exports;
- the effect on demand of the increasing use of electric arc furnaces; and
- the possible adoption of direct smelting technology.

With the continuing growth in Asian markets and the considerable investment by BHP in new technology and productivity improvement, steel production in Australia should continue to grow.

Greater use will be made of high-strength low-alloy steels in order to maintain steel's market position in the automotive, construction and packaging industries.

Improvements in processing technology such as strip casting and advances in joining and welding techniques will assist steels competitive position.

Impacting on local steel production to some extent will be the establishment by BHP of additional minimills in overseas locations to service Asian and US markets.

Successful development and adoption of direct smelting processes to provide feed material for minimills will lead to additional local production.

B12 NICKEL METAL AND ALLOYS

Nickel was in use well before it was identified as a metal. Iron from meteors containing up to 26 per cent nickel was used as long ago as 4000 BC for axes, knives and other implements. Nickel has been identified in both Chinese and Greek coins dated 800 BC and 300 BC respectively. In the fifteenth century copper miners in Saxony became aware of nickel as a mineral which they associated with their inability to obtain good quality copper and with arsenic poisoning. They called the unknown mineral *Kupfer-nickel* or Devil's copper (Street and Alexander, 1994).

Pure nickel was discovered by Axel Cronstedt and described in a paper published by him in 1751. However, it was almost 150 years before a commercial process was developed to remove the sulphur and carbon from the nickel ore and obtain nickel metal.

In the late nineteenth century it was found that the addition of nickel to steel considerably increased its strength and toughness. Its primary use at that time was in armour plate for military applications. During World War I military applications accounted for 80 per cent of nickel consumption (Mizzi, Maurice, Anders, 1987).

Nickel metal is strong, workable and corrosion resistant with chemical properties that allow it to be used as an alloy. Nickel has a melting point of 1453°C, low electrical and thermal conductivities and is ferromagnetic.[1] Nickel alloys and nickel bearing stainless steels are highly resistant to corrosion and oxidation and have excellent strength and toughness at elevated temperatures (INSG, 1994).

There are two sources of nickel:

- primary — produced from nickel ores; and
- secondary — recycled or scrap nickel, sourced from steel manufacturing or from obsolete plant and equipment.

1 A ferromagnetic material is one which possesses magnetic properties in the absence of an external magnetic field.

Primary nickel is further divided into Class 1 and Class 2 nickel. Class 1 or London Metals Exchange (LME) grade refined nickel has a nickel content of 99.8 per cent or more and includes:

- melting products such as pure nickel for the non-ferrous and foundry industries and for ‘finishing’ in stainless steel production;
- special products such as powders used in nickel-cadmium batteries and powder metallurgy and chemicals; and
- plating products cut to special sizes for use as anodes in the nickel plating industry.

Class 2 nickel includes charge nickel products such as ferro-nickel, nickel utility and nickel oxide.[2] These have a nickel content below 99 per cent and are produced mainly for the stainless steel and low-alloy steel industries.

There are two types of nickel ore — nickel sulphide ores and lateritic nickel ores. The sulphide ore deposits generally are associated with other minerals such as copper ores and are found in Canada, the CIS and Western Australia. The lateritic ores are found in sub-tropical regions such as Cuba, Indonesia, New Caledonia and North Queensland.

The process used to obtain pure nickel depends on the specific properties of the nickel ore deposit. The process described below is that used by Western Mining Corporation Holdings Limited (WMC) to obtain nickel from its nickel sulphide ore deposits in Western Australia.

Nickel is mined and the ore crushed and ground. The finely ground ore is then concentrated using flotation. The nickel concentrate is smelted to produce nickel matte, which contains approximately 72 per cent nickel, the balance being mostly sulphur with small amounts of copper and iron as well as other impurities.

The refining process is a hydrometallurgical operation in which nickel matte is dissolved and various elements then selectively recovered. The recovered nickel is sold as powder or pressed and sintered into nickel briquettes.

Lateritic type nickel ore deposits require different processing techniques to be used to obtain a pure nickel product. The Queensland based company QNI Limited mines and purchases lateritic ores. Nickel and cobalt metals are extracted from these oxide ores by systems based on the Caron process. This involves drying the wet ore in rotary dryers and using ball mills to grind the ore into a fine powder. The powder is mixed with a reductant and fed into a

[2] Charge nickel products are the raw materials fed to electric furnaces to produce stainless and low alloy steels. Generally, a Class 1 nickel must be used to finally adjust melt composition.

furnace. The nickel and cobalt are reduced and leached with ammonia or ammonium carbonate solution.

Next, a solution containing nickel and cobalt is separated from the wastes. The Ammoniacal Solvent Extraction process is then used to separate the nickel from cobalt.[3] Nickel carbonate is formed and then calcined to produce nickel oxide. The nickel oxide can be made into a number of high purity nickel products.

B12.1 International production and usage

Production

Kuck (1992) reports that in 1991 World mine capacity for nickel was 1.1 million tonnes and refinery and smelter capacity was 1.17 million tonnes. In 1991, 19 countries were involved in mining and 27 in the refining and smelting of nickel. Table B12.1 shows that six countries accounted for approximately 70 of total World mining capacity and nine countries account for approximately 70 per cent of smelting/refining capacity.

Table B12.1: Major nickel producing and smelting countries, 1991

Country	*Mine capacity*		*Smelting and refining capacity* [a]	
	(kilotonnes)	*Per cent of world mine capacity*	*(kilotonnes)*	*Per cent of world capacity*
CIS	300	27.0	300	26.0
Canada	205	18.5	155	13.2
Australia	75	6.8	54	4.6
New Caledonia	91	8.2		3.8
Indonesia	64	5.8		0.4
Cuba	54	4.8		2.6
US	5	0.4	50 [b]	4.3
Japan	-	-	112	9.5
Norway	-	-	55	4.6
Other	316	28.5	447	30.8
Total	*1 110*	*100*	*1 173*	*100*

a Smelter capacity for matte is not listed to avoid double counting. Matte is an intermediate product that must be refined before the nickel it contains can be used to make alloys or other products.

b Includes standby capacity.

Source: Kuck, 1993, p. 24.

3 This process was developed and patented by QNI. It improves the separation of nickel and cobalt, makes nickel extraction more cost-effective, and enables the production of near pure nickel products.

Figure B12.1 shows the level of Western World production of primary nickel and consumption of nickel for the period 1983 to 1993.[4] The excess of consumption over production is accounted for by imports from non-western World producers, and in 1993 by the sale of nickel from the US Strategic Defence Stockpile.

Figure B12.1: Western World nickel production and consumption, 1983–1993

Source: INSG, 1994, p. 5.

Nickel scrap used in the production of stainless steel adds significantly to the total world supply of nickel. Kuck (1993) reports that in the US in 1993, approximately 40 000 tonnes of nickel, representing 32 per cent of consumption, was recovered from purchased scrap metal.

Usage

In 1993, Western World demand for nickel was 685 000 tonnes (INSG, 1994, p.3). Figure B12.2 shows the pattern of nickel consumption by use and application for 1993. It is evident that stainless steel production is the largest user of nickel.

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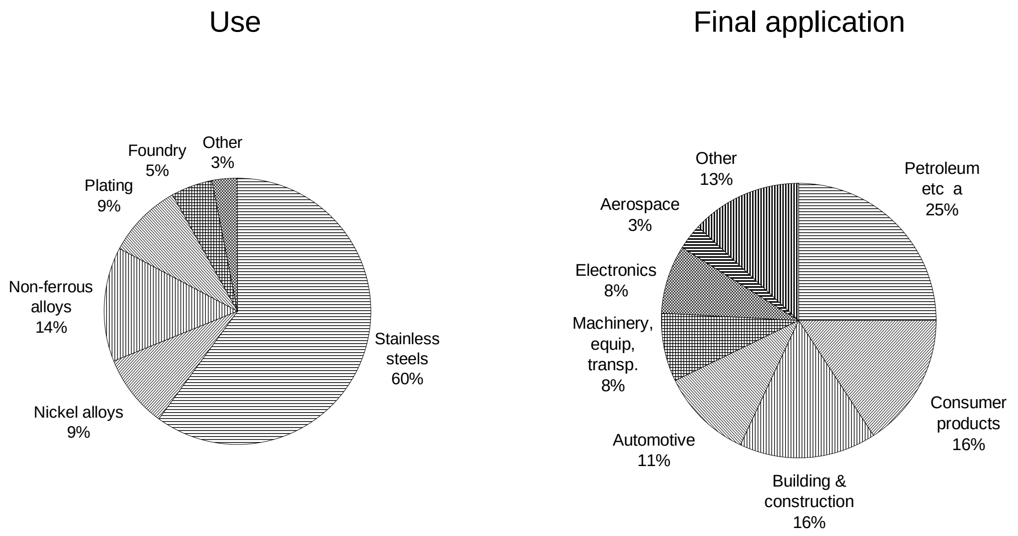
4 The non-Western countries involved in producing nickel include: Albania, Bulgaria, China, the CIS, Cuba, Estonia, Hungry, Latvia, Lithuania, Korea, Poland, Romania the former Czechoslovakia, Yugoslavia and German Democratic Republic.

Figure B12.2: World wide consumption of primary nickel, 1993



a Includes petroleum, chemical, process and power industries.
Source: NiDI, 1993.

The major uses of nickel are discussed below.

Stainless steels are iron alloys that contain at least 11 per cent chromium. Nickel bearing stainless steels are generally known as austenitic stainless, containing from 8 per cent to 11 per cent nickel. Stainless steels are discussed in detail in Appendix B11.

Heat resistant alloys, such as the Nimonics and Inconel series which typically contain 75 percent to 80 per cent nickel, are widely used in heating elements and other high temperature applications.

Nickel based ‘superalloys’ containing chromium, aluminium and other minor elements are used as components of gas turbine engines.

