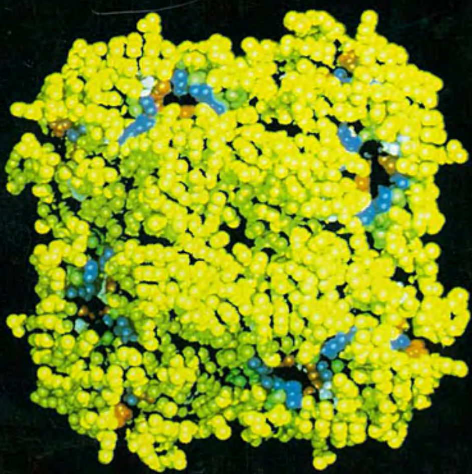
CREATING WEALTH FOR AUSTRALIA

CSIRO AND THE MANUFACTURING SECTOR



CSIRO
AUSTRALIA

Cover photo: Neuraminadase, a surface protein from the influenza virus. CSIRO structural analysis of this protein has formed the basis for development of an anti-influenza drug by Biota Holdings Ltd and Glaxo Australia.

CREATING WEALTH FOR AUSTRALIA

CSIRO AND THE MANUFACTURING SECTOR

FOREWORD

This document, prepared as part of CSIRO's input to the Industry Commission Inquiry into Research and Development, provides an overview of CSIRO's contribution over the past decade or so to wealth generation by Australia's manufacturing sector.

The report describes the two major aspects of CSIRO's contribution - namely its scientific and strategic research activities and the means by which it uses these to interact with Australian industry - through contract and collaborative research with companies, through consortia, and through industry associations and informal networks - with a view to maximising the return over time on public investment in R&D.

Three important points emerge from this analysis, I believe:

- CSIRO's strong strategic research base in a range of areas important to manufacturing
- evidence of significant achievement over the past decade in innovation and in wealth creation for Australian Manufacturing
- a commitment to build on these achievements and improve still further in our performance and in helping deliver valuable outcomes.

This document has been prepared by Garrett Upstill from the Institute's Canberra Office, and draws on a background report by consultant Christine Williams. It principally reflects the experience of the five Divisions of the Institute of Industrial Technologies which conduct the bulk of CSIRO's manufacturing-related research. Reference is also made to other parts of CSIRO as appropriate.

CM Adam
Director
Institute of Industrial Technologies

July 1995

1 CSIRO MANUFACTURING RESEARCH IN 1995

1.1 Facing New Challenges

The past decade has seen significant changes in the manufacturing sector as Australia has moved toward a more open and internationally competitive economy. These changes have been accompanied by an increased awareness of the importance of technology and innovation in achieving international competitiveness. Supported by programs such as the 150% tax concession, Australian companies have given greater attention to the role of innovation in improving their performance.

CSIRO has undergone significant changes in the past decade in response to the new environment, with a much stronger focus on the commercial needs of the manufacturing sector. CSIRO spends about $145M per year, or just under a quarter of its total budget, on Manufacturing Research.[1]

The challenge for CSIRO and local industry is to use our limited research and technology resources to enhance our competitiveness on international markets. The spectacular growth in elaborately transformed manufacturing exports over the past decade - 17% growth per annum - is grounds for believing that this challenge is being addressed.

Moreover, CSIRO is playing a critical support role for industry. This report sets out the way in which CSIRO has worked with the manufacturing sector and how its role has evolved and continues to evolve to meet Australia's new challenges.

1.2 The National R&D Setting

Australia's manufacturing R&D effort remains less than that of most of our major trading partners despite increases in recent years. R&D activity is thinly spread among the private sector with just a dozen or so companies spending more than $20M per annum and the balance being conducted by about 2000 companies. Small and Medium Enterprises (SMEs) with less than 500 employees account for about 50% of the total.

