The Parliament of the Commonwealth of Australia

SUPERCONDUCTIVITY
and related new materials

Report by the House of Representatives
Standing Committee on Industry,
Science and Technology

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Cover: A neodymium-iron-boron ('rare-earth') magnet levitates above an yttrium-barium-copper oxide ceramic superconductor cooled to liquid nitrogen temperature. Magnetic flux from the 'supermagnet' is expelled by the superconductor (Meissner Effect), which acts like a magnetic mirror: the magnet is held against gravity by the repulsive force of its own 'magnetic image' in the superconductor.

- Photo and caption from CSIRO submission

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TERMS OF REFERENCE

To examine and report on:

(i) Australia's core capacity within CSIRO, universities and other research organisations to develop new uses for superconductivity and related new materials which have potential for commercial development, and our areas of comparative advantage (such as access to raw materials).

(ii) The range of potential applications in industry, transport, medicine, electricity generation and transmission, and research generally, both in Australia and abroad.

(iii) The problems and opportunities in developing this research, especially the roles of government, industry, finance and marketing.

(iv) Identifying the obstacles to achieving the fulfilment of (ii) and (iii).

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A Perpetual Electric Current

Prof. Kammerlingh Onnes's discovery is, at any rate from the point of view of pure science, one of the most remarkable events in the progress of science during an epoch abounding with important developments. Whether it will have any direct practical application it is impossible to foresee at present, but indirectly, through the increase in our understanding of matter and electricity which is bound to follow from this discovery, there can be no doubt that many important material advantages will be gained.

Scientific American, 25 July 1914, page 54

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PREFACE

- **About the Committee**
- ***About the inquiry***
- **About the report**
- ***Acknowledgments***
- **Conclusion**

About the Committee

The House of Representatives Standing Committee on Industry, Science and Technology is one of eight general purpose standing committees which were established by resolution of the House on 24 September 1987. The resolution of appointment empowers each committee to inquire into and report on any matter referred to it, by either the House or a Minister, including any pre-legislation proposal, bill, motion, petition, vote or expenditure, other financial matter, report or paper.

Each of the general purpose standing committees corresponds in its areas of interest with a Federal Government department or group of departments; in the case of the Industry, Science and Technology Committee those departments are: Industrial Relations; Industry, Technology and Commerce; and Primary Industries and Energy.

The Committee received its first reference, to inquire into investment in Australian manufacturing industry, in December 1987 and presented its report to the House of Representatives on 25 August 1988. In addition to the inquiry which is the subject of this report, the Committee has embarked upon inquiries into: the problems faced by small business; and the promotion of elaborately transformed manufactures and traded services.

A list of members of the Committee appears at page (v).

About the inquiry

The recent breakthroughs in superconductors were referred to in both Houses of Parliament on several occasions during 1987, particularly in questions without notice asked of the Minister for Science, Customs and Small Business, the Hon. Barry Jones, MP. At the outset of the Committee's existence, then, there was a perception within Parliament that this was a potential area for inquiry.

At the request of the Committee, the Minister and his advisers briefed the Committee on the potential of superconductivity, in particular its relevance to the power industry, and following further expressions of interest by the Committee the Minister wrote to the Chairman on 27 April 1988 setting the terms of reference which appear at page (iii).

The Committee appointed a Sub-Committee to undertake the inquiry and the Chairman of the Sub-Committee wrote to over 130 individuals and organisations involved in science, technology and high technology industries in Australia inviting them to lodge submissions. Fifty-one submissions were received and they are listed at Appendix 1.

The Sub-Committee then held a series of public hearings in August and September at which witnesses were invited to provide evidence in addition to that which had been provided in the submissions. Over thirty-five witnesses appeared before the Sub-Committee. Details of the public hearings and a list of the witnesses appear at Appendix 2.

The Sub-Committee presented its report to the full Committee in November where it was subsequently adopted for presentation to the House.

A list of members of the Sub-Committee appears at page (v).

About the report

This report is of course bound by the terms of reference handed to the Committee by the Minister for Science, Customs and Small Business. At a first reading those terms of reference may seem quite narrow, focusing as they do upon the potential applications of superconductors and certain new materials and upon Australia's ability to exploit them. However, in examining the obstacles to making the most of that potential, the focus shifts successively through widening fields of view: many of the obstacles are not specific to superconductors but relate in general to science and technology in Australia today.

In making this report, the Committee has had to use its own judgment in drawing bounds to the field of inquiry; the issues which have been raised throw up fundamental questions about the position and direction of Australian science and technology. Those questions cannot be dealt with fully in this report for, apart from the principal demands of the terms of reference, it would take several inquiries to do so. The report does, however, attempt to identify those fundamental problems even if it does not proffer solutions.

The core questions with which this report deals, and in certain cases makes consequent recommendations, are:

. How important is superconductivity to Australia?

. What are its potential benefits?

. What stands in the way of gaining those benefits?

. What are the costs of doing nothing?

. What steps can Australia take?

A summary of conclusions and recommendations appears immediately after this Preface. A glossary of terms relevant to the technical aspects of superconductivity and new materials and a reference guide follow. Chapter 1 outlines what the Committee regards to be the subject of its inquiry. Chapter 2 explores existing and potential applications and assesses the fundamental importance of superconductivity to Australia. Chapter 3 describes the nature of research and development in superconductivity and new materials and identifies the key problem areas. Chapter 4 analyses Australia's current position, its strengths and weaknesses and Chapter 5 discusses Australia's options and makes recommendations in the light of the conclusions drawn in the preceding chapters.

Acknowledgments

The Committee commends the efforts of the Sub-Committee which it appointed to undertake this inquiry, the first by the Committee into a specifically scientific and technological area. It has been something of a trailblazing exercise, during which the Committee has established its first contact with the scientific community. The Committee hopes that this contact will be augmented and that the Committee will come to be seen as a means of greater communication between Parliament and the many players in Australian industry, science and technology.

The Committee thanks all those individuals and organisations who lodged submissions and particularly those who appeared as witnesses at the three public hearings; the substance of this report is based upon the evidence they presented.

Finally, the Committee is grateful for the assistance given the Sub-Committee at various times during the conduct of the inquiry, especially by Dr Colin Adam and Ms Judy Randall of the Commonwealth Scientific and Industrial Research Organisation, Dr Alan Jones and Mr Alan McCulloch of the Department of Industry, Technology and Commerce, and Mr Ian Shortt of the Australian Science and Technology Council.

Conclusion

The Committee would not wish to be seen as having a blinkered perception of where science and technology fit into Australian society, a view that science and technology exist purely for economic ends. The Committee agrees with the Australian Science and Technology Council that their 'benefits can be encompassed in three main headings: cultural enrichment, economic well-being, and the quality of life'. However, science and technology have a vital role to play if the nation is to recover lost ground as an industrially advanced democracy and it is upon the benefit to the nation's economic well-being that this report is predicated.

The Committee notes the number of reviews undertaken over the last decade - and indeed being undertaken now - into various aspects of national science and technology policy. An integrated, strategic approach has frequently been advocated and indeed the current Government launched a concerted effort to develop a National Technology Strategy in 1984. However, that effort has since languished. In the absence of a comprehensive, clearly articulated national policy on science and technology, this Committee has had to draw its own inferences with regard to national goals and the means of achieving desirable ends. The Committee strongly believes that such as policy is a priority.

The Committee has attempted to stress the challenges that confront Australia and therefore some may see the report as being unduly pessimistic in that certain weaknesses in Australia's position have been highlighted. The Committee, in doing so, casts no reflection either upon the Australian scientific community or upon Australia's primary producers. Having spoken to some of Australia's leading scientists in the course of the inquiry, the Committee is well enough aware of the diminished morale among scientists; the Committee would prefer to praise them, not to bury them. And neither should the advocacy of a greater research and development effort in manufacturing industry be seen as a call for a smaller effort in Australia's area of traditional strength, primary production. Our primary producers are far too easily taken for granted.

The sudden advent of high temperature superconductors offers Australia not deliverance but a test. Too many structural adjustments need to be made before Australia can fully exploit the opportunities. But recognising the adjustments which must be made and acting upon that recognition is the test, and how the nation responds may well provide an example for confronting the larger challenges which face the nation.

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

Importance to Australia

Conclusion 1:

> **The potential economic and technological impact of advances in the field of superconductivity is so great that Australia must assess that impact and develop an appropriate strategy to maximise benefit to the national economy and minimise any further erosion in Australia's relative position.**

(paragraph 2.80)

Main determinant of commercial development

Conclusion 2:

> **The essential precondition for the development of commercial applications for superconductivity and related new materials will be the recognition of strength and trend of demand for those applications, rather than the technological ability to produce them.**

(paragraph 3.74)

Factors to be considered in developing a strategy

Conclusion 3:

> **In developing an appropriate strategy to maximise the benefit to the national economy which may arise from the impact of advances in the field of superconductivity, it must be recognised that:**
>
> - **Australia has fundamental problems in the performance of its manufacturing sector, in the level and composition of its research and development and in the fragmentation of its science and technology infrastructure.**
>
> - **Australia is poorly prepared for the commercial development of these new materials in terms of manufacturing infrastructure, research personnel, funding and the will to compete internationally.**
>
> - **Australia may have a comparative advantage in its access to raw materials.**

- **Australia will be unable to match the efforts of the major competing nations across the whole spectrum of superconductivity and related research.**

- **Australians, in industry and more generally, must recognise the importance of science and technology to the nation's economic well-being and act upon that recognition.**

- **The morale of the Australian scientific community is adversely affected by a number of factors, including:**

  - **a decline in the funding of research and development;**

  - **the relatively low pay levels of post-doctoral research staff; and**

  - **the poor career prospects for researchers wishing to remain in Australia.**

(paragraph 4.83)

The need for a national strategy

Conclusion 4:

There is a need to adopt a strategy which will maximise benefit to the national economy arising from the economic and technological impact of advances in the field of superconductivity and related new materials.

(paragraph 5.27)

The co-ordination and development of a national strategy

Recommendation 1:

The Government co-ordinate the development of a strategy to maximise benefit to the national economy arising from the economic and *technological impact of advances in the field of superconductivity and* related new materials.

(paragraph 5.31)

Recommendation 2:

In co-ordinating the development of a strategy, the Government take the following steps:

- assess the existing market for applications employing LTS materials, both here and abroad, as well as the potential market for new superconductors;
- in the light of that assessment, evaluate the feasibility of local manufacture of applications employing LTS materials;
- in consultation with State governments, research organisations and industry, explore the setting up of an autonomous National Superconductivity Research and Development Centre which would:
  - involve participation of researchers, potential manufacturers and potential end users;
  - co-ordinate research and commercial development of applications employing both LTS and HTS materials;
  - contribute to the development of local manufacture of LTS and HTS applications;
  - co-ordinate funding from all available sources;
  - establish working relationships with similar groups overseas, such as the International Superconductivity Technology Centre in Japan;
  - provide common services to all participants, including:
    - collection and distribution of international information relevant to research activities;
    - advice on patenting;
    - advice on Government funding mechanisms; and
  - advise Government on policy preferences.

(paragraph 5.41)

Community attitude to science and technology

Conclusion 5:

> **Several promising initiatives are being undertaken to make the Australian people appreciate better the important contribution which science and technology make to national well-being but it is not clear that these are sufficiently focused to achieve the desired objective.**

(paragraph 5.47)

The desirability of existing LTS manufacturing infrastructure

Conclusion 6:

> **Australia would be better placed to develop and manufacture applications for high temperature superconductivity if it had an existing capacity to develop and manufacture applications for low temperature superconductivity.**

(paragraph 5.50)

Funding of research and development

Recommendation 3:

The Committee reiterates the recommendation it made in its report on investment in manufacturing that:

> **The tax incentive scheme for research and development expenditure not be further altered for at least five years from 1 July 1991 to ensure stability and predictability for business in making its investment plans.**[1]

(paragraph 5.53)

Recommendation 4:

> **The Australian Research Council implement a fast-track method of awarding grants to research projects in rapidly developing fields of potential importance to the national economy.**

(paragraph 5.54)

---

[1] *Investment in Manufacturing*, page 53.

Recommendation 5:

The Government consult urgently with the States with a view to developing a specific proposal towards the institution of a levy set at 0.125 per cent of turnover on the electricity generation industry to fund research into new technologies which would benefit the industry.

(paragraph 5.58)

Shortages of scientists and engineers

Conclusion 7:

The long-standing shortages in Australia of scientists and engineers and the impact those shortages have upon Australian industry, science and technology, have been recognised but corrective action is still being proposed and has yet to be resolved.

(paragraph 5.61)

Recommendation 6:

The Government act to expedite procedures for processing immigration applications by key scientific personnel.

(paragraph 5.63)

Protection of intellectual property

Conclusion 8:

International competition for patents will pose challenges to successful commercial development by Australians but the problems are so uncertain, complex and universal that the matter is worthy of its own inquiry.

(paragraph 5.67)

Representation of scientists and technologists in the political process

Conclusion 9:

Australian scientists and technologists should play a more positive role in the formulation of public policy by ensuring that they are publicly represented by a well recognised peak council.

(paragraph 5.71)

GLOSSARY

Absolute zero - Theoretically, the lowest possible temperature; zero degrees on the **Kelvin scale** and equivalent to -273.16 degrees Centigrade or -459.69 degrees Fahrenheit.

AC - Abbreviation for **alternating current.**

Alternating current - Electric current which, as distinct from **direct current,** flows alternately in opposite directions through a conductor; the number of alternations in a unit of time is a measure of the current's frequency.

Anisotropy - The non-uniformity of physical properties of a material in relation to direction within that material; for example the variation of resistance to an electric current according to the orientation of crystals within a **1-2-3 ceramic.**

BCS model - A theory of superconductivity which posits the interaction of pairs of electrons (Cooper pairs) with atomic vibrations (phonons) within a crystal lattice enabling one electron of a pair to pull the other though the lattice without energy loss; the model works for **LTS** but has been found to be inadequate for **HTS.**

Ceramics - Solid materials combining metallic elements with nonmetals, usually oxygen.

Critical - Marking the transition from one state to another.

Critical current density - (In relation to superconductivity) the **current density** above which a superconductor 'goes **normal'.**

Critical magnetic field strength - (In relation to superconductivity) the **magnetic field strength** beyond which a superconductor 'goes **normal'.**

Critical temperature - (In relation to superconductivity) the temperature, usually measured on the **Kelvin scale,** below which a material becomes superconductive; also referred to as **transition temperature.**

Cryogenic - Concerning the attainment and maintenance of temperatures close to **absolute zero.**

Cryogenics - The study of materials and phenomena at temperatures close to **absolute zero.**

Current density - The ratio between the quantity of current flowing at a point of a conductor and the area of cross section of the conductor at that point; the symbol for current density is J and it is typically measured in amperes per square centimetre (A/cm^2).

DC - Abbreviation for **direct current.**

Diamagnetic - Exhibiting a negative **magnetic susceptibility** and tending to align transversely to an applied magnetic field.

Direct current - Electric current flowing through a conductor in one direction.

H - The symbol for **magnetic field strength.**

H_{c1}, H_{c2} - The symbols, respectively, for lower and upper **critical magnetic field strength**

HTS - High Temperature Superconductivity; superconductivity occurring at relatively high temperatures (that is, higher than those for **LTS**).

Intermetallic compounds - Compounds of nominally fixed composition, one or more of the constituents being metals.

J - The symbol for **current density.**

J_c - The symbol for **critical current density.**

Josephson effects - A number of phenomena associated with the operation of a **Josephson junction;** they include the generation of very high frequencies proportional to the voltage of an applied **direct current** and the variation of current flow in proportion to an applied **magnetic field.**

Josephson junction - An electronic device consisting of two superconducting plates separated by a very thin insulating film; the device is useful because of the associated **Josephson effects;** a **superconducting quantum interference device (SQUID)** consists of two Josephson junctions.

Kelvin scale - Also known as the absolute temperature scale, an extrapolation of the Centigrade scale, starting at **absolute zero;** temperatures are expressed in degrees Kelvin (K).

LTS - Low Temperature Superconductivity; superconductivity occurring at temperatures close to **absolute zero.**

Maglev - Magnetic levitation by exploiting the **Meissner effect;** a method of propulsion for trains, for example.

Magnetic field - A field of force existing in the presence of a magnet or a material conducting an electric current.

Magnetic field strength - A measure of the force exerted by a magnetic field at a given point in space; the symbol for magnetic field strength is **H** and it is typically measured in teslas or kilogauss (1 tesla = 10 kilogauss).

Magnetic susceptibility - A measure of the degree to which a material is magnetised by a **magnetic field** in relation to the **magnetic field strength.**

Mechatronics - Synonymous with 'robotics'; in the same way as 'information technology' is a more accurate description of what was formerly called 'data processing', 'mechatronics' signifies the conjunction of mechanical and electronic technologies.

Meissner effect - A phenomenon synonymous with **perfect diamagnetism.**

Normal - (In relation to superconductivity) non-superconductive; a superconductor 'goes normal' when one or more of its critical properties - nil **resistance** to a **direct current,** or **perfect diamagnetism** - is lost and superconductivity is 'quenched'.

1-2-3 ceramic - A class of materials which can be made to exhibit **HTS;** the description is derived from their generic formula: $R_{(1)}Ba_2Cu_3O_{7-x}$, where R is a rare earth element; sometimes referred to as **perovskites.**

Operating temperature - An arbitrary temperature chosen to enable the optimal operation of a superconductor for a given function in a given set of circumstances; a temperature between **absolute zero and critical temperature** which makes allowance for constraints imposed by other factors, such as **critical current density** and **critical magnetic field strength.**

Perfect diamagnetism - The total expulsion of an external magnetic field from within a material and the setting up externally of an equal and opposite magnetic field; known as the **Meissner effect,** the phenomenon indicates that a material is superconducting; it produces magnetic levitation **(maglev).**

Perovskite - A mineral: a variety of calcium titanate formed at high temperatures.

Perovskites - A crystallographic family of ceramics that have a similar atomic arrangement to **Perovskite; 1-2-3 ceramics** are structurally flawed members of this family.

Phase - A distinct state of a substance reflecting its molecular energy; for example, steam, water and ice represent the gaseous, liquid and solid phases, respectively, of hydrogen oxide; the superconducting and **normal** states are different phases of a material.

Rare earths - (Strictly speaking the oxides of) A family of elements comprising scandium (Sc), yttrium (Y) and the range of elements known as lanthanides, namely: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dyprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb) and lutetium (Lu).

Resistance - Opposition to the flow of electric current through a conductor; resistance causes losses, usually in the form of heat or light, in the energy carried by the current.

Resistivity - A measure of a material's **resistance** for a given area of cross section for a given unit of length.

Shake and bake - Descriptive generally of techniques used to synthesise the early **1-2-3 ceramics**; reflects the freedom of approach facilitated by the absence of a theoretical base (synonym: hit or miss).

SMES - Abbreviation for **superconducting magnetic energy storage**.

SQUID - Abbreviation for **superconducting quantum interference device**.

Stoichiometry - An aspect of chemistry relating to the composition of materials, in particular the determination of their chemical formulae; identifying the superconducting **phases** of **1-2-3 ceramics** involves oxygen stoichiometry (as indicated by the variable element in the generic formula $RBa_2Cu_3O_{7-x}$).

Substrate - A backing material to provide rigidity; necessary to compensate for the fragility of superconducting thin films.

Superconducting magnetic energy storage - A system using superconducting magnetic coils to store energy in the form of a continuously circulating electric current.

Superconducting quantum interference device - An electronic device consisting of two joined **Josephson junctions**; it is extremely sensitive to magnetic fields and has a wide range of potential applications including biomagnetometry, mineral detection, corrosion detection, and high speed switching devices.

Superconductivity - The phenomenon of an electric current flowing against no resistance; **perfect diamagnetism** is concomitant.

Transition temperature - Synonymous with **critical temperature.**

Type I superconductors - The earliest, metallic, superconductors; distinguished from Type II superconductors by their sharp transition from superconducting **phase** to **normal** as external **magnetic field strength** is increased.

Type II superconductors - Materials which enter a mixed state - in which a **magnetic field** begins to penetrate - between two levels, the lower critical and upper critical, of **magnetic field strength,** as external **magnetic field strength** is increased; at upper **critical magnetic field strength, superconductivity** ceases.

REFERENCE GUIDE

Information has been derived from a number of sources, in addition to the oral and written evidence provided at public hearings and in submissions. The following guide sets out in fuller detail the sources referred to throughout the report, and the form in which those sources are cited.

Oral evidence

All oral evidence presented to the Sub-Committee at its public hearings is recorded in the Transcript of Evidence; references to transcript evidence take the form: *Evidence,* (page number).

Written evidence

Written evidence can take the form of a submission, a supplementary submission or an exhibit. The submissions of witnesses who appeared before the Sub-Committee at its public hearings have been incorporated in the Transcript of Evidence; references take the same form as for oral evidence. Other submissions have been consolidated in a separate volume of evidence and references take the form: *Evidence,* S (page number).

A list of all submissions lodged appears at Appendix 1.

