CHAPTER TWENTY-TWO

SCIENCE AND TECHNOLOGY

Science and technology directly influence the strength and competitiveness of industry by providing a basis for technological change and thereby encouraging economic growth and development. They can be seen as making major contributions to the achievement of many of Australia's social, economic and industrial goals.

There are many organisations in Australia concerned in some way with the development of science and technology in Australia.

The Commonwealth Government's conviction of the importance of science and technology is reflected in the functions of the Department of Industry, Technology and Commerce. Apart from having general responsibility for science and technology, the Department is concerned with the development and maintenance of Australia's scientific and technological capability.

A number of other Commonwealth Government organisations either support or carry out scientific and technological activities. State governments are also involved in science and technology via State government departments, science and technology councils and other organisations. Non-government organisations participating in scientific and technological activites include higher education institutions, professional and learned bodies, private organisations and industry groups.

Information on scientific and technological activities presented in this chapter includes:

- Australian Bureau of Statistics data on resources devoted to research and experimental development (R&D) and other innovative activities. The R&D surveys cover organisations in the business enterprise, general government, private non-profit and higher education sectors.
- Department of Industry, Technology and Commerce statistics on expenditure on R&D and other scientific and technological activities carried out or funded by Commonwealth Government organisations.
- Commonwealth Tertiary Education Commission statistics on tertiary student enrolments.
- Australian Bureau of Statistics information on manufacturing industry technology operations and trade categorised into high technology, medium technology and low technology (industries or commodities).

A special article on science and technology in Australia is included at the end of this chapter.

The Department of Industry, Technology and Commerce—DITAC

Following the Administrative Arrangements Order of 24 July 1987, the Industry, Technology and Commerce portfolio has primary responsibility for advising the government and implementing policy in relation to Australian science and technology; manufacturing and service industries; export services and customs and excise.

Within the portfolio, DITAC is the central point of contact for industry, unions, other Commonwealth departments, and State and local governments on matters relating to manufacturing and service industries. DITAC incorporates parts of the former Departments of Science, Trade, and Housing and Construction. The major scientific and technological aspects of the portfolio include the following bodies and activities.

The Commonwealth Scientific and Industrial Research Organisation—CSIRO

CSIRO was established as an independent statutory authority by the *Science and Industry Research Act 1949*. The Act has been amended on a number of occasions since then, but the most significant amendments were made in 1978, following the government instigated 'Birch Committee of Inquiry'. More recently, in November 1986, it was amended to reflect the decisions on the recommendations of the Review of Public Investment in Research and Development in Australia, including specifically CSIRO, carried out by the Australian Science and Technology Council (ASTEC).

The decisions announced by the Government in 1986 and reflected in the 1986 amendments to the Act, confirm that CSIRO's primary role is to continue as an applications oriented research organisation in support of major industry sectors and selected areas of community interest, but with a stronger commitment to the effective transfer of its results to users. The most recent amendments have also included changes to the top management structure and the Organisation's advisory mechanisms.

Briefly, CSIRO's primary statutory functions are to:

- carry out scientific research relevant to Australian industry, the community, national objectives, national or international responsibilities, or for any other purpose determined by the Minister;
- encourage or facilitate the application or utilisation of the results of such researchs.

Other functions include dissemination and publication of scientific information, international liaison in scientific matters, and provision of services and facilities.

The research work of the Organisation is carried out in Institutes, each headed by a Director and each specifically established to undertake work in support of industry or community interest sectors of the Australian economy. Institutes are comprised of Divisions, which are each responsible for broad programs of research in support of the objectives of the Institute.

Institute of Information and Communication Technologies: Divisions of Information Technology, Radiophysics, Mathematics and Statistics; CSIRO Office of Space Science and Applications.

Institute of Industrial Technologies: Divisions of Manufacturing Technology, Materials Science and Technology, Applied Physics, Chemicals and Polymers.

Institute of Minerals, Energy and Construction: Divisions of Construction and Engineering, Exploration Technology, Mineral and Process Engineering, Mineral Products, Coal Industry, Fuels Production.

Institute of Animal Production and Processing: Divisions of Animal Health, Animal Production, Wool Technology, Tropical Animal Production, Food Processing, Human Nutrition.

Institute of Plant Production and Processing: Divisions of Plant Industry, Tropical Crops and Pastures, Horticulture, Entomology, Soils, Forestry and Forest Products.

Institute of Natural Resources and Environment: Divisions of Water Resources Research, Fisheries, Oceanography, Atmospheric Research, Wildlife and Ecology; Centre for Environmental Mechanics.

On 30 June 1987, CSIRO had a total staff of 7,347 in more than 100 locations throughout Australia. About one-third of the staff were professional scientists, with the others providing technical, administrative or other support.

Commercial activities

The main aim of CSIRO's commercial activities has been to achieve the maximum possible economic and social benefits to Australia by contributing to commercially viable innovation. During recent years, there has been a greater emphasis on research that can be exploited by Australian industry, or that will bring more substantial benefits to Australia. The selection of commercial partners with the capability of developing, applying and marketing innovations has become even more significant in the planning and evaluation of research in CSIRO. A second but important aim of CSIRO's commercial policy is to continue to maximise CSIRO's revenue from its commercial transactions.

SIROTECH Limited

In the first eighteen months of its operation, SIROTECH has come to the forefront in technology transfer in Australia. SIROTECH was established by CSIRO in 1985 to help transfer research results with sound commercial potential to the Australian industry most suited to making use of those results. SIROTECH has been able to help identify and evaluate commercial opportunities, package and market them to industry and negotiate terms and finalise agreements. As a company set up to 'act commercially', it has continued to develop its capabilities in patent and intellectual property management, technology evaluation, market assessment and advice and successful negotiation of commercial agreements. By mid-1986 more than 60 commercial agreements had been negotiated in medium to large-scale projects as well as smaller projects.

CSIRO's budget for 1986–87 was $446m.

The Australian Nuclear Science and Technology Organisation—ANSTO

ANSTO was established on 27 April 1987 as a statutory authority by the Commonwealth Parliament under the *Australian Nuclear Science and Technology Organisation Act Number 3 of 1987*. ANSTO replaces the Australian Atomic Energy Commission, which had been in existence since 1953.

ANSTO is Australia's national nuclear organisation. It has its headquarters and all but a few of its staff at the Lucas Heights Research Laboratories, 30 kilometres south-west of Sydney. Of its staff of 1,050 about 270 are qualified scientists and engineers. Its mission is to benefit the Australian community by the development and application of nuclear science and technology in industry, medicine, agriculture, science and other fields. In this mission, ANSTO maintains a high regional and international standing in nuclear matters and carries out tasks as required by the Commonwealth Government.

The four major activities of ANSTO are:

- the conduct of research and development in the major areas of industrial applications, biomedicine and health, and environmental protection;
- the provision of expert technical advice;
- the operation of national nuclear facilities;
- the commercial marketing of products and services.

ANSTO's annual expenditure is in the order of $56m, with sales revenue of approximately $4m.

The 150 per cent Tax Concession for Research and Development

As an encouragement to the private sector to carry out more R&D, the Government offers a tax incentive for certain R&D expenditures. The concession applied from 1 July 1985 and is available to eligible companies undertaking R&D in Australia. Allowable R&D expenditures over $50,000 per annum attract a 150 per cent taxation deduction, with a phased scale for deductibility of amounts less than $50,000 but more than $20,000.

The Grants for Industry Research and Development Scheme

The scheme provides grants to support approved R&D projects in three areas, being: discretionary grants of up to 50 per cent of agreed costs, generally for companies unable to benefit from the tax concession; generic technology grants, providing up to 90 per cent of agreed costs, designed to support new technologies with particular significance for industry development; and national interest agreements, providing up to 100 per cent of costs for R&D projects with significant benefits for Australia. The scheme applied from 1 July 1986 and replaced the Australian Industrial Research and Development Incentives Scheme.

Patent, Trade Marks and Designs Office

The office protects Australia's technological and commercial interests through the industrial property program. It also protects the public interest through examination and registration of patent, trade mark and design applications and provides a patent information service.

The National Industry Extension Service—NIES

NIES is a joint Commonwealth and State Government initiative established in July 1986 to upgrade and co-ordinate the wide range of advisory and assistance services available to industry. NIES is helping Australian firms achieve international competitiveness by encouraging the adoption of improved technologies, management and business practices. Through a single contact point in each State and Territory, firms can be provided with information, or referred to appropriate specialist sources of advice, on issues that include strategic business planning, product innovation, design, quality, the application of new technologies, marketing, the contribution of labour, and issues of particular concern to small business. Financial assistance may be provided towards the cost of business planning services.

Funds are provided through DITAC's Budget allocation to the States and Territories to assist them in delivering NIES services to industry. In addition, funding is provided for the national NIES program, which includes the development of new elements of the program and assistance to five non-profit providers of extension services: the Technology Transfer Council, Australian Productivity Council, Industrial Design Council of Australia, Standards Association of Australia, and National Association of Testing Authorities.

The Management and Investment Companies Program

In 1984, the Government established the Management and Investment Companies Licensing Board to encourage the development of a venture capital market in Australia. The main objective of the program is to attract management and financial support for the start-up and early growth of those Australian based enterprises which have the potential to grow rapidly into substantial businesses, are export oriented and use innovative technology. To 31 August 1987, over $102m had been invested in 125 businesses in a wide variety of industries.

The Bureau of Industry Economics

Primary responsibility for the Department's Industry Research Program lies with the Bureau of Industry Economics, which was established in 1977 as a centre for research into the Australian manufacturing and commerce sectors of the economy. The Bureau is assisted in devising its research program by a Council of Advice, comprising business and union leaders and prominent academics.

The Bureau's research program is concerned with a broad range of industry policy issues, including:

- individual industry studies as well as the investigations of general issues affecting a broad range of manufacturing and service industries;
- forward-looking studies on the likely future development of Australian industry, as well as detailed investigations of the factors responsible for the performance of industry in the recent past;
- aspects of industrial technology and production as well as pricing and marketing issues.

Evaluation of the effectiveness of existing government policies and programs is an important part of the Bureau's research. The Bureau also contributes to policy reviews, including Industries Assistance Commission and other public inquiries, and assesses the economic aspects of papers put to it by industry and trade unions.