Total manufacturing R&D undertaken in Australia in 1992/93 amounted to $2.1B, which although sizeable is less than the R&D budgets of many multinational companies. CSIRO manufacturing research accounted for about 7% of the national total. Although not a dominant R&D player overall, CSIRO is particularly important in relation to longer-term **strategic research.** Private sector R&D is heavily weighted toward **experimental development.** (See Figure 1)

1.3 Tracking the Changes

While CSIRO research dates back some decades its integration with Australia's industry base has more recent origins. A key marker in this development was the 1977 Birch Review which noted that for Australian industry:

> 'The picture is one of firms of small scale, by international standards, with low levels of investment'... and ... 'a correspondingly low level of research awareness within manufacturing firms' (Birch Report p127)

CSIRO's main role was 'to fill a gap in national research, with what we call strategic mission-orientated work, which would otherwise remain unfilled. This is the kind of rather long-term work for the community benefit which cannot be, and is not being, carried out by industry or other organisations.' (Birch Report, p. xxvii)

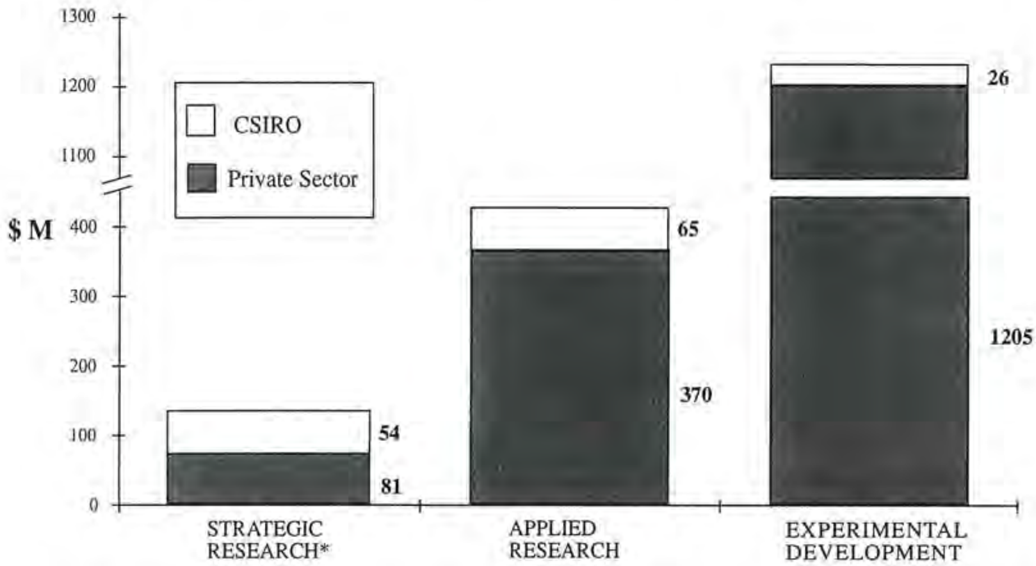
The Review led CSIRO to the establishment of Institutes based on 'national development sectors'.

Subsequent events in the 1980s and 1990s included:

- **the lowering of tariffs** and the opening of Australian industry to international competition which formed a backdrop to changes in CSIRO's role. These changes meant Australian manufacturers were no longer protected from international competition, and were obliged to look beyond domestic markets and to indigenous technology to compete internationally. Quality and performance have become more closely linked to technological innovation and R&D. Business R&D spending grew from 0.22% of GDP in 1981 to 0.69% of GDP in 1992 (1995/96 S&T Budget Statement) although Australia ranks relatively low among industri-

[1] In this report CSIRO manufacturing is taken to consist of the research activities of the Institute of Industrial Technologies (Divisions of Applied Physics, Biomolecular Engineering, Chemicals & Polymers, Materials Science & Technology, and Manufacturing Technology). Other manufacturing research conducted within CSIRO is explicitly identified when referred to in the report.

Figure 1 Manufacturing R&D Expenditure 1992/93



ABS 8104.0, 1992-93 Research and Experimental Development, Business Enterprises, Australia; CSIRO data.
*ABS Classification comprises Strategic Basic and Pure Basic research. CSIRO effort is 90% Strategic and 10% Pure Basic research

alised countries in terms of business R&D spending.