Other sources

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CHAPTER I

SUPERCONDUCTIVITY AND RELATED NEW MATERIALS

- **Introduction**
- **Generic technologies**
- **New materials**
- **Superconductivity: LTS & HTS**
- **Superconductivity and related new materials**

Introduction

1.1 This chapter describes the subject area of this inquiry. The objective is a working definition, for the purposes of the inquiry, of superconductivity and related new materials.

1.2 Superconductivity is shown to be not so novel as the reports in the popular press may suggest: the phenomenon was first noted over 75 years ago and there is an existing technology and an existing and increasing market. However, recent advances have led to a widespread belief that a milestone has been reached and that the successful exploitation of high temperature superconductivity, in combination with a number of newly developed materials, will have an enormous impact in a relatively short time, both economically and technologically.

1.3 Because their economies are now so interactive, the industrially advanced nations have reached a stage where each nation must make conscious decisions about its long term economic behaviour, taking into account the decisions being made by the others. A modern economy needs constant innovation to survive in this environment. Innovation can be either fostered or left to the determination of market forces. Many nations find the latter course to be inadequate for long term planning and thus develop science and technology strategies which comport with their economic and social goals.

1.4 The generic technology is a key analytical concept at the strategic level. A generic technology straddles the area between science and proven technology. A number of generic technologies have been identified as being fundamental to innovation over the next decade and beyond: they include microelectronics, biotechnology, information technology, mechatronics and new materials.

1.5 New materials comprise a generic technology of the same importance as information technology or biotechnology. The new superconducting materials are only one of a number of promising families of new materials but a family whose significance is amply demonstrated by the recognition being accorded them by the governments of the industrially advanced nations.

1.6 The future of some of the other new materials is inextricably linked with that of the new superconductors. This report is about both.

Generic technologies

1.7 There is a conventional model of innovation which sets pure or basic science at the beginning and then paves a one-way path through applied science, into technology and then onto commercial development. It is a simple model which does not comprehend some of the more complex interrelationships between science and technology, between research, development and demand.

1.8 More often than not an innovation is the outcome of its being seen to be needed and the developmental stage of its realisation may proceed simultaneously with, or in anticipation of, whatever theoretical and basic research is necessary. Almost any item of consumer electronics is an example on a small scale of this principle; a large scale example is the US Strategic Defense Initiative.

1.9 The one-way path exists only in a logical sense: basic science logically precedes applied science; research logically precedes development. Between applied science and a proven technology lies the ground covered by 'enabling' or generic technologies. Pushing the generic technology is the weight of discovery, pulling it is the demand for new or improved products and services.

1.10 The word technology is used here in a very general way. Technology can be described as 'a perishable resource comprising knowledge, skills and the means of using and controlling factors of production for the purpose of producing, delivering to users, and maintaining goods and services for which there is an economic and/or social demand'[1] or it can be put more crudely as 'the way we make things'. A specific technology might be the set of processes and procedures we employ to make a certain type of product.

1.11 Distinguishing a generic technology from a specific technology is a matter of judgment. Several technologies may arise from a generic technology. A specific technology in spawning new technologies may itself be regarded as a generic technology. The essence of a generic technology is that it enables the genesis of others, that it is the progenitor of a set of new technologies.

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[1] US National Academy of Science quoted in *National Technology Strategy*, page vi.

New materials

1.12 New materials, or advanced materials, can be distinguished from old materials, such as glass, iron, steel, concrete, bricks, wood and paper. New materials have superior characteristics to old: they may be cheaper, lighter, stronger or more easily processed. They come from 'the mind of the scientist in the laboratory rather than in the ground'; they result from design rather than adaptation.[2]

1.13 New materials can themselves be classified generically: plastics, ceramics, composites, alloys, semiconductors, optical fibres and biomaterials are examples. More specific instances are such materials as carbon fibres, superglues, conducting polymers and metallic glasses.

1.14 Considered en bloc, new materials and advanced processes comprise a quintessential generic technology. A whole range of proven technologies will ultimately arise; some already have. Many discoveries of new materials and processes have been made in advance of any economic application: technology push; others have been developed to meet an existing requirement: demand pull.

1.15 Such materials are intrinsically high value added: their manufacture and marketing will increase the economic and technological advantages which accrue to the adders of value, and which is forgone by the mere producers and suppliers of raw materials.

Superconductivity: LTS & HTS

1.16 Superconductivity is not new. The phenomenon of immeasurably minute, if not zero, resistance to the flow of an electric current was first recorded by the Dutch physicist Heike Kamerlingh-Onnes at his laboratory in Leyden in 1911. Onnes had been the first to liquefy helium - in 1908 - and over the next few years became a trailblazer in low temperature physics; he was awarded the Nobel Prize for Physics in 1913 in recognition of his work in cryogenics.

1.17 The discovery of superconductivity came as a surprise to physicists. Indeed, some had expected that as the temperature of a conductor approached absolute zero, resistance would tend towards infinity, with current ceasing to flow altogether at absolute zero. Figure 1.1 shows the relationship between degrees absolute and degrees Centigrade.

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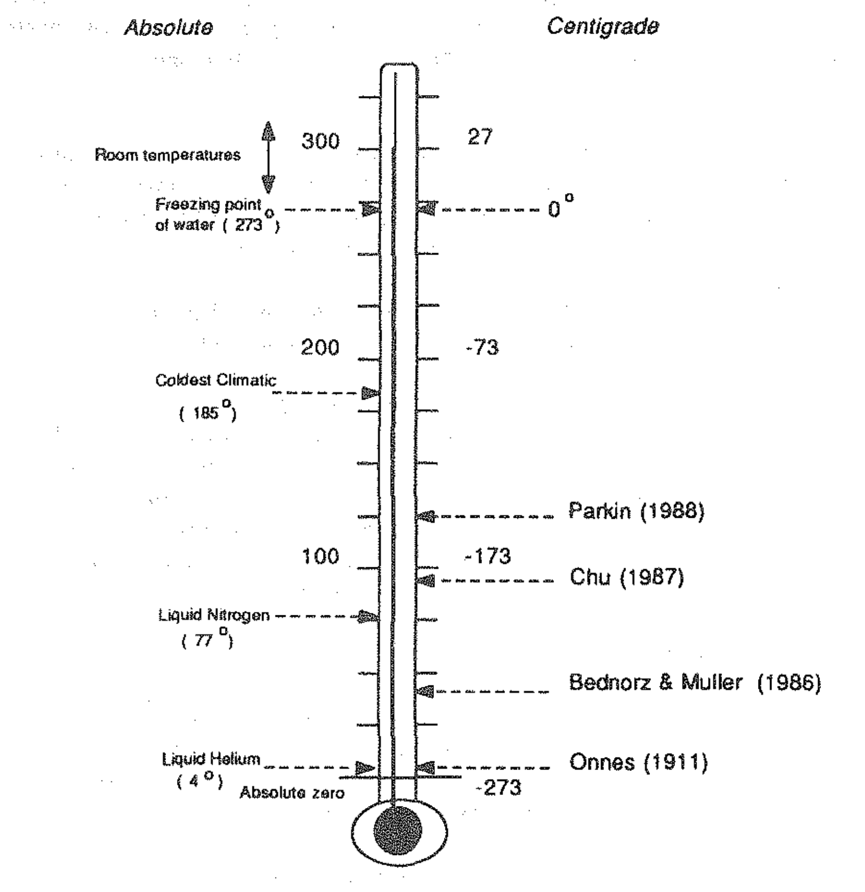
[2] *Forester.*

Figure 1.1 **Temperatures**



1.18 Mercury, cooled to 4.15 degrees above absolute zero - just under the boiling point of liquid helium - was the first material in which the phenomenon was observed. It was later noted in other metals such as tin and lead. The highest temperature - the critical or transition temperature - at which a metal became superconductive was found to be 9.25 degrees above absolute zero, in niobium. These metals became the first generation of superconductors.

1.19 The next generation were intermetallic compounds, such as niobium-tin, vanadium-silicon and niobium-titanium, which were developed from the 1930s onwards. The highest critical temperature observed for an intermetallic compound was 23.2 degrees absolute, for niobium-germanium, and this remained the record until the discovery of the third generation of superconducting materials.

1.20 Another significant point was reached in the 1930s. In 1933 Meissner and Oschenfeld observed in superconductors the phenomenon of perfect diamagnetism, the exclusion of all externally applied magnetic flux, subsequently referred to as the Meissner effect.

1.21 The intermetallic compounds differed from the metals in their transition from the superconducting to normal phase: in metals, the transition occurred at a fixed magnetic field strength; in intermetallic compounds there was an intermediate or mixed state of diamagnetism between two levels of magnetic field strength. Accordingly, the metals were classified as Type I superconductors and the intermetallic compounds as Type II. One characteristic they had in common was the need to be cooled in liquid helium.

1.22 An adequate theoretical explanation for the superconducting phenomena was not developed until 1957. John Bardeen, Leon Cooper and J. Robert Schrieffer proposed a model based upon the interactions between electrons and phonons, or atomic vibrations. Their theory, for brevity called the BCS model, earned them the Nobel Prize for Physics in 1972. The following year the Physics prize was awarded to Leo Esaki, Ivar Giaevar and Brian Josephson for further work in both microelectronics and superconductivity.

1.23 The first commercial applications of superconductors did not arrive until the late 1960s. There is now a well developed market in such areas of application as electronics, instrumentation and medical, aerospace, defence and industrial, employing magnets, rods, wires and cables fabricated from the metallic and intermetallic superconductors. The topic of existing applications for superconductors is discussed at greater length in Chapter 2.

1.24 In early 1986 two researchers at the IBM Research Laboratories in Zurich, Johannes Bednorz and Karl Muller, observed superconductivity and the Meissner effect in the first of the third generation of materials, rare earth ceramics. These materials had been developed in the early 1980s by French scientists engaged in new materials research; while the French were interested in their structure and properties, they were not looking for superconductivity and did not find it. However, superconductivity had been observed in perovskites - the crystallographic family to which these rare earth ceramics belong - as far back as 1975, though at very low critical temperatures.

1.25 Having some familiarity with perovskites, Bednorz and Muller acted on a hunch that these materials had potential as superconductors and in 1983 began searching for the phenomena in variations of the perovskite family. Their discovery was published in late 1986 and they were subsequently awarded the 1987 Nobel Prize for Physics for their work.

1.26 The critical temperatures attained with the third generation of superconductors were so significantly higher than those of previous generations (35 degrees absolute to begin with and successively upwards to 100 degrees and beyond) that they became known generically as 'warm superconductors' or, more commonly, 'high temperature superconductors' (HTS), despite the frigidity of liquid nitrogen temperatures (below 77 degrees absolute; the coldest recorded climatic temperature is about 185 degrees absolute, that is about minus 88 degrees Centigrade). Inevitably, the older materials became known as 'low temperature superconductors' (LTS). 'Room temperature superconductors' (RTS) are as yet a matter of conjecture but their ultimate discovery cannot be dismissed.

1.27 To achieve optimal performance and to allow a margin for variations in operating conditions, a working superconductor must operate at a temperature somewhat lower than its critical temperature. While the raising of the critical temperature above the liquid nitrogen threshold has been the subject of most attention, it is the relativity of the operating temperature to the boiling point of liquid nitrogen which makes HTS economically significant. Nitrogen is much more abundant than helium and liquid nitrogen is not only consequently less expensive than liquid helium but also much easier to handle. So while refrigeration would still be essential for an operational HTS device, it would be significantly cheaper.

1.28 In the two years or so since Bednorz and Muller's discovery, further advances have been made. Compounds other than rare earth ceramics have been identified, including other copper-oxide ceramics containing bismuth and thallium. The frontiers of current research and development and the challenges thereof are discussed in greater detail in Chapter 3. The important point to be made at this stage is that a range of materials exhibit superconductivity and that doubtless more will be discovered.

1.29 While there is the prospect of further progress, the fact that the BCS (Bardeen-Cooper-Schrieffer) explanation for superconductivity does not hold for HTS has made research into superconductivity not just the province of materials scientists but also of theoreticians.

Superconductivity and related new materials

1.30 The development of more useful superconducting materials has traversed at least three kinds of advanced materials: metals, alloys and ceramics. Some researchers are investigating a fourth, organic superconductors. It can be seen from this that superconductors permeate the realm of new materials.

1.31 It will also become apparent from the discussions of the applications for new superconductors - in Chapter 2 - and the various research and development challenges which stand in the way of their successful exploitation - in Chapter 3 - that materials other than superconductors will be involved. For example, in microelectronics there are bound to be requirements for hybrid semiconducting-superconducting devices; in developing thin film superconductors, better substrate materials must be discovered.

1.32 The phrase 'superconductivity and related new materials' thus itself presents a challenge. Where, within the whole field of new materials should the line separating the related from the non-related be drawn? It is a difficult decision but for the purposes of this report the Committee has focused on metallic glasses and rare earth permanent magnets as being sufficiently representative of related new materials. The way in which they will be used with high temperature superconductors in the power industry is indicative of the partnerships between new materials which will prove necessary in other applications areas. Other prospectively related new materials, while not being excluded, will be given less emphasis.

CHAPTER 2

APPLICATIONS

- **Introduction**
- **Existing applications**
- **Potential applications**
- **Aspects of the potential impact**
- **Conclusion**

Introduction

2.1 This chapter examines the potential technological and economic impact of recent advances in superconductivity. While the emphasis is on the new superconductors, reference is made, too, to metallic glasses and rare earth permanent magnets since they are representative of the many technological alliances which will be forged as the recent advances are consolidated and further advances made. The chapter concludes with a statement on the importance to Australia of what may follow those advances.

2.2 It was mentioned in the previous chapter that superconductors are not new and that there is an existing technology and an existing and expanding international market. While there is further scope for new applications using low temperature superconductors (LTS) and indeed a future for LTS technology, it is the new high temperature superconductors (HTS) which promise a greater technological and economic impact. The applications for superconducting materials, in general, include:

- existing applications using LTS
- *potential applications using LTS*
- potential applications using HTS to:
    - replace non-superconducting materials
    - replace LTS materials
    - meet new demands.

2.3 It should be borne in mind, too, that there may be progress beyond HTS, that materials which superconduct at normal temperatures - room temperature superconductors - may eventually be discovered.

2.4 As with any advanced material, there are two ways in which superconductors can meet an economic or technological demand:

- They have unique properties which are useful
- They have advantages over other materials in terms of:
  - cost
  - performance
  - size

2.5 The unique properties of superconductors which make them useful include zero resistance to a direct current, perfect diamagnetism, rapid phase change, highly sensitive frequency responses to small changes in voltage, flux quantisation and nonlinear current-voltage characteristics. Of course some of these unique properties also confer advantages over established materials in certain applications, such as, for example, the transmission of electric current.

2.6 The cost advantages which new materials might enjoy over old do not simply equate to the cost of production. Operating costs are especially critical to superconductor applications where a significant overhead might be imposed by the operation and maintenance of the requisite refrigerating apparatus. Other factors, such as operating life and replacement cost of existing plant, are determinants of their ability to be exploited commercially.

2.7 The special properties of the new materials and the problems in developing both the materials and applications for them are discussed in greater detail in the next chapter.

Existing applications

2.8 The commercial possibilities of superconductors were apparent from the outset and indeed Onnes himself, though he was first and foremost a pure scientist, shaped some of his experiments in that direction. The most obvious application was the transmission of electric power. However, it was soon discovered that putting this into practice was some way off: the superconducting effect disappeared when all but the minutest of electric currents was passed through the material.

2.9 The generation and maintenance of intense magnetic fields, with very little power consumption, was another possibility which was examined soon after the initial discovery was made. Again, the effect disappeared at a disappointingly low level of magnetic field strength. The Type I superconductors remained little more than a scientific curiosity.

2.10 With the development of the Type II superconductors from the 1930s onwards came the possibility not only of conducting higher currents but also of generating strong magnetic fields. A major difficulty in putting superconductors to work had been the need to maintain very low temperatures but concurrent with the development of Type II superconductors, breakthroughs were made in refrigeration technology. The first commercial applications of superconductivity followed.

2.11 The predominant applications area for LTS is in the manufacture of high field electromagnets. These devices are used in medical diagnostic equipment, scientific instrumentation and particle accelerators for physics research. LTS electromagnets generating high-gradient magnetic fields are used in the separation of materials such as ores and waste solids.

2.12 The commercial development of LTS high field electromagnets entailed several advances which are illustrative of what lies ahead for HTS technology. In addition to overcoming the refrigeration problem, a compromise had to be made between the ductility of the selected superconducting material, niobium-titanium, and a lower critical magnetic field than was possible with less tractable intermetallic compounds.

2.13 Furthermore, techniques had to be developed to optimise the current carrying ability of the material: the result was a braided cable containing thousands of very fine filaments. As well, provision had to be made for the material 'going normal' while conducting large currents - without a conventional conductor in tandem, the cable would disintegrate; to this end the superconductive filaments were set in a copper matrix.

2.14 Niobium-titanium electromagnets operate slightly below the boiling point of liquid helium, about 4.2 degrees absolute. Maintaining that temperature requires expensive on-line refrigeration. While refrigeration is a major operating cost of LTS electromagnets - most of the power consumed by the electromagnet goes to refrigeration - they are still far cheaper to operate than conventional electromagnets of similar strength.

2.15 LTS high field electromagnets have also been used experimentally in ways suggestive of potential applications for superconductors generally. Prototype magnetic levitation (maglev) trains, exploiting the Meissner effect, have been developed in Japan and Germany. Magnetohydrodynamic (MHD) propulsion for ships is another application being investigated in Japan. It may be possible using LTS magnetic containment of plasma to build thermonuclear fusion reactors for the safer and cleaner generation of electricity than is currently possible. Prototype LTS power cables have been developed as have electric generators and magnetic energy storage devices.

2.16 Despite these many prototypes, there is as yet little prospect of a significant impact by LTS technology on power engineering.

2.17 Small electronic devices occupy a much smaller place in the existing LTS market than do electromagnets. The Josephson junction, which arose from the discovery of Josephson effects in the early 1960s, is central to LTS electronics. The Josephson junction consists of two superconducting layers separated by a very thin insulating layer. It exploits the 'tunnelling' of electrons through the insulating material from one superconducting layer to the other.

2.18 The Josephson junction is extremely sensitive to magnetic fields, and changes in magnetic field strength. Its sensitivity to a magnetic field - the fact that at a certain threshold, a magnetic field will quench superconductivity and the material will thereby switch phase - makes the Josephson junction a very fast switching device which consumes little power. Its sensitivity to changes in magnetic field strength - the fact that current flow through the device is 'quantised', that is to say that it varies in discrete steps as magnetic field strength varies - makes the Josephson junction a pre-eminent detector and measurer of weak magnetic fields.

2.19 The use of superconductors in electronics is still in its infancy but there is an established market, particularly in scientific and medical instrumentation. A device which consists of a pair of interconnected Josephson junctions, the superconducting quantum interference device, or SQUID, is also gaining an increasing foothold and will be discussed further in the ensuing section on potential applications.

2.20 Decades of research and development and a well developed, albeit growing, international market make low temperature superconductivity a mature technology. In 1986 the world market for LTS products stood at A$360 million with a projected growth rate of 10 per cent per annum. Electromagnets comprised more than two thirds of the market.[1]

2.21 There are probably more than 50 manufacturers of LTS products, most of them based in the US. About 10 companies are active in Japan and 6 in Europe. There are no manufacturers of superconductors in Australia.[2]

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1 *Evidence*, pages 626-8.
2 Ibid.

Potential applications

2.22 As has been shown above, many of the proposed potential applications of superconductors in general have been conceived during the development of LTS technology. While there may be an even transition between the two technologies it is important to consider the implications of the failure of the BCS model to explain HTS behaviour.

2.23 It may well be that the potential applications for HTS will far exceed those for LTS for reasons other than the less prohibitive cooling requirements of the former. HTS materials may be able to perform functions that LTS cannot. Conversely, LTS may have its own advantages, for example, as it presently has with signal-to-noise ratio in electronic devices. There may be both shared and separate destinies for the two.

2.24 As with existing applications, the major potential applications can be seen to fall under three categories: microelectronics, power engineering and magnetic field generation. There are smaller, more specific, areas, too, in which an impact can be predicted. Perhaps those applications which are yet to be conceived will outnumber and overshadow them all.

2.25 The successful development of many potential applications will depend on researchers breaking the 'nitrogen barrier'. It will be explained in Chapter 3 that the optimal operating temperature for a superconductor is somewhat below its critical temperature and the fact that critical temperatures have been achieved above the boiling point of liquid nitrogen does not signal a final victory: it is the operating temperature which must be attainable at that level.

Microelectronics

2.26 Most of the unique characteristics of superconductors make them potentially useful in microelectronics and, as was explained above, LTS materials are already used in commercial applications.