Nickel–copper alloys, such as the Monel series, are widely used in marine applications because of their excellent resistance to salt water corrosion. They are also widely used to produce coinage.

In plating applications, nickel is generally applied to a base metal (usually steel) under a thin chromium top coat. Nickel is used to provide corrosion protection for the base metal in a wide variety of applications including office equipment, domestic hardware and automotive components.

Nickel powder and nickel compounds are used primarily in batteries, such as the nickel–cadmium battery, and in catalysts.

Examples of products which feature nickel or nickel-containing alloys are listed in Box B12.1.

Box B12.1: Products containing nickel

Nickel is used in many final products found in everyday applications. Some of the products made of stainless steel which include nickel, are:

- pipelines, valves, seawater systems, topside cladding used in the offshore oil and gas industry;
- vessels, ducts and flue liners for coal-fired power stations and waste incinerators;
- containers for the long-term storage of nuclear waste;
- heat-exchangers, pipes and valves for water desalination plants and for waste water treatment;
- cooking vessels and work-surfaces for commercial food processing;
- kitchen waste and table ware for the home;
- processing, storage and transportation vessels for milk, wine, beer and other beverages; and
- 'curtain-wall' cladding for modern city centre buildings.

Non-stainless steel uses of nickel include:

- combination zinc-nickel coatings for the rust-protection of car body panels;
- rechargeable batteries for 'cordless' electrical appliances;
- turbine blades and other vital components of aero-engines;
- plated radiators and other items of automotive trim; and
- furnace tubes for the chemical process industry.

Source: INSG, 1994.

B12.2 Australian production and usage

Production

Australia is involved in the mining, smelting and refining of nickel (see Table B12.1). Nickel mines and smelters operate in both Western Australia and Queensland. Australia has developed an internationally competitive nickel industry providing 8 per cent to 10 per cent of the world's nickel supply. ABARE estimated that in 1993 Australia produced 88 000 tonnes of primary nickel, which was approximately 10.5 per cent of World production. The value of Australian exports of primary nickel in 1992–93 was $640 million (Manson, Gooday and Meek, 1994). Nickel exported from Australia is generally used in the production of steel.

Australian nickel operations and their projected output in 1995 are listed in Table B12.3 along with nickel deposits which have the potential to be mined. Australia has the potential to double its nickel production over the next decade. The price of nickel will determine to what extent this potential is realised.

Table B12.3: Australian nickel mine production and deposits, 1995

Producer	*Estimated production, (kilotonnes)*		*Potential production (kilotonnes)*	
(Company — mine name)	*Mine*	*Refined*	*Mine*	*Refined*
W.M.C.[a]	95	42	125	50
Q.N.I.[b]	3	28	3	28
Potential new mines				
C.R.A and Outokumpu Oy — Honeymoon Well			40	
Dominion Mining and North Ltd — Yakabindie			20	20
Gencor and Forrestania Gold — Maggie Hays			14	14
Normandy and Poseidon — Sally Malay			18	
Resolute — Bulong			12	12
— Radio Hill			3	
Defiance Mining— Carr Boyd Rocks			2	
Total	98	70	237	124

a The production of WMC's refined nickel is determined by their refinery capacity of 42 kilotonnes. WMC export the intermediate product nickel matte.

b The QNI refinery processes nickel imported from Indonesia and New Caledonia.

Source: Western Mining Corporation.

Western Australia

The location of nickel mining and refining activity in Western Australia is shown in Figure B12.3.

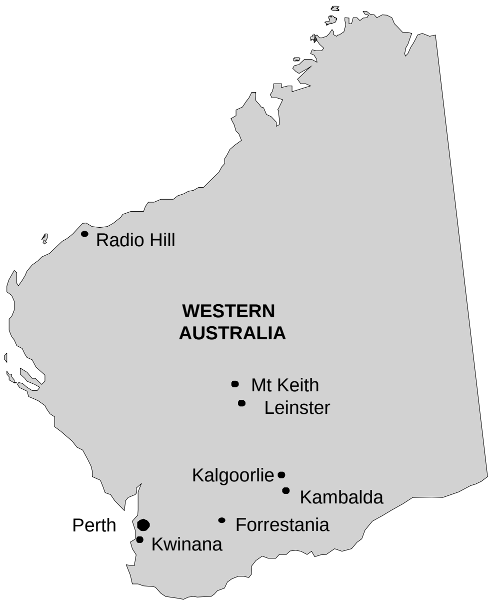
Australia's largest nickel producer is Western Mining Corporation Holdings Limited (WMC). WMC is one of the four largest nickel producers in the Western World. It operates nickel mines and concentrators at Kambalda, Leinster and Mt Keith.

In addition, WMC operates a nickel smelter at Kalgoorlie and a nickel refinery at Kwinana.

In 1995, WMC anticipate production of 95 000 tonnes of nickel contained in concentrates.

Of this, 79 000 tonnes of contained nickel will be processed to matte at the Kalgoorlie smelter, with 16 000 tonnes sold as concentrate. Just under half of the matte production will be sold, and the remainder processed at WMC's Kwinana refinery to produce 42 000 tonnes of nickel metal, predominantly in the form of LME Grade nickel briquettes.

Figure B12.3: Nickel operations in Western Australia



WMC products are exported to the United Kingdom and European markets (40 per cent), the US (30 per cent), and Asia - particularly Korea, Taiwan, Japan and India (30 per cent).

Queensland

The location of nickel mining and refining activity in Queensland is shown in Figure B12.4. It includes the now exhausted Greenvale nickel mine.

Until February 1995, the nickel operations in Queensland were owned and operated by the Queensland Nickel Joint Venture (QNJV) which was 80 per cent owned by QNI Limited and 20 per cent by Nickel Resources North Queensland. Nickel operations in Queensland are now wholly owned and operated by QNI Limited. The major nickel operation in Queensland is nickel refining which occurs at Yabulu north of Townsville.[5]

Nickel ore for the refinery was originally sourced from the Greenvale nickel mine. This mine was worked from 1975 until it was depleted in 1993. As the Greenvale mine came to the end of its economic life, larger amounts of the nickel feedstock have been imported from New Caledonia and Indonesia. In 1989–90, 35 per cent of nickel ore being refined at Yabulu was imported (ABS, 1994). In 1993–94, this had increased to 90 per cent. The remainder was sourced from the Brolga mine and a stockpile from the Greenvale mine.

[5] Cobalt is also refined at the Yabulu refinery.

The traditional product of QNJV was nickel oxide, a product having 85 per cent to 90 per cent nickel. In 1992, QNJV began production of high purity nickel products. It now sells QN Nickel Rondelles with 98.5 per cent nickel and QN Higrade which is 99.5 per cent nickel. These products have increased from 8 per cent to 21 per cent of total company sales in the two years since their introduction (QNI Annual Report, 1994).

Almost all QNI nickel output is exported with sales to western Europe (40 per cent), Asia (40 per cent) and the US (20 per cent) (QNI Annual Report, 1994).

Figure B12.4: Location of nickel operations in Queensland

Use

As noted above, nickel is used mainly in the production of stainless steels. As there is no stainless steel production in Australia only relatively small quantities of nickel are used directly by Australian industry. Both WMC and QNI report that they supply only small amounts of nickel to the domestic market. WMC reports that the majority of its domestic nickel sales are to foundries.

Other forms of nickel are imported into Australia and compete directly against Australian produced nickel in most markets. In 1993–94, the value of primary nickel imports was $6 million (ABARE, 1994c).

Nickel is the main raw material used by Western Australian Specialty Alloy (WASA) in the manufacture of superalloys ingots (see Box B12.2). Superalloys have characteristics of high-temperature strength and superior creep and stress rupture resistance. Their main use is in gas-turbine engines. WASA imports the nickel it uses as the grade of nickel required is not produced in Australia.

Box 12.2: The production of superalloys in Australia

WASA was established in 1992 and production began in 1994. The firm manufactures both nickel and cobalt-based superalloy ingots which are sold to forging companies to produce parts for use in the aerospace, power generation and petrochemical industries.

The company is owned:

- 50 per cent by Western Aerospace Limited, a Western Australian public company which invests in the aerospace industry;
- 25 per cent by United Technologies International Corporation, a US corporation of which Pratt & Whitney is a division; and
- 25 per cent by Wyman-Gordon Company, the world's largest casting and forging company for the aerospace industry.

The estimated cost of establishing the WASA plant was $40 million. The firm anticipates export sales of approximately $500 million in its first ten years of operation.

The establishment of the firm was assisted by the provision of fully serviced land and financial assistance for the construction of buildings by the Western Australian Government and the provision of offsets for the American companies involved.

Source: Information provided by WASA.

B12.3 Markets

The price of nickel

Inco Alloys International is a Canadian company which has traditionally dominated the World nickel market. Until the 1970s, Inco's power in the market was such that it largely determined the price of nickel products in the international market. It acted as a price leader by publishing a list of 'Producer Prices'. These 'Producer Prices' were used as a benchmark by other nickel producing firms when setting their prices.

Mizzi, Maurice and Anders (1987) report that Inco allowed other firms to supply as much nickel as they desired at the set price, then themselves supplied the remaining market demand. In times of excess supply Inco decreased production and allowed inventories to increase. If there was increased demand, Inco would increase production and run down inventories. Price changes were infrequent.

However, as Inco's market share declined in the 1970s so did their ability to determine nickel prices. Inco halted publication of its benchmark prices in

1977. From 1978 nickel has been traded on the LME and it has been the LME price, rather than Inco's price list, which determines the price of nickel.