- **the 1985 ASTEC** review which recommended increased applications-oriented research. It noted low private sector support for applied research and experimental development in Australia compared with most other developed countries and pushed for greater emphasis on shorter term, more directly applicable activities, so that CSIRO could fill the private sector gap. CSIRO's role then changed to give increased focus on important practical problems confronting industries as well as long-term, high-risk strategic research which would be broadly applicable to a range of industries.

- **the 1987 review of CSIRO by McKinsey & Co** which led to significant changes in the Organisation's structure, ethos and operations. These were designed to improve its focus on the transfer of research results into Australian industry as well as providing an awareness of important international technology trends. The Review led to the present Institute of Industrial Technologies which groups together five front-line manufacturing Divisions. One subsequent development was a new charter for the Division of Biomolecular Engineering to focus on support for Australia's burgeoning pharmaceutical industry.

- **the 1988 Ministerial Guidelines** which required, *inter alia,* CSIRO to conduct strategic and applied research in support of national economic, social and environmental objectives and that CSIRO should strengthen means to ensure that its research results were exploited to the greatest benefit of the Australian community. These were linked to the requirement that the Organisation should move to earn 30% of its funds from external sources, a level reached in 1991 and maintained since then.

- **increased industry involvement** and funding of CSIRO research. Sponsored research in CSIRO funded by the Australian private sector companies climbed from $13.5M to $58.6M over the 6 years to 1993/94. In the case of the Division of Manufacturing Technology external earnings increased sixteen-fold in seven years, from about $0.5M in 1986-87 to more than $8M in 1993-94. Notable changes have been the increased role of firms in setting priorities for manufacturing research, and early-stage company involvement in major research projects.

- **stronger industry orientation of CSIRO researchers.** The redirection of researchers' attention over the past decade towards greater emphasis on productive industrial outcomes has been substantial. The central challenge remains how best to use CSIRO's strong strategic research base to help Australian manufacturers generate internationally competitive products and processes - to generate wealth for Australia.

- the **1995 Board Evaluation** of CSIRO's management and structure has led to a discussion paper (March 1995) with a number of proposals directed toward enhancing the customer focus, flexibility, adaptability and corporate orientation of the Organisation. The paper is currently under review.

2. PUTTING SCIENCE TO WORK

2.1 Core Capabilities

CSIRO has been home to many of Australia's best physical and biological scientists over the years and has a distinguished research tradition in many areas. While the focus on delivering outcomes for the manufacturing sector has increased in recent years there have been a number of notable past achievements in manufacturing. These include the invention of the Atomic Absorption Spectrophotometer (an instrument widely adopted across the world and the source of several hundreds of millions of dollars of export income), high-performance ceramics, Australia's advanced banknote technology, and ground-breaking work towards a new anti-influenza drug. In addition, CSIRO has provided a world class measurement standards capability in support of manufacturing for the past three decades.

The Organisation's strategic research role hinges on its core capabilities in a wide, but by no means comprehensive, range of research areas. These core capabilities are characterised by:

- **people** - in these core capabilities CSIRO maintains world-class research teams of "critical mass"
- **equipment** - equipment support and facilities that enable them to match research teams in similar fields elsewhere in the world
- **intellectual property** - strategic research in these areas is directed toward developing and expanding a strong intellectual property (IP) position so as to allow the benefit of future applications to be captured by Australian companies.

Examples of research in areas of world-class core capabilities are protein crystallography, plasma physics, solid-state oxide crystallography, organic chemical design and synthesis, machine vision and measurement science, to name just a few.

These core capabilities are not fixed but evolve over time in the light of scientific developments and market opportunities. One of CSIRO's key attributes is its *flexibility* in assembling teams to respond to new opportunities, drawing on a wide range of disciplines and skills.

Access to specialist **equipment and facilities** is central to performance. CSIRO endeavours to make these available to the manufacturing sector. For example, the electron microscopy facility at CSIRO's Clayton site provides a range of services for small and large businesses related to its capability in materials testing, ceramics, metals, building materials, minerals refining, refractories and fibre analysis. ICI Advanced Ceramics, Comalco and BHP and numerous SMEs are amongst its users. The facility includes an analytical transmission electron microscope, two scanning electron microscopes and X-ray diffraction equipment. Another example is the production-level diecasting equipment being instrumented and used for technical training for Australia's growing automotive component casting industry.