The Snowy Mountains Engineering Corporation

A statutory authority operating on a commercial basis, the Corporation utilises the professional engineering expertise developed during construction of the Snowy Mountains Hydro-electricity Scheme. It has completed nearly 1,300 projects in 45 countries, including Australia.

The Australian Institute of Marine Science

The responsibilities of the Institute are to conduct research and to arrange and co-operate with other institutions or individuals, in conducting marine science research as well as to collect and disseminate information relating to marine science. Its objectives are to advance the development of national knowledge of the marine environment; to communicate this knowledge so that it can be applied to the development, conservation and management of the marine resources, to create opportunities for technological and commercial development and to foster co-operation between researchers with similar interests.

The Institute's core research is organised into four closely integrated programs—coastal processes and resources, reef studies, environmental studies and marine systems analysis. These core research programs have been augmented by funding from other agencies which allows for continuing major research on the crown-of-thorns starfish phenomenon, accelerated research on weather records in corals and mangrove forests and assistance to ASEAN countries to develop technologies for assessing their coastal marine resources, especially mangroves and coral reefs.

The Institute's total budget in 1987–88 was $11.4m, of which $1.2m was funded from other agencies. Its core staff of 106 is supplemented by some 22 staff funded by other agencies.

The Commission for the Future

The Commission's objective of raising community awareness of all aspects of the social and economic impacts of technological change is based on the premise that industrial restructuring and technological development alone are insufficient for the development of a productive Australian culture. A need exists for an information and education program directed at increasing support for, and understanding of, scientific and technological change and long-term options for Australia.

The National Building Technology Centre

The objectives of the Centre are to develop and promote innovative and cost-effective building practices and to advise on formulation of appropriate codes and standards.

The Australian Space Board

The Board was established to advise the government on space R&D priorities in accordance with the government's broader industry and technology policies. Part of the Board's functions include supervising and accounting for National Space Program activities funded through the Department. Those activities include providing financial incentives to companies for involvement in space-related technologies and R&D.

The National Standards Commission

The National Standards Commission is responsible for determining the legal units and standards of physical measurement, co-ordinating the national measurement system and approving measuring instruments for use in trade. In September 1984, the Weights and Measures (National Standards) Act was amended and the title changed to the National Measurement Act. The amendments clarified the functions of the Commission and transferred to it responsibility for completing the introduction of the metric system of measurement into Australia. This was previously a function of the Metric Conversion Board.

Following a review of the trade measurement system in 1984, the Commission has been chairing a working party of State and Territory Weights and Measures Authorities to develop Uniform Trade Measurement Legislation for Australia.

Expenditure

Science and technology (S&T) expenditures within the portfolio of the Minister for Industry, Technology and Commerce for 1986-87 were as follows:

Intramural (in-house) R&D expenditure $454m.

Extramural (grants, contracts, etc.) R&D expenditure $60m.

S&T (including R&D) expenditure $688m.

Other Commonwealth Government science and technology activities

Many other Commonwealth Government agencies play a significant role in the science and technology area. A number of these agencies are involved with R&D activities either as funders, performers or both; others are active in the S&T areas of information dissemination, scientific services and scientific training.

The Australian International Development Assistance Bureau

The Bureau provides funds under a number of arrangements to provide scientific development and training in many third world countries. In 1986-87 the Bureau spent $219m on science and technology, $39m of which was provided as R&D funding.

The Defence Science and Technology Organisation—DSTO

DSTO is a major R&D performer in the defence field in Australia, spending $148m on its own research programs in 1986-87. Other S&T activities include provision of scientific and technological advice on defence policy matters and equipment, and development and maintenance of a skill base in defence science and technology.

The Commonwealth Department of Employment, Education and Training

The Department funds scientific and technical training in tertiary institutions via the Commonwealth Tertiary Education Commission. In addition, the Department has established the Australian Research Council to provide advice on national research policy priorities and on the co-ordination of national research effort. The Council will also co-ordinate and advise on specific research funds for tertiary education institutes, post-graduate research awards and research grants and fellowship schemes.

The Commonwealth Department of Community Services and Health

The Department is the major Australian provider of medical research funds through the National Health and Medical Research Council. In 1986–87, the value of grants awarded to medical researchers was $59m. Other S&T activities of the Department include provision of funds for the National Biological Standards Laboratory ($13m in 1986–87), Commonwealth Pathology Laboratories ($17m in 1986–87) and the Commonwealth Serum Laboratories ($10m in 1986–87).

The Australian Telecommunications Commission

'Telecom Australia' operates and maintains the national telecommunications network. It is a major R&D and S&T performer ($56m and $141m respectively in 1986–87). Its R&D activities include planning and specification of Australian telecommunications requirements and the solution of technical problems arising during the operation of its telecommunication networks. Telecom's other S&T activities include planning and operation of new facilities and development of the network infrastructure.

The Australian Bureau of Statistics

The Bureau is the Commonwealth Government's central statistical authority and is responsible for providing statistical services to government and private users. Other activities include the co-ordination of statistical activities of official bodies and the provision of statistical advice and assistance to official bodies. All of the Bureau's expenditure ($164m in 1986–87) is considered to be on science and technology (predominantly data collection in the social sciences), with a small proportion ($10m in 1986–87) attributable to R&D.

The Bureau of Meteorology

The Bureau provides the national meteorological service and performs the R&D needed to maintain the service. The Bureau's total S&T expenditure for 1986–87 was $86m, of which $3m was for R&D.

The Antarctic Division of the Department of Arts, Sport and the Environment, Tourism and Territories

The Division manages Australia's Antarctic program. It organises expeditions and maintains research stations, as well as funding, co-ordinating and conducting research. The Division's S&T spending for 1986–87 was $42m and its R&D expenditure was $27m.

The Rural Industry Research Schemes

The schemes, administered by the Department of Primary Industries and Energy, cover one general and 15 specific rural industries. They provide funds for rural research and dissemination of agricultural information. Funding for most of the schemes comes equally from the Commonwealth and industry (via a levy on produce). In 1986–87, the schemes contributed $26m to rural research ($10m of which was industry funded).

The Bureau of Mineral Resources—BMR

The Bureau's main functions are to understand and assess Australian geology as a basis for mineral exploration, to be the primary information source for geoscience data, and to monitor earthquake activity and underground nuclear explosions. BMR's R&D activities are in the areas of fossil fuel, minerals and ground water; spending on R&D in 1986–87 was $30m. Total S&T expenditure in 1986–87 was $37m.

Advice on science and technology

Apart from DITAC, the most significant Commonwealth Government advisory body on science and technology is the Australian Science and Technology Council (ASTEC), a statutory authority advising the Prime Minister and government on science and technology matters. ASTEC's 1986–87 expenditure was $1.4m. For a fuller discussion of ASTEC's role and functions *see Year Book* No. 70.

State government science and technology activities

State governments are major performers and supporters of scientific and technological activities. Many States have particular departments established for the purpose of encouraging and co-ordinating the use of technology in industry (e.g. the Victorian Department of Industry, Technology and Resources). Several States (New South Wales, Queensland, Western Australia and South Australia) have also established science and technology councils which provide advice to State governments on science and technology matters and promote the expansion of technology.

In addition to fostering science and technology, many State government departments are large performers of scientific and technological activities. Traditionally, for instance, those departments involved with agriculture (e.g. the Victorian Department of Agriculture and Rural Affairs and various State departments of agriculture) spend large sums on the R&D which they perform and also have a high profile in the general S&T activities of extension and laboratory services.

The total 1984–85 expenditure for R&D carried out by State government organisations on agricultural objectives was $197m, 68 per cent of total State government R&D spending for that year. Other major areas of State government R&D activity are Forestry and Fisheries ($24m in 1984–85) and Health ($22m in 1984–85).

Tertiary education institutions' science and technology activities

Tertiary education institutions play a vital role in the two major S&T areas. These being R&D and scientific and technical training.

Universities receive direct funding for research purposes from a number of sources, the major one being the Commonwealth Government. Commonwealth funds include those administered by the Commonwealth Tertiary Education Commission (special research grants, research equipment grants); those grants and awards distributed through the Australian Research Council; and grants awarded by the National Health and Medical Research Council and through the National Energy Research, Development and Demonstration Program. Direct Commonwealth research funding for 1986 totalled $127m. Direct funds for research from other organisations and individuals totalled $58m in 1986.

Indirect research funding for universities includes both the proportion of general funds from the States Grants (Tertiary Education Assistance) Act allocated by universities to research ($104.0m in 1986) and the amount attributable to research but coming from general teaching-and-research funds (e.g. the estimated research portion of the salaries of teaching-and-research staff). The latest available figures for total university research expenditure (direct plus indirect sources) came from the ABS inter-year R&D survey for 1985 which gives an estimated expenditure of $708m.

CAE's and institutes of TAFE receive very little research funding from the Commonwealth. The Australian Bureau of Statistics measures R&D effort for CAEs ($23m in 1984) but does not survey institutes of TAFE.

Data on university and advanced education enrolments by field of study are presented in the table below. Other enrolment data for universities and advanced education and data on TAFE enrolments are presented in Chapter 10, Education. That chapter also gives a more detailed picture of higher education facilities in Australia.

Other organisations' science and technology activities

There are many other non-government organisations playing an important part in Australia's scientific and technological development. They include various learned and professional bodies such as the Australian Academy of Science, the Australian Academy of Technological Science, the Academy of Social Sciences in Australia and the Australian and New Zealand Association for the Advancement of Science. Their activities include provision of advice in the relevant scientific fields, dissemination of scientific information and enhancement of communication on scientific matters.

A number of private organisations from time to time provide advice to government on specific matters relating to science and technology. Examples from the business sector are the Australian Chamber of Manufactures, the Business Council of Australia and the Confederation of Australian Industry. Other organisations with an interest in scientific and technological issues include trade unions, industry groups with an interest in specific technologies and individual private organisations.

As performers of research and experimental development, private organisations in Australia are making an increasingly important contribution to Australia's R&D effort. Private business enterprises, for instance, spent an estimated $818m on R&D in 1985–86, a figure which, whilst still relatively low compared with the spending of comparable OECD countries, represents an increase of 26 per cent over 1984–85 expenditure. Private non-profit organisations in 1985–86 spent $47m on R&D, the majority of it on health related research.