2.27 When there is no resistance to a current, no energy is lost within the conductor. In a conventional conductor energy lost because of resistance is usually dissipated as heat. One of the impediments to miniaturisation of electronic components is the accumulation of heat within them: the same quantity of heat has a more damaging effect on a smaller mass than a larger, in terms both of raising the temperature of the body, and of the ability of the body to radiate and thereby lose that heat. Much smaller components, such as computer chips, could be made with a material which offers no resistance to an electric current.

2.28 Further, lower voltages are required to operate superconducting devices. But the more significant characteristic of superconductors is their ability to change rapidly from the normal phase to superconductive. This enables the construction of high speed switching devices, the heart of computer electronics. The goal, then, is smaller, faster and even less power hungry computer hardware. It is believed the Japanese are already well advanced with prototypes.

2.29 The Josephson junction is central to microelectronics applications but it is largely restricted to the role of a switching device. Two Josephson junctions connected together form what is known as a superconducting quantum interference device (SQUID), which further exploits the abilities of the Josephson junction particularly as a highly sensitive detector of magnetic fields. Devices which detect and measure magnetic fields, magnetometers, are used in such diverse areas as:

- medicine (medical scanners using nuclear magnetic resonance imaging (MRI) and spectroscopy (MRS), magneto-encephalography (MEG));

- geology (detection of ore bodies), and

- defence (submarine detection).

2.30 Beyond these existing uses for SQUIDs lies further exploitation of their sensitivity to weak magnetic fields. It is known that during the chemical reaction involved in corrosion, very weak magnetic fields are generated; SQUID devices could be used in corrosion control, detecting its early onset.

2.31 Other microelectronics applications which may use the unique properties of superconductors include analog/digital converters (which transform gradations into discrete units, for example shades of grey into binary digits in the case of computerised image enhancement); voltage standards (exploiting the property of a Josephson junction to generate high frequencies which are sensitive to infinitesimal changes in applied voltage); and, bolometers (detectors of infrared radiation).

2.32 Many of these applications will require combining superconductors with other specialised materials. For example, a hybridisation between superconductors and semiconductors is envisaged. As will be explained in Chapter 3, there are problems in physically joining HTS materials to other materials, not least because of their chemical instability.

Power engineering

2.33 Widespread applications in power engineering have already been shown to be technically feasible using LTS technology. The general areas in this field are: power generation, power distribution and energy storage.

2.34 Electrical generators using LTS technology have already been demonstrated. The main advantages are in lower internal energy losses and smaller size. There are, however, apart from certain technical problems, economic reasons - broadly similar in nature to those for distribution systems, as will be outlined below - for doubts about their commercial development in the short term. Electric motors and their associated technology are similar to generators in most regards and similar considerations apply.

2.35 From the outset, the transmission of electrical current without the power losses inherent in conventional distribution systems was seen as a major contribution which superconductors could make to power engineering.

2.36 One aspect of superconductivity which is often overlooked in the reportage of major advances and in speculation on their impact is that a superconductor offers zero resistance to a direct current only; it is quite a different matter with alternating current, where resistance is proportional to temperature, magnetic field strength and frequency. Even so, superconductors offer potential advantages in the transmission of alternating current.

2.37 Energy losses in power distribution systems originate not only in the power lines themselves: there are many steps between source and destination, the generator and the appliance. A small amount of the energy which is produced by a generator is lost internally through resistance. A fraction of a generator's output is used to power auxiliary systems, such as motors to supply coal or air, to pump steam and water and to dispose of waste, and a fraction of that energy is lost similarly.

2.38 The voltage of the output from a generator must be increased by several factors, typically to a level 15 or 20 times that of the output, to minimise transmission losses: less power is lost at higher voltages. This 'stepping up' of the output voltage is achieved through generator transformers which also lose a small amount of energy through resistance.

2.39 The power lost within main transmission lines is directly proportional, of course, to the length of those lines; other factors also influence power losses, such as load patterns and, to a lesser degree, weather. Further losses occur successively at substation transformers (where the voltage is 'stepped down' again, having been carried most of the distance between source and destination) and transmission and distribution feeders.

2.40 If one makes certain assumptions about the appliances that consume the delivered power - for example, the proportion of those where the incorporation of superconductors would minimise consumption, such as appliances using electric motors - then the breakdown in Table 2.1, provided in their submission by the Australian Electrical Research Board, is indicative of the energy wasted in delivering, and to an extent consuming, electrical power by conventional means.[3]

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[3] *Evidence*, pages 245-7.

Table 2.1

BREAKDOWN OF TYPICAL LOSSES IN POWER DISTRIBUTION SYSTEMS	
Generators	0.33 %
Auxiliary motors	0.25 %
Generator transformers	0.33 %
Main transmission	3.5 % (average)
Substation transformers	2.25 %
Transmission and distribution	3.0 %
Utilisation	2.0 %
TOTAL (approximate)	12.0 %

2.41 It can be seen from these figures that some 75 per cent of the power losses occur within the distribution system and it is in this area that the potential promise of superconductors is most clearly visible.

2.42 To determine the economics of replacing conventional technology with HTS, first the percentage of energy which would be consumed in maintaining HTS operating temperatures would need to be deducted from what would be saved. Then replacement costs, installation costs, lifetime costs, and a host of other factors would need to be considered.

2.43 The fact that theoretically an electrical current would flow forever in a superconductor - and in reality does for a very long time - leads inevitably to the realisation that energy could be stored and retrieved with practically none being lost. There are many areas, small and large scale, in which efficient storage of electrical energy satisfies an economic or technical demand.

2.44 A large scale superconducting magnetic energy storage (SMES) device, wired into a power grid, would allow power stations to operate their plant at constant output: the excess power generated when demand slackened, such as overnight, could be stored to be retrieved during peak periods. In existing power stations, the engineering constraints of operating machinery at constant loads entails wastage of energy at times of low demand: excess power is often 'burnt off' in large heat-producing devices, 'toasters'.

2.45 An additional advantage of such a device would be its ability to regulate supply, to compensate rapidly for sudden shifts in demand, and systemic fluctuations, such as power surges, which would otherwise cause large scale blackouts.

2.46 Smaller scale devices could serve in remote localities and involve a marriage with photovoltaic technology: a more efficient exploitation of electrical energy converted from solar radiation. Ultimately, small scale SMES devices might replace relatively primitive energy storage systems such as conventional batteries.

Magnetic field generation

2.47 Apart from their use in power engineering, magnetic devices using superconductors have potential applications in medical scanners (for the generation of magnetic fields, in addition to the detection role played by SQUIDs), magnetic levitation, magnetohydrodynamic propulsion, particle accelerators and magnetic separation.

2.48 There are other new materials which are used in the area of industrial magnets, including rare earth permanent magnets and metallic glasses.

2.49 Permanent, or 'hard', magnets differ from 'soft' magnets in their ability to retain magnetism. Their evolution as a family of new materials shares certain similarities with that of superconductors. Metallic magnets, typically of steel, gave way in the 1940s to an alloy of aluminium, nickel and cobalt - Alnico - followed by ferrites in the 1950s. Rare earth permanent magnets, from samarium-cobalt in the 1960s to neodymium-iron-boron in the early 1980s, comprise the latest generation.[4]

2.50 Not only has this family reached a stage where rare earths are involved; not only has the improvement in their properties followed the same accelerating path of superconductors; but also, in common, is the prospect of further advances.

2.51 The main application for rare earth permanent magnets will be in electric motors - the benefits will be similar to those deriving from the use of superconductors in the windings of motors and generators: the finished product will be smaller, lighter and more energy efficient. Electric motors vary in size and function from tiny stepper motors in watches - consuming electricity at microwatt levels of power - to marine propulsion units, consuming power in megawatts.[5]

2.52 Running through the list of potential uses - motors, audio transducers, nuclear magnetic resonance tomography, maglev transport, actuators, impact printers, bearings and couplings, separation, beam control - one can see points

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[4] *Evidence*, pages 47-60.
[5] Ibid.

of contact not only with other new materials, especially superconductors, but also other generic technologies, such as information technology and mechatronics.

2.53 Metallic glasses - also known as glassy metals or amorphous metals - comprise a family of metallic alloys which are formed by very rapid cooling from their molten state so that in their solid state they are non-crystalline, or amorphous. This amorphous structure imparts different properties from those possessed by their crystalline analogues.

2.54 Table 2.2 indicates the superior combined properties of metallic glasses, in comparison with metals and glasses.[6]

Table 2.2

COMPARISON OF PROPERTIES OF METALS, GLASSES AND METALLIC GLASSES

PROPERTY	METALS	GLASSES	METALLIC GLASSES
Structure	crystalline	amorphous	amorphous
Bonding	metallic	covalent	metallic
Strength	not ideal	ideal	ideal
Deformation	good, ductile	bad, brittle	good, ductile
Hardness	small	large	large
Fracture limit	high	low	high
Corrosion	susceptible	resistant	resistant
Optical	opaque	transparent	opaque
Thermal Cdtvty	high	low	high
Elect Cdtvty	high	low	high
Magnetism	several para- & ferromagnetic	non-magnetic	several mainly soft-magnetic

2.55 As can be seen from the table, metallic glasses combine useful properties of both metals and glasses; potential applications include:

. cores for such electromagnetic applications as transformers, motors and ballasts

. reinforcements for composites

. medical applications based on corrosion resistance

[6] Ibid.

- magnetic reading and recording heads (audio, video and data)
- sensors and transducers
- magnetic shielding

2.56 The transition from one set of applications, in this case electromagnetic, to other ostensibly unrelated areas, such as biomedical, is typical for new materials and suggests the unpredictability of future technologies deriving from the generic technology.

Others

2.57 Another application which would exploit the efficient generation of intense magnetic fields would be the coupling of moving mechanical components without physical contact between them: frictionless bearings. Their impact upon engineering can only be guessed.

2.58 A further use involving intense magnetic fields lies within experimental physics. A major stumbling block in particle physics is the expense of the apparatus required for experimentation. Indeed, the scale and cost of the proposed US Superconducting Super Collider (SSC) - it would cost an estimated US$4.4 billion to build, employing 4500 construction workers, and would cost $270 million a year to operate, employing 2500 permanent staff - are such that the SSC has become a political issue, involving heated debate for over a year and inspiring accusations of 'quark barrelling'.[7] The SSC would use LTS technology. Thus, were HTS to enable cheaper apparatus, pure science itself would be rewarded.

2.59 Superconductors have other potential uses in telecommunications apart from their role as switching devices. For example, superconductors may make excellent low loss transmitting antennae. They may have a part to play not only in the detection, as outlined above, but also in the generation of microwave frequencies - superconductor-lined resonant cavities have been shown to minimise energy losses within the cavity walls.

2.60 Since temperatures in space may be sufficiently cold for HTS materials to operate without any refrigeration, the whole range of applications, from large magnets to microelectronic devices, could be profitably employed, for example, in space-based manufacturing.

2.61 In an age when entertainment, consumer electronics and novelty items occupy significant market niches, superconducting devices have inestimable potential.

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[7] *Kuntz.*

Aspects of the potential impact

2.62 The prime determinant of the potential impact of superconductors, as with other new materials, will be the economics of their development and implementation. But there are other aspects which are worthy of mention. They include: the competition between nations; the time it will take for the impact to be felt; the possibility of unforeseen side-effects; and the significance of a military interest.

Economics

2.63 Some appreciation of the economic considerations involved in the adoption of superconducting alternatives can be gauged from the preceding discussion on superconducting power transmission lines. This is clearly an instance where technology push is at present stronger than demand pull.

2.64 It will be the consumers - at the vanguard of whom will be the manufacturers and marketers - who will ultimately set the pace, not the researchers. And those consumers will make their decisions only after complicated cost-benefit analysis. This aspect will be taken up again in the ensuing chapter when discussion turns to commercial development.

A race between unequal competitors

2.65 The pursuit of commercially useful superconductors can be likened to a crooked steeplechase. The runners are unequal, by wide degrees and in many ways. Further, while some obstacles face all runners, there are others which lie in the way of only a few.

2.66 The size of a nation's economy, the structure of its manufacturing base, its cultural attitude to science and technology, the relationship between its industrialists and its scientists, the skill of its workforce, its willingness to plan and the timescale over which it does so, are all guides to a nation's form as it enters the race.

2.67 Clearly in the race to exploit superconductivity, some runners are starting ahead of others. Some are going to have to run much harder than others. Some are going to have to content themselves with something less than first prize.

Different horizons

2.68 An assessment of how long it will take for certain applications to be developed can only be made with varying degrees of conviction. Clearly the relationship between technology push and demand pull varies from application area to application area. Generalised projections have been made, however, and Table 2.3, abstracted from an OECD report on the possible impact of HTS,[8] shows a typical evaluation:

Table 2.3

BROAD TIME-FRAMES FOR HTS APPLICATIONS

Device	Application	Market	LTS stage	HTS commercial
Magnet	NMR imaging	Medical	Reached	Short-medium
	Fusion, MHD	Research		Medium
	Accelerators	Physics	Reached	Medium-long
	Maglev	Transport		Long
	Energy storage	Utilities	Prototype	Very long
Cavity resonator	Accelerators	Physics		Medium-long
Gyrotron	Large scale fusion	Research		Very long
Generator	Electricity	Utilities	Prototype	Long
Transformer	Electricity	Utilities	Prototype	Long
Circuit devices	Electricity	Utilities	Reached	Long
Cable	Electricity	Utilities		Medium-long
Motor	Electro-mechanical	Utilities	Reached	Long
Micro-electronic	Magnetic sensors	Medical	Reached	Medium
	SQUIDs	Geophysics	Reached	Short
	Digital	Computers	Prototypes	Medium
	Analogue	Communications	Reached	Medium
	Transmission lines	Communications	Reached	Medium

[8] *Verie.*

2.69 The generalisation to be drawn from such projections is that microelectronic devices will be developed in the short to medium term; power engineering and high field magnetic applications are longer term propositions.

2.70 The influences on the development of individual applications may not lie simply within the dynamics of the generic technology; external factors such as the strength of the global economy, the state of international relations, patterns of world trade, technological developments in other fields, could all play their part.

The scope for unintended consequences

2.71 Sudden technological 'gear changes' can effect widespread perturbation, causing ripples, crossing into areas which might seem remote and disconnected; often these effects cannot be anticipated. It may be stretching an analogy to liken the advent of HTS to the discovery of the transistor and then to speculate on how superconductivity might affect our lives in the many ways as has the semiconductor. But the potential is there.

2.72 Thought has already been given to the effects of HTS on patterns of energy usage and the future demand for fossil fuels.[9] In this case alone there are geopolitical implications. No doubt there are potentially other ramifications.

Defence

2.73 There are obvious and not so obvious defence applications for superconductivity, as well as for a host of new materials. Many of these applications are and will be, of course, analogues of civilian applications. But the importance of defence applications should not be underestimated, not so much because of the applications themselves, but because of the developmental mechanisms involved.

2.74 Responses to changes in the balance of military power - and especially to opportunities to alter the balance in the subject's favour - are usually made much more rapidly and with greater intensity than to, say, economic or technological changes. If a new generation of strategically important military hardware was dependent on the development of a new technology, one could be assured that at least two nations, and almost certainly several more, would be prepared to spend large sums of money on tightly directed research and development.

2.75 The implementation of the Strategic Defense Initiative would entail the development of a range of devices and systems as yet largely in the conceptual stage. The areas in which superconductivity might be deployed include: lasers,

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[9] *Starks.*

rail guns, electromagnetic shielding and energy storage. The US Department of Defense has already commissioned developmental work on superconducting magnetic energy storage.[10]

2.76 The impact, then, of the defence requirement is two-edged: it may accelerate development because high levels of funding are made available and because the usual commercial restraints, including the imperatives of the profit motive, are removed; conversely, it may hinder development because large areas of technology become out of bounds for reasons of national security.

Conclusion

2.77 It should be clear from the preceding discussion - and it will be further illustrated in the ensuing chapter - that commercial development of applications using superconductors will be faster in some areas than in others; it may be anticipated, for example, that most of the major envisaged power engineering applications are long term prospects, if at all. In many areas it appears technology push is stronger than demand pull. However, there is widespread confidence that the materials already developed can soon be turned to commercial use.

2.78 It is as impossible now to predict the full extent of superconductivity's impact as it would have been, in the 1950s, to predict the range of technologies and devices enabled by the invention of the transistor.

2.79 But even with those areas of application which are clearly visible, Australia has an obvious interest in what is happening and what will happen. Australia is a heavy user and consumer of transport, communications and energy. As will be argued in Chapter 5, Australia has a desperate need to galvanise its manufacturing sector. Further, science and technology in Australia is at a watershed, and any opportunity to mobilise Australian researchers should be taken. Most probably, Australia holds many of the raw materials which will be strategically important in the fabrication of the new products. Finally, technological improvements in a host of important fields, such as medicine, defence, and science, itself, will ensue. Australia needs the new technology.

2.80 The Committee concludes that:

> **The potential economic and technological impact of advances in the field of superconductivity is so great that Australia must assess that impact and develop an appropriate strategy to maximise benefit to the national economy and minimise any further erosion in Australia's relative position.**

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[10] *Commercializing HTS*, page 162.

CHAPTER 3

RESEARCH AND DEVELOPMENT

- **Introduction**
- **Basic science**
- **Materials science**
- **Commercial development**
- **Aspects of research and development**
- **Conclusion**

Introduction

3.1 This chapter outlines the nature of research and development in the area of superconductivity and, by extension, related new materials. Particular emphasis is placed upon the technical problems which must be overcome. There are varying degrees of optimism on the question of whether all the research and development hurdles can be cleared. Nevertheless, as was shown in Chapter 2, there is widespread confidence that even the materials developed to date can be put to commercial use.

3.2 It was conceded in Chapter 1 that the word 'technology' was being used in a very general way. The Committee is aware of the formal definitions of such terms as 'pure basic research', 'strategic basic research', 'applied research' and 'experimental development'[1] but for the sake of a general discussion on research and development, a simple distinction will be made between:

- basic science - being principally, though not exclusively, concerned with the acquisition of knowledge without any particular application or use being necessarily in view;

- materials science - being concerned with optimising the synthesis and characteristics of useful materials, and

- commercial development - being concerned with the translation of experimentally developed materials into manufactures.

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[1] *Public Investment in R&D*, page 157.

3.3 There are various aspects of superconductivity research and development which are worthy of note. They include: uncertainty, interdisciplinarity, pace, media attention, the conflict between open science and commercial secrecy, international competition on one hand and international co-operation on the other.

Basic science

3.4 It should be noted that the initial discovery by Onnes in 1911 was a work of pure science:

> For forty years past Kammerlingh Onnes has been spending his working life in a laboratory specially called into being for the production of the lowest temperatures attainable. For nearly twelve years there has been one goal before him: to liquefy the last gas which still resisted the greatest cold as yet experimentally produced ... helium. ... In his cryogenic laboratory at Leyden Kammerlingh Onnes first attacked the problem from the point of view of theory. When his mathematical investigations were complete, he started out on the decisive experimental work.[2]

Having liquefied helium, 'Professor Onnes did not look upon this result as an end in itself, but rather considered it the beginning of a new period which marked the discovery of a mighty weapon which might aid him in his efforts to fathom some of Nature's secrets'.[3] The subsequent discovery of superconductivity was thus a spin-off from Onnes' single-minded pursuit of one objective. Clearly, this was research 'carried out without looking for long term economic or social benefits other than advancement of knowledge'.[4]

Lack of a theory

3.5 The most fundamental problem with research into HTS exists at the level of understanding. It is generally, though not universally,[5] agreed that the body of theory which was developed to account for low temperature superconductivity (LTS) is inadequate.

3.6 As was explained in Chapter 1, John Bardeen (who, incidentally, shared the 1956 Nobel Prize for Physics with Walter Brattain and William Shockley for their invention of the transistor), Leon Cooper and J. Robert Schrieffer finally developed an adequate theoretical explanation of LTS - the BCS model - some 45 years after its discovery.

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[2] *Scientific American*, 27 December 1913.
[3] *Scientific American*, 29 August 1914.
[4] *Public Investment in R&D*, page 157.
[5] For example, *Evidence*, page 199.

3.7 An electrical current is analogous to the flow of water through a pipe: electrons flow through a conductor. In a normal metallic conductor, individual electrons, as they move through the atomic lattice of a metallic crystal, lose some of their energy in collisions with other electrons; in effect this resistance to the flow of electrons results in a transfer of energy - from the current to the conductor - which takes the form of heat.

3.8 The BCS model proposes a rather different form of electron flow. In the right crystalline structure, and at a sufficiently low temperature, an electron's charge will distort the pattern of atomic vibrations, or phonons, within the crystal lattice in such a way that the motion of an electron through the lattice will facilitate the passage of another electron in the same direction; the motion of the paired electrons is thereby co-ordinated and they make their way through the lattice without collision, thus retaining their energy.

3.9 BCS fails with HTS because it sets an upper limit for critical temperature of about 30 degrees absolute. Since the demonstration of HTS, attempts have been made to modify BCS, to replace it entirely or even to promote existing alternative theories.[6] One theory currently being tested is a modified form of the BCS model - based on magnon-pairing rather than electron-phonon interactions - which sets an upper limit for the copper-oxide based HTS materials of about 225 degrees absolute.[7]

3.10 Of course, even if the latter theory is verified it does not preclude the existence of different families of materials with higher critical temperatures. There may well be many mechanisms for superconductivity, and thus many theories valid for their own special cases.