Figure 2 shows how **intellectual property** can be used and renewed for national benefit. A core capability may underlie collaboration with a number of different companies for several different applications. For example, in the case of a core capability in machine vision, current applications include traffic monitoring systems, food packaging and remote identification and management systems, all licensed to different customers. At the same time CSIRO, through retention of intellectual property rights, can develop its skill base through contact with leading edge customers and market feedback. This enables the skill base to evolve and to respond to future opportunities.

2.2 Maintaining a balance

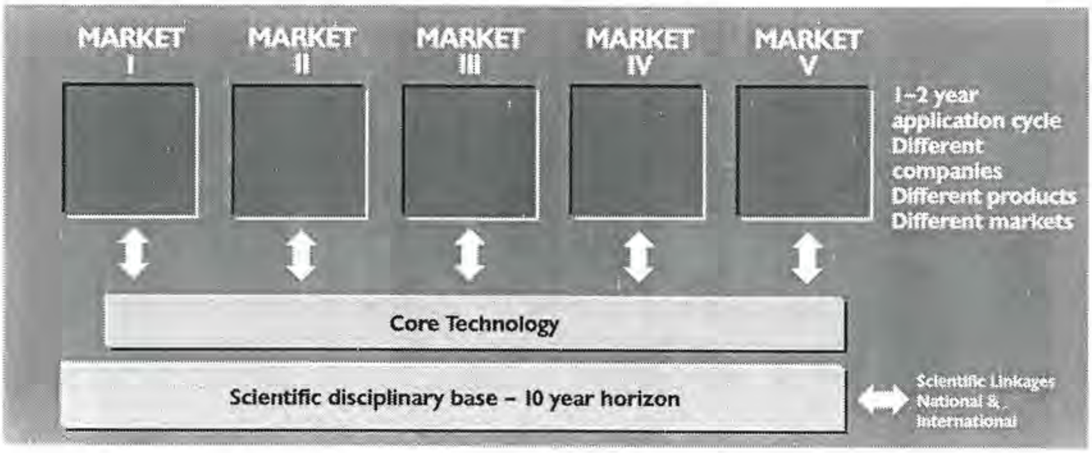
At each level of its organisation, managing CSIRO's research portfolio involves relationships with different groups of clients and stakeholders, and a balance

- between research areas - which areas should be encouraged and which wound back
- between long and shorter term activities (strategic vs. applied research vs. experimental development)
- between high and lower risk activities
- between different end-users.

In each case the objective is the same - maximising the long term benefits to Australia from the taxpayers' investment in R&D.

At the corporate level, CSIRO's Priority Framework is used to determine resource shifts between major purposes or socioeconomic objectives (SEOs) based on expected return to Australia. This Framework brings together assessments of the relative 'attractiveness' and 'feasibility' of research in different areas. The process involves external stakeholders such as representatives from industry, government and the community as well as research staff and management. Incorporation of stakeholder views in the decision process is not just welcome but necessary. (Blyth and Upstill, 1994)

Figure 2. Core Research Capabilities and the Market



The CSIRO Board funding decisions for the triennium which began in July 1994 involved a process based on this Priority Framework and led to an increased share of appropriation funding for research in the Manufacturing, Minerals, and Information & Communications SEO subdivisions, while maintaining the share of appropriation funding for the two Environmental subdivisions.

Payoffs from Strategic Research

An example from the Division of Biomolecular Engineering helps illustrate the way the outcomes of strategic research are not always obvious from the start it dates back to the employment in 1978 of a plant pathologist to work with protein chemists to develop new approaches to the detection of viruses using electron microscopy and antibodies.