UNIVERSITIES AND ADVANCED EDUCATION COMMENCING AND TOTAL STUDENTS BY COURSE LEVEL AND FIELD OF STUDY, AUSTRALIA, 1986

(*Source*: Commonwealth Tertiary Education Commission)

Field of Study (a)	Commencing Students				Total Students			
	Higher Degree	Bachelor Degree	Other	Total	Higher Degree	Bachelor Degree	Other	Total
UNIVERSITIES								
Agriculture/Forestry	187	593	73	853	862	1,848	115	2,825
Architecture	110	848	73	1,031	590	3,272	150	4,012
Arts	1,932	18,532	2,922	23,386	6,330	52,462	4,781	63,573
Dentistry	42	244	5	291	214	1,155	9	1,378
Economics/Commerce	1,266	7,041	822	9,129	3,290	20,598	1,333	25,221
Education	1,312	2,554	2,579	6,445	4,357	7,389	3,440	15,186
Engineering	553	3,298	261	4,112	2,143	11,564	363	14,070
Law	258	2,317	368	2,943	892	8,510	567	9,969
Medicine	422	1,682	173	2,277	1,763	8,654	244	10,661
Science	1,198	9,043	1,509	11,750	4,636	25,479	2,334	32,449
Veterinary Science	73	296	23	392	243	1,182	31	1,456
Miscellaneous	49	17	424	490	110	70	503	683
Total 1986	**7,402**	**46,465**	**9,232**	**63,099**	**25,430**	**142,183**	**13,870**	**181,483**
1985	**7,131**	**44,189**	**8,916**	**60,236**	**24,554**	**137,490**	**13,432**	**175,476**
ADVANCED EDUCATION								
Agriculture/Forestry	107	416	1,197	1,720	157	1,152	2,777	4,086
Applied Science	1,894	5,572	2,429	9,895	3,780	14,575	5,142	23,497
Visual/Performing Arts	387	3,268	1,879	5,534	620	7,325	4,018	11,963
Architecture/Building	201	962	202	1,365	500	3,096	525	4,121
Comm/Business Studies	3,236	12,911	2,388	18,535	6,249	35,991	5,709	47,949
Engineering	640	3,407	1,047	5,094	1,289	11,011	2,774	15,074
Social Sciences/Humanities	1,381	6,402	2,127	9,910	2,550	15,598	4,790	22,938
Health Sciences	518	1,717	4,902	7,137	933	4,817	9,348	15,098
Education	6,857	8,471	9,432	24,760	12,408	23,345	26,340	62,093
Non Award	—	—	1,941	1,941	—	—	2,404	2,404
Total 1986	**15,221**	**43,126**	**27,544**	**85,891**	**28,486**	**116,910**	**63,827**	**209,223**
1985	**13,684**	**38,613**	**26,927**	**79,224**	**26,416**	**107,528**	**61,287**	**195,231**

(*a*) Some Field of Study data may not be comparable with data previously published.

Statistics on science and technology

Expenditure and human resources devoted to research and experimental development

The Australian Bureau of Statistics' Surveys of Research and Experimental Development provide comprehensive data on research and experimental development activities in Australia by organisations in the business enterprise, general government, higher education and private non-profit sectors. They also provide some data on other innovative activities, such as technical know-how payments and receipts and patenting activity. Activities not covered by the survey include scientific or technological services, extension services, education and training, etc.

The first comprehensive survey on R&D was carried out for the financial year 1968-69. There have been five major surveys since then, the latest for which comprehensive results are available being in respect of 1984-85 (1984 calendar year for the Higher Education Sector). Less detailed data in respect of 1985-86 are available from the smaller 'inter year' R&D survey conducted by the Bureau.

The estimate of gross expenditure on R&D (GERD) carried out in Australia, as derived from the results of the 1984-85 survey, is $2,408m. This represents a 54 per cent increase compared with the 1981-82 survey. At constant (1979-80) prices, GERD increased by 19 per cent over the same period. The total estimate of human resources devoted to R&D during 1984-85 in Australia was 51,000 person years; this represented a 13 per cent increase compared with the previous survey.

See Year Book No. 70 for a detailed description of survey methods and concepts.

Definitions

The survey's definitions follow guidelines described by the OECD for national R&D surveys. The OECD defines R&D as comprising 'creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications'. The Bureau provides sector specific definitions which clarify the OECD definitions for respondents and users (*see* ABS catalogue 8112.0).

Survey results

A summary of results for 1968-69 is given in *Year Book* No. 60. Results for the second survey, 1973-74; the third survey, 1976-77; the fourth survey, 1978-79; and the fifth survey, 1981-82 are given in *Year Books* No. 61, 64, 67 and 70 respectively.

A summary of results from the 1981-82, 1984-85 and 1985-86 surveys is presented below.

RESEARCH AND EXPERIMENTAL DEVELOPMENT CARRIED OUT IN AUSTRALIA: HUMAN RESOURCES DEVOTED TO R&D BY SECTOR

(person years)

Sector	*1981-82*	*1984-85*	*1985-86*
Business Enterprise—			
Private Sector	7,478	11,121	(*a*) 12,968
Public Sector	1,054	1,342	1,449
General Government—			
Commonwealth	11,412	11,126	11,196
State	6,382	6,092	6,285
Higher Education	18,241	20,580	(*b*) 20,143
Private Non-profit	688	740	814
Total	**45,255**	**51,000**	(*a*) **52,855**

(*a*) The standard error associated with this estimate is 112.5 person years. (*b*) Excludes colleges of advanced education. Their 1984 contribution to total person years was 1,047.

GROSS EXPENDITURE ON RESEARCH AND EXPERIMENTAL DEVELOPMENT (GERD) CARRIED OUT IN AUSTRALIA: GERD AT CURRENT AND CONSTANT (AVERAGE 1979–80) PRICES
($ million)

Sector	*1981–82*	*1984–85*	*1985–86*
AT CURRENT PRICES			
Business Enterprise—			
Private Sector	319	650	(*a*) 818
Public Sector	61	87	103
General Government—			
Commonwealth	515	670	727
State	200	289	317
Higher Education	452	668	(*b*) 708
Private Non-profit	21	44	47
Total	**1,568**	**2,408**	(*a*) **2,720**
AT CONSTANT (AVERAGE 1979-80) PRICES			
Business Enterprise—			
Private Sector	240	396	(*c*) 468
Public Sector	51	56	62
General Government—			
Commonwealth	382	396	407
State	164	180	186
Higher Education	387	418	(*b*) 413
Private Non-profit	17	28	27
Total	**1,240**	**1,474**	(*c*) **1,563**

(*a*) The standard error associated with this estimate is $6.7m. (*b*) Excludes colleges of advanced education. Their 1984 contribution to current price GERD was $23.1m, and to constant price GERD, $16.2m. (*c*) The standard error associated with this estimate is $3.8m.

GROSS EXPENDITURE ON RESEARCH AND EXPERIMENTAL DEVELOPMENT (GERD) CARRIED OUT IN AUSTRALIA, 1984–85: GERD BY SECTOR BY SOURCE OF FUNDS
($'000)

	Source of funds						
Sector	*Total*	*Commonwealth Government*	*State government*	*Business enterprises*	*Higher education*	*Private non-profit and other Australian*	*Overseas*
Business Enterprise—							
Private Sector *r*	649,932	61,193	3,064	568,766	210	3,959	12,741
Public Sector	87,148	4,786	310	82,021	—	—	31
General Government—							
Commonwealth	669,940	645,773	1,134	5,837	73	13,905	3,218
State	288,832	24,223	248,378	6,329	231	9,095	576
Higher Education	667,509	623,468	8,375	10,751	393	19,097	5,425
Private Non-profit	44,133	17,679	8,190	2,094	438	11,689	4,042
Total	**2,407,493**	**1,377,121**	**269,450**	**675,797**	**1,344**	**57,746**	**26,034**

Business enterprise sector

The estimate of expenditure on R&D carried out in Australia by private and public business enterprises during 1985–86 is $921m at *current* prices. This represents a 25 per cent increase in expenditure compared with 1984–85. At *constant* (average 1979–80) prices, R&D expenditure is estimated to have increased by 17 per cent over the same period.

RESEARCH AND EXPERIMENTAL DEVELOPMENT CARRIED OUT BY BUSINESS ENTERPRISES (a), BROAD INDICATORS BY INDUSTRY OF ENTERPRISE(b)

Industry of enterprise		Enterprises that carried out R & D (number)		R & D expenditure ($m)			Person years of effort on R & D		
ASIC code	Description	1981–82	1984–85	1981–82	1984–85	1985–86	1981–82	1984–85	1985–86
11–15	*Mining (excluding services to mining)*	*23*	*31*	*22.6*	*29.2*	*n.a.*	*381*	*289*	*n.a.*
	Manufacturing								
21	Food, beverages and tobacco	72	91	14.1	27.9	n.a.	390	601	n.a.
23–24	Textile, clothing and footwear	16	26	0.8	3.8	n.a.	24	43	n.a.
25	Wood, wood products and furniture	19	29	1.7	3.4	n.a.	43	68	n.a.
26	Paper, paper products, printing and publishing	12	22	5.3	6.4	n.a.	125	139	n.a.
27	Chemicals, petroleum and coal products	128	179	57.3	91.8	97.0	1,307	1,572	1,578
28	Non-metallic mineral products	22	33	5.8	12.9	n.a.	126	223	n.a.
29	Basic metal products	27	32	27.1	46.1	67.2	672	681	889
31	Fabricated metal products	83	92	7.1	15.6	n.a.	170	309	n.a.
32	Transport equipment	54	65	48.1	94.1	128.8	1,087	1,540	1,778
334	Photographic, professional and scientific equipment	26	30	6.3	16.5	n.a.	183	283	n.a.
335	Appliances and electrical equipment	159	284	41.4	89.0	117.9	1,029	1,689	2,063
336	Industrial machinery and equipment	156	176	15.7	27.3	n.a.	443	556	n.a.
33	Total other machinery and equipment	341	490	63.4	132.8	159.5	1,655	2,528	2,888
34	Miscellaneous manufacturing	66	79	7.6	12.4	n.a.	186	253	n.a.
C	*Total manufacturing*	*840*	*1,138*	*238.3*	*447.2*	*(c) 559.1*	*5,784*	*7,955*	*(c) 8,918*
	Other industries								
F	Wholesale and retail trade	106	191	12.5	35.9	n.a.	296	615	n.a.
63	Property and business services	206	449	20.2	81.7	n.a.	499	1,324	n.a.
8461	Research and scientific institutions	31	42	23.0	27.8	n.a.	485	489	n.a.
(d)	Other n.e.c.	72	123	63.1	115.3	n.a.	1,086	1,790	n.a.
16, D-I-K-L	*Total other industries*	*415*	*805*	*118.9*	*260.7*	*362.1*	*2,368*	*4,219*	*5,499*
	Total all industries	**1,278**	**1,974**	**379.7**	**737.1**	**921.2**	**8,533**	**12,463**	**14,417**

(a) Excludes enterprises in ASIC Division A. (b) Broad industry data only available for 1985–86 data. (c) Not equal to sum of manufacturing components. (d) ASIC Codes 16, D, E, G-H, 61-62, J-L excluding ASIC class 8461.