3.11 It may be argued that until an adequate theoretical model is developed - until the how and why is well understood - overcoming the present limitations imposed by critical properties can only be undertaken in a hit-or-miss way. If this view is held then the fact that the BCS model was not formalised until at least four decades after the initial discovery of LTS must be profoundly depressing.

3.12 Further, without a working theory it cannot be known or even reliably conjectured just how far critical temperature - or any of the other critical properties, for that matter - can be taken. Of course, it may well be that a theory developed for HTS would be as inadequate of predicting further breakthroughs as was BCS in respect to HTS. An authoritative theory may to some extent be an inhibitor of further exploration. However, much wasted effort could also be avoided.

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6 *Economist.*
7 *Pool.*

Critical properties

3.13 The critical properties which limit the usefulness of high temperature superconductors include temperature, current density and magnetic field strength. When each of these properties exceeds a certain level the phenomena of superconductivity - zero resistance to a direct current and perfect diamagnetism - disappear.

3.14 The critical temperature of a superconductor is that temperature at which the material 'goes normal', that is, changes from its superconducting phase to non-superconducting. As has already been explained, the maintenance of these temperatures requires expensive cooling systems and there is thus a series of barrier points which, when crossed, represent significant technological breakthroughs. Such a breakthrough was made in bettering 77 degrees absolute, the boiling point of liquid nitrogen.

3.15 The critical current density is the upper limit of electrical current which can flow through a unit area of cross section of the material; the critical current density is more important for some applications than for others. For example, it is not particularly important in low current devices such as Josephson junctions but it is crucial to the development of power engineering applications. In such applications current densities of the order of 100 000 amperes per square centimetre are necessary; in the bulk material required for this kind of application only about 1000 amperes per square centimetre has been achieved.

3.16 The critical magnetic field strength is the upper limit of magnetic field, applied from without or generated internally, which can exist before the field 'quenches' superconductivity. Like critical current density, it is more important for some applications, such as, of course, the generation of intense magnetic fields, than for others. Type II superconductors have two critical levels of magnetic field strength. Below the lower level, zero resistance and the Meissner effect both exist. However, between the two levels diamagnetism becomes imperfect and magnetic field is trapped within the material to an increasing degree until the upper level is reached and the material goes normal.

3.17 Each of these critical properties is not independent of the others: for example, the higher the operating temperature, the lower becomes the critical current density. The interrelationship between the three is represented in Figure 3.1: a three dimensional space in which superconductivity exists for a given material is defined by the axes indicating the magnitude of each of the properties and enclosed by a surface marking the presence of the critical value for each property. While superconductivity exists at any point within that space, some points are preferable to others depending on the performance desired. To determine the best operating point for a material conducting a high current would entail reaching a compromise between temperature and current density.

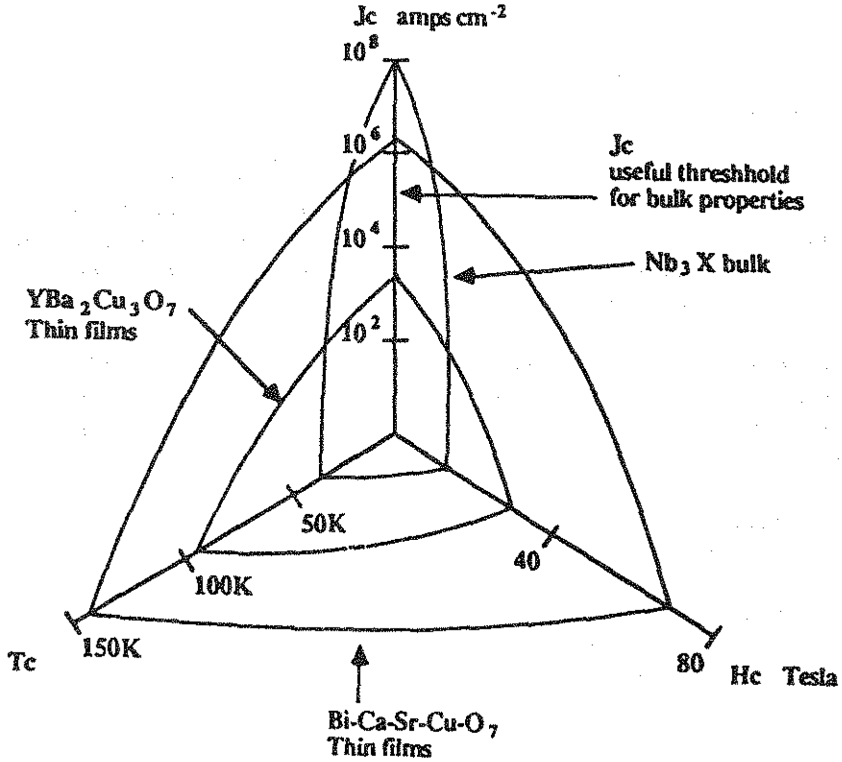

Figure 3.1 Critical properties

Hc = critical magnetic field strength
Jc = critical current density
Tc = critical temperature
Source: *Evidence,* page 568.

3.18 Researchers at the level of basic science are interested in discovering and understanding the properties of the new materials. While they may be well aware of the commercial implications of their work, and indeed be influenced by it, the nature of the work itself is distinct from that of the ensuing stages in that knowledge alone is being pursued. However, as will be discussed further below, there is no clear boundary separating basic science from the rest.

3.19 Beyond this, the objective then is to increase the threshold levels of all three properties: higher critical temperatures will lead to cheaper and less cumbersome refrigeration; higher critical current densities will lead to the ability to conduct more current; and, higher magnetic field strengths will lead to the ability to generate more intense magnetic fields. Developing materials which will conform to these requirements is the province of materials science.

Materials science

3.20 Research at the materials science level focuses on three major aspects: synthesis of the materials, their characterisation and the discovery of structure-property relationships.

3.21 Researchers at this level must begin to take into account the purposes for which the materials might be used. For applications involving the generation of intense magnetic fields or the conduction of large currents, 'bulk' materials will be required. For microelectronic applications, 'thin films' are needed. Each has its own challenges.

3.22 The development of LTS materials foreshadowed many of the difficulties being experienced with HTS. However the 1-2-3 ceramics have a number of specific problems which did not apply to LTS, principally anisotropy, extreme brittleness and chemical instability.

3.23 Anisotropy is the absence of uniformity in a property of a material depending on the direction in which it is being observed. For example, critical current density varies considerably within a 1-2-3 ceramic depending on the relationship between the direction of current flow and the orientation of the grains within the ceramic. Discovering the source of this anisotropy may lead to raising the current density limits of a material.

3.24 The 1-2-3 ceramics are extremely brittle and this imposes limitations on the ways in which they can be handled. For power engineering applications such as use in windings in motors and generators, high ductility is preferable and if ceramics are to take their place, special techniques must be developed to overcome their lack of ductility. Brittleness is more significantly a problem for bulk materials than for thin films.

3.25 Chemical instability is much more a problem for thin films. Because of their thinness, thin films need backing material, a substrate. One of the many difficulties in the placing of 1-2-3 ceramic thin films onto substrates is the tendency for chemical reaction between the two materials.

3.26 But chemical instability is also a general problem. Care must be taken during fabrication to achieve a precise combination of ingredients; the superconducting varieties of the 1-2-3 ceramics are easily contaminated by oxygen, water and carbon dioxide. Even after the greatest care, it has been found that samples of the material are not uniform in composition and that areas of material which are superconducting exist side by side with areas which are not. Even after fabrication, the materials can be degraded by external contaminants.

3.27 This uncertainty of outcome illustrates the immaturity of materials science in HTS; indeed the exploratory techniques of fabrication have been referred to as 'shake and bake', suggesting the speculative nature of much of such research.

3.28 In summary, the problems confronting the materials scientists are taking place on two fronts: bulk materials and thin films. Critical properties - temperature, current density and magnetic field strength - must be optimised according to the relative importance of each for given situations. Anisotropy, brittleness and chemical instability must all be managed. These are the major barriers to fabricating useful superconductors.

Commercial development

3.29 After the materials science phase there comes a stage where a material's performance is of more significance than its composition. Of course that performance is determined by the material's properties but what interests the developer of a new or improved application most is what the material can do, less what it is made of. Further, the material, if it is not unique in its ability to perform the desired role, must have advantages over other materials. It can be seen, therefore, that there must be interaction between development and research, that the developer inform the researcher of what is required and the researcher inform the developer of what is available and what is possible.

3.30 Certain applications will require different performance standards from others. Compromises between critical properties will need to be made. In the case of employing superconducting material in a high field strength electromagnet, it would be worth sacrificing temperature, up to a point, for magnetic field strength.

3.31 But the first requirement of the developmental stage is the existence of an application, of a purpose for the objective of the research and development. After perceiving a need and conceiving a plan for filling it, a forecast must be made of how well the product will be accepted. This is the essence of demand pull. It is neglected far too often when people speculate about the impact of the new superconductors. At issue is to what degree superconductivity can contribute to the provision of 'goods and services for which there is an economic and/or social demand'.[8]

3.32 The previous chapter examined the range of potential applications mainly from the perspective of the possibilities suggested by discoveries, a technology push perspective. It is now time for a brief examination from the standpoint of demand pull.

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[8] *Paragraph 1.10.*

3.33 As was pointed out in the previous chapter, a number of applications already exist using LTS technology. More will be developed. HTS may replace LTS in some cases and may meet new demands entirely. However, detailed analysis[9] indicates that the time frames over which certain applications will find a place in the market vary considerably; there are short, medium and long term prospects, as well as some which appear highly unlikely at this stage.

3.34 There are three main applications areas: electromagnets, power and microelectronics. In the area of electromagnets, where there is already a well established superconductor presence, the factors which bear most heavily on the commercial development of HTS relate to its ability to take over from LTS. Niobium-titanium has a greater ability to cope with the strains induced in a material by high magnetic fields than does the typical 1-2-3 ceramic, which has poor tensile strength. HTS materials have yet to demonstrate an adequate critical current density to compete against LTS where intense fields must be generated. In terms of their relative abilities, LTS materials are currently cheaper by volume than HTS. The main advantage HTS enjoys is only at present significant where the cost of refrigeration is a major component of total cost. HTS also has a weight advantage. Finally, there are many materials problems to be overcome. In general, the development of HTS electromagnets is a short to long term prospect.

3.35 The use of both LTS and HTS in power engineering applications was discussed in the previous chapter. It was shown that their use in this area, particularly in the case of transmission lines, is very much a long term prospect since their advantages at this stage appear marginal, at best. But apart from performance comparisons there are other factors militating against the implementation of superconductors. The power industry is capital intensive - replacement would be large scale and therefore very expensive - and there is little prospect of the level of growth in demand which would require new installations.

3.36 The most promising area for the rapid commercial development of HTS is in microelectronics. But even here there are critical factors. Signal-to-noise ratio decreases as temperature increases and thus the optimal temperature for applications which require high sensitivity is of the same order, that is close to absolute zero, regardless of the material: HTS has no real advantage. Further, progress in other technologies, such as gallium arsenide semiconductors, has narrowed the potential advantages of superconductors. The overriding factor which enhances the prospects in microelectronics, however, is the strong growth in markets, primarily in computers and communications but also in improved manufacturing technologies.

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[9] *Malozemoff et al.*

3.37 It should be apparent from this brief treatment that the driving force in commercial development is strong demand. In commercial terms an incremental improvement which confers an advantage to a product in a large and growing market is more significant than a major improvement to a technology for which demand is stagnant.

Aspects of research and development

Uncertainty

3.38 Uncertainty operates at a number of levels in all research and development. There is uncertainty as to outcome, uncertainty as to whether the right course is being followed and, often, uncertainty as to how long the effort will be supported.

3.39 In the particular case of research into HTS, the uncertainty of outcome relates very much to the absence of theory. It is not known how far critical temperature or any other of the critical properties can be raised nor is it known if and when much better materials - organic room temperature superconductors, say - will be developed.

3.40 During the course of superconductivity's evolution there have been points where efforts have halted because doubt exceeded hope. A recent example was IBM's abandonment of its Josephson junction research, in 1983, because of a perception that progress with conventional semiconductors had closed the gap on whatever advantage might be achieved.[10] That decision may yet stand as having been commercially correct but it may also be shown with the benefit of hindsight to be the point at which the US forsook a comparative advantage over the Japanese.

3.41 The need to reassure the investors in research funding that an end is in sight may lead researchers to exaggeration, ultimately to the disillusionment of the investors. The possibility that another breakthrough elsewhere may instantly nullify a large investment is a very real risk. The lack of a clear timetable of progress in overcoming materials problems might make other avenues of investment preferable. There are many incentives for industry to adopt a 'wait and see' attitude towards HTS.

3.42 But as will be argued in a later chapter, waiting and seeing is standing still. When the decision to jump is made, others will be running and it will be very hard to catch up. The better approach is not to avoid the presence of uncertainty but to allow for it.

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[10] *Commercializing HTS*, page 71.

Interdisciplinarity

3.43 One of the most obvious features of research into high temperature superconductivity is the participation of practitioners from many scientific and technical disciplines: physicists, chemists, materials scientists, ceramicists, electrical and electronics engineers, and others all have a part to play.

3.44 This blurring of interdisciplinary boundaries is concomitant with what has been described as the connectedness of technologies:

> Particular technological advances seldom stand alone. They usually are connected both to prior developments in the same technology and to complementary or facilitating advances in related technologies.[11]

3.45 A number of points follow from the need for convergences of, and interactions between, the traditional disciplines: first, that the ideal applied scientist should be flexible, versatile and, most of all, mobile; second, that the conceptual basis of scientific disciplines, as they stand, may be outdated; third, that contact between scientists must be optimised.

Pace

3.46 An early feature of HTS research was the speed with which other researchers responded to the initial discovery. One reason, of course, was that the usefulness of superconductors was already appreciated: by the 1980s, HTS was not merely a scientific curiosity.

3.47 A second factor was the magnitude of the breakthrough. It had taken about 45 years to develop an adequate theory and this theory predicted a ceiling of about 30 degrees absolute; there was little incentive for further research. When that barrier was broken and when the nitrogen barrier fell, too, there was a mounting sense of liberation from old constraints. The possibility of superconductivity at room temperatures could not be dismissed out of hand.

3.48 Thirdly, research in the general area of superconductivity has a good track record in terms of recognition. Bednorz and Muller won the Nobel Prize for Physics the year after their discovery was announced; it has been described as being 'one of the most rapid recognitions of a major scientific breakthrough by the Nobel committee since the establishment of the prize for physics 86 years ago'.[12] As has already been mentioned, three other Nobel prizes have been awarded for work closely related to superconductivity. Reports in the media over the last two years have made almost folk heroes of some researchers.

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[11] *High-Technology Policies*, page 8.
[12] *Foner and Orlando*.

3.49 A fourth factor is the number of players, in no small part determined by the size of the field; there is a vital role for theorists as well as experimentalists in all the disciplines alluded to earlier. Fifth, is the 'fax factor',[13] the rapid dissemination of research results which is not only a reflection of the pace of HTS research but an influence upon it.

3.50 Together, these factors have given HTS research its momentum: there are clear goals, a history of breakthroughs, worthy recognition of pioneers, plenty of competition and rapid feedback.

Media attention

3.51 The speed with which researchers responded to the initial breakthrough was mirrored in the response by the media. Coverage has not been restricted to the specialist press and some of the mass circulation media have tended to overemphasise the 'revolutionary' aspect of recent developments. What may be a revolution in science may not be so in technology.

3.52 The danger of such overemphasis is that it may raise expectations which when dashed inhibit further initiative. This is particularly critical at the political level: much of the future of research and development into HTS may be heavily influenced by public policy decisions. The credibility of not just the potential of HTS but of the scientific community in general could be damaged.

3.53 However, 'talking up' the importance of HTS may well have beneficial effects, too. The recognition it bestows on scientists may not only encourage them to greater efforts but also serve to raise public awareness of the contribution they make to the community.

Open science versus commercial secrecy

3.54 The notional division between basic and applied science does not accommodate the considerable overlap which exists between them. Somewhere between the levels of precompetitive research and commercial development, information becomes economically valuable.

3.55 Scientists, generally, are not driven solely by a thirst for knowledge; there is also often a strong desire for recognition. Recognition comes with publication of results and this, of course, leads to the free flow of knowledge. But openness in science is not merely the by-product of self-interest. The sharing of insights is part of the scientific culture. It is seen as being not only of benefit to scientists themselves, but to humanity.

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[13] *Voss.*

3.56 At the absolutely pure level of research there is little resistance to the free flow of ideas. However, at some critical point information becomes commercially valuable - that is, its possession can be turned to financial profit - and an increasing tendency to restrict its possession prevails. The increasing susceptibility of research results to commercial secrecy has been attributed to the blurring of the distinction between science and technology. Discoveries are translated into practical applications more rapidly than ever.

3.57 The conflict between principles - the ethical desirability of freedom of information, on one hand, and the protection of valuable property, on the other - is unresolved and is indeed currently the subject of widespread debate within the scientific community. It is not an abstract problem but one which impinges upon any program of research and development within a generic technology.

International competition

3.58 The competition between nations to capitalise on technology operates at at least two levels: expenditure of effort and protection of advantages. For example, at a national level the US has mounted a massive effort to exploit information technology; it has also taken concrete steps to ensure that its advantages are not lost to its competitors, particularly the USSR.

3.59 As can be seen in that example, technology may be important not solely for its commercial potential. Just as information may have commercial value, it may also have strategic value to nations. This is most clearly visible in military technology but it is also applicable in the commercial sphere where the economic health of nations depends on the strength of their resident business enterprises.

3.60 The major advanced industrial nations have reacted swiftly to the challenge of commercialising HTS. Attempts have been made to compare national efforts in terms of funding quantities, numbers of institutions involved and numbers of scientists engaged but there are far too many other factors - such as the quality, level and direction of research - to make these comparisons particularly useful. Often, because of various forms of secrecy, the extent of a nation's effort cannot be known.

3.61 Nevertheless, figures do exist; Table 3.1, taken from the submission of the Department of Industry, Technology and Commerce,[14] showing various government expenditures on HTS research and development, is indicative of the imperfect state of knowledge. Further mention of the levels of national expenditure on HTS research will be made in the next chapter, in comparing Australia's effort against those of the major competitors.

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[14] *Evidence*, page 649.

Table 3.1

NATIONAL GOVERNMENT SUPPORT FOR SUPERCONDUCTIVITY R&D

COUNTRY	GOVERNMENT AGENCY	COMMITMENT DATE	INSTITUTIONS (1)	RESEARCHERS (2)	FUNDS (US$ mill) (3)
AUSTRALIA	GIRD	1987	15	120	1.6
CHINA (PRC)*	CENTRAL	1959	40	800	2
FRG*	BMFT	1967	35	>80	
INDIA	APEX	1987	>20		10-12
ITALY*	CNR	1967	80		37
JAPAN*	MITI	1962	>20		27
	STA	1966	5	120-130	52
	EDUC	1979			12
	TRANSPORT	1968			
	ISTEC	1988	1	45	10-100
KOREA	CENTRAL	1987	10	150	40
TAIWAN	NSC	1987	3	19	4.2
UK*	DII	1967			28.5
	SERC		5		11.5
USA*	NSF	1973			
	DOE				95
USSR*	CENTRAL	1987	>10		50

Notes: * Countries with precommitment to research
1 Approximate number of research establishments, excluding industry
2 Approximate number of researchers
3 Funding over 3-5 year periods

3.62 At least one nation is taking legislative steps to strengthen its international competitiveness in the race to commercialise superconductivity. The *National Superconductivity and Competitiveness Bill 1988,* which was still to be passed by the US Senate (October 1988), is intended:

> To establish a national Federal program effort in close collaboration with the private sector to develop as rapidly as possible the applications of superconductivity to enhance the Nation's economic competitiveness and strategic well-being, and for other purposes.[15]

[15] *National Superconductivity and Competitiveness Bill 1988,* Long title.

Though the Bill contains provision for international co-operation[16] there are fears - both within the US and particularly in Japan - that the resulting Act would restrict the dissemination of US research results and exclude access to foreigners. The danger of this course of action has been expressed as follows:

> A more dangerous form of protectionism concerns inhibitions on the free flow of ideas - not merely proprietary information within particular firms, but also more generic information available to specialized professional communities. Restricting information will not so much preserve commercial advantage to the restrictive country as reduce the overall rate of technological advancement.[17]

International co-operation

3.63 Just as the connectedness of new technologies is tending to break down the barriers between the traditional scientific disciplines, the increasing internationalisation of industry and commerce, largely under the influence of technological change, is tending to break down national barriers, 'to reduce the autonomy of governments, and to increase the permeability of societies'.[18]

3.64 There are many examples of a general trend towards international co-operation in areas of economic significance. Nowhere is this more evident than in the European Economic Community. Co-operation in HTS research between different member countries is already taking place. However, international co-operation in science and technology can take place in much less formalised environments.