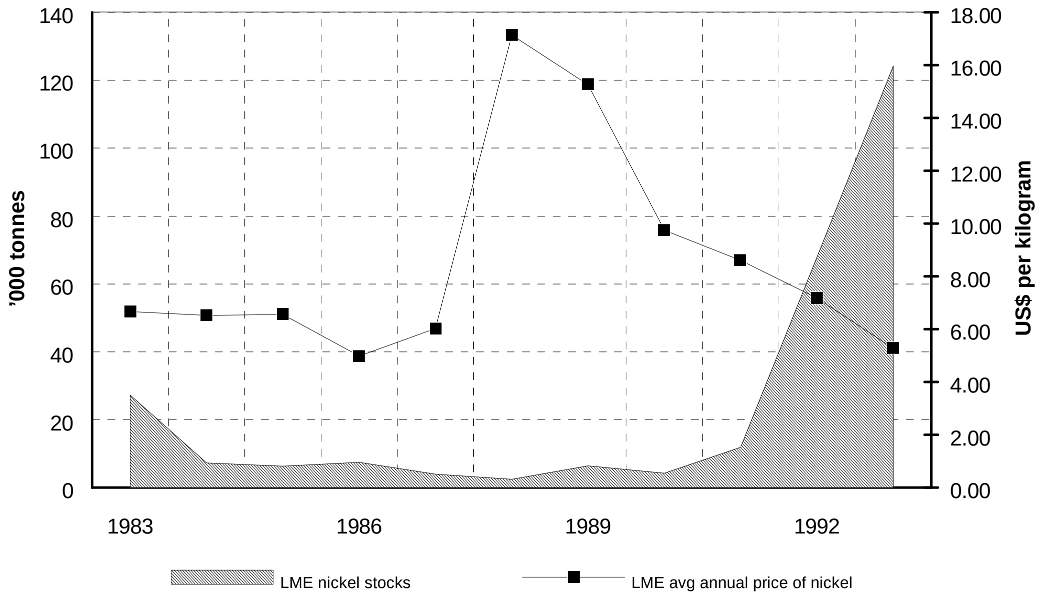
It is of note that not all nickel is sold through the LME and prices charged by individual companies will generally be higher than LME prices due to transportation costs, terms of credit and product quality (Mizzi, Maurice and Anders, 1987).

The average cash LME price of nickel from 1981 to 1994 and LME nickel stocks are shown in Figure B12.5.[6]

The average LME price for 1993–94 was US$5.24 per kilogram which continued the trend of price decline which began in 1988.

The LME price is influenced by the actions of traders and investment funds who choose to invest in nickel. Annual volumes traded on the LME are approximately 40 times higher than annual World production. This creates the situation where demand and supply of nickel by producers or consumers is not necessarily the major determinant of the LME price.

Figure B12.5: Average cash LME price and stocks of nickel 1983–1993[a]



a In real 1993 dollar terms.
Source: INSG 1994.

6 'Cash price' refers to the price paid for primary nickel which is delivered the next market day. This price differs from the '3 month price' which applies when nickel is purchased, but not delivered for three months.

In September 1993, the LME cash price of nickel dropped to $US4 per kilogram. This is the lowest nickel price ever recorded in real terms. The low price was influenced by the high level of exports from the CIS that followed a decline of consumption in that country when the former Soviet Union disbanded.

The low price was also influenced by Western World nickel producers maintaining high production levels while prices declined. These high levels of production are apparent from the increasing levels of nickel stocks held by consumers and the LME seen in Figure B12.5.

Inco attempted to halt the situation of falling prices and increasing stock levels by reducing production. However, when it became apparent that other producers intended to continue producing at full capacity, Inco reverted to full capacity production (QNI Annual Report, 1994).

However, from the low of 1993, the LME price of nickel has been firming. The average price of nickel in the third quarter of 1993 was $US4.70 per kilogram. By the third quarter in 1994, the price had increased to be $US6.15 per kilogram (INSG, December 1994).

Because other minerals are extracted in the process of mining nickel the LME price is not the sole determinant of whether or not nickel will be mined. In sulphide-type nickel ore deposits, copper, cobalt and precious metals such as gold, silver and platinum, may be recovered, and it is the total return to the mining operation which matters.

B12.4 Supply Conditions

Production Technologies

New technologies are being developed in Australia to process what are currently sub-economic nickel ore deposits. A breakthrough in any one of these research areas could mean substantial additions to Australian nickel output.

For instance, Forrestania Gold is investigating the use of bacterial leaching for its Maggie Hays deposit in Western Australia. This new production technology could significantly reduce the environmental problems associated with conventional smelting.

B12.5 Demand Conditions

As noted earlier, stainless steel production is the major use of nickel, therefore demand for nickel is largely derived from the demand for stainless steel. The current long-term growth in production of austenitic stainless steel has been estimated at 4.5 per cent per annum (Hansen, 1994). Demand for stainless steel is expected to increase with the improving fortunes of the US economy and in the longer term significant demand is expected from the newly industrialising countries in Asia (Manson, Gooday and Meek, 1994).

Worldwide a number of organisations have been established with the express role of promoting the use of nickel and austenitic stainless steels in new applications. One new use of stainless steel, and consequently nickel, is in roofing (Hansen, 1994).

Significant growth is expected in demand for duplex-alloy stainless steels as they are stronger than traditional stainless steels. This will increase demand for nickel, but to a lesser extend than would growth from stainless steels as duplex-steels have a lower nickel content than stainless steel.

For a detailed discussion of the steel industry see Appendix B11.

B12.6 Potential for further production and use

Producers

As indicated in Table B12.3, Australia has significant deposits of nickel which may be developed. Factors which will influence the establishment of new nickel mines in Australia include the success of developing new processing technologies, improvement in the price of nickel, and continued growth in demand from stainless steel producers.

Users

As noted earlier, the largest volume use of nickel is in stainless steel and there is currently no stainless steel production in Australia. With recent commitments to major new stainless steel production facilities in South Africa and Asia it is unlikely that a stainless steel production facility of economic size will be justified in Australia in the foreseeable future.

Expanded use of stainless steel in Australia, particularly the new duplex stainless steel, will occur in accordance with world wide trends and be serviced by imports.

An area of potential growth for nickel is in battery applications. The well established nickel-cadmium battery is currently used in applications such as lap-top computers and cellular telephones. However, this does not represent significant tonnage and is unlikely to grow significantly because of cost and concerns about the health risks associated with cadmium.

The drive to commercialise electric vehicles in the US has resulted in heightened interest in the development of new battery systems. The California *Clean Air Act* requires that 2 per cent of all new vehicles sold in California will produce zero emissions by 1998, increasing to 10 per cent of all vehicles sold in 2003 (Rand, 1994). Automotive companies in the US are seeking a battery which can propel a car 480 kilometres on one charge, recharge in 15 minutes and last 160 000 kilometres (Kuck, 1992).

Any new system that replaces the traditional lead-acid batteries must offer advantages in specific energy, specific power, recharge time or cost. A number of nickel-based systems are under intense investigation for these applications (Rand, 1994).

One of the most promising is the nickel metal hydride system which has double the specific power of a lead acid battery. Problems exist however in the cost and self discharge propensity of the system.

Other nickel-based systems under investigation are nickel-iron and nickel-zinc. Should any of these come to commercial usage this would be a significant new source of nickel consumption. Success for electric vehicle applications could lead to other high volume applications in stationary power systems.

Kuck (1992) is optimistic about the outlook for nickel demand for use in superalloys. This optimism is based on an expected increase in construction of civil aircraft after 1995, as current fleets are ageing and the volume of air traffic is increasing.

C1 EDUCATION, TRAINING AND AWARENESS

Many inquiry participants doubted whether skills and training in new and advanced materials are adequate in Australia. The same participants and others argued that there is a lack of awareness by industry of the beneficial properties of the materials, and that this impedes innovation and the achievement of competitive advantage.

A number of propositions were put by participants. First, that there is a shortage of people trained in materials science and related disciplines in Australia. Second, there has been a decline in the materials science content of existing science, engineering and related courses. Third, university laboratories were not being maintained and upgraded to keep apace of advances and new challenges in materials science. Fourth, these features of the education system had negative influences on industry decision-makers' awareness of developments in materials. The potential result is that Australian industry will not be able to make informed choices in materials selection and is in danger of falling behind.

Many participants submitted that these problems impacted on the whole materials area, including the proper selection and use of traditional materials.

C1.1 Skill requirements

The skill requirements to innovate and achieve competitive advantage in the field of new and advanced materials are broad-ranging. They include materials selection, product and engineering design, and product processing skills that result in efficient production runs and quality control. Recently, a group sponsored by the Institute of Engineers Australia and the Australian Academy of Technology, Science and Engineering (AATSE), has been formed to review the whole question of training and research in materials. The group, called the National Council for Materials, is chaired by Dr Colin Adam, Director of the Institute of Industrial Technology at CSIRO. Membership includes senior academics and research managers from both government and industry. The Commission held discussions with members of this group and received valuable input from them.

Specification of the appropriate materials is crucial to product manufacture. The Industry Research and Development (IR&D) Board commented that:

> It will not be sufficient merely to have access to expertise in the key input areas, because successful manufacturing will depend on ability to integrate design and process skills with materials technology.

> There will also be a need for comprehensive understanding of the opportunities for application of new materials and the constraints imposed by the wider environment in which manufacturing takes place (sub. 24, p. 3).

The MTIA stated that:

> [The] general lack of data and supply infrastructure .... means Australian designers are not acquainted with the more advanced materials and hence do not feed technologically more advanced concepts into the design cycle as is commonplace in other countries (sub. 35, p. 3).

The IR&D Board said that:

> ... successful manufacturing will depend on ability to integrate design and process skills with materials technology. This ability will flow from the capacities of people who have knowledge and experience which crosses traditional disciplinary boundaries (sub 24, p. 3).

The preceding quote indicates that the selection and application of materials in the modern World requires something more than, say, traditional engineering knowledge and traditional trade skills. This raises questions pertaining to training at both the tertiary and sub-tertiary levels. There are two aspects to this issue.