Fundamental studies of the structure and variation in potyviruses began in the early 1980s. A decade later the research team, composed of about a dozen individuals over that extended period, had solved a plant classification puzzle that would enable scientists to detect, identify and control the largest group of plant and crop viruses, leading to significant savings. Potyvirus plant diseases account for about $10B of crop damage each year. Even more significantly perhaps, in working out the methodology for potyvirus classification, new light has been thrown on viruses in general. This includes human viruses with, as a first step, a discovery concerning Hepatitis C that has important implications for its detection and control.

At the Institute and Divisional level the CSIRO Priority Framework is applied to the determination of research priorities and is used as a screening grid in deciding the detailed allocation of sectoral funds. The **system of advisory committees** in place for all Divisions and Institutes is an important channel for industry to provide an input into the direction of CSIRO manufacturing research. Companies ranging in size from the Australian subsidiaries of multinationals, such as ICI Australia or Philips Defence Systems, to SMEs such as Gibson Chemicals or Remproc are represented on the committees to offer a balance of views about the effectiveness of CSIRO/industry contacts.

The critical consideration in selecting between alternative projects is the expected long-term benefits (commercial and other) to *Australia* gained from the use of CSIRO funds.

Consistent with the need for systematic processes to determine research priorities based on expected benefit to Australia is the need to maintain a strong research base linked to cutting-edge fundamental research. This is critical to CSIRO's future business and a well-spring for future R&D. Moreover, decisions on longer term research need both informed judgement and risk-taking as the outcomes are often not obvious at the start.

Frontier Science

Maintaining a strong base in fundamental research is essential to the health of a research organisation such as CSIRO. Some exciting areas now under study include:

- antibody engineering
- biocompatible materials for human implants
- biosensors for diagnosis and chemical detection
- control of gene expression
- diabetes/prostate cancer drug development
- high-performance materials for portable, low polluting solid oxide fuel cells
- high-temperature superconductivity
- intelligent manufacturing systems
- laser-cooled atoms and ions
- microwave chemical processing
- non-shrinking specialty polymers
- plasma arc processing for toxic chemical destruction
- rare-earth magnetism
- ultrasonic measurement and detection

3 WORKING WITH AUSTRALIAN INDUSTRY

3.1 Commercialisation

The Government requirement that CSIRO earn 30% of its income from external sources has been an additional stimulus to CSIRO in the past few years in research related to manufacturing research. Overall the result has been to improve interaction with industry and to increase the return on government investment.

The move to a more commercially oriented organisation has not been without teething problems. SIROTECH was established in 1984 as CSIRO's technology transfer arm. This has been superseded by a system of Business Managers at Divisional and Institute level who now oversee commercial aspects of CSIRO's research and advise research managers in relation to commercial collaboration and technology transfer. CSIRO's Commercial Practice Manual codifies best practice within the Organisation.

The principle of maintaining high credibility with industry through excellence in research is testified through the flow-on from one research project to another. One example is work on the Optical Surface Profiler (OSP 130) which allowed the **Royal Australian Mint** to measure in a non-contact way the profiles of all master tooling used in the minting process for faster, more efficient analysis and improved quality control. This was followed by another project, the Filtered Arc Deposition System (FADS 3000), which developed technology offering the Mint a new way of applying thin-film materials as hard coatings to the surfaces of coin dies. Another example is the ongoing interaction between **BHP** and a number of CSIRO Divisions covering areas such as mineral and metal processing, waste management, remote sensing and gas conversion. A further example is the collaboration of CSIRO with **Boeing** in areas such as carbon fibre composites, ozone studies, non-destructive testing of bonded structures and cellular manufacturing under a rolling $27M program over six years. This research is linked to manufacturing opportunities in Australia and development of Australia's aerospace industry, via companies such as **Hawker de Havilland** and **Aerospace Technologies of Australia** (ASTA).

CSIRO has developed a number of arrangements to allow it to work effectively with industry including infrastructural support in relation to national measurement standards. In each case the key has been to assess potential CSIRO involvement in terms of maximising return to Australia. The principal ways in which CSIRO delivers benefit to different groups of end-users are set out below.