Payments and receipts for patent licence fees and other technical know-how

Many Australian business enterprises supplement their R&D efforts by either purchasing or licensing foreign or Australian technology. Data for 1981-82 and 1984-85 are presented below.

PAYMENTS AND RECEIPTS FOR TECHNICAL KNOW-HOW BY BUSINESS ENTERPRISES PAYMENTS AND RECEIPTS BY INDUSTRY OF ENTERPRISE ($ million)

Industry of enterprise		Payments for technical know-how		Receipts for technical know-how	
ASIC code	Description	1981–82	1984–85	1981–82	1984–85
	Manufacturing—				
21	Food, beverages and tobacco	14.9	16.3	–	1.1
23-24	Textiles, clothing and footwear	1.4	8.9	–	n.p.
25	Wood, wood products and furniture	} 2.9	0.1	–	n.p.
26	Paper, paper products, printing and publishing		4.1	n.p.	0.2
27	Chemicals, petroleum and coal products	34.3	37.4	3.6	6.6
28	Non-metallic mineral products	5.6	7.8	n.p.	n.p.
29	Basic metal products	7.6	4.7	2.0	6.1.
31	Fabricated metal products	3.3	2.3	0.7	1.1
32	Transport equipment	13.8	17.4	2.0	0.9
334, 335	Photographic, professional and scientific equipment, appliances and electrical equipment	16.9	37.4	1.3	n.p
336	Industrial machinery and equipment	3.2	3.2	0.2	1.4
33	Total other machinery and equipment	20.1	40.6	1.5	4.8
34	Miscellaneous manufacturing	3.3	5.2	0.9	n.p
C	*Total manufacturing*	*107.1*	*144.7*	*11.5*	*23.9*
	Other industries	*28.9*	*17.9*	*5.9*	*12.3*
	Total all industries	**136.0**	**162.6**	**17.4**	**36.2**

Expenditure by Commonwealth Government organisations on science and technology

The Commonwealth Department of Industry, Technology and Commerce conducts the annual Science and Technology Statement Collection which obtains expenditure data on R&D and broader scientific and technological activities. The collection covers Commonwealth Government organisations (including public business enterprises) and includes expenditure on both intramural (inhouse) activity and R&D extramural funding (grants, contacts etc.).

Latest published results show total Commonwealth Government S&T expenditure in 1986–87 to be $74,899m. Of this, total R&D expenditure was $1181.7m ($728.4m intramural, $453.3m extramural).

The table below gives an overview of 1986–87 R&D expenditure by the Commonwealth, classified by socio-economic objective.

TOTAL COMMONWEALTH GOVERNMENT EXPENDITURE(*a*) ON R&D BY SOCIO-ECONOMIC OBJECTIVE, 1986–87
($ million)
(*Source*: Department of Industry, Technology and Commerce)

Socio-economic objective	*R & D expenditure (b)*
National security (defence)	*153.6*
Economic development—	
Agriculture	166.6
Forestry and fisheries	28.4
Mining—	25.8
Manufacturing	136.3
Construction	14.3
Energy	60.3
Transport	6.5
Communications	63.5
Economic services n.e.c.	17.8
Total economic development	*519.6*
Community welfare	
Urban and regional planning	1.5
Environment	22.1
Health	100.2
Education	2.6
Welfare	4.8
Community services n.e.c.	57.6
Total community welfare	*188.9*
Advancement of knowledge—	
Earth, ocean and atomsphere n.e.c.	96.8
General advancement of knowledge	222.9
Total advancement of knowledge	*319.7*
Total	**1181.7**

(*a*) Excludes expenditure by Commonwealth Government organisations funded from recoveries and external sources such as industry and State Government. Also excludes recurrent funding for Higher Education Institutions and the costs to the Commonwealth of tax incentives. (*b*) Sum of intramural plus extramural expenditures.

General government sector

The estimate of expenditure on R&D carried out in Australia by organisations in the general government sector during 1985–86 was $1,044 million at *current* prices. This represents a 9 per cent increase in expenditure compared with 1984–85. At *constant* (average 1979–80) prices, R&D expenditure is estimated to have increased by 3 per cent over the same period.

Higher education sector

The estimate of expenditure on R & D carried out in Australia by higher education organisations (excluding CAEs) during 1985 is $708m at *current* prices. This represents a 6 per cent increase in expenditure compared with 1984. At *constant* (average 1979–80) prices, R & D expenditure is estimated to have decreased by 1 per cent over the same period.

RESEARCH AND EXPERIMENTAL DEVELOPMENT CARRIED OUT BY GENERAL GOVERNMENT ORGANISATIONS
R&D EXPENDITURE AND HUMAN RESOURCES BY SOCIO-ECONOMIC OBJECTIVE

	R & D expenditure ($m)		*Person years of effort on R & D*	
Socio-economic objective	*1981–82*	*1984–85*	*1981–82*	*1984–85*
National security (defence)	*113.2*	*151.0*	*3,625*	*3,232*
Economic development—				
Agriculture	236.0	323.3	5,681	5,925
Forestry and fisheries	44.2	48.4	1,140	941
Mining (prospecting)—				
energy sources	12.0	11.5	244	173
other	9.1	22.4	236	321
Mining (extraction)—				
energy sources	5.0	7.9	124	120
other	8.7	8.4	228	138
Manufacturing	73.6	103.3	1,658	1,718
Construction	7.1	13.3	207	265
Energy	42.7	51.8	731	644
Transport	6.2	22.2	134	303
Communications	0.6	0.3	26	6
Economic services n.e.c.	22.6	18.1	558	335
Total economic development	*467.8*	*630.8*	*10,966*	*10,886*
Community welfare—				
Urban and regional planning	2.8	0.4	81	12
Environment	43.6	28.8	1,034	559
Health	24.8	43.0	890	1,072
Education	2.7	2.7	99	81
Welfare	1.7	3.7	64	88
Community services n.e.c.	3.6	9.2	85	196
Total community welfare	*79.2*	*87.8*	*2,253*	*2,008*
Advancement of knowledge—				
Earth, ocean and atmosphere n.e.c.	34.3	75.2	542	882
General advancement of knowledge	20.1	14.0	408	210
Total advancement of knowledge	*54.4*	*89.2*	*950*	*1,092*
Total	**714.6**	**958.8**	**17,795**	**17,218**

RESEARCH AND EXPERIMENTAL DEVELOPMENT CARRIED OUT BY HIGHER EDUCATION ORGANISATIONS
R & D EXPENDITURE AND HUMAN RESOURCES BY SOCIO-ECONOMIC OBJECTIVE

	R & D expenditure ($m)		*Person years of effort on R & D*	
Socio-economic objective	*1981*	*1984*	*1981*	*1984*
National security (defence)	*0.7*	*1.2*	*19*	*29*
Economic development—				
Agriculture	35.5	58.7	1,554	1,922
Forestry and fisheries	4.3	7.9	167	282
Mining (prospecting)—				
energy sources	1.8	1.8	64	71
other	1.8	3.3	67	108
Mining (extraction)—				
energy sources	1.0	1.0	44	34
other	2.4	3.6	104	128
Manufacturing	13.0	18.1	583	622
Construction	2.7	7.0	107	224
Energy	21.7	24.7	764	769
Transport	2.6	3.7	98	129
Communications	3.2	5.8	143	196
Economic services n.e.c.	21.0	17.9	677	429
Total economic development	*110.9*	*153.5*	*4,372*	*4,915*

RESEARCH AND EXPERIMENTAL DEVELOPMENT CARRIED OUT BY HIGHER EDUCATION ORGANISATIONS
R & D EXPENDITURE AND HUMAN RESOURCES BY SOCIO-ECONOMIC OBJECTIVE—*continued*

Socio-economic objective	*R & D expenditure ($m)* 1981	*R & D expenditure ($m)* 1984	*Person years of effort on R & D* 1981	*Person years of effort on R & D* 1984
Community welfare—				
Urban and regional planning	4.0	4.2	161	116
Environment	5.7	13.4	256	441
Health	87.3	136.3	3,345	4,147
Education	18.1	26.3	923	894
Welfare	5.7	8.3	202	245
Community services n.e.c.	11.3	13.1	427	336
Total community welfare	*132.1*	*201.6*	*5,314*	*6,178*
Advancement of knowledge—				
Earth, ocean and atmosphere n.e.c.	26.3	41.4	1,019	1,127
General advancement of knowledge	182.4	269.8	7,516	8,332
Total advancement of knowledge	*208.7*	*311.2*	*8,535*	*9,459*
Total	**452.5**	**667.5**	**18,241**	**20,580**
Universities contribution	443.5	644.4	17,699	19,533
CAEs' contribution	9.0	23.1	542	1,047

RESEARCH AND EXPERIMENTAL DEVELOPMENT CARRIED OUT BY PRIVATE NON-PROFIT ORGANISATIONS
R&D EXPENDITURE AND HUMAN RESOURCES BY SOCIO-ECONOMIC OBJECTIVE