3.65 As well as directing its efforts strongly towards being a front runner in the race to commercialise HTS, the Japanese have promoted an 'internationalisation' of HTS research and development through the establishment, in January 1988, of the International Superconductivity Technology Centre near Tokyo. Two factors are said to have contributed to this initiative: first, the pressure, particularly from the US, upon the Japanese for a greater contribution to global welfare; second, the perception by the Japanese that foreign researchers could help Japan improve its capacity for basic research.[19]

3.66 Australia is party to a number of bilateral science and technology agreements. They have their advantages and their pitfalls, as the Australian Science and Technology Council pointed out in a report to the Prime Minister in 1984:

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16 Ibid., section 9.
17 *Cooper and Hollick.*
18 Ibid.
19 *Commercializing HTS*, page 77.

> The benefits considered by practising scientists and technologists in planning international co-operative activities are largely the immediate ones of making relevant and useful contacts, and of generally facilitating their own work and objectives by learning new techniques, obtaining access to new materials or particular facilities, and participating in creative discussions or in co-operative research projects. Clearly, science and technology co-operation as an instrument of foreign policy must be considered in a much wider context and cannot be left to decisions made on the basis of benefits that will flow to individual science and technology programs. There is a real danger however that, if science and technology agreements are entered into only for diplomatic, trade or political reasons, the interest among the scientific community may be so low that problems will arise in attracting worthwhile proposals.[20]

3.67 Those pitfalls suggest a third level for international co-operation, one which does not involve governments. This can and does occur on two fronts: links between individual scientists and research institutions and commercial links between companies, such as consortia.

3.68 Clearly the scope for international co-operation is but another factor in the conduct of research and development in generic technologies. However, because generic technologies are characteristically of strategic importance at a national level, its influence will be countered by the imperatives of international competition.

Conclusion

3.69 This chapter has attempted to sketch the dynamics of research and development within a generic technology. Certain aspects have been mentioned which will be taken up again in later discussion. The prime intention, though, has been to develop the concept of innovation as a nonlinear process involving the interaction of many forces; it is not a one-way path.

3.70 There are distinct stages in the transition from the initial discovery to the marketable product. However, this transition does not follow a chronological sequence from basic science to commercial development; furthermore the different stages, where they do meet, overlap.

3.71 In the development of superconductors and related new materials there is work to be done at the level of basic science, particularly in the elaboration of theory. There is much work to be done, too, at the level of materials science: the critical properties have to be optimised for different applications and techniques found to cope with problems of anisotropy, brittleness and chemical instability.

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[20] *Science and Technology Agreements*, page 9.

3.72 But most importantly, a case has to be made on economic and technical grounds for each of the portended applications. The product has to be wanted by its potential customers. Thus, ideally, there is feedback from the demand side of the process to both levels, materials science and basic science.

3.73 Finally, there are many factors beyond the immediate concerns of those undertaking research and development which nevertheless have an impact upon their activities and the course those activities take. The effects of these factors are difficult to assess but their influence must be recognised.

3.74 The Committee concludes that:

The essential precondition for the development of commercial applications for superconductivity and related new materials will be the recognition of the strength and trend of demand for those applications, rather than the technological ability to produce them.

CHAPTER 4

AUSTRALIA'S POSITION

- **Introduction**
- **Australian industry, science and technology**
- **Australia's response to HTS so far**
- **Australia's core capacity**
- **Australia's comparative advantages**
- **Australia's competition**
- **Conclusion**

Introduction

4.1 This chapter examines Australia's strengths and weaknesses: its core capacity to exploit the opportunities offered by superconductivity and related new materials and the comparative advantages, if any, which the nation possesses to this end.

4.2 The examination is preceded by a brief commentary on industry, science and technology in Australia, including reference to the major research institutions and existing funding and policy mechanisms, with a view to identifying the overall strong and weak points. This is followed by a resume of the response to date within Australia to the recent advances in HTS.

4.3 An assessment is then made of where Australia stands in relation to other industrialised nations, not just with respect to superconductivity and related new materials but at the level of the generic technology.

4.4 The scene is thus set for the final chapter, an evaluation of the opportunities and problems and a discussion of the options available to Australia, in light of its strengths and weaknesses and the opportunities and problems.

Australian industry, science and technology

4.5 Australia has survived on the strength of its primary industries. However, it is now widely recognised that with the deterioration in the nation's terms of trade - attributable not only to the vagaries of commodity prices but also to the need to import increasingly higher priced manufactured goods - Australia must develop manufacturing and services industries able to compete on world markets.

4.6 Despite, in recent months, the often reported optimistic outlook in Australian manufacturing, there is a fundamental weakness in terms of its contribution to Australia's international trade. In its recent report on investment in Australian manufacturing, the Committee noted:

> The decline of the contribution of the manufacturing sector to Gross Domestic Product (GDP) in Australia, especially since the 1960s, is well documented. The manufacturing sector has focused very largely on the domestic market, seriously underachieving as an earner of export income. At the same time import penetration of the domestic market for manufactured goods increased substantially between the mid-1970s and the mid-1980s.[1]

4.7 Australian science and technology is characterised by a relatively strong performance in basic research but a weak performance in experimental development. A crude comparison between the relative numbers of scientific papers published and of patents taken out by Australians supports this observation: in a recent report on Australian science and technology indicators it was noted that in the decade to 1982 Australian scientists 'consistently published around 2 per cent of the world's scientific literature'[2] whereas over a similar period applications by Australians for patents had increased from 0.7% to 1.1%.[3] As the OECD examiners noted in their most recent review of national science and technology policy in Australia:

> The process of technological development ... is seen as discontinuous: the transition from research to design of a product or service, or from design to sales, seems sometimes to involve the collision of mutually uncomprehending cultures.[4]

4.8 This dichotomy is also evident in the sources of support for research and development. In 1987 the Department of Industry, Science and Technology reported that:

> Comparisons with other OECD nations reveal the Australian R&D effort as weak, whether measured in absolute terms or as a percentage of GDP. The source of the weakness is our very low level of business enterprise R&D. As a percentage of GDP, government levels of R&D are within the normal range.[5]

4.9 There are several factors which make any simple explanation for this situation risky. Obviously, the composition of the broad industry sectors is important: mature industries - such as, steel, passenger motor vehicles, or textiles, clothing and footwear - which, in general, make tried and true

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[1] *Investment in Manufacturing*, page 1.
[2] *Measures of Science and Innovation*, page 183.
[3] Ibid., page 203.
[4] *OECD, Reviews*, page 13.
[5] *Measures of Science and Innovation*, page 11.

products, may tend to reinvest a lower proportion of their revenues in research and development than new 'sunrise' industries, such as the information and communications industries. The National Science and Technology Analysis Group has outlined the pitfalls in drawing conclusions from comparisons of such simple performance indicators as expenditure on research and development:

> Simple comparisons were drawn, and still are, between R&D spending and the technological successes of the major industrial nations. Only slowly has the recognition grown in our [science and technology] analysis that gross differences in scale, history, industrial structure and geography make these comparisons of dubious value.[6]

Nevertheless, as the OECD examiners have commented:

> The criticism of Australia's low industrial research is another way of saying that Australia does not have enough high technology industries. This is probably true. It is a truth that is being voiced in practically every developed country today, and all are trying to do something about it. Australia must do likewise or it will be left behind.[7]

Performance of Australian research and development

4.10 The majority of Australian research is conducted in public institutions, such as universities and government research organisations. Table 4.1, adapted from the latest annual *Science and Technology Statement,* indicates in broad terms where research and development is conducted in Australia. In these figures, there is a noticeable trend of increasing performance by the private sector; while there is a belief that the sudden rise in 1984-85 merely reflects the greater willingness of business enterprises to report research and development activity because of the provision of 150 per cent tax deductibility from 1 July 1985, the rise is probably due to a number of factors.[8]

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[6] *Science and Technology in Australia,* page 12.
[7] *OECD, Reviews,* page 24.
[8] *Measures of Science and Innovation,* pages 29-32.

Table 4.1

PERFORMANCE OF GROSS DOMESTIC EXPENDITURE ON RESEARCH & DEVELOPMENT

PERFORMING SECTOR	$million and % of total									
	1976-77		1978-79		1981-82		1984-85		1985-86	
	$m	%	$m	%	$m	%	$m	%	$m	%
Federal Government	290	33	321	31	515	33	670	28	727	27
State Government	126	15	149	14	200	13	289	12	317	11
Higher Education	244	28	326	31	452	29	668	28	732	27
Business Enterprise	203	23	246	23	374	24	721	30	905	33
Other Performers	11	1	13	1	21	1	44	2	47	2

Source: Department of Industry, Technology and Commerce, *Science and Technology Statement 1987-88*, page 22.

4.11 The overwhelming majority of research undertaken by business enterprises takes place in the manufacturing sector: based upon 'industry by product field' figures, manufacturing accounts for 88 per cent with mining, and services and others, equally sharing the rest.[9] The research effort within manufacturing is distributed across a number of broad fields, such as: electronics, computing and electrical appliances; transport equipment; chemical, petroleum and coal products; and industrial machinery and equipment.[10]

4.12 The major Government research organisations, ranked in terms of their running costs, are set out in Table 4.2; it can be seen that within the public sector, the research effort is distributed through a number of Government departments.

[9] Ibid., page 34.
[10] Ibid., page 39.

Table 4.2

RESEARCH ORGANISATION	PORTFOLIO	STAFFING Est ASL	RUNNING COSTS Est $ ('000)
Commonwealth Scientific & Industrial Research Org.	DITAC	5 970	357 607
Defence Science and Technology Organisation	Defence	4 132	157 304
Australian Nuclear Science & Technology Organisation	DITAC	938	52 136
Bureau of Mineral Resources Geology & Geophysics	DPIE	596	38 813
Antarctic Division	DASETT	260	21 019
Australian Bureau of Agri-cultural & Resource Econ.	DPIE	298	12 172
Australian Institute of Marine Science	DITAC	105	9 117
Supervising Scientist & Alligator River Region Research Institute	DASETT	73	5 416

Source: Budget Paper No. 3 - Portfolio program estimates 1988-89

DASETT Arts, Sport, the Environment, Tourism and Territories
DITAC Industry, Technology and Commerce
DPIE Primary Industries and Energy

Funding of Australian research and development

4.13 The flow of funding in Australian research and development is set out in Figure 4.1. Just as the majority of research and development is performed by public sector institutions, most of the funding comes from the public sector. However, Table 4.3, adapted from the latest annual *Science and Technology Statement,* indicates, again, an improving contribution by the private sector.

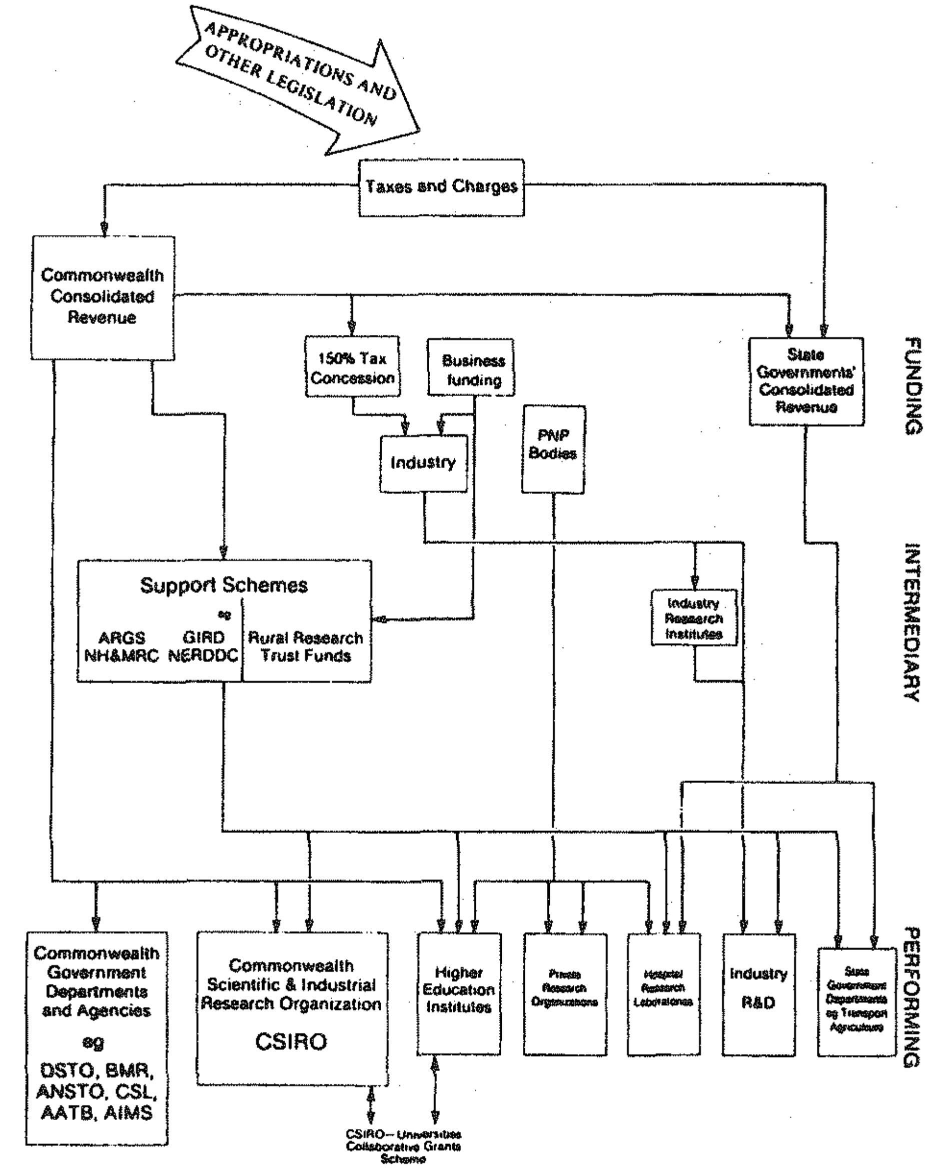

FIGURE 4.1 Flow of funding of R & D

Source: Department of Industry, Technology and Commerce, *Measures of Science and Innovation*, page 147.

Table 4.3

FUNDING OF GROSS DOMESTIC EXPENDITURE ON RESEARCH AND DEVELOPMENT

FUNDING SOURCE	$million and % of total									
	1976-77		1978-79		1981-82		1984-85		1985-86	
	$m	%	$m	%	$m	%	$m	%	$m	%
Federal Government	541	62	666	63	976	62	1377	58	1494	55
State Government	114	13	140	13	185	12	269	11	288	11
Business Enterprise	195	22	217	21	353	23	660	28	859	31
Other Sources	24	3	31	3	48	3	85	3	88	3

Source: Department of Industry, Technology and Commerce, *Science and Technology Statement 1987-88*, page 21.

4.14 Public sector funding of research and development undertaken by organisations other than those set out in Table 4.2 takes a number of forms, the major of which are broadly set out in Table 4.4. Again it can be seen that several Government departments are involved.

Table 4.4

FUNDING MECHANISM	PORTFOLIO	PROJECTED EXPENDITURE 1987-88 ($ '000)
Estimated R&D component of General University Funding		490 000
Estimated costs of Industrial R&D tax incentives		150 000
Grants to Universities	DEET	135 000
National Health & Medical Research Council	DCSH	64 360
Australian Research Council	DEET	35 610
Australian International Development Assistance Bureau	DFAT	25 900
Grants for Industrial R&D	DITAC	25 630
Assistance under *Bounty (Computers) Act*		20 900
Post-graduate awards	DEET	19 840
Wool R&D Fund	DPIE	16 240
Larger Rural Industry R&D Funds	DPIE	15 140
Australian Meat and Livestock R&D Corporation	DPIE	14 200
Australian Industrial Research & Development Incentives Scheme (now superseded)	DITAC	13 630
Energy Research Trust Fund	DPIE	11 810
Others	DASETT DEET DFAT DITAC DPIE DTC Treasury	43 130

Source: Department of Industry, Technology and Commerce, *Science and Technology Statement 1987-88*, pages 14-5.

DASETT	Arts, Sport, the Environment, Tourism and Territories
DCSH	Community Services and Health
DEET	Employment, Education and Training
DFAT	Foreign Affairs and Trade
DITAC	Industry, Technology and Commerce
DPIE	Primary Industries and Energy
DTC	Transport and Communications

4.15 Among the various funding mechanisms for Australian research and development, the two which are particularly relevant to the funding of HTS research are Grants for Industrial Research and Development (GIRD) and grants from the Australian Research Council (ARC).

4.16 The GIRD scheme is administered by the Industry Research and Development Board, a statutory body responsible to the Minister for Industry, Technology and Commerce. The scheme replaces the former Australian Industrial Research and Development Incentives Scheme (AIRDIS). It 'aims to promote the development and improve the efficiency and international competitiveness of Australian industry by stimulating R&D spending, and is designed to complement the 150 per cent tax concession scheme for eligible research and development'.[11]

4.17 There are three components of the GIRD scheme:

. Discretionary grants - grants of up to 50 per cent of eligible research and development expenditure conducted either in-house or by an approved research institution.

. Generic technology grants - grants to cover emerging technologies which are considered to have fundamental significance for industry competitiveness in the 1990s but would be unlikely to develop if left to the market alone. These grants fund research in collaboration with industry to a stage where the private sector will take up further development.

. National interest agreements - for projects of significant national interest which would not otherwise have been undertaken by industry.

4.18 On 2 December 1986 the Minister for Industry, Technology and Commerce formally declared that Biotechnology, Information Technology and New Materials Technology would be areas of generic technology for the purpose of the GIRD scheme. A New Materials Technology Advisory Committee was appointed; on 23 June 1987 it added high temperature superconductors to its list of target areas warranting priority attention in 1986-87.[12]

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[11] *Science and Technology Statement*, page 107.
[12] *Industry Research and Development Board*, page 86.

4.19 The Australian Research Council was set up in mid-1988; its immediate priorities were to concentrate and co-ordinate a number of existing research schemes and to make those research funds more competitive.[13] Its objectives are to:

- support both fundamental research and research which will directly contribute to national economic and social development;
- enhance the training of research personnel; and
- improve the interaction between the higher education research sector and industry and other government research sectors.

The ARC advised the Committee that grants totalling $167 384 would be made in 1989 for research projects related to HTS.[14]

Australian science and technology policy

4.20 In their most recent review of science and technology policy in Australia, the OECD examiners repeated an observation made by their predecessors a decade earlier, that there was 'a proliferation of councils, committees, working parties, etc., exceptional in the OECD countries, including those with a federal structure'.[15]

4.21 Figure 4.2 provides a reasonably current depiction of the flow of advice in the formulation of science and technology policy in Australia. One of the unfortunate results of the rearrangement of Federal Government departments in mid 1987 has been the further dispersal of science and technology related functions throughout increasingly self-sufficient mega-departments. Clearly, the process has become more complicated since the OECD examiners observed, in 1984, that:

> We are also convinced that those two topics - science and technology - should be treated within a single portfolio, since they are so completely intertwined. Many of Australia's technological opportunities ... lie in facilitating the process of transition from science to technical application; it would be perverse to divide the two within central government ...it seems anomalous to us that the Ministry at present has no relationship to decision-making in the area of the medical and health sciences.[16]

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[13] *Science and Technology Statement*, pages 2-3.
[14] *Evidence*, page 587.
[15] *OECD, Reviews*, page 12.
[16] Ibid., page 31.

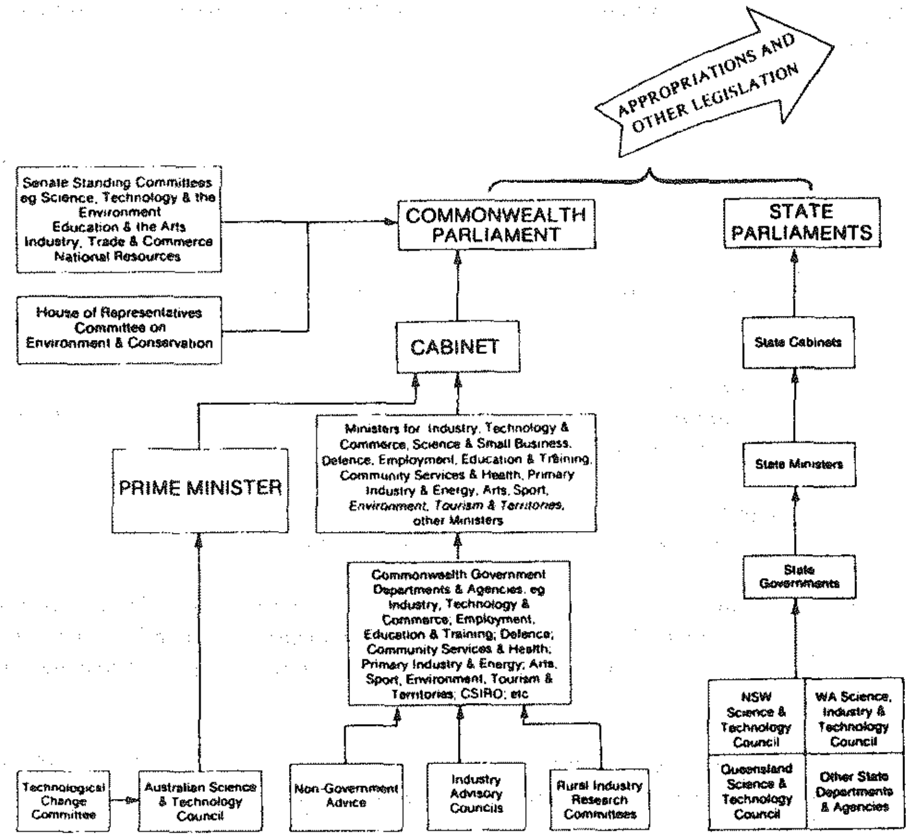

FIGURE 4.2 Flow of policy advice

Source: Department of Industry, Technology and Commerce, *Measures of Science and Innovation*, page 146.