The first is about the appropriateness of education and training. What is the appropriate mix of disciplines in a tertiary course? Is proper training being provided at the sub-professional level? At the sub-tertiary skilled trade level, the same question has to be asked but the appropriate range of skills fall into a much narrower (technical) band.

The second aspect pertains to the numbers who should be trained. How many people at tertiary and sub-tertiary levels should we train in Australia, given the size of our economy, our population, and the demography of the nation?

These are not easy questions to answer, however, if Australia is to participate to its full capacity in advanced manufacturing and product design and development in the future, these questions warrant particular attention. Without pre-empting the answers that will come from detailed consideration of these issues by the full range of interested parties, there is a *prima facie* case that increased resources are likely to be required in the short term. It is most likely that these resources will have to come from both industry (via industry associations) and government (in as much as it addresses education, training, R&D and industry information needs by allocating new funds or by re-allocating existing funds).

Declining materials content in courses

The Institute of Metals and Materials Australasia (IMMA), the Composites Institute of Australia (sub. 20), and the Australian Composites Structures Society (sub. 14) are all concerned that there is insufficient materials science content in relevant courses. The National Council for Materials also supports this view (sub. 65), as do a number of individuals who presented information to the Commission (and whose views are quoted in numerous places throughout this report).

It was put to the Commission that the materials content in engineering courses (such as mechanical and civil engineering), and also in architecture, has declined over time:

> ... the content of these courses has shrunk considerably and would not be sufficient to [enable those] who have elected to take the courses to design competently with new materials (Department of Materials Engineering – Monash University, sub. 32, p. 1).

The problem has been exacerbated by current funding mechanisms in the tertiary sector. Teaching materials science and engineering has expensive infrastructure requirements, and the cost of this has become a disincentive to include a significant component of materials science in engineering courses. In addition, a tendency has developed for materials training to be given by non-specialists within engineering schools, rather than as service courses given by materials science specialists, and this suggests a downgrading of materials science.

Responsibility for the development of curriculum rests with the individual educational institutions; however, curriculum content is also influenced by professional bodies such as the Institution of Engineers, and by accreditation processes.

Notwithstanding professional input, the situation has changed to the extent that, as stated above, various professional bodies and individuals recognise that something should be done to redress the decline in materials science.

There is a problem with a number of materials science courses which still exist. It is that they concentrate on materials properties and behaviour, rather than on the processing of materials, which is often the most critical part of the manufacturing process. This imbalance partly arises from the run-down in infrastructure in tertiary institutions, and because equipment for research and training in materials processing is particularly expensive. This infrastructure problem can be partly solved by greater co-operation in the use of existing facilities. Initiatives to achieve this co-operation by, for example, the Queensland Manufacturing Institute (QMI) and the Materials Institute of Western Australia (MIWA) are welcome and should be encouraged.

TAFE colleges often have better access to processing equipment than do universities and in both these Institutes, equipment and facilities from a number of government laboratories, universities and TAFE colleges have been brought together on one site to provide a state-of-the-art facility to which all teaching organisations and industry can have access. Both these Institutes had significant seed funding from their respective State Governments.

C1.2 Supply of science and engineering skills

Science and engineering are the two core disciplines most likely to lead to a career in materials science or materials engineering. Depending on the level of expertise required, the skills required for such a career can be obtained at university or TAFE level. In addition to formal training, there is considerable scope to add both depth and scope to existing knowledge and skills via on-the-job or short-course training. In fact, given the rapid changes in materials science and technologies, continuous education is a prerequisite not only for a successful career for those in materials-related work, but also for the future of Australian manufacturing and product innovation.

Graduate level

Amongst OECD and ‘Asian-tiger’ countries, Australia ranks lowly in the combined number of scientists and technicians in the population, but relatively higher in the proportion of science graduates (see Table C1.1). This indicates that Australia does not train large numbers of technology-oriented people.

It has been suggested that there is an imbalance between science and engineering, and that science has dominated at the expense of engineering, so much so that:

> ... industry’s capacity in engineering design and development skills continues to lag behind that of our overseas competition (Dack, 1994, p. 23).

Because of the degree of aggregation and some imprecision in definition of disciplines, statistics like those in Table C1.1, and claims of imbalance between disciplines, need to be interpreted with caution.

Table C1.1: Scientists and technicians numbers, 1990–91

Country	*Scientists and technicians (per 1000 people)*[a]	*Science graduates (per cent of total graduates)*
Japan	110	26
Canada	174	16
Norway	231	17
Switzerland	202	25
Sweden	262	26
US	55	15
Australia	48	19
France	83	27
Netherlands	92	22
UK	90	26

a 1986 to 1990.
Source: United Nations Development Program, 1994.

There is another problem and that is relying on official statistics to determine the number of graduates who are *material scientists* or *materials engineers*.

The complications in ascertaining who is, or is not, a materials scientist or materials engineer are illustrated by an investigation in the US. The US National Materials Advisory Board (NMAB) reported that a 1986 survey by the National Research Foundation revealed there were 53 000 individuals who identified themselves as materials scientists and engineers, and had backgrounds in metallurgy, materials and ceramics. However, it was estimated that a further 30 per cent or approximately 22 000 of the 73 000 physicists and astronomers, and 33 per cent or 61 000 of the 185 000 chemists in the US, had specialised in materials science and engineering, yet did not identify themselves as either materials scientists or materials engineers (NMAB, 1993). When these two other groups were added, a total of approximately 136 000 individuals were, potentially at least, professionals in the area.

A survey similar to that conducted in the US has not been undertaken in Australia. The aggregate number of students completing science and engineering courses in any one year is known, but there has been no attempt to produce data showing how many of these graduates could be regarded as working in materials-related areas. However, even if that number was available, it would not help determine whether it was the optimal number. This is because the demand for people with materials qualifications is not an independent variable if it is accepted that industry is not aware of the benefits of employing such people.

TAFE level

In the 1980s, the TAFE sector was believed to have been neglected relative to university education (EPAC, 1993). In an attempt to increase the quality of education provided at TAFE colleges a competency-based framework was endorsed by the Government through the National Training Reform Agenda in 1989. Under this framework, industry sets out the skills that are needed to perform work at various levels. The National Training Board has responsibility for endorsing the competency standards developed, which then become the basis for curriculum design and training provision.

Despite this attempt to improve the quality of TAFE education in Australia, some individuals with a background in materials science education are concerned that Australia is not doing enough. One such individual is Professor Dunlop who argued that, in contrast to Australia, the education systems in countries such as Sweden and other Northern European countries place a greater emphasis on vocational or sub-tertiary level training (as quality alternatives to university). In these countries there are likely to be strong links between educational institutions and employers, and significant investment by firms in on-the-job training (transcript, p. 113 to 125). Similar comments have been made when comparing the US education system to those in Japan and Germany (Porter 1990).

The National Council for Materials (sub. 65) believes that a dramatic swing away from two and three year diploma courses, which were taught in the technical colleges up to the 1970s, has had very detrimental effects on the skill levels in the manufacturing industry, particularly in small- to medium-sized enterprises (SMEs). This view was supported by the results of the survey conducted by IMMA on skill levels and training needs in the Australian Heat Treatment Industry.

The TAFE system is starting to recognise this gap exists and fill it with initiatives such as the new Diploma course in Applied Science (Materials Engineering) being introduced by Casey College of TAFE in Victoria. The curriculum for this course was developed with input from a variety of education and employer organisations and with a view to articulation into higher studies such as the Bachelor of Technology and Bachelor of Engineering (Materials Engineering) degree courses at Monash University. Interest is being shown in the Casey course by a number of TAFE colleges around the country.

Some employers of technicians rely on developing staff expertise in-house. Anecdotal evidence presented to the Commission indicates that this occurs because TAFE colleges have not been providing appropriate, state-of-the-art training in materials. An industry representative perceived the TAFE system to be lagging behind in new technology developments, and attributed this to a low level of demand for materials courses, and the inability of the TAFE system to anticipate training needs in ‘sunrise’ industries. However, as with university training, the education providers can only do so much if the industry is not aware of the value of materials training.

If the two fundamental problems of determining the appropriate numbers to be trained by TAFE and course content can be resolved, the TAFE system has some desirable characteristics. It encourages alternative mechanisms of course provision, such as short courses, industry level and enterprise level training, or private provider training where it sees that the firm or industry needs can be more effectively met in this way. The Australian die casting industry has developed its own industry specific training program to ‘... train people at all levels with the skills they need to run their own industry’ (transcript, p. 165). This program has been approved by TAFE, and the industry is believed to be planning a higher level program for professional engineers.

An effective and potentially cost-effective way for TAFEs to establish closer links with industry and higher education research institutions is to consolidate and share expensive research and training facilities as done by Wembley TAFE in Western Australia (transcript, p. 598).

The role of industry associations in on-the-job training and continuing education

The NSW Department of Mineral Resources makes the point that:

> ... most specialised training for the advanced materials industry is ‘on the job’ (sub. 4, p. 6).

Specialised on-the-job training is usually industry-specific, meaning that there are insufficient students to warrant universities or TAFE colleges offering separate courses. Where this type of training is not provided by traditional education providers, industry associations may need to fill the gap.

An example has been the recent industry response to a decline in courses specialising in heat treatment, with the last remaining heat treatment course in Australia conducted at the Royal Melbourne Institute of Technology (RMIT) being under threat of closure (transcript, p. 591). This situation has led to an initiative by IMMA with the support of the Department of Industry, Science and Technology (DIST) to examine what needs to be done to maintain expertise in this area. A report is to be released shortly but initiatives already underway by IMMA include the production of a heat treatment capability register, video training resources to increase awareness of the benefits of heat treatment, upgraded library services for IMMA members, and the use of interactive methods in conducting its training and awareness programs.

IMMA is running a number of materials-related short courses. With education now considered more than ever as a life-long learning experience, particularly in areas like materials where knowledge is changing rapidly, these courses help to maintain the currency of knowledge.