Field of science	*R&D expenditure ($'000)* 1981–82	*R&D expenditure ($'000)* 1984–85	*Person years of effort on R&D* 1981–82	*Person years of effort on R&D* 1984–85
National security (defence)	—	—	—	—
Economic development				
Agriculture	36	55	3	2
Forestry and fisheries	—	—	—	—
Mining (prospecting)—				
energy sources	—	—	—	—
other	—	158	—	1
Mining (extraction)—				
energy sources	—	—	—	—
other	—	—	—	—
Manufacturing	—	—	—	—
Construction	—	159	—	2
Energy	3	535	1	8
Transport	196	427	12	8
Communications	—	3	—	1
Economic services n.e.c.	512	780	18	18
Total economic development	*747*	*2,116*	*34*	*40*
Community welfare				
Urban and regional planning	—	397	—	6
Environment	—	4	—	—
Health	17,758	39,446	563	643
Education	1,739	1,228	63	24
Welfare	420	558	22	16
Community services n.e.c.	35	88	1	2
Total community welfare	*19,952*	*41,720*	*649*	*691*
Advancement of knowledge—				
Earth, ocean and atomsphere n.e.c.	—	45	—	1
General advancement of knowledge	210	251	6	8
Total advancement of knowledge	*210*	*296*	*6*	*9*
Total	**20,909**	**44,133**	**688**	**740**

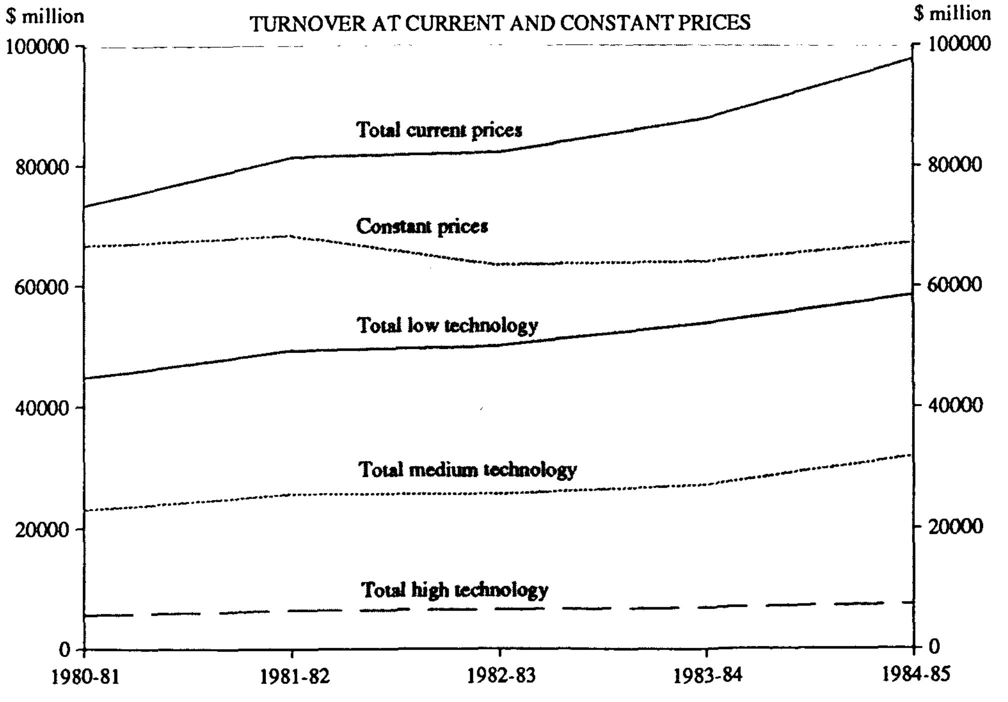
Statistics on manufacturing industry technology

The level of technological development in manufacturing industry can be viewed by classifying industries to high, medium and low technology according to the intensity of their R&D effort. Using the OECD classification by this method, high technology industries are defined as those manufacturing establishments classified to aircraft (Australian Standard Industrial Classification [ASIC] Class 3244). Communications and other electronic equipment (ASIC Classes 3351 and 3352); electrical appliances and machinery (ASIC Classes 3353–3357); pharmaceutical and veterinary products (ASIC Class 2763); and photographic, professional and scientific equipment (ASIC Group 334). Medium technology covers chemicals (apart from ASIC Class 2763); petroleum and coal products; non-ferrous metals and basic products; motor vehicles and parts, railway equipment and other transport equipment (ASIC Class 3245); industrial machinery; rubber and plastic products; and, other manufacturing (ASIC Group 348). Low technology covers food, beverages and tobacco; textiles, clothing and footwear; wood and wood products; paper and paper products, etc.; petroleum refining; non-metallic mineral products, basic iron and steel products; fabricated metal products; ships and boats; and, leather products.

The figure below shows that high technology industries as a group showed only modest current price growth in turnover in the four year period from 1980–81 to 1984–85 (31 per cent). Low and medium technology groups have performed comparably with four year growths of 31 per cent and 38 per cent respectively. In constant prices terms, total manufacturing industry turnover has shown little growth (1 per cent over the four year period).

MANUFACTURING ESTABLISHMENTS, AUSTRALIA

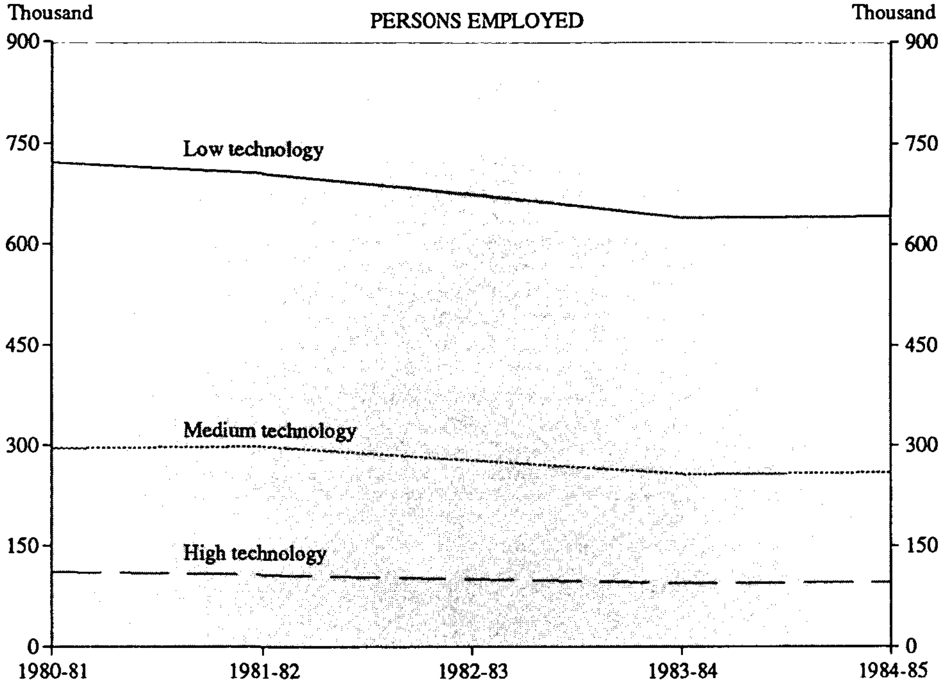
TURNOVER AT CURRENT AND CONSTANT PRICES



The following figure shows a downturn in manufacturing industry employment levels (net drops over the four years of 13 per cent, 12 per cent and 11 per cent for high, medium and low technology industries respectively). Data for the latest year available (1984–85) show modest rises over 1983–84 (1.0 per cent, 1.2 per cent and 0.4 per cent for high, medium and low technology industries respectively).

MANUFACTURING ESTABLISHMENTS, AUSTRALIA

PERSONS EMPLOYED



Trade statistics

Another way of viewing Australian manufacturing industry's level of technological development is to look at trade of high technology products. Products are classified initially according to commodity (Australian Import and Export Commodity Codes) but converted to an ASIC basis. Definitions of high, medium and low technology groups according to ASIC are the same as above.

The current price value of exports of Australian manufactures is increasing for all groups but most of all for low technology products (17 per cent increase between 1984–85 and 1985–86 compared to 9 per cent and 10 per cent for medium and high technology products respectively), as shown in the figure below.

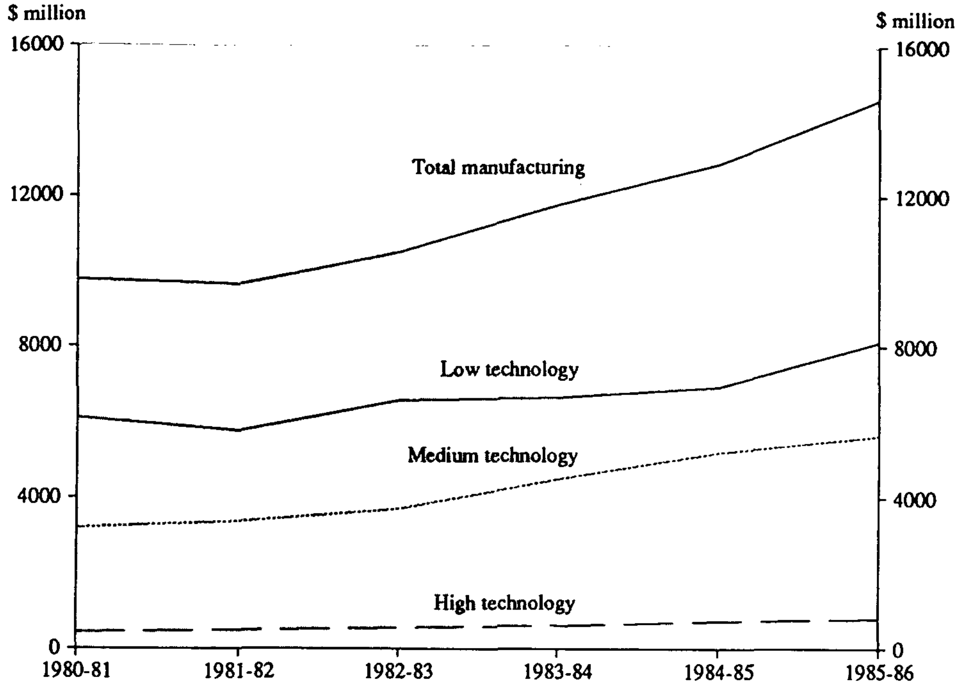
Current price export growth over the four year period 1980–81 to 1984–85 is, in contrast, highest for the high technology group (65 per cent compared with 62 per cent for medium and 13 per cent for low technology).