That observation leads to the conclusion drawn by the examiners that Australia needs to integrate its science and technology policies with economic and social policies.[17]

4.22 Clearly, such integration is desirable; however, the problem extends further. A lack of integration can be seen throughout Australian science and technology: in the performance of research and development, in its funding, and in the formulation of policy. While there is strength in diversity, there is also a resistance to co-ordination which militates against rapid response to new developments.

[17] *Ibid., page 33.*

4.23 In short, the following points can be made about Australian industry, science and technology:

- primary industries alone cannot reverse the decline of Australia's share of world trade;
- the manufacturing sector must make a greater contribution to Australia's export income; however, it is seriously underachieving in this regard;
- while Australia is relatively strong in basic research, it is weak in capitalising on it;
- overall, primary industries excepted, Australia's research and development effort is comparatively weak, largely because of a lower contribution by the business enterprise sector;
- most research and development undertaken by the business enterprise sector is by manufacturing firms and is widely dispersed;
- while performance and funding of research and development by the public sector is comparable with those of other industrially advanced nations, the structure of funding and policy mechanisms inhibits rapid responses to sudden changes;
- linkages between universities and industry are not as well developed in Australia as in other industrially advanced nations.

Australia's response to HTS so far

4.24 The initial response in Australia to the breakthroughs in high temperature superconductivity - the first of which were published by Bednorz and Muller in September 1986 - was made by individual researchers; for instance, from March 1987 onwards, researchers at the Australian National University synthesised and studied the 1-2-3 ceramics.[18] An early starter, the Superconductivity Group of the School of Materials Science and Engineering at the University of New South Wales claims the distinction of being the first in Australia to prepare each of the successive groups - rare-earth, bismuth and thallium - of HTS materials.[19] Informal links were established rapidly between researchers in a number of universities and research organisations.

4.25 On 29 May 1987 at the CSIRO Division of Applied Physics at Lindfield, New South Wales, a meeting of more than 150 people interested in superconductivity recommended that a workshop be held. The then Depart-

[18] *Evidence*, pages 477-8.
[19] Ibid., pages 339-40.

ment of Science organised the workshop, which was held in Wollongong from 16 to 18 July 1987 and attended by about 50 people from CSIRO, universities, industry and Government.[20]

4.26 It was noted at the Workshop that at that stage about 80 people were working on HTS in universities, CSIRO and industry. Workshop syndicates examined: potential applications and problems to be solved; target areas and their relative priority; funding; and co-ordination of the research effort. The outcome was a recognition of the significance of the recent breakthroughs and of the need for a co-ordinated national research effort. The Workshop instigated the preparation of a 'business strategy' - a document incorporating the views of both researchers and the business community outlining potential market opportunities over a period of at least ten years - and the setting up of a national committee of experts to:[21]

- act as a clearing house for information transfer;
- monitor and encourage collaboration, both intra- and internationally;
- promote the formation of industry consortia;
- initiate national and international market surveys;
- co-ordinate future conferences and meetings; and
- lobby industry and Government for enabling support.

4.27 The first GIRD grant within the generic technology area of the scheme specifically for work on HTS was awarded in June 1987. The project involved collaboration between the University of New South Wales and the AWA Technology Group on applications in microelectronics.

4.28 A conference held in Melbourne in November 1987 - 'Materials Technology and Profit', intended to alert Australian industry to recent developments, and the commercial opportunities arising from them, in materials technology - dedicated an entire session to HTS.[22] A strategy for the development of HTS in Australia, prepared by nominees of the Wollongong Workshop, was presented at the conference (an abstract of this document appears in the Transcript of Evidence[23]).

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20 *Wollongong Workshop*, page 9.
21 Ibid., pages 10-1.
22 *Evidence*, page 572.
23 Ibid., pages 577-9.

4.29 In December 1987 three further GIRD grants for work on HTS were awarded. The details of the four grants then extant, each to cover 3 years, are set out in Table 4.5.

Table 4.5

GIRD PROJECTS

RESEARCH ORGANISATION	COMMERCIAL COLLABORATION	AMOUNT AWARDED	PROJECT TITLE
University of NSW	AWA Technology Group	452 400	HTS for microelectronic applications
Monash University and CSIRO Division of Materials Science	SECV and Olex Cables	663 949	Superconductor energy storage device
CSIRO Division of Applied Physics	BHP Melbourne Research Labs and AWA and Ausonics	379 300	Development of HTS instruments and sensors
University of NSW and CSIRO Division of Applied Physics and Australian Nuclear Science & Technology Organisation	Metal Manufactures and Elcom (NSW)	478 490	HTS for power applications

Source: *Evidence*, pages 580-1.

4.30 In March 1988 the New Materials Technology Advisory Committee established the National Superconductivity Steering Committee (NSSC), in order to 'focus HTS research and encourage the synergism necessary to maximise the effectiveness of the generic GIRD grants', and specifically to provide:[24]

- a means for the co-ordination of superconductivity research projects funded by the generic scheme and the development of links with other Australian R&D activities in HTS;

- a forum for consultation between research groups working on HTS, particularly those funded by the generic scheme; and

- strong direction of Australian HTS research towards commercial objectives.

It was agreed by those who had been involved with the Wollongong Workshop that the overlap between the membership and objectives of the NSSC and that for the national committee of experts proposed at the Workshop were sufficiently similar for the formation of the latter not to be proceeded with.[25]

4.31 In July 1988 the Australian Science and Technology Council released a paper[26] which focused on 'current international research; the potential for (and barriers to) applications; policy and funding actions being taken in other nations; and research and policy developments in Australia'.

4.32 In May 1988 this Committee launched this inquiry; submissions were invited and public hearings were held during August and September.

Australia's core capacity

4.33 The first element of the terms of reference concerns 'Australia's core capacity within CSIRO, universities and other research organisations to develop new uses for superconductivity and related new materials which have potential for commercial development'.

4.34 The terms of reference refer to the core capacity of Australia's research organisations 'to develop new uses'. It was pointed out in the submission from the University of Sydney, that this may be seen to imply 'only the utilisation of existing materials developed elsewhere' resulting in consideration of Australia as merely 'a follower of overseas research'.[27] However, the Committee construes the terms of reference in their totality - especially inasmuch as they include

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[24] Ibid., page 573.
[25] Ibid.
[26] *ASTEC Occasional Paper No. 2.*
[27] *Evidence*, page 329.

'problems and opportunities in developing ... research' - as enabling an examination of all aspects of research and development in superconductors - old and new - and related new materials, ranging from basic research through to commercial development.

4.35 Australia's core capacity can be evaluated in terms of infrastructure, personnel, funding and the will to deploy them.

Infrastructure

4.36 Clearly, in covering the ground from basic research through to commercial development, the term infrastructure signifies more than merely laboratories and scientific equipment. It also includes the support services, such as access to information and means of communication for researchers. Ultimately the industrial infrastructure required to translate research into commercial applications - to give effect to demand pull - and the mechanisms to establish a market presence must also be considered.

4.37 One of Australia's clear weaknesses in industrial infrastructure is that it has no existing capacity to manufacture LTS products.[28] The overlap between the existing and incipient superconductor technologies was discussed in Chapter 2. Since many of the foreseeable applications for HTS will follow on from LTS technology, it is obvious that existing practitioners of LTS technology will be in a better position to turn new discoveries into commercial applications. Japan is one nation in which there is not only a strong manufacturing presence in LTS applications[29] but also an adventurous approach to potential applications using existing technology.[30]

4.38 But the ability to manufacture superconductor applications is only part of the story. In addition to its strong presence in LTS manufactures, Japan has well developed heavy engineering, shipbuilding, microelectronics, consumer electronics and telecommunications industries which can incorporate superconductor technology in their manufactures. By comparison Australia's opportunities are limited.

4.39 Australia has no strong manufacturing capacity in any of the three broad applications areas for superconductors: electromagnets, power engineering and microelectronics. The position is no better in regard to applications for rare earth permanent magnets and metallic glasses.[31]

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28 Ibid., page 628.
29 Ibid.
30 *Commercializing HTS*, page 64.
31 *Evidence*, pages 47-72.

4.40 The picture at the research end of the infrastructure spectrum is not so bleak. At the level of basic science and even in significant areas of materials science the 'entry cost'[32] is low. Given the circumstances of the recent breakthroughs, 'it is quite possible that the next quantum leap will come from an obscure group and an unlikely place, working with limited funding and rudimentary facilities'.[33] Nevertheless, those breakthroughs were made with far less intense competition than now prevails. The evidence submitted to the Committee depicted a mixed picture.

4.41 While Australia does not have a manufacturing capability in LTS technology, it does have some research involvement. The Department of Industry, Technology and Commerce remarked that:

> ... Australia is well poised with capabilities in the preparation of ceramic oxides ... and in the tools used for the characterisation of materials, e.g., scanning electron microscopy, electron micrography, scanning Auger spectroscopy, secondary ion mass spectroscopy, X-ray diffraction and emission, neutron diffraction, Fourier transform infra-red and nuclear magnetic resonance spectroscopy, electron spin resonance, microwave and visible spectroscopy.[34]

4.42 Some institutions, such as the Australian Defence Force Academy, admitted to possessing 'excellent scientific equipment and supporting facilities'.[35] Others pointed to the limitations on involvement which were imposed by the 'high cost and elaborate laboratory facilities required'[36] and the lack of 'sorely needed infrastructure'.[37] However, the Committee formed the impression that infrastructure at the research level was a relatively minor area of weakness, if at all given other circumstances, and one that could be overcome by sharing existing resources.

4.43 Another area in which the Committee received divergent opinions was that of the subsidiary components of infrastructure: access to information and communication between researchers. Given the pace of HTS research, information flow is clearly a major consideration.

4.44 Access to information, in particular, research results from all over the world, was recognised as being important to any Australian effort from the outset. In proposing the formation of a national committee of experts, the Wollongong Workshop saw one of that committee's roles as being 'to act as a clearing house for information transfer'; it is notable that the National Superconductivity Steering Committee was not given a similar role.

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32 *ASTEC Occasional Paper No. 2*, page 9.
33 *Evidence*, page S.21.
34 Ibid., page 639.
35 Ibid., page S4.
36 Ibid., page S6.
37 Ibid., page 138.

4.45 One of the advantages which HTS research enjoys over more mature fields is that because of its youth its progress has been able to be more thoroughly captured in modern information distribution, storage and retrieval systems, such as on-line databases. In their submission, the Solid-state Inorganic Research Group at the Australian National University Research School of Chemistry referred to the 'superconductor databases, published and preprint literature, and information dissemination mechanisms, the like of which science has not previously known' and commented that 'some Australian scientists appear oblivious' of them.[38]

4.46 Nevertheless, many witnesses stressed the need for co-ordinated access to databases. The State Electricity Commission of Victoria advocated not just the accumulation of information but also its critical appraisal.[39]

4.47 Beyond gaining access to the available information on HTS research is the need for direct communications between researchers. The CSIRO explained that reading the literature was insufficient for knowing what was going on in overseas companies and that it was necessary for Australian scientists to travel internationally. But this involved establishing one's credentials as a contributor within the international scientific community.[40] Macquarie University complained that 'many university scientists and engineers cannot even get the funding to go to the CSIRO workshops on superconductivity organised inter-state!'. [41]

Personnel

4.48 Much of the evidence submitted to the Committee contained praise for the quality of Australian scientists and indeed there is sufficient evidence elsewhere to suggest that Australia's scientists are capable of holding their own internationally, and that in some disciplines, notably Chemistry, they rank well above the average.

4.49 However, the overwhelming impression formed by the Committee was of a crisis in the quantity of research personnel. The message was consistent: Australia is not producing enough of its own scientists and engineers. And not only were there insufficient personnel for superconductivity research, but the problem extended across most areas of industrial research and development.

4.50 A number of reasons were adduced as contributing to the problem. The Federation of Australian Scientific and Technological Societies referred to the 'longstanding feeling within the community that pursuing higher degree studies

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[38] Ibid., page 487.
[39] Ibid., page 16.
[40] Ibid., pages 94-6.
[41] Ibid., page S9.

in science does not lead to some form of identifiable profession'.[42] The Royal Australian Chemical Institute raised the need for 'an industrial base that wants high level people of the right kind to help development in industry'. This was seen to be a consequence of the way in which industry had evolved in Australia. [43]

4.51 Many witnesses alluded to the disincentives presented by poor remuneration. Dr Colin Adam of the CSIRO highlighted the effect of poor salaries for post-doctoral research staff:

> At present, the stipend that we pay postgraduate students is really inadequate to attract them into the work force. It is much easier for them to go and work as a bachelor's level engineer and earn $30 000 a year rather than working toward a higher degree and only earning half that.[44]

4.52 Concomitant with the perceived poor prospects for a scientific career in Australia is the relative attractiveness of opportunities overseas. Several witnesses expressed their concern at the quality of the people who were being lured overseas. The submission from the University of Sydney referred to an instance:

> American and European universities are having trouble making quality appointments to existing academic positions in Chemistry. In the past it was not uncommon for young Australian researchers to accept appointments in America or Europe whilst overseas on their postdoctoral training. Now, American universities have begun recruiting staff from tenured positions in Australia's top universities. ... Drs P Wright and J B Parise have recently been recruited from tenured positions at the University of Sydney to [American universities] ... several other staff members have received similar offers. ... Dr Parise was one of Australia's top young solid state inorganic chemists. His research interests included high critical temperature superconductors. ... [His loss] to an American university does not merely reduce Australia's research capability in the area of superconductors. In ten years' time, Australia will be importing the technologies developed by Dr Parise's American students, instead of exporting to America the technology which his Australian students would have developed locally if he had stayed here.[45]

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42 Ibid., page 180.
43 Ibid., page 182.
44 Ibid., page 686.
45 Ibid., page 329-30.

4.53 The Federation of Australian Scientific and Technological Societies encapsulated the majority of views expressed on shortages of research personnel:

> Australia already faces a serious shortage in the production of trained research personnel in physical science and areas of engineering. Recent years have seen a steady decline in the number of Australian students electing to continue into higher degree studies in these areas. ... The training of research personnel in superconductors and other advanced materials is vital. Incentives must be found to encourage wider participation by Australian graduates in the physical sciences and engineering. Career structures and economic rewards must become more commensurate with the level of skills and training required to complete a higher degree.[46]

4.54 The national shortage of scientists and engineers is a major weakness and one which will inhibit Australia's HTS research effort. Moreover, since the problem is general to Australian research and development, its effects will be exacerbated by competition from other projected growth areas such as aerospace, telecommunications and information technology.

Funding

4.55 Another commonly perceived weakness is the level of funding available to Australian researchers. Perhaps the main factor contributing to Australia's limitation in this regard is its size relative to the other nations mounting national efforts and more will be said of that below.

4.56 There are two broad sources of funding, Government and business enterprises. The small, albeit increasing, contribution made by business enterprises in Australia has already been noted and will be raised again below as it is a symptom of attitudes within Australian industry towards the needs to innovate and compete. There were, however, concerns expressed about Government funding, too.

4.57 As has been explained above, the two funding mechanisms most relevant to HTS research are the Grants for Industrial Research and Development (GIRD) scheme and grants by the Australian Research Council (ARC). The principal complaints were that between the two of them they did not cover a sufficient area between the poles of pure research and commercial development and that in the case of the ARC the response to applications for funding was far too slow.

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[46] Ibid., page 175.

4.58 At the heart of the ability of existing funding mechanisms to cover the ground between pure research and commercial development is the perennial problem of striking a balance between basic and applied science. So far as it relates to superconductivity research a resolution is not made any easier by the wide range of views as to what area, basic, applied or developmental, should receive priority.

4.59 It is much easier to come to a conclusion on the responsiveness of the ARC mechanism to sudden developments. The ARC awards its grants once a year, and then after a considerable lead time. Professor Bowden illustrated the problem:

> ... from the Australian Universities' point of view the 'timing' of B. Chu's discovery, early in 1987, was a disaster. Most Universities had already submitted their ARC proposals for 1988. Consequently, many were forced to wait until March 1988 to submit new proposals. The successful applicants will be awarded funds for [HTS] research in [January 1989]! This is intolerable.[47]

4.60 Given the pace of progress since the initial breakthrough, clearly such a funding mechanism is not sufficiently responsive. There is scope for a fast track method of funding basic research in rapidly developing fields.

4.61 A further cause for alarm among researchers was that because of its fashionableness, superconductivity research was diverting funding away from other more worthy areas. The competition for funding, it was claimed, could even have a corrupting effect:

> It should be noted that in the present climate of scarce research funds, many scientists and administrators seek to work on superconductors because there is funding to be had. Some are sufficiently desperate that they are prepared to make unrealistic claims and promises to win support. There is now a genuine concern among scientists not currently working on or aspiring to work on superconductors that funds directed into [HTS] research will further diminish funding in other fruitful, but less fashionable, areas of research.[48]

4.62 The funding of research and development is an extremely complicated matter not least because of the number of conflicting principles which have to be resolved. However, in the case of superconductivity research in Australia it is, for the time being at least, perhaps a lesser problem than that of shortages of research personnel. Nevertheless, the matter of funding is crucial and it has been argued that it would be at least one step in overcoming the shortage of personnel.[49]

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47 Ibid., page 277.
48 Ibid., page 488.
49 Ibid., page 194.

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4.63 The level of investment in research and development by Australian industry is a reflection of a deep-seated complacency about the need for innovation and a lack of will to compete in international markets. The Committee has examined this aspect in a previous inquiry. In its report on investment in manufacturing it remarked that:

> Surveys conducted in 1982 and 1984 revealed a problem in the attitudes of Australian business management. The fact that Australia's industries were technologically behind those of its competitors was recognised but the apparent reaction was one of complacency. A further study in 1984 indicated a correlation between internal R&D activity and an inclination on the part of firms to introduce new products or processes or to be involved in international markets. In other words it was important to have an internal R&D involvement rather than simply purchasing externally developed technology. An involvement in R&D also places a firm in a better position to assess which of the overseas technology to purchase.[50]

4.64 In the course of the inquiry into superconductivity and related new materials there were many complaints, particularly by scientists, about the attitude of Australian industry. Some were fatalistic:

> Even were a breakthrough to come from Australian resources, commercialisation and development of such a discovery would proceed overseas with no significant advantage to Australia.[51]

The common view was that:

> ... Australia is at a disadvantage because of the small scale of involvement in research by Australian industry. There is little tradition or mechanism for translating pure science advantage to commercial application in this or many other fields of materials science.[52]

4.65 If there is no reduction in this complacency, if Australian industry insists on waiting for technology to be developed overseas before even considering buying it, then Australia's fate is sealed. As for superconductivity, unless there is demand pull within Australia there is little justification for expending research effort at the level of applied science and beyond.

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[50] *Investment in Manufacturing*, page 51.
[51] *Evidence*, page 484.
[52] Ibid., page 487.

Australia's comparative advantages

4.66 If it is presumed that the commercialised superconductors will be based on rare earth ceramics, or even if the bismuth and thallium compounds prevail, then Australia may hold a distinct comparative advantage. Australia possesses in abundance the majority of mineral resources required for the fabrication of a whole range of new materials. According to the Bureau of Mineral Resources:

> Economic demonstrated resources of aluminium, barium, copper, iron ore, nickel and titanium should be adequate to meet likely demand for domestic consumption and exports over the next 15 to 20 years at least ... Deposits of [magnesium and silicon ores] are widespread in Australia ... From information available to it, BMR believes Australia probably has substantial resources of arsenic, beryllium, gallium, germanium, indium, scandium, selenium, tellurium and thallium ... arsenic, bismuth, niobium, selenium and tantalum are extracted in Australia in some form as a by-product or co-product of the recovery of other commodities.[53]

4.67 Where Australia is currently weak is in the capacity to add value to its mined resources; however, this situation is changing with the construction of a number of processing plants around Australia. A silicon smelter was commissioned in Tasmania in 1987 and another is planned to be built in Western Australia.[54] A plant to produce zirconia powder was built recently at Rockingham in Western Australia.