Co-operative activities

The quality of laboratories and related research infrastructure has a bearing on the quality of research and this flows through to training. As noted previously, concern was expressed that Australian universities are not keeping pace with World standards. ANSTO pointed out that Australian educational laboratories do not have adequate funds to purchase new equipment:

> The infrastructure of Australian University materials departments is poor by international standards. They are not equipped to carry out research on materials processing on modern equipment. A natural result is that the scientists and engineers graduating from Australian universities are not adequately trained in modern process technologies (sub. 29, p. 1).

One promising approach is to consolidate and co-operate in the use of existing facilities at one site, as has been done in Perth and Brisbane. The Queensland Manufacturing Institute was established in Brisbane in 1991, with funds from the State Government, in a collaborative effort between the Queensland Department of Industry and Regional Development, the University of Queensland, Queensland University of Technology, TAFE and CSIRO Division of Manufacturing Technology.

In Western Australia, the State Government has allocated funding over five years to establish a Materials Institute. Under the Materials Institute proposal, Mr Kingsnorth stated that all the materials technology laboratories in semi-government authorities will be brought together at one location (Wembley TAFE) together with existing TAFE facilities (transcript, p. 553). This one materials laboratory would then have responsibility for education, training, testing and setting standards. The universities would continue their role primarily in research, with the Institute concentrating more on materials development, but the universities and TAFE will use the Institute’s facilities for student training. The Institute will also act as an extension service to provide information to industry on materials usage.

The approach of establishing a critical mass of facilities will also be applied to personnel. This will be done by establishing a database of people interested in various aspects of materials science and technology, with the Institute acting as a conduit to get people in (what are generally) small professional associations to communicate regularly. Mr Kingsnorth remarked that in Western Australia:

> ... there are a large number of disparate groups ... What we [the Materials Institute] would like to do is to bring all of those people together and have one newsletter that goes out to advise people of courses and meetings that are taking place and from that we would then be able to develop a database of people interested in various aspects of materials science and technology (transcript, p. 558).

C1.3 Poor appreciation of the value of materials skills

As a general rule there is a difference between large and small business in terms of senior management's awareness of developments in materials, the need to keep abreast of changes, and the benefits of having suitably trained staff at all levels.

Large businesses are more likely to be foreign owned or have foreign links than are small businesses. The former are likely to have more resources or easier access to resources than small businesses. These characteristics are likely to mean that larger businesses are aware of the developments in materials science, the benefits of making appropriate choices of materials, and the need to have skilled staff. However, there are exceptions, with some smaller Australian firms being World leaders in the use of materials.

The majority of businesses in the Australian manufacturing sector are SMEs. Many SMEs are unaware of the properties, uses and value of new and advanced materials, or the steps necessary to achieve a World-competitive position. According to Professor Dunlop:

> [These companies are] often technically underqualified. They are not capable of making use of what is currently available technically in the world, and they have great difficulty in recognising the steps which they should be taking to step from their current position into a World-competitive position (transcript, pp. 114 to 116).

Professor Dunlop argued that even where firms are large enough to employ or consult people with the necessary expertise in materials science, this does not always occur. He believed there was a culture in Australia that did not place an emphasis on science and engineering (of which some evidence was presented in Table C1.1), and so as a consequence firms tend not to employ graduate engineers or materials scientists. Not only do these firms forego the ability to recognise the value of developing materials and technologies, but their communication and potential collaboration with materials experts in educational and research institutions is severely diminished (transcript, p. 117).

Professor Dunlop argued that simply increasing student numbers in the relevant courses at universities will not necessarily address the problem. In his view the problem is more an attitudinal one, which is exhibited in a reluctance to employ graduates because of the failure of businesses to appreciate the benefits that such graduates can bring. The IR&D Board supported this view and stated that the 'cycle' had to be broken:

> We have to break a cycle and introduce some people with skills who will put innovation into the design process and say, 'We could use this material' (transcript, p. 167).

How to break this cycle is the challenge. There is little doubt that a large part of the knowledge on optimum use of materials, both traditional and new, exists in Australia in one or other of the following groups: materials suppliers, technical services groups, industry associations, universities, government research institutions, and private consultants.

The challenge is to develop effective mechanisms to get this knowledge into manufacturing enterprises, particularly the SMEs, so that it can enable firms to implement world best manufacturing practice.

In the following section, strategies which have been, or could be, used to close this awareness gap are outlined.

C1.4 Strategies to increase awareness and develop skills

Strategies that establish closer links between universities, industry, and professional bodies can result in increased awareness and skill development that is more closely attuned to society's needs.

Overseas initiatives

Linking research, education and industry is a concern of most governments. In the context of materials, a recent initiative of the UK Government is germane.

An investigation of the utilisation of advanced materials undertaken for the UK Department of Trade and Industry revealed similar awareness problems as exist in Australia today. As a result, the Department established the *Materials Matter* scheme in 1990. This program is a three year technology transfer program which provides practical information and advice to manufacturing companies about modern materials and their processing methods:

> The purpose of the program is to provide useable information about modern materials and processes. For example, you may want to find out more about composite materials, to judge whether these are relevant to your business needs. Alternatively, you may be interested in the use of a particular surface treatment, to improve the properties of your existing products (Department of Trade and Industry (UK), 1989a, p. 10).

The program was funded at the level of £1 million per year and had as main components:

- a materials information service operated by experienced materials engineers through Design Council central and regional offices;
- a range of information booklets and videos on specific areas of materials;
- a demonstration company program, whereby companies using new and advanced materials were subsidised to allow groups of visitors from other companies to visit and inspect their activities; and
- a materials audit program — a self administered program to identify deficiencies in materials usage.

The specific materials and processes covered by the program are polymers, engineering ceramics, composite materials, new metals and alloys, surface technologies, cutting and joining and, near net shape forming.

The program was judged by the Confederation of British Industry as being highly successful (Wardrop, 1992), but has now been subsumed under a broader industry scheme.

The issues of technological advancement and the role of the SMEs in the process have been subject to government policies in various countries. For example, there have been a series of programs in Japan. Their objectives have been to promote invention itself, encourage rival firms to exchange technological information (while still competing with one another in the market place), and provide assistance to SMEs so that they may adapt to technological change. The latter objective has been pursued by the provision of grants to support R&D and subsidised loan schemes. The latter, in particular, have been aimed at encouraging SMEs to enter the fields of new and advanced materials and biotechnology.

A major initiative during the 1980s was the Technopolis scheme. What this meant was that a number of regional cities (25 by the end of the 1980s) were designated as Technopolises and benefited from increased infrastructure spending and special grants. The concept was to make these centres attractive locations for advanced industries and research centres. The aim has been stated to:

> infuse the energy of high technology industry into the culture, traditions and natural abundance of the regions, and to achieve the creation of urban communities by harmonising industry (advanced technological production), learning (academic and experimental research institutions) and lifestyle (a rich and comfortable living experiment) (Quoted in Morris-Suzuki, 1994, p. 226).

Morris-Suzuki (1994) presents a mixed assessment of the Technopolis scheme, with some objectives being met (in some of the centres) while others have not. In that author’s analysis the success of Japanese technological transformation was partly based on ‘social networks of innovation’, with ideas being rapidly passed from large, modern enterprises to SMEs. Industry associations played a crucial role in this process.

In the US, a wide variety of technology assistance programs to SMEs are conducted, mostly by State Governments. Jaffrey (1994) reported that a 1989 study by the National Governor’s Association, ‘Promoting Technology Excellence: The Role of State and Federal Extension Activities’, examined 42 such programs in 28 states of the US. Half of them were administered by universities (often via a manufacturing centre), and were small in size (less than 10 staff).

Australian initiatives

National Industry Extension Service (NIES)

The NIES schemes, now co-ordinated by *AusIndustry*, represent a vehicle by which information on materials can be transmitted to industry.

NIES is a joint Commonwealth, State and Territory network of business information, referral and advisory services. It is designed to help SMEs become internationally competitive.

Subsidies to engage consultants (to advise on a range of business practices) are provided. NIES has also initiated a four year program to provide SMEs with a comprehensive package of information and advisory services through *AusIndustry*.

The most relevant NIES program to materials is the Technology Access Program. This has two components. In one component, competitor grants are available for groups of institutions or centres for feasibility studies, or for seed funding, directed at jointly upgrading or expanding facilities and services to assist firms in improving their uptake of technology. The Queensland Manufacturing Institute and the South Australian Centre for Manufacturing have both received funds from this source.

The second component involves technology awareness and demonstration projects and includes activities such as technology audits.

An important new component of the initiative is the establishment of networks of firms with common interests, and this could be a vehicle for producers and users of new and advanced materials to further their common interests.

The extent to which NIES programs provide assistance on materials usage varies considerably form state to state, with some (notably Queensland and South Australia) placing substantial emphasis on this matter.

CRCs

An objective of the CRC program was to improve communication between industry and the research institutions.

The CRCs bring together people with different technical backgrounds who can provide a range of perspectives on an R&D project. For example, amongst other things the CRC for Aerospace Structures is seeking to provide a 'co-operative base' for companies so that they have access to expertise and technology (transcript, p. 192). This should help to increase awareness and technology transfer, as well as providing a feedback loop on training needs. However, several participants have questioned the extent that the networking and awareness-raising objectives of the CRC program are being met. Because of intellectual property problems, companies and researchers who are not already members of a CRC often have great difficulties in becoming involved and sharing in R&D outcomes. From anecdotal evidence put to the Commission, there is a case to reconsider the procedures applied in formulating the membership of CRCs. It was claimed that potential members could be excluded because some influential core members would not accept rival firms as members.

University based programs

A number of the universities have established specific centres to tackle the awareness problem.