The figure below shows that the current price value of total imports of manufactured goods has increased more than exports over the period 1984–85 to 1985–86 (20 per cent compared to a 13 per cent increase for the total current price value of exports). The highest increase was for high technology products (27 per cent compared with 24 per cent and 10 per cent for medium and low technology products respectively).

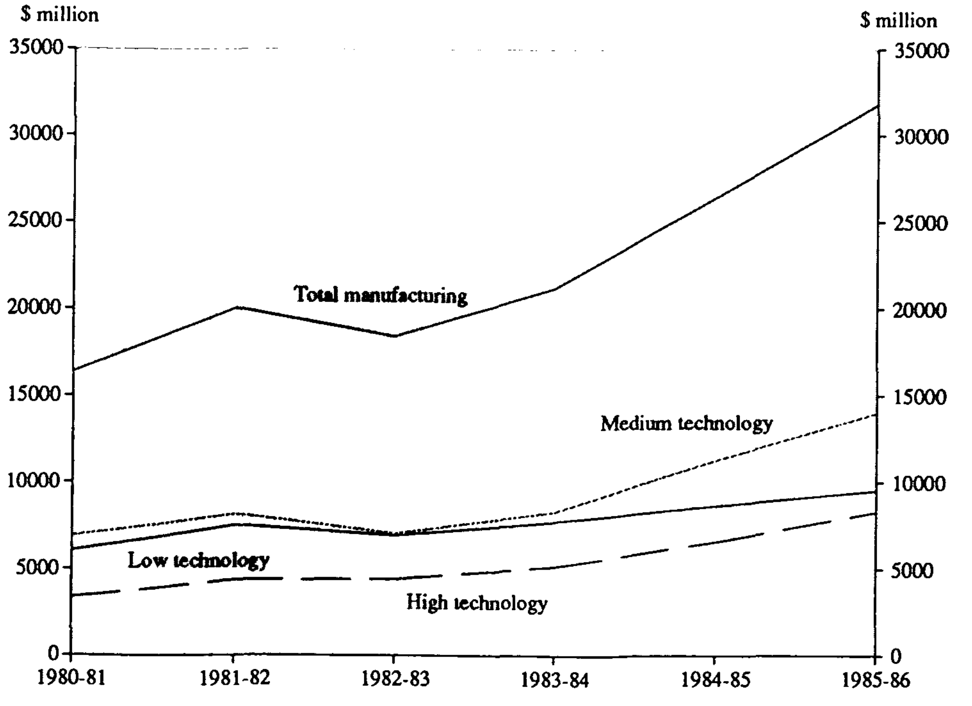
Over the four year period 1980–81 to 1984–85 the value of imports of high technology goods has increased the most (95 per cent compared to 62 per cent and 42 per cent for medium and low technology goods respectively).

The sudden devaluation of the Australian dollar in 1983 will have contributed to some extent to the rise in the value of imports. To a lesser extent perhaps, it can be expected that the value of exports will continue to rise in the future due to the relatively low value of the Australian dollar.

EXPORTS OF MANUFACTURES, AUSTRALIA



IMPORTS OF MANUFACTURES, AUSTRALIA



Other activities

For information on other activities related to science and technology, *see Year Book* No. 70. That edition contains information on scientific and technological information services (page 640), social science and humanities research (page 652) and international activities (page 653).

Additional information

Additional information on topics presented in this chapter may be found in the annual reports of the organisations mentioned, particularly the Department of Industry, Technology and Commerce, the CSIRO, the Australian Nuclear Science and Technology Organisation, the Department of Defence, and in the annual *Science and Technology Statements*. Statistical information on R&D for the years 1968–69, 1973–74 and 1976–77 may be found in the reports published by the (then) Department of Science on Project SCORE. Statistical information on R&D relating to 1978–79, 1981–82, 1984–85 and 1985–86 may be obtained from the Australian Bureau of Statistics (ABS). Further statistical information on higher education is obtainable from the Commonwealth Tertiary Education Commission. Trade and industry operations data are available from the ABS.

The Department of Industry, Technology and Commerce *Australian Science and Technology Indicators Report*, published in 1988, gives a good overview and analysis of science and technology information in Australia by the use of S&T indicators. It presents information on R&D effort and expenditure, science and technology workforce, S&T information resources, scientific equipment and facilities, literature-based S&T measures, patent activity, technology training, financial support for technological development, industry operations and trade by level of technology, and transfer of technical knowledge.

SCIENCE AND TECHNOLOGY IN AUSTRALIA

(This special article has been contributed by the Commonwealth Scientific and Industrial Research Organisation—written by Graeme O'Neill)

Several lines of evidence indicate that by 60,000 years ago, a coastal culture from the Indonesian archipelago developed a sailing craft capable of undertaking short ocean voyages. From this culture came the ancestors of Australia's Aboriginals. Uniquely, the colonisation of Australia demanded the use of maritime technology—the world's other inhabited continents were all colonised via overland routes. No direct overland connection has ever existed between Australia and the Indonesian archipelago; the smallest gap even at times of low sea level was at least 70 kilometres. Thus, the presence of humans in Australia some 50-60,000 years ago can only be explained by their use of boats or rafts.

In time, these early marine technologists made a successful transition to a hunter-gatherer existence, and developed a unique hunting weapon, the boomerang, with aerodynamic principles that anticipated the curved aerofoil wing that millenia later would permit man himself to take to the air. Aboriginal technologists also developed the woomera, a mechanical throwing device based on the lever, which enabled a spear to be thrown with much greater force and accuracy than by the human arm alone. They also developed tools for making fire at will, and employed fire to modify the environments in which they hunted, and as an aid to hunting itself. And although Aboriginal cultures never studied their environments in a scientific sense, they understood the world around them with an intimacy that has not yet been achieved by formal scientific study.

Australia's geographic isolation and harsh environment demand innovation; the technological achievements of the continent's original colonisers were an impressive response to adversity. It cannot be claimed that innovation began with the arrival of the continent's first European colonists 200 years ago; the scientific and technological achievements of Australians during those two centuries must be seen as part of a 60,000-year continuum of human progress, impelled by isolation and environmental adversity.

Indeed, the efforts of Australia's first British colonists to transplant agricultural systems evolved for temperate Europe's climate and fertile soil proved a failure in the warmer, drier climate and poor soils of the Hawkesbury region. English winter wheats were poorly adapted to such conditions and susceptible to disease, and yields were poor. The wheat industry, which today dominates Australian agriculture, limped on throughout the greater part of the 19th century. It took an historic confluence between a scientific revolution and a scientific genius in the 1880s to establish it as a major force in the Australian economy. Amid scepticism from his peers and the community, William Farrer, former Oxford mathematics wrangler, showed that systematic breeding principles could be applied to improving and adapting wheat to Australian conditions. Farrer bred rust-resistant varieties, but his more important achievement was to develop earlier-maturing varieties like 'Federation' which, by avoiding the worst heat of summer, enabled the wheat industry to expand out of the cooler, wetter highlands into the broad, drier plains of the inland. By the second decade of the 20th century, the wheat industry was booming. Although the genetic legacy of Farrer's wheats has been diluted, the systematic, scientific approach to breeding, which he was among the first in the world to exploit, remains his monument. It set a pattern for wheat breeding that is still used in Australia's wheat breeding institutions today.

Australia's other great agricultural industry, wool-growing, had its genesis soon after the founding of the colony. Captain John Macarthur, the Reverend Samuel Marsden, William Cox and Alexander Riley imported a number of Spanish Merino sheep. Macarthur and Marsden were probably the most prominent figures in developing an improved merino strain yielding an exceptionally fine, high-quality wool. The wool industry boomed. By the early 1890s, sheep numbers had reached a peak of 100 million but then went into sharp decline, particularly in drier regions, due to the impact of overgrazing on native pastures, drought and competition from introduced rabbits. Australian scientists have continued to grapple with these problems during the 20th century with mixed success.

Innovation in Australia during the 19th century was largely the domain of the individual; given the central importance of agriculture, grazing and minerals—chiefly gold—to the colony's economy, it was in these areas that Australians displayed their greatest inventiveness.

Some inventions were bizarre, others highly practical. The stump-jump plough, invented by Robert and Clarence Smith in 1876, enabled cultivation of mallee lands that had previously proved untillable because of the huge sub-surface mallee roots left after surface growth had been removed.

In 1877, Frederick Wolseley patented on the world's first mechanical shearing equipment, whose basic design still edures in modern shearing sheds. Another durable invention was James Alston's unique Australian windmill, used to pump artesian water for livestock in arid areas.

In 1884, 19 year old Hugh McKay demonstrated a prototype of his wheat stripper-harvester, which became the first commercially successful machine capable of stripping, threshing, cleaning and bagging wheat in one continuous operation. By 1902 McKay was exporting harvesters, mainly to Argentina.

In the 1890s, Christian Koerstz developed a cheap wool press which could be operated by two men, allowing even small graziers to build their own wool sheds, where previously they had taken their sheep to large landholders for shearing.

The same year saw Australian veterinary scientists develop a vaccine against anthrax after a successful visit by one of Louis Pasteur's staff—an early example of the extensive international exchanges that have so benefited 20th century Australian science and technology.

Australian research during the 19th century was focused on the natural sciences. The richness of Australia's unique flora and fauna was hinted at by the first formal collections of plants, animals and insects by Joseph Banks and Daniel Solander, naturalists with Captain James Cook's *Endeavour* expedition to the east coast in 1770. This was confirmed by a succession of explorer-naturalists and botanists, chiefly of British origin. Robert Brown, naturalist on Mathew Flinders *Investigator*, during its Admirality expedition to Australia in 1801, collected more than 3,000 plant specimens. The first part of his *Prodromus Florae Novae Hollandiae et Insulae Van-Dieman*, published in 1801, revolutionised botanical classification, and its insights into the anatomy, physiology and function of Australia's plants stimulated interest in the new science of geography. John Gould studied and painted many of Australia's birds and animals in 1838-40 and Joseph Hooker investigated the flora of Tasmania and in his *Flora Tasmania*, published in 1859, discussed its biogeography in terms of the new theory of natural selection propounded by Charles Darwin. Darwin himself had visited Australia in 1836 as the *Beagle* made its way home from its voyage to South America and the Galapagos Isles.