4.68 The latter signifies a promising development in Australia's use of its resources. Australia is the world's largest supplier of zircon sand, from which zirconia, an oxide of the metal zirconium, is refined. Zirconia is used in the fabrication of ceramics which have useful mechanical as well as electrical properties. The world market is expected to grow from an estimated $6 billion in 1987 to $29 billion by 1995.[55] The joint venture which produces the powder also operates a subsidiary which manufactures zirconia-based ceramic products.

4.69 Once again, the 'connectedness' of technologies arises. The development of the zirconia ceramics technology involved collaboration between ICI Australia and the CSIRO. As ICI pointed out in their submission:

> ICI Australia has a strong commitment to research and development and export oriented production in ceramic powders and parts. This is currently centred on zirconia powders and PSZ [partially stabilised zirconia] ceramic parts made by Nilcra. These are oxide ceramics as are the new superconductors and hence some of the know-how we are developing in ceramics may eventually be useful to superconductors, although they are

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[53] Ibid., page S99.
[54] Ibid., page S98.
[55] *Townshend.*

quite different chemically and physically.[56]

4.70 Another area in which it may be argued that Australia has a comparative advantage is in the flexibility of its scientists. Notwithstanding all the problems which are being outlined in this chapter, Australian researchers were able to mount a creditable effort to reach the level attained to date.

4.71 However, in light of the major weaknesses identified above, Australia's comparative advantage in terms of its access to raw materials and potential expertise in a related technology can only be regarded as conditional.

Australia's competition

4.72 A number of nations, and indeed groups of nations, have launched national efforts to commercialise high temperature superconductivity. It is obvious that in considering a response at a national level, Australia must take into account the abilities and intentions of the nations it would be competing against.

4.73 As was pointed out in Chapter 3, crude ratios based upon per capita expenditure on research and development do not take sufficient account of a number of aspects, such as the composition of the research, its quality, the amount of duplication, and so on. But by whatever measure is used, Australia is clearly unable to match the efforts mounted by the like of the United States, Japan or the European Economic Community. The differences lie not simply in the quantities of funding involved but in the way innovation is promoted.

4.74 In Chapter 1 the strategic aspect of generic technologies was outlined. Generic technologies by their nature are amenable to the influences of national policies. Different industrially advanced nations use different approaches to strike a balance between fostering innovation and allowing it to be determined by market forces. Naturally enough, these approaches tend to be shaped by each nation's experience.

4.75 In a comparative study of national high-technology policies, Nelson outlines the historical influences which have affected the policy approaches of the US, France, the UK, West Germany and Japan.[57]

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[56] *Evidence*, page 218.
[57] *Nelson*.

It is apparent that national crises can be the triggers for a reappraisal of direction. The crucial element is the nation's perception of that crisis. For example:

> The active, shaping role of the Japanese government in industrial development is not new. It goes back to the Meiji restoration of 1867, which was, after all, triggered by the shock of awareness of Japan's great technological and economic inferiority compared with Western development. Since that time Japan has been catching up.[58]

4.76 Other industrially advanced nations now look enviously upon Japan. However, the 'shaping role' adopted by the Japanese Government in its industrial policy works more through incentives than through direct funding:

> Ministries seek advice from business leaders in the early stages of policy development. The processes through which officials in government and the private sector interact, and informal encouragement of industry efforts by government, arguably play a role at least as important as direct financial support. Government funding for R&D projects tends to be modest; consistently, private industry has paid for three-quarters or more of all Japanese R&D, compared with about half in the United States.[59]

4.77 The Committee was told that Australia may have 'missed the ceramic superconductivity boat';[60] if that is so then it may be 'in the same boat' with some illustrious company. Even the US is worried by the intensity of the Japanese effort: in a report to Congress the Office of Technology Assessment (OTA) observed that 'American companies may already have begun to fall behind'.[61]

4.78 The OTA makes some interesting comparisons between the US and Japanese efforts. It estimates that the Japanese Government will provide about US$70 million for research (exclusive of salaries) into superconductivity, both LTS and HTS, during 1988.[62] On the other hand, the US Government will provide an estimated US$94.8 million for 1988, half of which will be channelled through the Department of Defense.[63] The following table compares aspects of projected 1988 research and development expenditure by companies in the two nations:

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58 *Nelson*, page 39.
59 *Commercializing HTS*, pages 73-5.
60 *Evidence*, page 329.
61 *Commercializing HTS*, page 3.
62 Ibid., page 75.
63 Ibid., page 87.

Table 4.6

SUPERCONDUCTIVITY (LTS & HTS) R&D IN US & JAPANESE FIRMS (Projections for 1988 based on incomplete surveys)		
	US	JAPAN
Funding (US$ million)	97	90
Number of firms	55	38
Number of scientists and technicians (full-time and part-time)	625	900
Composition of research staff (%)		
Physicists	43	28
Chemists	15	18
Materials scientists	30	34
Electrical engineers	12	20

Source: OTA, *Commercializing High-Temperature Superconductivity,* pages 58 & 65.

4.79 As the figures in Table 3.1 suggest, there are far many more players than the US and Japan and it can be inferred that some are making comparable efforts. Australia's effort is, as the Department of Industry, Technology and Commerce says in its submission 'a microcosm of world activity', comprising approximately 120 researchers engaged full-time and part-time. Expenditure for 1988 would be somewhat less than a million dollars.

4.80 In the face of such competition, Australia cannot afford the luxury of undirected research into superconductivity. Every dollar must count. There is an overwhelming need for a co-ordinated, well planned national approach.

Conclusion

4.81 It was mentioned early in this chapter and it will be reiterated in the next that Australia's continuing existence as an industrially advanced nation is in jeopardy. Perhaps the tardy awareness of this stems from the absence of shock, the fact that the decline has been gradual. A good deal of readjustment is necessary if the nation is to avoid the shock of entering the next century technologically backward.

4.82 How Australia reacts to the potential impact of advances in superconductivity is only one small part of the process of readjustment. But as will be argued in the ensuing chapter, it will only be possible to make the most of the promises of superconductivity and related new materials if major readjustments are made throughout Australian industry, science and technology.

4.83 The Committee concludes that:

In developing an appropriate strategy to maximise the benefit to the national economy which may arise from the impact of advances in the field of superconductivity, it must be recognised that:

- **Australia has fundamental problems in the performance of its manufacturing sector, in the level and composition of its research and development and in the fragmentation of its science and technology infrastructure.**

- **Australia is poorly prepared for the commercial development of these new materials in terms of manufacturing infrastructure, research personnel, funding and the will to compete internationally.**

- **Australia may have a comparative advantage in its access to raw materials.**

- **Australia will be unable to match the efforts of the major competing nations across the whole spectrum of superconductivity and related research.**

- **Australians, in industry and more generally, must recognise the importance of science and technology to the nation's economic well-being and act upon that recognition.**

- **The morale of the Australian scientific community is adversely affected by a number of factors, including:**

  - **a decline in the funding of research and development;**

  - **the relatively low pay levels of post-doctoral research staff; and**

  - **the poor career prospects for researchers wishing to remain in Australia.**

CHAPTER 5

AUSTRALIA'S PATH

- **Introduction**
- **The need to enhance secondary and tertiary industries**
- **The opportunities and problems for Australia**
- **Strategy**
- **Specifics**
- **Conclusion**

Introduction

5.1 This chapter begins with the premise that as a matter of survival Australia needs to improve its performance as an international trader; this means improving the performance of not only primary (rural and mining) industries, but more urgently that of the secondary (manufacturing) and tertiary (services and high technology activities) industries.

5.2 The development and commercialisation of new materials will intensify while the trend in global trade continues to favour the marketing of elaborately transformed manufactures. But new materials will also have an impact on traditional manufacturing technologies. This is particularly the case with superconductors. Even to stay in the race as an industrially advanced nation, Australia must use new materials and new processes.

5.3 Choosing the path Australia should take entails assessing both the opportunities and the problems. Among the opportunities, is the chance to involve Australian industry to a greater extent in the production of elaborately transformed manufactures, the key growth area in international trade. Among the barriers in this respect is Australia's historical weakness as a manufacturer.

5.4 But the opportunities open to Australia are not so narrow as the coming into being of new potential markets for manufactured goods, or improved manufacturing processes, and the chance thereby to invigorate manufacturing. The spin-offs which would follow an early and continuing involvement in a potentially boundless technology range from the practical to the fanciful. They might include a platform for increasing the value which Australia adds to its primary products, a cornerstone for reforming education, the opening of the Australian mind to the importance of science and technology to society, and a more telling Australian presence in the community of industrially advanced nations.

5.5 Australia can only succeed if its business enterprises are convinced that they must become more aggressive in the international market place and realise that to do so they must combine innovation with strategy.

The need to enhance secondary and tertiary industries

5.6 In its report on investment in Australian manufacturing the Committee noted the economic crisis in which the nation finds itself. Australia must improve its trading performance. Traditionally, Australia has relied on primary production for exports; now it must increase not only those exports but the contribution from the manufacturing and services sectors, as well.

5.7 During the recent debate over funding of Australian research, in particular that of the Commonwealth Scientific and Industrial Research Organisation, some have criticised the redirection of the emphasis of public funding from the rural sector to the manufacturing sector. Their argument is that the nation should be directing its research and development effort towards improving the things it has always done best, mining and agriculture. They point to the historical weakness of Australian manufacturing and to past attempts to improve it which ended in expensive failure. They conclude that public funds are better spent on Australia's proven strengths, the rural and mining industries sector, and that money directed to industrial research and development is largely wasted because Australian manufacturers cannot compete internationally.

5.8 The Committee believes that while not reducing the research effort in the rural and mining industries sectors, Australia must improve its effort in the manufacturing sector. In its report on investment in manufacturing it noted:

> Australia has a massive external debt problem reflecting many years of a serious imbalance between exports and imports and large external borrowings aggravated by adverse exchange rate movements. Australia's share of world trade has been declining for some decades. Australia's exports are predominantly raw materials or low value-added products while the growth areas in world trade are elaborately transformed manufactures and services. Australia's dependence on primary exports therefore means it is particularly vulnerable to fluctuations in rural and export prices.[1]

5.9 Another argument is used, too, against trying to upgrade Australia's manufacturing base: that it is too late. Some commentators propose that a post-industrial economy is emerging, that manufacturing is in decline worldwide and that it would be better therefore for Australia to bypass manufacturing altogether and proceed directly into services and high technology activities. In its report on investment in manufacturing the Committee remarked that:

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1 *Investment in Manufacturing*, page 1.

> ... such analyses fail to take account of the close linkages between manufacturing and many of these activities. The loss of manufacturing would also mean the loss of a range of associated service activities which serve as inputs.[2]

5.10 In fact, advances in superconductivity and new materials do offer opportunities for Australia to benefit at all three levels of industry: primary, secondary and tertiary. But many problems must be overcome. The opportunities and problems are discussed below.

The opportunities and problems for Australia

Opportunities

5.11 As was shown in Chapter 2, the range of potential demand is incalculable. The most obvious opportunity which this affords any industrially advanced nation is an optimal share of the market. Much of the market will be in elaborately transformed manufactures. However, as was proposed in the preceding paragraph, potential benefits are available to all levels of Australian enterprise.

5.12 The benefits to Australia's primary industries might arise in three ways: increased demand for certain of Australia's raw materials; the chance to increase the value added to Australian raw materials; and the use of existing and new superconductor technology to improve the processing of those raw materials.

5.13 Australia holds large reserves of many of the minerals essential to the fabrication of superconductors and new materials. While there is some doubt as to the part rare earths will play in the ultimate high temperature superconductor, it is highly probable that since Australia possesses such a wide range of mineral resources, it will have stocks of the minerals required.

5.14 Digging minerals out of the ground, carrying them to the waterfront and loading them onto ships should not be the full extent of Australia's involvement with its raw materials. In the previous chapter, a promising development was noted: the mining and refining of zirconia sands, the marketing of a value-added product (partially stabilised zirconia) and even the manufacture of components made from the refined material, all within Australia.

5.15 It was mentioned in Chapter 2 that existing LTS technology has a part to play in the refinement of ores through the use of superconducting electromagnets for materials separation. If the trend to refine and add further value within Australia continues then there would be an increasing domestic

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[2] Ibid.

market for superconductors. In the long term, increasing use of superconductors might be made in transport and communications, both areas of relevance to exploitation of mineral resources; in the short term, SQUID-based applications may find use in prospecting and in geological and geophysical surveying.

5.16 The benefits to Australia's secondary industries would lie, in the long term, both in potential products and in improved processes. These were discussed at some length in Chapter 2. The connectedness to other generic technologies such as mechatronics and information technology has already been noted.

5.17 Beyond manufacturing lies the very real possibility of Australia being a leader in certain areas of science and technology. In considering the potential of Australia to promote the level of research and development activity by foreign companies within Australia, the OECD examiners commented in their most recent review of national science and technology policy in Australia:

> Australia has more to offer in this respect than is commonly believed. It is a democratic, stable country with universities and research institutions that have shown excellence in many areas. It is located far away from Europe and the Eastern US, to be sure, but it is comparatively close to those markets which at present are showing the strongest growth. A well-planned effort to 'sell' Australia as a place to locate R&D product centres may therefore well have a chance of success.[3]

5.18 One of the essential features of a generic technology is that it generates a whole range of new technologies each offering its own commercial opportunities. It is fertile ground for the growth of new enterprises and new firms. It is the ideal environment for a nation such as Australia. At this stage, while much of the research is precompetitive, conditions are better than they will be later for nations not particularly competitive in the mature manufacturing technologies.

5.19 Clearly, Australia cannot pin its economic recovery on the opportunities which superconductivity, by itself, offers. What this new technology does offer, though, is the chance for Australia to prove itself in generic technologies. If Australia can successfully exploit superconductivity, it can successfully exploit other technologies.

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[3] *OECD, Reviews*, page 26.

Problems

5.20 There are problems which apply globally and those which are peculiar to Australia. Many of the former were set out in Chapter 3: they include the developmental problems researchers are experiencing with the materials and the risk that some of those problems may prove insurmountable.

5.21 The problems confronting the researchers into high temperature superconductivity (HTS) are appreciable. It should not be forgotten that about half a century elapsed between the discovery of low temperature superconductivity (LTS) and its being put to commercial use. It can be argued that the pace of scientific research has accelerated since 1911; nevertheless, wider chasms than confronted the commercialisation of LTS may need to be bridged to reach the major potential HTS applications.

5.22 However, the probable front runners, the Japanese, are in general very optimistic; there is a certainty that the technical problems will be overcome and that demand can be assumed. Some, at least, in the US treat the Japanese optimism with respect; the US Office of Technology Assessment reported to Congress that:

> Most Japanese managers believe HTS to be closer to the marketplace than do their American counterparts. Seeking growth and diversification, they have assigned more people to HTS than US firms, and may also be spending more money. The Japanese have committed funds, not only to research, but to evaluating prospective applications. Executives there see HTS as a vehicle for creating new businesses, while Americans are more likely to view it in terms of existing lines of business. And if American managers have been reluctant to commit resources to HTS, the Japanese seem confident that investments now will pay off - some time and in some way.
>
> The Japanese could be wrong. In spending money on feasibility studies and engineering analyses, they may miss other opportunities. But given the scale of current investments - in the range of $200 million dollars in each country (including both government and industry R&D), small compared to overall corporate R&D spending - there is much to be said for taking the risks.[4]

5.23 Even while the global problems are being confronted, Australia faces unique problems. Many of these, while they will present steep hurdles to exploiting superconductivity, exert their influence indirectly and are problems which apply generally to Australian industry, science and technology. The problems peculiar to Australia begin with the weaknesses identified in the previous chapter but there are other obstacles.

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[4] *Commercializing HTS*, page 10.

5.24 Specific problem areas, such as the community attitude to science and technology, weakness in infrastructure, funding, personnel, protection of intellectual property and the representation of scientists in the political process will be discussed later. The Committee believes that the first problem to be overcome is choosing a course of action.

Strategy

The need to act

5.25 The simplest question to ask is the first: should Australia get involved in superconductivity? The simple answer is: yes, it must. The Committee concluded in Chapter 2 that the potential impact of the advances in superconductivity was so great that Australia must assess the impact and develop an appropriate strategy.

5.26 It should be apparent from the discussion in Chapter 2 that the impact of the new superconductors will be pervasive. Other nations have made a commitment to developing the new technology. The notion that Australia can wait for the technology to be developed elsewhere, and then buy it from elsewhere, commits the nation to accepting the same contributions to its trade imbalance as is currently being made within the international information technology market. In the words of AUSTRADE:

> Failure on our part to develop and adopt superconductors at the earliest opportunity can be expected to result in a widening of the technology and trading gap between us and countries such as the USA, Japan, France, West Germany and Britain. At the same time we will face the newly emerging economies such as Brazil, Republic of Korea, China, Taiwan and India leaping well ahead of Australia in at least some of the high value added industries - electronics, communications, space technology; a position from which it would be very difficult indeed to recover and one likely to have greater impact on Australia than the relative position we might have with the advanced economies.[5]

5.27 In short, then, the Committee concludes that:

> **There is a need to adopt a strategy which will maximise benefit to the national economy arising from the economic and technological impact of advances in the field of superconductivity and related new materials.**

[5] *Evidence*, page 544.

The need for a co-ordinated national approach

5.28 The next question is: who should co-ordinate the development of the strategy? It has been argued above that Australia must be involved. It will be argued below, that there is not a single, simple answer to the question of what must be done. Several initiatives must be taken and they must be co-ordinated and complementary. Further, the strategy to make the most of superconductivity must be just one strand of a more general strategy to harmonise the activities of Australian industry, science and technology so far as they can contribute to national well-being.

5.29 Individuals and institutions who value their autonomy bridle at the looming presence of government intervention. Business corporations and academic institutions seem to hold similar views on this matter. But there has to be some reconciliation between the desire to preserve autonomy and the need to contribute to a co-ordinated set of initiatives to benefit all parties.

5.30 There must be a national approach and it is desirable that it be co-ordinated by the organisation which is most accountable to all parties, the Government.

5.31 The Committee recommends that:

> **The Government co-ordinate the development of a strategy to maximise benefit to the national economy arising from the economic and technological impact of advances in the field of superconductivity and related new materials.**

A co-ordinated national approach

5.32 It is not simply a matter of saying 'Yes, we'll do it', then offering large sums of money to the Australian research community and sitting back and waiting for the results. A frontal attack will not work by itself: a national effort will only succeed if supporting advances are made on a number of fronts, but most of these, since they involve fundamental readjustments, will take time.

5.33 The fundamental readjustments which need to be made include:

- an acceptance by Australians that they must discard their propensity towards passive consumption and instead embrace innovative production;
- the development of a vigorous economy with sufficient rate of growth to encourage increased business investment in innovation and new enterprises;
- the concomitant revitalisation of Australian manufacturing;

- the development of an integrated science and technology policy which conforms with economic and social policies; and
- the development of a more highly skilled workforce, and especially the provision of greater numbers of scientists and engineers.

5.34 Most of these matters have already been referred to in earlier discussion. If the underlying problems are not overcome then any specific initiative to exploit superconductivity commercially must at the outset be modest in its objectives. Because of the scope of this inquiry, the Committee is not in a position to make recommendations on overcoming these problems but wishes to emphasise the limitations they impose on any recommendations it *does* make.

5.35 A constant theme throughout this report has been the overriding importance of demand as a determinant of innovation. First and foremost, there has to be a market for the developed product. Next, there has to be the ability to make the product. Finally, there needs to be a commitment to a long-term plan to reach the position of exploiting the market.

5.36 There is no doubt that there will be a market for superconductors; the difficulty lies in accurately predicting its range and then deciding upon which areas of the market to aim for. Where and when the demand will arise for individual applications, and how long it will take to develop them, are critical questions. The abilities and intentions of potential competitors must be taken into account.

5.37 But there is already an existing market for LTS technology. The submission from the Department of Industry, Technology and Commerce shows that there is indeed a domestic demand, all of which of course is met by imports.[6] Given that existing practitioners of LTS technology will be in a better position to turn new discoveries into commercial applications the Committee believes that the development of a domestic capacity to manufacture LTS applications should be actively encouraged. The time it will take to develop the major applications of HTS could be profitably used in strengthening Australia's technological arm.

5.38 Any national effort must have a locus. The Committee is aware of the proposal being considered by the Government of New South Wales for the establishment of a Superconductivity Development Centre.[7] The Committee was advised by the NSW Minister for Business and Consumer Affairs that he would be contacting the Federal Minister for Industry, Technology and Commerce to

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[6] Ibid., page 628.
[7] Ibid., page S177.

seek Federal involvement. The Committee is unaware of what progress has been made to this end but sees merit in the idea of a co-ordinating organisation as envisaged in the proposal but operating at a national level.

5.39 The Committee has some general ideas about how such a body should be initiated and the role it should play. At the heart of any national effort is the *need to involve not just the researchers but more importantly the prospective* end users and then the prospective manufacturers. For example the mining industry should be represented, not simply as a prospective provider of raw materials but also as a potential beneficiary of new equipment and processes, and further as a potential victim of decreased demand for minerals used for traditional materials which have been supplanted by new materials.