At Monash University, the Centre for Advanced Materials Technology (CAMT) is a Key Centre, funded under an ARC program. Part of its activity is the provision of an industry extension service (Jaffrey, 1994). This service has now been running for five years and involves two to three staff full-time. The full-time staff draw on other expertise in the Centre or the university as required. The Key Centre funding has been approximately $2.4 million over the five years, of which approximately 40 per cent has been recovered from clients in consulting fees.

A recent assessment of the benefits of the service (Kimberly Smith and Associates, 1995) indicated that the financial value to participating firms was, on average, several times the cost of the program and while the assessment was not a formal cost-benefit analysis (and a more rigorous methodology would need to be applied to determine the precise gains), it does provide *prima facie* evidence of considerable net benefits.

A review of the Centre (Jaffrey, 1994) states that in spite of the documented benefits, clients are unwilling to pay the full cost of the Centre's services. Unless new sources of funding can be obtained when the ARC Key Centre grant is phased out over the next three years, it is probable the Centre will be closed. CAMT maintains that a subsidy to them would be a very cost effective mechanism to provide industry extension services.

Other universities have centres which focus on materials, but they generally place more emphasis on research as opposed to extension services. However, they understand the advantage of close interactions with industry.

The commercial arm of the University of Wollongong (the Illawarra Technology Corporation) said:

> [Scientists should] work collaboratively with the best technical people in industry to get things done more expeditiously and economically (transcript, p. 157).

The ANU Centre for the Science and Engineering of Materials aims to bring together a range of relevant resources (researchers and laboratories) and seek *ad hoc* relationships with industry. Another is the Warren Centre for Advanced Engineering at the University of Sydney.

A simple initiative suggested by the two Sydney-based centres was the publication of a new materials newsletter. They also suggested publication of a register or database on new materials.

Closer linkages with industry can also result from non-university representation on academic boards or advisory councils. IMMA is presently seeking to be involved in university advisory boards.

A materials database?

A database would outline the properties of new materials and identify areas of potential application. Dr Terry Wilks suggested that such a database be managed by a university or research institution such as CSIRO (transcript, p. 497). The idea was supported by Professor Roger Smart, who pointed out that at present enterprises find it difficult to know where to go for professional advice (transcript, p. 527). Mr Dudley Kingsnorth, Chief Executive Officer of MIWA, suggested that databases should include the interests and expertise of relevant personnel in academia and in industry, as well as information on materials.

The Warren Centre (sub. 41) has proposed an all encompassing database that would be used by design engineers and would incorporate a wide range of design information on all materials, on CD-Rom in Multimedia format. A number of databases are already available in areas such as adhesives, but no comprehensive database exists.

The Commission has some concerns as to the practicality of such a complex undertaking as the Warren Centre proposes, and believes that if a genuine demand existed, then a commercial enterprise would take up the opportunity.

Staff exchange

The 1993 NBEET report on forming and maintaining research links between industry and universities mentions that personnel mobility across university-industry boundaries is acknowledged as important for improving understanding between the sectors. This is something that could be very important in the materials area. NBEET reported that mobility was low. One organisation that has a secondment program to industry is CSIRO. The concept and its benefits deserve greater publicity.

Demonstration programs

Professor Dunlop suggested that demonstration programs may have a role in encouraging SMEs in particular to recognise the benefits of assessing new materials and recruiting employees with new materials expertise. Consistent with this philosophy, the CRC for Alloy and Solidification Technologies has in place a technology transfer program, where short courses are developed for the education and training of people employed in the industry (transcript, p. 119).

The IR&D Board has just established 'new technology forums', where experts in a particular technology are brought together with representatives from organisations that use the technology. Interested parties are also invited. The focus is on the practical use of the technology in commercial applications (transcript, p. 167). The forums have achieved some success in awakening the interest of smaller companies to technological innovations.

Internships

A strategy to develop skills that has been applied with success in some disciplines is to expose students to practical professional situations by requiring them to spend some time in industry during their formal education. Industry should also benefit from this practice by being informed of the most recent developments. Examples of this approach are common in architecture and some areas of engineering, and the concept is applied in some materials-related programs, such as in the School of Physical Sciences at the University of Technology, Sydney.

The internship (or practice school) concept is not divorced from the German model of professional training as practised by Germany's Fraunhofer Institutes. Admittedly these bodies operate at a different scale and have a much more developed philosophical base. The German institutes have apprenticeship programs for undergraduates and masters students, and they employ doctoral students in research (National Materials Advisory Board, 1993).

Attachment C1.1 Courses

The following Australian courses incorporate a component on materials or design at the undergraduate and TAFE levels. The list was obtained from the Job and Course Explorer database of each State and Territory (compiled by the corresponding Education Departments). Examination of the exact nature of the subjects contained within these courses has not been possible. As is obvious from their titles, some courses are more focussed on materials science than others. It is possible that the list is not comprehensive.

Table C1.2: Australian Bachelor and Associate Diploma courses incorporating components on materials or design, 1994

State	*Institution*	*Course*
Universities		
NSW	Macquarie University	B. Science
	University of Newcastle	B. Arts (industrial design)
		B. Engineering
	University of NSW	B. Engineering
		B. Industrial Design
		B. Science
	University of Sydney	B. Engineering
		B. Science
	University of Technology, Sydney	B. Applied Science
		B. Architecture
		B. Design
		B. Engineering
	University of Western Sydney	B. Applied Science
		B. Building
		B. Design and Technology
		B. Engineering
		B. Industrial Design
		B. Science
	University of Wollongong	B. Engineering
		B. Technology

Table C1.2: Australian Bachelor and Associate Diploma courses incorporating components on materials or design, 1994, cont.

State	*Institution*	*Course*
Victoria	Ballarat University College	B. Technology
	Deakin University	B. Engineering B. Technology
	La Trobe University	B. Technology
	Monash University	B. Science B. Engineering B. Technology
	Royal Melbourne Institute of Technology	A. Dip. of Engineering B. Applied Science B. Engineering
	Swinburne University of Technology	B. Design B. Engineering A. Dip of Applied Science
	University of Melbourne	B Engineering
	Victoria University of Technology	B. Engineering
Qld	Griffith University	B. Engineering
	James Cook University	B. Engineering
	Queensland University of Technology	B. Engineering B. Science
	University of Central Queensland	B. Applied Science B. Engineering
	University of Queensland	B. Applied Science B. Engineering B. Science
	University of Southern Queensland	B. Engineering
WA	Murdoch University	B. Science
	University of Western Australia	B. Engineering B. Science

Table C1.2: Australian Bachelor and Associate Diploma courses incorporating components on materials or design, 1994, cont.

WA	Curtin University of Technology	B. Engineering B. Science
SA	Flinders University of South Australia	B. Engineering
	University of Adelaide	B. Engineering
	University of South Australia	B. Engineering B. Technology
Tas	Australian Maritime College	B. Engineering B. Technology
	University of Tasmania	B. Engineering
ACT	Australian National University	B. Engineering B. Science
	University of Canberra	B. Industrial Design
TAFEs		
Victoria		A. Dip of Engineering A. Dip of Applied Science
NSW		A. Dip in Metals Technology A. Dip of Engineering A. Dip in Materials Technology and Manufacturing (proposed)
WA		A. Dip of Engineering
SA		A. Dip of Production Engineering

Source: Job and Course Explorer database for each State and Territory; Ashenden and Milligan, 1994; NSW TAFE, sub. 37.

C2 RESEARCH AND DEVELOPMENT ASSISTANCE SCHEMES

Both in Australia and overseas most government research programs are targeted at increasing the level of R&D in general. Overseas, some government programs are directly aimed at assisting new materials. The majority of programs in Australia do not directly target new and advanced materials. However, the ubiquitous nature of materials is recognised by some bodies and materials science is allocated funds form their budgets.

This appendix outlines R&D spending on new and advanced materials in selected overseas countries and Australia. Data limitations prevent a comprehensive presentation and most attention is given to Australia.

C2.1 Assistance to new and advanced materials research overseas

Participants drew the Commission's attention to the amounts of money spent on new materials research in the United States, Japan, and Europe. The Federation of Materials Societies estimated that the in United States alone about $US1.2 billion was spent on materials research in 1988. ANSTO stated:

> Governments in the European Community, U.S.A. and Japan have recognised the pervasiveness of materials technologies and the strategic importance of materials R&D on the economic vitality of a nation. The governments of these nations as well as a host of other nations, including Taiwan, have realised that coordinated government sponsored R&D efforts in materials can have a significant impact on industrial capabilities to compete. In Japan, MITI [Ministry for International Trade and Industry] is funding long term research projects (10 years) in emerging areas of materials R&D that it considers are 'too risky' for private companies to proceed with on an independent basis. The European Community has a number of key materials technologies underwritten by governments, through schemes that foster better cooperation between industry, national laboratories and universities (sub. 29, p. 1).

Several large programs dedicated to advanced materials have been established overseas, including:

- the US Advanced Materials and Processing Program (AMPP);
- the Industrial Science and Technology Frontier Program in Japan;
- the European Union has programs such as the Basic Research in Industrial Technologies for Europe (BRITE) and European Advanced Materials Program (EURAM); and

- the *Materials Matter* program developed by the Department of Trade and Industry in the UK.

Further information on these programs is provided in the following sections.

United States

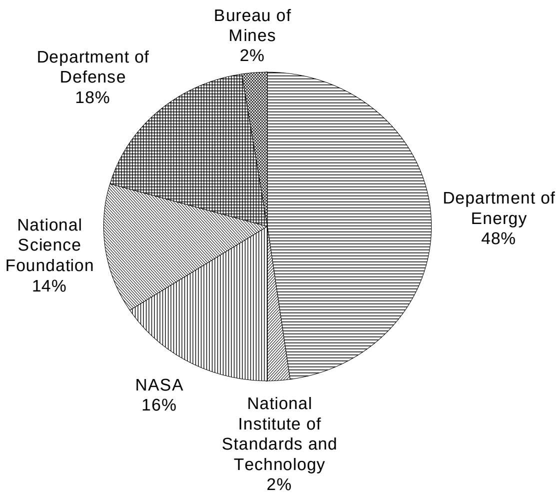
Public funding into materials research in the United States is co-ordinated by AMPP. AMPP co-ordinates research and development in the ten government agencies responsible for materials R&D.