German-born botanist Baron Ferdinand von Mueller, who was appointed Victorian Government botanist in 1853, travelled throughout south-eastern Australia developing a formidable collection and knowledge of Australia's flora. He published 800 papers and many books and was left embittered when the task of writing the first *Flora Australiensis* went to eminent British botanist George Bentham. Bentham drew heavily on von Mueller's data, but never visited Australia himself.

Astronomy, the science which was ultimately responsible for Australia's colonisation (the *Endeavour* had journeyed to Tahiti to allow scientific observations of the transit of Venus across the face of the sun in 1796), was also a significant research activity in Australia. Southerly latitudes and clear skies offered a much richer vista of the universe. Sir Thomas Brisbane, Governor of New South Wales in 1821 and who in the same year became president of the Philosophical Society (forerunner of the Royal Society of New South Wales), was a keen amateur astronomer. He brought with him the best available astronomical instruments and two expert astronomers, Carl Rumker and James Dunlop. Brisbane built a small observatory at Government House in Parramatta which rapidly gained an international reputation. Among its achievements was the first observation of Encke's comet in 1822.

John Tebbutt's astronomical observations from 1854 onwards led to the discovery of several more comets, as well as several double stars and variable stars, and several new satellites of Jupiter. From such beginnings, Australia developed a reputation in international astronomy which has been continued in modern times by the achievements of its optical and radio astronomers.

One of Australia's most brilliant scientists, but one who received little recognition in his time, was British-born Lawrence Hargrave, inventor of the box kite, who developed a theory of aeronautics based upon his experiments with kites and model aircraft. He discovered that wings with curved surfaces gave twice the lift of flat wings, and that a tail plane gave added stability to his model aeroplanes. Both principles were of fundamental importance to the development of flight. Hargrave also developed a workable radial rotary airscrew engine which formed the basis for the first engines used in European aircraft in the 20th century.

Henry Sutton, a music shop proprietor, designed a continuous current dynamo as early as 1870, constructed as many as 20 different types of telephone at the same time that Alexander Graham Bell was achieving recognition for his invention of the telephone in America. During the 1870s, Sutton carried out experiments with heavier-than-air materials for flight.

Australia's first university, the University of Sydney, had been founded in 1850, but did not establish a separate science faculty until 1879. Melbourne University was founded in 1853, Adelaide University in 1874, and the University of Tasmania in 1889.

By the late 19th century, Australian science had developed considerable momentum. Royal Societies or Philosophical Societies existed in all the eastern States by 1884, and university researchers were making important contributions to international science and technology, principally in the area of fundamental studies. Horace Lamb, who became the first Professor of Mathematics at Adelaide University a year after it was established in 1874, was later elected a Fellow of the Royal Society for outstanding research into the motion and properties of fluids. Melbourne University chemist, Professor David Masson, was also elected to the Royal Society for his fundamental work on the constitution of atoms and his theory of the dissociation of electrolytes in water.

The steady expansion of agriculture in Australia confronted the industry with a range of environmental and agronomic problems. Additionally, crops and animals that had been selected for northern hemisphere conditions performed relatively poorly in Australia. The need for scientific study of agriculture was realised, and in 1885, Roseworthy Agricultural College was founded in South Australia to teach the principles of agriculture and to investigate its problems. Victoria's Dookie Agricultural College was founded a year later. N.S.W's Hawkesbury Agricultural College was founded in 1891; that same year a horticultural college was founded in Victoria.

Australia's geology was very different from that of other countries; there was lively debate over the age of the continent, and the discovery of major mineral deposits during the 1800s provided economic incentive for geological research and exploration. The State governments sponsored geological and mineralogical surveys which, in addition to discovering mineral deposits, also yielded geological, mineralogical and topographical maps upon which renewed mineral exploration in the 20th century was based.

Australia's minerals industry traces its beginnings to the 1797 discovery of coal on the banks of the Hunter River, as well as at Coalcliff 65 km south of Sydney. The mining technology of the day was inadequate to extract the coal; Australia's distinctive geology has continued to pose special problems for mining operations, and throughout the 1800s required the development of innovative mining techniques for important minerals. By the late 1800s, gold, tin, copper, silver, lead and zinc orebodies were being mined, often at considerable depth, where hazards to miners were great. Australia was the world's largest producer of gold, and at Bendigo, novel deep-drilling techniques had been developed which permitted recovery of ore from considerable depths, at a time when most gold mines were still extracting gold from basically alluvial sources. Research for safer and more efficient mining techniques continues today.

Mineral extraction techniques evolved; the bromo-cyanide process for gold extraction was first demonstrated at Kalgoorlie to recover gold from telluride ores in 1899 and the world's most important mineral extraction and separation technique, the flotation process, was first developed on a commercial scale in Australia by Charles Potter, a Melbourne brewer and chemist. Potter's process, patented in 1901, employed a late 18th century discovery that powdered mineral ores particles could be brought to the surface and suspended by attaching to bubbles passed through ore-charged liquids. First used at Broken Hill in 1901, Potter's flotation process initially yielded a collective aggregate of silver, lead and zinc, but later developments, some of them arising from fundamental studies, saw the flotation process progressively refined to the point where lead, zinc and many other commercially important minerals could be floated out selectively.

Science and technology in 20th century Australia

With Federation in 1901, and with the Australian economy evolving rapidly in diversity and complexity, the administration and funding of science in Australia took on a more systematic pattern, chiefly because of the increasing involvement of the new Commonwealth Government. In time, it would become the major sponsor of Australian science and technology, giving it the cohesion and direction that had been absent in the previous century. Australia's traditional reliance upon agricultural and mineral exports saw both government and private industry research focused in these areas, a pattern which was to predominate until recent times.

Australia's fifth university, the University of Queensland, was the first university established in the 20th century, in 1910; Western Australia became the last State to establish a university, the University of Western Australia, in 1913. By the 1980s, Australia had 19 universities—Sydney and Melbourne each have three, Brisbane, Adelaide and Perth each have two, Hobart has one and there are universities in the Australian capital, Canberra, and the major provincial centres of Geelong, Armidale, Townsville, Newcastle and Wollongong.

Australia's universities have made important contributions to international science and technology. In 1907, Professor O. U. Vonwiller of Sydney University showed that amorphous selenium would conduct electricity induced by light, anticipating the development of the modern photocopier. In 1928, E. J. Hartung of Melbourne University showed that the photographic paper darkened when exposed to light because silver chloride decomposed, giving off chlorine and precipitating silver.

In the first half of the 20th century, universities concentrated on their educational role. Their links with industry were oriented mainly towards agriculture and mining, and interaction with manufacturing industry was at a low level.

In 1926, the Commonwealth established the Council for Scientific and Industrial Research (CSIR), progenitor of the Commonwealth Scientific and Industrial Research Organisation. CSIR's early work focused on research for agriculture which, as the economic impetus of great gold rushes of the latter half of the 19th century ebbed, had become the mainstay of the economy. Agriculture was centred on wheat and grazing; wool had been established as a major export the previous century, and after a faltering start, the wheat industry was prospering from the legacy of breeders such as Farrer.

CSIR's early work was constrained by limited resources but gradually it built up individual research programs, and then specialised research divisions, studying animal health and nutrition, soils, economically-significant plants, fisheries, food preservation and transport. Not until 1936 did the Australian Government decide to extend CSIR's activities into secondary industry. It proved a timely decision, providing a springboard for the development of industries that strengthened Australia's effort during World War II.

During the War three new divisions were formed, dealing with dairy research, radiophysics, and lubricants and bearings—the latter became the Division of Tribophysics (surface physics). Some of CSIRO's most significant achievements, even to the modern day, trace back to the wartime establishment of these divisions.

One of the most important developments in CSIR was the establishment of a National Standards Laboratory in 1939 to administer and refine standards of measurement, as well as to calibrate the measurement tools of Australian industry. It underpinned the contribution of manufacturing industry to the war effort.

In the same year, CSIR began a top-secret radar project in a laboratory at Sydney University, which later allowed the deployment of a transportable radar system in the Pacific war theatre.

In 1947, man-made rain fell for the first time in Australia, and probably in the world, when a CSIR aircraft seeded clouds over the Blue Mountains with silver iodide. Research into rainmaking was finally discontinued in 1981 after it was concluded that no useful increase in rain could be produced by cloud seeding, a finding which itself produced controversy.

In the years immediately after the War, a debate arose over potential conflict between CSIR's need for scientific freedom, and the preservation of national security. The Science and Industry Research Act of 1949, which formally established the Commonwealth Scientific and Industrial Research Organisation (CSIRO), resolved the issue by specifically precluding its involvement in secret or classified research of a military nature.

CSIRO's management was now conducted by a small Executive, instead of the council that had guided CSIR. The Executive's first chairman was Ian Clunies Ross (later Sir Ian), whose vision of the potential contribution of scientific research to Australia's development, alloyed with his exceptional skills as an advocate and lobbyist for science, was primarily responsible for a remarkable decade of expansion and diversification of the Organisation from 1949 to 1959.

In 1945, CSIR had established a Division of Radiophysics to study the sun. By the 1950s, CSIRO led the world in radioastronomy, and in 1961 began studies of the radio universe with one of the world's largest radiotelescopes at Parkes, New South Wales. The instrument, which in enhanced form is still in use today, has yielded important discoveries about the evolution of the universe. Among other things, it has located half of the known pulsars—rapidly rotating remnants of stars destroyed by supernovas—and has identified complex organic molecules in space which could have been building blocks for life. From the mid-1960s, it served as a powerful primary receiver for transmissions from US spacecraft, relaying Mans' first words from the moon, and playing major roles in the dramatic rescue of the astronauts aboard the ill-fated Apollo 13 mission and the tracking of the Giotto space probe to Halley's Comet in 1986. CSIRO's new Australia Telescope, an array of radio antennae incorporating the Parkes radiotelescope, is due to be completed during 1988. It will have equivalent power to a radiotelescope 300 km in diameter, and will be capable of mapping the furthest reaches of the universe.