5.40 The body must be seen by those three groups - researchers, manufacturers and end users - to fulfil their needs and each must be prepared to sustain the body. The Government's role should as much as possible be limited to that of midwife. The Committee notes the workshops already convened by the Department of Industry, Technology and Commerce. The Committee notes initiatives taken with the Multi-Function Polis, with the Australian Artificial Intelligence Institute, and with the Cape York Spaceport. What is required for *a national strategy on superconductivity is a similar initial step.*

5.41 The Committee recommends that:

In co-ordinating the development of a strategy, the Government take the following steps:

- **assess the existing market for applications employing LTS materials, both here and abroad, as well as the potential market for new superconductors;**
- **in the light of that assessment, evaluate the feasibility of local manufacture of applications employing LTS materials;**
- **in consultation with State governments, research organisations and industry, explore the setting up of an autonomous National Superconductivity Research and Development Centre which would:**
  - **involve participation of researchers, potential manufacturers and potential end users;**
  - **co-ordinate research and commercial development of applications employing both LTS and HTS materials;**
  - **contribute to the development of local manufacture of LTS and HTS applications;**

- **co-ordinate funding from all available sources;**
- **establish working relationships with similar groups overseas, such as the International Superconductivity Technology Centre in Japan;**
- **provide common services to all participants, including:**
  - **collection and distribution of international information relevant to research activities;**
  - **advice on patenting;**
  - **advice on Government funding mechanisms; and**
- **advise Government on policy preferences.**

Specifics

5.42 There are several specific problem areas which the Committee wishes to highlight: the community attitude to science and technology, the weakness in industrial infrastructure, funding of a national superconductivity research and development effort, shortages of scientists and engineers, protection of intellectual property and the representation of scientists and technologists in the political process.

Community attitude to science and technology

5.43 Perhaps the most fundamental problem of all in making public policy decisions about industry, science and technology derives from the attitude and understanding of the Australian people, which has been likened to almost an aversion from technology. In an oft-cited paragraph, the OECD examiners reported in 1986:

> We were struck by what seemed to be a widespread Australian view of technology as in some sense external to national life. This is in part, no doubt, a consequence of Australia's historical idiosyncrasies. A high proportion of the techniques used in Australian industry (although not in agriculture) are indeed imported from overseas, mostly by foreign-owned companies. Australia has a tradition of importing technical and professional workers, rather than (or as well as) educating them from childhood. The country's institutions for labour/management relations are such that new technical procedures are frequently seen as being imposed 'from outside' on local factories or offices, often with minimal consultation.[8]

[8] *OECD, Reviews*, page 13.

5.44 In considering the community attitude to science and technology, it is important to recognise that the tendency to aversion does not necessarily imply hostility, though of course this is a component. In addition to historical influences, there are contemporary forces at work. The cumulative effect of the manner in which issues such as environmental pollution, the greenhouse effect, the hole in the ozone layer, nuclear weapons, and so on are presented by the media - with industry, science and technology typically being the villains of the piece - must tell. However, recent surveys show that 'overall, and contrary to prevailing views, Australians appear fairly well disposed towards [science and technology]'.[9]

5.45 The problem, then, is perhaps not so much the attitude itself but the lack of any translation of it into action which influences public policy. In an address to the ANZAAS Congress in May 1988, a speaker firmly placed the onus on scientists, themselves:

> ... scientists need to think less in terms of winning public approval, more in terms of winning public recognition of their importance. And to win that recognition, they need to extend their thinking and their activities beyond their research. There needs to be more emphasis on the message, less on the examples; more on the context, less on the science.
>
> Above all scientists must recognise that they are engaged in a political debate about what sort of science Australia should have, and who does it and controls it. Political debate is a vigorous, and sometimes vicious, interactive process: for scientists, it means effectively countering the ideological excesses and heeding the legitimate public calls for change, not just pumping out information about the achievements of Australian science.[10]

5.46 The Committee is aware of a number of initiatives being undertaken to overcome this problem. They include the setting up of the Australian Science and Technology Information Service (ASTIS) and the opening of the National Science and Technology Centre. However these are isolated and there is little evidence of a concerted effort on the part of the Government nor a clearly discernible objective.

5.47 The Committee concludes that:

> **Several promising initiatives are being undertaken to make the Australian people appreciate better the important contribution which science and technology make to national well-being but it is not clear that these are sufficiently focused to achieve the desired objective.**

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[9] *Eckersley.*
[10] *Ibid.*

Weakness of industrial infrastructure

5.48 The limiting effect which a weak national industrial infrastructure will have on the growth of new technologies in Australia has already been discussed in Chapter 4. Australia lacks not only an existing capacity to manufacture LTS products, it also has no strong capacity in any of the three broad applications areas for superconductors: electromagnets, power engineering and microelectronics.

5.49 In recommending the development of a national strategy, the Committee has emphasised the need to encourage the growth of a domestic capacity to manufacture LTS applications as a means not only of servicing existing demand but also of putting in place the necessary industrial infrastructure for the commercial development of HTS applications.

5.50 The Committee reiterates its belief that this precondition is critical to commercial development and concludes that:

> **Australia would be better placed to develop and manufacture applications for high temperature superconductivity if it had an existing capacity to develop and manufacture applications for low temperature superconductivity.**

Funding of a national superconductivity research and development effort

5.51 Implicit in the Committee's proposal for the co-ordination of a national research and development effort in superconductivity is the necessity for the ultimate beneficiaries to contribute to its funding. The beneficiaries include the manufacturers, the end users and the community at large. As was shown in Chapter 4, the public sector currently bears a disproportionate load, by international standards, in the funding and performance of research and development in Australia.

5.52 While the Committee believes the matter of funding the national effort must be resolved through consultation as described in its main recommendation, it wishes to comment on some specific matters concerning funding.

5.53 First, the Committee noted in its report on investment in manufacturing that the level of business investment in research and development had recently risen from an extremely low base and that this had been encouraged by the 150 per cent tax incentive scheme. However, the scheme had not been used by business enterprises as much as had been hoped, for reasons including fears that government policy might suddenly change. The Government has announced its intention to reduce the level from 150 per cent to 100 per cent in 1991 and the Committee feels that it is important that business perceive stability and predictability when making investment plans. The Committee reiterates the recommendation it made in its report on investment in manufacturing that:

The tax incentive scheme for research and development expenditure not be further altered for at least five years from 1 July 1991 to ensure stability and predictability for business in making its investment plans.[11]

5.54 Second, the Committee considers that a major weakness in the funding of basic research should be eliminated as far as possible. The Committee noted in Chapter 4 that the Australian Research Council was insufficiently responsive to suddenly appearing opportunities for important basic research. Since one of the Council's stated objectives is to 'support both fundamental research and research which will directly contribute to national economic and social development' due recognition should be given to the rapid pace of research typical of generic technologies. The Committee recommends that:

The Australian Research Council implement a fast-track method of awarding grants to research projects in rapidly developing fields of potential importance to the national economy.

5.55 Finally, many of the researchers who made submissions or appeared as witnesses before the inquiry strongly argued against diverting scarce funding resources from other worthwhile projects merely because superconductivity was in vogue. If additional money was to be spent on a national research and development effort on superconductivity then that money should largely come from outside the present funding mechanisms.

5.56 The most clearly articulated 'alternative source' was proposed by the CSIRO. In their submission they noted that the 'electrical power industry stands to benefit greatly from recent developments in superconductivity and related new materials' and they observed that a 'levy of 0.3% on energy sales in Australia would represent a potential R&D fund of about A$23 million per annum'.[12] An augmented proposal, as outlined below, would generate about $40 million per annum:[13]

- Increase New Materials GIRD grants to several grants of $1 million per year, rather than 8-10 $0.5 million grants ($4 million);
- Focus discretionary grants of the Industry Research and Development Board to provide $5-10 million per company for post-GIRD development projects which involve, as partners ($20 million);

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[11] *Investment in Manufacturing*, page 53.
[12] *Evidence*, pages 74-5.
[13] Ibid., pages 629-30.

- Institute EPRI (US Electrical Power Research Institute) type levy at 0.125% of Australian sales ($10 million);

- Continue 150% tax deductibility for R&D in selected areas of new materials technologies and information/communications technologies ($8 million).

Taken collectively these initiatives should generate roughly $40 million per annum. They should be reviewed after 5 years.

5.57 The Committee recognises that any proposal which includes a levy may attract the objection that an unjustifiable impost is being placed on an industry that is only one of the potential beneficiaries from superconductivity research, and a relatively long-term beneficiary at that. As against this, however, it should be noted that the ultimate benefit to the electricity generation industry may be huge. Further, in Australia electricity generation authorities are overwhelmingly public owned, and the performance of some community service obligations is a generally accepted feature of Australian public enterprise. Furthermore, the public utilities have a dismal recent record of investment in research and development.

5.58 The Committee strongly supports the CSIRO's proposal, including a levy set at 0.125 per cent of turnover on the electrical generation industry similar to the 0.3 per cent levy which funds the Electrical Power Research Institute in the United States. The Committee notes that a levy of that magnitude should have a minimal impact on the individual consumer. The funds should be directed towards research into new technologies, including superconductivity, which would benefit the industry. The Committee therefore recommends that:

> **The Government consult urgently with the States with a view to developing a specific proposal towards the institution of a levy set at 0.125 per cent of turnover on the electricity generation industry to fund research into new technologies which would benefit the industry.**

5.59 The Committee believes that funding specifically for superconductivity is so integral to the development of a national research and development effort that it can only be resolved in full consultation with all the parties involved. It would be nugatory to recommend specific measures before that consultation had occurred.

Shortages of scientists and engineers

5.60 In the previous chapter the Committee concluded that the chronic shortage of researchers left Australia poorly prepared for the commercial development of superconductors and related new materials. This problem may more than any other limit the level of Australia's response. However it is not confined to new materials research and affects industry, science and technology in Australia generally.

5.61 The Committee is well aware of the Government's current proposed initiatives to restructure Australian higher education as a means of providing a more highly skilled workforce, including more scientists and engineers. Debate on this issue is being conducted at a national level and all sides are being heard. The Committee feels no need to comment beyond voicing its endorsement of any initiative to improve the skills levels of Australians. The Committee concludes that:

> **The long-standing shortages in Australia of scientists and engineers and the impact those shortages have upon Australian industry, science and technology, have been recognised but corrective action is still being proposed and has yet to be resolved.**

5.62 However, whatever is resolved will take time to have effect and there is a need for short-term measures which will ameliorate current shortages. The most obvious measure is the traditional Australian practice of importing expertise. The University of New South Wales highlighted impediments:

> ... there are insufficient PhD graduates in Australia willing or interested in undertaking further research at post-doctoral level, while on the other hand departments like the Schools of Physics and of Materials Science and Engineering are inundated by requests from overseas graduates seeking post-doctoral funding, some of whom would undoubtedly seek permanent resident status, especially if appointments of longer duration than 3 years were available. The present immigration rules which favour family reunion rather than skilled immigration mean that there is typically 6 to 12 months delay in such applicants being granted a work or resident visa. If Australian research on [HTS] is to be significantly expanded a more enlightened approach to such immigration is required.[14]

5.63 The Committee believes it is imperative that Australia become self-sufficient in the education of scientists and engineers but that in the short-term it make the most of opportunities to attract overseas research staff. The Committee notes the strong argument, presented in the report of the FitzGerald Committee, that 'Economic priority cases must be given access to a fast-tracking mechanism, ensuring a minimum of delay before their arrival in Australia'.[15] The Committee is aware that skilled immigration is a component of existing immigration programs, however the Committee recommends that:

> **The Government act to expedite procedures for processing immigration applications by key scientific personnel.**

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[14] Ibid., page 351.

[15] *Immigration (FitzGerald)*, page 88.

Protection of intellectual property

5.64 The Committee was told on many occasions of problems falling within the general area of intellectual property. For example, there is the problem scientists have in sharing information when some of that information is of commercial value to their industrial collaborators. This is a problem that is being experienced between the four groups operating under GIRD grants.[16]

5.65 The main concern, however, was with patents. In its submission the CSIRO identified this as a major problem:

> A potentially great, but unknown, obstacle to success in this area is the position with regard to patents. It is certain that many, if not all, applications that have been envisaged in this area are already the subject of patent protection overseas. The scientific community needs expert assistance in this complex area from bodies such as the Australian Patents Office. We simply do not know how best to ensure that promising advances made in this country can be fully exploited for Australia's benefit. Patents will be increasingly difficult to obtain and protect; violation already occurs by Japanese companies with relative impunity.[17]

Others saw a need for the Australian Patents Office to keep Australian researchers informed of increases in overseas patent activity in particular scientific areas.[18]

5.66 Recent reports in the media indicate that this is not a peculiarly Australian problem. Different patenting requirements in different countries seem to have led to the position where it is not clear who can claim the patent to the initial invention, the first 1-2-3 ceramic superconductor.[19]

5.67 The Committee believes that the problems surrounding patents and the wider issues of intellectual property are too complex and universal to be dealt with adequately in this report. The Committee concludes that:

> **International competition for patents will pose challenges to successful commercial development by Australians but the problems are so uncertain, complex and universal that the matter is worthy of its own inquiry.**

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[16] *Evidence*, page 18.
[17] Ibid., page 45.
[18] Ibid., page 333.
[19] *Fox*.

Representation of scientists and technologists in the political process

5.68 In the course of the inquiry the Committee became aware of the range of societies and associations which exist within the Australian scientific and technological community. It is not just a reflection of the low level of awareness of science and technology among Australians in general that even the largest are hardly household names.

5.69 The Committee does not question the raisons d'etre of these many organisations. However, the political process has evolved in Australia, as in most Western democracies, to a stage where groups of citizens with common interests are best served if they are publicly represented by some form of peak council, able to articulate a common view in a way clearly discernible by government, the media, other interest groups and the wider community.

5.70 It would seem, therefore, that an indispensable step in making their voice more widely heard and heeded would be for Australian scientists and technologists to set up such a peak council. The Committee understands that this is the intended function of the Federation of Australian Scientific and Technological Societies but its existence and objectives must be more widely known if it is to be as politically effective an organisation as the Australian Council of Trade Unions, the National Farmers' Federation, the Returned Services League or the Confederation of Australian Industry.

5.71 The Committee concludes that:

> **Australian scientists and technologists should play a more positive role in the formulation of public policy by ensuring that they are publicly represented by a well recognised peak council.**

Conclusion

5.72 The sudden advent of high temperature superconductors offers Australia not deliverance but a test. Too many structural adjustments need to be made before Australia can fully exploit the opportunities. But recognising the adjustments which must be made and acting upon that recognition is the test, and how the nation responds may well provide an example for confronting the larger challenges which face the nation.

D P BEDDALL, MP
Chairman
24 November 1988

APPENDIX 1

SUBMISSIONS

The Chairman of the Sub-Committee wrote to 135 individuals and organisations in May 1988, inviting them to lodge submissions in accordance with the terms of reference set by the Minister for Science, Customs and Small Business on 27 April 1988.

Submissions were received from the following:

Federal Government Departments and agencies

Department of Industry, Technology and Commerce
Australian Nuclear Science and Technology Organisation
Australian Research Council
Australian Trade Commission
Bureau of Mineral Resources, Geology and Geophysics
Commonwealth Scientific and Industrial Research Organisation
Defence Science and Technology Organisation
Industry Research and Development Board
National Energy Research, Development and Demonstration Council
National Health Technology Advisory Panel

State Governments

New South Wales
South Australia
Tasmania

Electricity authorities

Australian Electrical Research Board
Electricity Trust of South Australia
Power Directorate, Northern Territory
State Electricity Commission of Victoria

Universities and Institutes of Technology

Australian Defence Force Academy
Australian National University
Australian National University - School of Chemistry - Solid-state Inorganic Research Group

Chisholm Institute of Technology
Deakin University
Griffith University
James Cook University - Department of Civil and Systems Engineering
James Cook University - Department of Electrical and Electronic Engineering
Macquarie University
Monash University
Royal Melbourne Institute of Technology
South Australian Institute of Technology
Swinburne Institute of Technology
University of Adelaide
University of Melbourne
University of New South Wales
University of Queensland
University of Sydney
University of Technology, Sydney
University of Western Australia

Corporations

Australian Industry Development Corporation
ICI Australia
Metal Manufactures Limited
Overseas Telecommunications Commission of Australia
Telecommunications Commission of Australia

Societies and Associations

Australian Academy of Science
Australian Electrical and Electronic Manufacturers' Association
Australian Institute of Physics
Federation of Australian Scientific and Technological Societies
Royal Australian Chemical Institute

Individuals

Professor Graeme Bowden
Dr Maxwell Crossley
Mr Richard Thompson
Professor John White

APPENDIX 2

PUBLIC HEARINGS AND WITNESSES

MELBOURNE, 18 August 1988: David Rivett Laboratory, CSIRO Institute of Industrial Technologies, Clayton (M)

SYDNEY, 6 September 1988: Morgan Grenfell House, Phillip Street, Sydney (S)

CANBERRA, 26 September 1988: Parliament House (C)

ADAM, Dr Colin, Director, Institute of Industrial Technologies, **Commonwealth Scientific and Industrial Research Organisation (C)**

ADAMS, Mr Robert, Section Executive, **Australian Electrical and Electronic *Manufacturers' Association Ltd* (C)**

BATES, Mr Ian, General Manager Transmission, **State Electricity Commission of Victoria (M)**

BOWDEN, Professor Graham, private citizen (S)

COLLINS, Dr John, President, **Australian Institute of Physics (S)**

CROSSLEY, Dr Maxwell, private citizen (S)

CROSSLEY, Dr Maxwell, Senior Lecturer, School of Chemistry, **University of Sydney (S)**

GRAINGER, Mr Warwick, Contact Engineer, **Australian Electrical Research Board (S)**

HOUSTON, Mr Donald, Project Manager, Export Development Group, **Australian Trade Commission (C)**

HYDE, Dr Stephen, Research Fellow, Research School of Physical Sciences, **Australian National University (C)**

JONES, Dr Alan, Acting Director, Strategic Industrial Research Branch, **Department of Industry, Technology and Commerce (C)**

JOSTSONS, Dr Adam, Director - Advanced Materials, **Australian Nuclear Science and Technology Organisation (S)**

KELLY, Mr Geoffrey, Manager, Light Industry Group, **Australian Trade Commission (C)**

LEONARDI, Dr Ezzelino, **Australian Electrical and Electronic Manufacturers' Association Ltd (C)**

McPHERSON, Professor Reginald, Associate Professor, Department of Materials Engineering, **Monash University (M)**

MASTERS, Dr Anthony, Lecturer in Organic Chemistry, School of Chemistry, **University of Sydney (S)**

MAYER, Mr Hans, Member, **Australian Electrical and Electronic Manufacturers' Association Ltd (C)**

MILLIKIN, Mr Peter, Research Business Manager, **ICI Australia (M)**

MOODIE, Dr Alec, Fellow, **Australian Academy of Science (C)**

NICOL, Dr Donald, Chief of Technology Development, **Overseas Telecommunications Commission (S)**

NINHAM, Professor Barry, Head, Department of Applied Mathematics, **Australian National University (C)**

NORMAN, Dr Peter, Senior Lecturer, Applied Physics Department, **Chisholm Institute of Technology (M)**

OPAT, Professor Geoffrey, Professor of Experimental Physics, School of Physics, **University of Melbourne (M)**

PUGH, Mr Ray, Head of Division of Digital Technology, **Chisholm Institute of Technology (M)**

ROBINSON, Dr Peter, Group General Manager - Technical, **Metal Manufactures Ltd (S)**

ROBINSON, Dr Peter, Board Member, **Industry Research and Development Board (C)**

RUSSELL, Professor Graeme, Associate Professor, **University of New South Wales (S)**

SABINE, Dr Harvey, Head of Telecommunications Technology Branch, **Australian Telecommunications Commission (M)**

SMITH, Professor Fred, Past President, **Federation of Australian Scientific and Technological Societies (M)**

SMITH, Dr Geoffrey, Reader, Department of Applied Physics, **University of Technology, Sydney (S)**

SORRELL, Dr Chris, Lecturer, School of Material Science and Engineering, **University of New South Wales (S)**

SPURLING, Dr Thomas, Manager - Policy and Planning, Institute of Industrial Technologies, **Commonwealth Scientific and Industrial Research Organisation (M)**

THOMPSON, Dr John, Research Fellow, Research School of Chemistry, **Australian National University (C)**

THOMPSON, Mr Richard, private citizen (S)

WEST, Professor Bruce, **Royal Australian Chemical Institute (M)**

WHITFIELD, Dr Harold, Principal Research Scientist, Division of Materials Science and Technology, **Commonwealth Scientific and Industrial Research Organisation (M)**

WILKINSON, Dr Peter, Vice-President, **Royal Australian Chemical Institute (M)**

WILSON, Professor Geoffrey, Member of Council, **Australian Research Council (C)**