On the basis of the available data it is not possible to determine what percentage of expenditure in the US is relevant to new and advanced materials (as defined in this report).

The US Bureau of Mines estimated that industry spends at least US$1 billion to US$2 billion in the United States each year. Most of this expenditure is on advanced ceramics and polymer research. Publicly funded research into advanced materials is over US$1 billion per year. A breakdown of new materials expenditure by agency is given in Figure C2.1.

Much of the spending is on defence and nuclear applications.

Figure C2.1: US public materials budget, 1989



Source: US National Critical Materials Council.

Department of Energy

The US Department of Energy (DOE) spends about US$500 million a year on materials science, making it the largest materials-related program in the United

States. These funds are allocated over three areas — nuclear energy, defence needs, and basic materials research.

The nuclear energy program focuses on uranium enrichment and breeder technology projects, while the defence program concentrates on nuclear weapons technology.

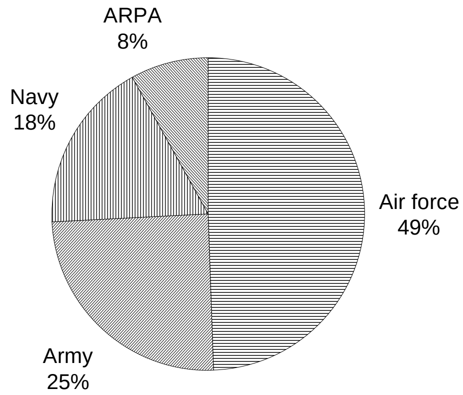
Most advanced materials research within the DOE is conducted in the Materials Science sub-program in the Office of Energy Research.

Department of Defense

Unclassified Department of Defense (DOD) expenditure on generic materials technology programs is about US$180 million a year.[1]

A breakdown of DOD expenditure on materials research is given in Figure C2.2. The research conducted by the three military institutions is for relatively shorter-term, applied applications, while the Advanced Research Projects Agency (ARPA) conducts projects of a more forward-looking nature, aimed at meeting defence needs of the next decade.

Figure C2.2: US Department of Defense material research



Source: Federation of Materials Societies.

Current DOD materials research programs include research on ceramics, electronic and optical materials, polymers and metal-matrix composites. However, many of these programs are for unique defence related needs, which

1 Large amounts of defence-related spending is classified, and therefore goes unreported.

at present, at least, have little or no private sector application. According to the US National Research Council (NRC):

> Programs funded by DOD are often directed towards specific applications... In many cases, the mission areas are unique, the technological demands rigorous, and the costs irrelevant, so that program success produces a material of no use to the domestic market. A good example of such a ‘boutique’ material is the recently announced tank amour made out of steel-clad depleted uranium (US NRC, 1989).

National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA) spends about US$150 million annually on materials research. It has three research programs dedicated to improving new materials:

- Transatmospheric Research and Technology;
- Materials Processing in Space; and
- Materials and Structures Research and Technology.

In addition, NASA also manages some DOE projects to develop engines that incorporate ceramic parts.

National Science Foundation

The US$140 million which the National Science Foundation (NSF) spends each year on material development includes research into high-performance ceramics, conducting polymers, metallurgy and electronic materials.

Most NSF work is conducted at universities, the essence of which is described in the following quote by the US Department of Interior and US Bureau of Mines:

> Nine universities have Materials Research Laboratories, which originated in a DARPA program in 1960 and have been funded by NSF since 1971. These laboratories serve as centers for materials technology requiring multi-investigator, interdisciplinary research teams. However, NSF also provides grants to individual faculty members for materials research in fields such as chemistry, engineering, mathematics, metallurgy and physics (1992).

The NSF also fund a variety of collaborative research projects, such as the Collaborative Research Centre program. Initiated in 1973, these centres bring together university and industrial researchers to work on problems of common interest (US National Research Centre, 1989).

Japan

The pervasive culture behind materials research in Japan is one dominated by a long-term outlook and consistency of government policy. Government agencies, particularly the Science and Technology Agency and the Ministry of International Trade and Industry (MITI), focus the direction of materials research, with much of the funding and 'hands-on' development provided by industry.

Three government agencies are responsible for materials research in Japan. The Science and Technology Agency is responsible for controlling research in government and public research agencies. The Ministry of Education, Science and Culture supports university programs. MITI supports 16 national laboratories.

Ministry of International Trade and Industry (MITI)

MITI receives relatively small public funding compared to other agencies and relies heavily on cooperative research. MITI formulates industrial technology plans, determines subsidy funding for materials research, and selects participating industrial R&D groups and associations to work with and help fund its 16 national laboratories.

In 1993, MITI combined three existing programs into a new program called the Industrial Science and Technology Frontier Program. The program involves co-operation between industry, universities and government, via national institutes. It focuses on superconductors, high-performance carbon composites, fibre reinforced metallic compounds, chemical processing technologies that enable the ultra high purification of metals, silicon based polymers, and biomedical applications.

The Agency of Industrial Science and MITI have announced a new national project named 'Synergy Ceramics'. The two agencies, as well as a wide variety of private interests, will invest about ¥5 billion (approximately US$50 million) over two years in the project.

> The aim of the project is to create a new family of advanced ceramics based on novel concepts which allow compatibility of a wide range of properties and integration of different functions into the same material — synergy (High Tech Ceramics News, 1994).

However, although government supported research is viewed as an essential ingredient to material development, it should be noted that a large proportion of Japan's material research is privately funded, and independent of government agencies. As Porter noted about research in general:

> Japanese companies participate in MITI projects to maintain good relations with MITI, to preserve their corporate images, and to hedge the risk that competitors will gain from the project — largely for defensive reasons. Companies rarely contribute their best scientists and engineers to cooperative projects and usually spend much more on their own private research in the same field. Typically, the government makes only a modest financial contribution to the project (Porter, 1990).

C2.2 Assistance to materials research in Australia

In Australia, R&D on materials has to compete with other fields of science for allocations from general R&D schemes. This does not mean that granting institutions, such as the Industry Research and Development Board (IR&D) and the Australian Research Council (ARC), do not recognise the fundamental role of materials science in their funding decisions. Likewise, research institutions (the universities, ANSTO, CSIRO and DSTO) undertake materials science; for example it is one of the key activities at ANSTO.

The Industry Research and Development Board

The IR&D Board is the primary source of research funding to new materials researchers:

> Since its inception in 1986, the IR&D Board has administered a number of granting programs that have supported new materials R&D to a greater or lesser extent. The most significant role in terms of specific support for new materials R&D was the Generic Technology Grants Program (sub. 24, p. 10).

In 1993, the Board's general programs — any of which could assist new and advanced materials R&D — included:

- Tax Concessions for Research and Development;
- Discretionary Grants Scheme;
- Generic Technology Grants Scheme;
- National Procurement Development Program;
- Advanced Manufacturing Technology Development; and
- National Teaching Company Scheme.

After the release of the Federal Government's *Working Nation* White Paper on Employment, Industry and Regional Development, these programs have been combined into a single scheme of Competitive Grants for Industry Research and Development. A new program, Concessional Loans for the Commercialisation of Innovations has also been put in place. These are both discussed under the *AusIndustry* sub-heading below.

150 per cent tax concession

Since 1985, Australian companies have been able to claim 150 per cent of their R&D expenditure as a tax deduction. Last year this represented about $415 million in tax revenue foregone. According to DIST:

> The tax concession enables eligible companies to deduct up to 150 per cent of eligible expenditure on R&D activities from their taxable income, thus providing a valuable stimulus to firms to increase their level of investment in R&D. At the concessional rate, the after-tax cost of R&D is reduced to just 50 cents in the dollar (1994a).

The *Working Nation* White Paper introduced a number of changes to the programs that were already in place. This included reducing the threshold for eligible tax expenditure on R&D to $20 000, originally $50 000. This change was aimed at bolstering the accessibility of research to small- to medium-sized firms (SMEs). To claim the concession companies must register annually with the IR&D Board.

The *Working Nation* paper opened the way for certain R&D activities to be carried out overseas, and still be eligible for the 150 per cent concession. However, no more than ten per cent of core R&D activity must be carried out overseas if it is to be eligible.

Syndication

A program for the syndication of research is also in operation. DIST has described the program as follows:

> Syndication is a specialised part of the tax concession program which provides the opportunity for projects which are too big or too risky for any one company to undertake, to be carried out by a group of companies. It is essentially a financing scheme that provides companies with access to scarce critical-mass finance for close-to-the-market R&D projects (DIST, 1994a).

Syndication gives an opportunity for researchers and inventors who wish to commercialise a product or process but cannot afford to do that to join with established businesses. The researchers get to continue their work, the commercial partners get the tax concessions, and if the research leads to a commercial product or process the partners get to share the financial benefits.

Changes as a result of the *Working Nation* White Paper include lowering the R&D expenditure threshold for participation in R&D syndication to $0.5 million, originally $1 million.

A problem that arose as a result of the syndication scheme was the high legal costs associated with forming partnership arrangements. *AusIndustry* has attempted to reduce these administrative costs by developing a generic syndicate structure.

AusIndustry

The Office of AusIndustry was established to facilitate and co-ordinate the newly constituted Competitive Grants Scheme, the Concessional Loans for the Commercialisation of Innovation Scheme and the National Industry Extension Service (NIES). The latter scheme is discussed in Appendix C1.

Competitive Grants Scheme

The Discretionary Grants Scheme, National Procurement Development Program, Advanced Manufacturing Technology Development Program and the National Teaching Company Scheme were all incorporated into a single scheme of competitive grants. These grants are available for those companies that cannot take full advantage of the tax rebate scheme (for example, those companies making zero or negative profits for income tax purposes).