The Division of Radiophysics has made two outstanding contributions to air navigation technology; firstly with the development of the Distance Measuring Equipment system, based on triangulation with radio beacons, and secondly, with Interscan, a microwave-based landing system that allows aircraft to locate their position in three-dimensional space with great precision under all weather conditions. Interscan allows a choice of widely-varying landing approaches to be chosen, helping to minimise noise pollution and greatly increasing the flexibility and safety of air traffic control. In 1978 the International Civil Aviation Organisation selected Interscan as the international standard for aviation landing systems to serve into the 21st century.

The three decades after World War II saw CSIRO establish a reputation for excellence in research in many fields. A huge rabbit plague had developed during the war years, and was having a disastrous effect on the productivity of grazing land. CSIRO imported a virus for the rabbit disease myxomatosis, which after initial failure, took hold in Victoria in 1950 and killed millions of rabbits.

In 1952 CSIRO scientist Alan Walsh developed the atomic absorption spectrometer, a device capable of rapdily analysing the chemical constituents of materials as diverse as mineral samples, human blood or polluted water. Described as the greatest advance in chemical analysis this century, the atomic absorption spectrometer has saved mineral exploration companies millions of dollars by performing in minutes complex chemical analyses that had once taken many days.

So extensive and diverse are CSIRO's research activities that any account of its achievements is necessarily eclectic. Other significant advances in the post-war decades include:

- Partially-stabilized zirconia (PSZ), described as the world's toughest ceramic.;
- A new generation of safe, potent insecticides called insecticidal esters, based upon fundamental studies of the interaction of chemical molecules with insect nerve membranes. Insecticidal esters will not persist in the environment and have very low toxicity to other animals;
- Biological control of skeleton weed during the 1960s, and sirex wood wasp in pine plantations in the 1970s. More recently, a highly successful biological control program against the world's worst water weed, the floating fern *Salvinia,* in Australia, Papua-New Guinea and several Asian and African nations. *Salvinia* is expected to be reduced to an insignificant economic problem around the world by the 1990s;
- SIROTEM, a new electromagnetic device which allows hidden sub-surface orebodies to be detected at depths up to 300 m;
- Advanced satellite image-analysis techniques, which have revolutionised strategic exploration for minerals, allowed large-scale mapping of Australia's environments, and permitted monitoring of the development of crops;
- A computerised system for managing cotton and its pests, based on an understanding of how the crop develops and of the life cycles of pests and their natural predators;
- Several advanced methods of purifying water, based on ion-exchange resins or tiny magnetic beads which selectively remove salts and other impurities;
- Genetically engineered animals. CSIRO produced Australia's first genetically-engineered sheep in 1986. The technique ultimately promises sheep which will grow faster and larger under the influence of an extra growth hormone gene in their cells;
- A vaccine which promotes twin births in sheep, accelerating productivity for the fat lamb industry;

- Genetic engineering of plants. CSIRO produced Australia's first genetically engineered plant in 1985, and is now working to produce genetically engineered cereals;
- A technology for custom-designing computer chips containing more than 100,000 transistors. The technology allows research institutions and industry to design chips for specialised applications in scientific devices or high-technology manufactured goods;

Other Commonwealth instrumentalities, universities and other education institutions, medical research centres, State research bodies and, to a lesser extent, private industry, have provided the warp to CSIRO's weft in the fabric of Australian science and technology. Some of their achievements in recent decades include:

- Development of a new high-efficiency solar cell by the University of NSW, employing a simpler metal-insulator semiconductor system;
- Melbourne University's 'bionic ear', an implant for the totally deaf, which analyses sound and encodes it for detection by the brain;
- A new process for producing ethanol by fermentation, using the bacterium *Zymomonas mobilis,* instead of yeast, developed by the University of NSW;
- The identification and isolation by the Australian Institute of Marine Science of a natural agent that protects corals from damaging ultra-violet radiation. The compound has potential uses in commercial sunscreens, and in weathering-resistant paints and plastics;
- Commercial development and release by a private company, Biotechnology Australia, in 1986 of Australia's first genetically-engineered vaccine for use against lethal diarrhoea in piglets;
- Development by Comalco of a highly durable lightweight aluminium alloy, called 3HA, suitable for use without steel liners in alloy engine blocks, as well as in diverse applications involving high strength aluminium castings;
- A new type of automotive engine, employing an orbital motion, developed by the Perth-based private inventor, entrepreneur and engineer, Ralph Sarich, and developed by his company. The new engine has considerably fewer moving parts than any existing automotive engine, and delivers equivalent power from a much smaller size. Sarich has also devloped a revolutionary new fuel injection system; both inventions are approaching commercial release;
- The Jindalee over-the-horizon radar system, developed by the Defence Science and Technology Organisation, which bounces transmission off the ionosphere, allowing targets hundreds of kilometres off Australia's north-west coast to be detected;
- Synroc, a synthetic composite mineral for the safe, long-term immobilisation and storage of radioactive wastes, developed by the Australian National University;

Medical science in the 20th century

At the time of Federation, the States ceded many functions to the Commonwealth, but preserved their responsibility for the health of their communities. As a result, many of Australia's medical research institutions are administered by their respective States, or in conjunction with the Commonwealth. However, most derive a significant part of their research funding from the Commonwealth, principally from the National Health and Medical Research Council, or from various private foundations such as the National Heart Foundation and the various State Anti-Cancer Councils. Under this system, medical research has flourished and Australia enjoys an international reputation for excellence in many fields. Some of the important achievements of Australian medical research include:

- Australian researcher Priscilla Kincaid Smith was one of the first to recognise the link between indiscriminate use of analgesics and a high incidence of kidney damage;
- Although the first birth resulting from in-vitro fertilisation occurred in England, Australia has become pre-eminent in the treatment of human infertility and has a higher success rate than any other country in the world, due largely to the pioneering work of Professor Carl Wood and his associates at Monash University;
- Researchers from Melbourne University and the Royal Children's Hospital in the early 1970s established that rotaviruses were the most important single agent responsible for infantile diarrhoea in both developed and developing nations. Research is in progress to develop a genetically engineered vaccine;
- In collaboration with the Australian National University, CSIRO has determined the structure of one of the key proteins of the influenza virus, and is working with ANU to develop a drug to treat influenza, as well as a synthetic vaccine;

- The Walter and Eliza Hall Institute's recent development of a prototype vaccine against malaria, from basic studies of the antigenic components of the protein coat of the malaria parasite. An estimated 300 million people around the world suffer from malaria, and an effective vaccine would represent one of the most important developments of 20th century medical science;
- Adelaide University's development, via genetic engineering, of a prototype oral vaccine against cholera and typhoid, two other major diseases in developing nations;
- A synthetic human growth hormone, developed by Sydney's Garvan Institute of Medical Research, the University of N.S.W. School of Biotechnology, and California Biotechnology, which could provide a safe treatment for hereditary dwarfism.

The future of Australian science and technology

The future of Australian science and technology appears bright. The nation has no shortage of original thinkers, as attested to by the volume of Australian research papers contributed to the international scientific literature, particularly in areas of fundamental knowledge. That very strength, however, hints at a chronic problem—the low rate at which original ideas are translated into practical applications, or into marketable products or processes that can be marketed within Australia and overseas.

The underlying reasons are historic; most Australian companies were small by overseas standards and could not sustain their own in-house research programs. In the post-War years, Commonwealth Governments actively encouraged multi-national companies to establish subsidiaries in Australia, as a means of diversifying the economy and providing employment, but a penalty in this approach was that such companies were able to rely upon imported technology and ideas from their overseas parents. Some even absorbed progressive local companies, with adverse effect on the level of private research and development.

In the past three decades, the level of privately sponsored research and development declined to one of the lowest levels of any Western nation. There has been little economic pressure to innovate or to maintain technological parity with overseas manufacturers. As a consequence, privately sponsored research stagnated and declined. Until quite recently, Australia's need for foreign exchange has been satisfied by international markets for wheat, wool and minerals, and manufacturing industry fell behind its counterparts in Europe and the United States—not only in its level of involvement in export markets, but in the production technologies it was employing, so that its efficiency declined as well. By the late 1970s, with international export markets for agricultural produce and raw materials declining, and dominated increasingly by manufactured, high-technology goods, the imbalance in Australia's economy was increasingly apparent, and the need to restructure and reorient science and technology towards the task of improving manufacturing industry's performance had become imperative.

Historians may argue that Australia failed to heed the first major warning of the vulnerability of its economy to changes in the marketplace. In the 1950s a new generation of synthetic fibres began to erode markets that had traditionally been dominated by wool. In an intensive research effort from that time onwards, CSIRO studied the biological, biochemical and physical properties of wool and produced innovations in wool processing and wool treatment, such as permanent-pleat wool garments, shrinkproof wool fabrics, and Self-twist spinning—a faster and more economical spinning technique which revolutionised wool spinning around the world. CSIRO also developed cheaper methods of processing wool and evolved a marketing system based on objective measurement of wool's properties, which had traditionally been assessed by eye and hand. This intensive and comprehensive research and development program maintained wool's reputation as the premier fashion fibre in world markets, where the industry might easily have foundered in the 1960s, with disastrous effect upon the Australian economy.

In the past few years Australian research institutions have begun to pay increasing attention to the commercialisation of their research. CSIRO, a number of universities, and private medical research centres have individually or jointly established their own commercial companies. Medicine, veterinary science and agriculture, the historical strengths in Australian research, seem destined to play an important role in Australia's economic future.

Australian scientists and technologists are contributing to the spectacular international growth of information technology, through the development of innovative computer hardware and software, networking systems, and advanced information storage and retrieval systems. Information technology is a growth industry that provides marketable commodities in its own right, but its greater contribution may be as a catalyst for the advancement of existing industries in Australia, which are showing encouraging signs of exploiting technology to improve their production efficiency, and to develop innovative products for local and export markets. It also provides a means of gaining access to a vast pool of information and ideas held in international data bases and overseas laboratories. Australia's substantial and continuing contribution to this pool has given it reciprocal rights to employ the information to its own advantage; the nation's prosperity during the next two centuries will be founded on the sharing of information with the international community, its own continuing intellectual vigour and a resurgence of the enterprise and industrial dynamism that characterised its earlier years.

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