The competitive grants scheme costs around $40 million a year. The White Paper stated that:

> A single scheme of competitive Grants for Industry Research and Development will assist:
>
> - market-driven R&D undertaken by dynamic firms needing financial assistance but unable to utilise the 150 per cent Tax Concession for R&D;
> - collaborative R&D activities between industry and research institutions;
> - collaborative R&D activities, which are high risk but could provide substantial benefit to Australia; and
> - trial and demonstration activities between technology developers and potential customers.
>
> The single scheme will provide the flexibility to better respond to the needs of individual firms as well as emerging priority areas of research. It will have a single set of eligibility and merit criteria, replacing the differing criteria required for each of the existing schemes. All the types of R&D activities which are supported under the existing schemes will continue to be supported under the single scheme (DIST, 1994b.)

Applying for a grant is a two-stage process. First, a five page expression of interest is lodged. If the expression of interest is successful, applicants must lodge a formal application detailing the full aims, costs and specifications of the proposed project.

Grants are based on merit, with the assessment committees targeting market-driven research in innovative firms, as well as collaborative high risk R&D.

Concessional loans for the commercialisation of technical innovation

Because it is considered that financed capital is not readily available to SMEs, the Commonwealth Government has put in place a scheme of concessional loans for the commercialisation of technical innovation. Concessional loans are available for small technology-orientated firms with less than 100 employees to undertake commercialisation activities. In the 1994–95 financial year, $48 million is to be made available to SMEs under this scheme. The grants can provide up to 50 per cent of finance for R&D projects. Loans are interest free for the first three years and after that subject to interest at less than the Commonwealth bond market rate.

National Nanotechnology Facility

In 1993–94, funding of $3 million was provided by the Commonwealth Government for the establishment of the National Nanotechnology Facility. The facility is designed to support the work already undertaken by 13 research groups in Australian universities and by DSTO and CSIRO. The facility is run by a consortium of four CRCs, and assists Australian companies in the development of nanotechnology applications (see Box C2.1).

Box C2.1: Nanotechnology

Nanotechnology is the fabrication and use of devices with component size less than 100 nanometres, that is 10^{-9} metres (which is a billionth of a metre). A useful description of nanotechnology is science and engineering at the atomic scale, since nanotechnology allows the manipulation of materials atom by atom.

Currently, nanotechnology is most advanced in the fabrication of semiconductor devices. For new material development, nanotechnology can provide a procedure to improve the control over size and orientation of grains, particles and fibres which will help improve the mechanical, thermal, electrical and magnetic properties of ceramics, sintered metals and composites.

Nanotechnology should not be confused with micro-engineering which is the production of micron size mechanical devices such as motors and robots. While size defines the technology, it is important to realise that miniaturisation for its own sake is not the driving force.

Major National Research Facilities Program

The *Working Nation* White Paper established a major national Research Facilities Program with total funding of $60 million over eight years.

Initial applications are currently being reviewed with a decision expected by June 1995. Of the 35 applications currently being assessed one is related to the materials area, namely, a proposal to establish a high energy laser materials processing facility. Funds will, however, only be sufficient to fund two or three of the 35 applications.

Australian Research Council

The ARC oversees a number of research funding programs with a total budget of $250 million. The programs are all aimed at funding high quality research primarily in the universities (outlined below).

Large Grants Scheme

This scheme has a budget of approximately $80 million and funds basic and applied research across all disciplines. From 1992 to 1995 materials and materials processing was designated as one of the five priority areas. These research areas received priority treatment in the allocation of funds. For 1995, approximately $3 million was allocated to materials research. From 1996 the priority area will be minerals and materials processing.

Collaborative Grants Scheme

This scheme, with a budget in 1995 of $16 million, is aimed at encouraging co-operation between the universities and industry. Projects must have an industry partner who contributes a minimum of 50 per cent of the cost of the project. The scheme has grown rapidly since its inception in 1992, and is considered to have been a very successful initiative (Hill and Turpin, 1993). For 1995 approximately 20 of the 98 grants awarded were for research in advanced materials.

Post Graduate Research Awards (Industry)

This scheme is also aimed at encouraging co-operation between universities and industry. It provides the stipend for post-graduate students to work on collaborative projects with industry. Industry is expected to provide $5 000 per annum in cash, and a similar amount of in-kind to support the student's program. 125 awards are made each year. For 1995, 20 of the awards were for work in the materials area.

Infrastructure

This scheme provides funding for major equipment. A number of recent grants have been for equipment to be used in materials research.

Key Centres and Special Research Centres

These schemes provides annual funding of $200 000 to $600 000 per annum for up to nine years to assist in the development of centres of excellence. Of the 35 Key Research Centres two are concerned with materials processing, and six of the 18 Special centres focus on materials.

Fellowships

Approximately 85 post-doctoral and senior fellowships are awarded each year. A number of these are for research in the materials area.

Co-operative Research Centres

The Co-operative Research Centres (CRCs) program was introduced in May 1990. Its goal is to foster links between tertiary institutions, government funded research organisations and private businesses. The Commonwealth Government is providing $847 million to the CRC program over seven years.

There are 61 CRCs in the program. Commonwealth funding at around $121 million a year makes the CRC program one of the major initiatives in recent Australian science policy, although it should be noted that on average each centre receives only $2 million per year.

Rationale for the CRC scheme

When details of the CRC program were announced in March 1990, the principal objective of the initiative was to ensure that Australian research and research training remained at the forefront, specifically in areas of greatest importance to the country.

CRCs were established to rectify a perceived or real gap in the institutional organisation of the science in Australia — the absence of large integrated research teams with links to ‘users’ of research. The rationale behind the CRC program is outlined in Box C2.2.

Box C2.2: The rationale behind the CRC program

Before the establishment of the CRC program, it was felt that although Australia’s combined scientific and technological resources were substantial they were too dispersed, both geographically and institutionally. This made it difficult to establish the concentrations and networks of researchers needed to keep pace with rapid scientific and technological change occurring internationally. The duplication of facilities and equipment was also considered very expensive.

The Co-operative Research Centre scheme, devised by the then Chief Scientist Ralph Slatyer, was developed after analysis of major research programs in other countries, and consultation with representatives from Australia’s science community. Slatyer stated that the basic approach would be to relocate and link outstanding university, CSIRO and other research groups, whenever and wherever appropriate, into Co-operative Research Centres with facilities concentrated in one location.

> Most research funding in Australia is from institutional sources and flows down from management through administrative channels to operational units and individual researchers. Except in the Commonwealth science agencies and the Institute of Advanced Studies at the Australian National University, this pattern of funding has not enabled large integrated research teams to be built and, even in those organisations, has caused difficulties. Competitive funding sources, such as the Australian Research Council, the National Health and Medical Research Council and the Rural industry research bodies have also, with few exceptions, had difficulty in building such teams (Slatyer, 1993).

Thus the pattern of research funding in Australia was held to have contributed to a relatively low level of cooperative research in Australia even within institutions and between universities, between universities and CSIRO, between State organisations and those funded by the Commonwealth, between corporate sector research groups and those which were publicly funded and between different firms.

In redressing this deficiency in Australia’s research effort, CRC resources were to be linked as effectively as possible to the various sectors of the economy, the work of the centres would be focused on research areas which underpin existing or emerging industry sectors and industrial firms were to provide a commercial focus where necessary.

Establishing a CRC

There are two requirements that must be met in order to establish a CRC. First, ‘core’ participants — organisations providing the major contribution to the centre’s activity, staffing, infrastructure and other resources — are each required to sign a legally binding agreement with the Commonwealth Government. The agreements define the commitments, typically for a period of five to seven years, covering strategies, milestones, outcomes and performance indicators that apply to the centre's activities in research, technology transfer, industry co-operation and education.

Second, each centre must also include at least one higher education institution among its core participants in order that the education and research training objectives are met. Beyond these requirements, the CRCs have a wide variety of organisational arrangements.

CRCs involved in new and advanced materials

Of the existing 61 CRCs, a number are undertaking research related to new and advanced materials. Those primarily concerned with materials are:

- Aerospace Structures;
- Alloy and Solidification Technologies (CAST);
- Eye Research and Technology;
- Materials and Welding Technologies;
- Polymer Blends; and
- International Food Manufacturing and Packaging Science.

Materials research is also a significant activity of the following CRCs:

- Australian Maritime Engineering;
- Intelligent Manufacturing Systems and Technologies;
- Australian Photonics;
- Cardiac Technology;
- Water Quality and Treatment; and
- Diagnostic Technologies.

C2.3 Sharing R&D

The high cost and uncertainty of success in R&D can prevent businesses (especially small ones) from participating in gains that can occur from innovation.

The nature of new materials is such that to be successful in either commercialising a new material or incorporating a new material into a product, the design team must be aware of how the materials will behave during processing and in the final product. As well as being costly, the necessary R&D is likely to require multi-disciplinary teams. The Centre for Materials Technology claimed:

> Materials research is often expensive as it requires a broad range of research facilities, and is interdisciplinary, requiring many different skills (sub. 10, p. 2).

Given the multi-disciplinary nature of the development and use of new materials it is not likely that all the necessary skills with be found within one business.

Collaboration can help to spread R&D costs and possibly lead to reduced costs for any one business. Despite the advantages of collaborating on R&D, inventor–entrepreneurs often do not enter into collaborative arrangements because they seek to maximise personal gain from innovation. This attitude is illustrated by the following comment of the NSW Department of Mineral Resources:

> Companies that have developed or own leading edge technology are generally reluctant to establish commercial partnerships for fear of diluting or losing this technological advantage. Such companies would generally prefer to 'do it themselves', and in particular retain the technology in Australia, but may be forced to enter into a joint venture in order to commercialise the product, or to delay/shelve product development (sub. 5, p. 6).

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