3.2 Working With Companies

a. Working with Large Companies

Large leading-edge customers account for an important part of CSIRO's manufacturing research portfolio. Larger firms are often better positioned to establish well-funded programs with long term goals – to take risks. Working with leading-edge customer companies also gives CSIRO researchers an important window to local and overseas markets and assists in keeping them at the cutting edge of latest developments and applications.

CSIRO has strategic alliances with several large companies - BHP, ICI, ADI, Sydney Water Board, Memtec, Du Pont and Boeing with others under development. These alliances provide an umbrella for a program of continuing research in certain

Placing composite materials in a mould.

defined areas. They are structured so as to safeguard the confidentiality for specific commercial applications but at the same time enable renewal and extension of the research base within the Organisation.

WORKING WITH INDIVIDUAL COMPANIES

CSIRO has sought to generate benefit for the manufacturing sector through its interactions with groups of companies and industry sectors but also through interaction with individual companies, through two means:

- **contract research,** where the required outcome is generally well-defined in advance and which is usually conducted on a full-cost recovery basis with transfer of intellectual property, and
- **collaborative research,** which is longer-term in character with less precisely defined outcomes and in which a collaborating firm shares the costs, risks and expected benefits.

CSIRO does not seek to provide contract research in manufacturing where this can be provided by private sector organisations. In some cases though, through its expertise or equipment, it is particularly suited to deliver contract research outcomes for industry.

Collaborative research is seen as critical to maintaining a strong relevant core research base within CSIRO and to its role in helping generate national wealth via Australian companies, large and small. It accounts for about two-thirds of total company-related research in the manufacturing area. Collaborative research provides an efficient and cost-effective way for companies to access CSIRO core capabilities, links researchers to the market through practical feedback, and enables funding of significant projects that would otherwise not take place. The alternative - for companies to build their own in-house capacities *for specific projects* - is prohibitively costly for most Australian companies. Moreover these companies are frequently disadvantaged in R&D because of their small size relative to their international competitors.

Figure 2 shows how a shared cost, shared risk, shared benefit approach is consistent with CSIRO developing and expanding its research base for future applications.

b. Working with SMEs

Interaction with small-medium sized enterprises may take the form of contract research, collaborative projects, or as members of consortia involving larger companies. In some cases a combination of small and larger companies can be the most effective way of generating results, as illustrated by the roles of Biota and Glaxo in developing an anti-flu drug, and of Robofoods and Golden Circle in a machine vision application for food processing and packaging.

CSIRO is committed to working with Australia's best companies regardless of size and is increasing its collaboration with selected SMEs. The general level of interaction with SMEs in 1994 increased by more than 25% in 1994 over the previous year, and is scheduled to continue to increase, in line with CSIRO Board commitments. The provision of specific government funding in the 1994 Working Nation Statement has facilitated the ongoing increase in support for SMEs.

c. Working with Consortia

CSIRO uses consortium-type arrangements in a variety of its dealings with industry, in both a leading and complementary role:

- **As a research focus for companies in the same industry:** eg the involvement of Ford, Toyota, Mitsubishi and Nissan, with other companies in a pre-competitive low-pressure aluminium die

CSIRO and SMEs

CSIRO has upgraded its SME interactions via a new Industry Liaison Manager (ILM) Network. Several ILMs have been recruited in Sydney, Melbourne, Brisbane and Adelaide to establish links between CSIRO and specific industries. These links will be developed through personal ILM involvement and via access to CSIRO resources for advice with product and process development, technical problem-solving and technology assessment, and planning and acquisition within a strategic business framework.

Annual targets for the program include interaction with more than 250 companies, provision of technical assistance to a significant number, and generation of identifiable and quantifiable benefits such as increased exports, new products and improved competitiveness. The program is being conducted in close collaboration with other Government initiatives being mounted under the NIES program component of AusIndustry.

casting project at the Australian Automotive Technology Centre, established within the Division of Manufacturing Technology. Other examples include the CAMTRON (computer-aided manufacturing) group of companies within the Metals Trade Industry Association and companies from the Australian Diecasting Association, both of which are collaborating with CSIRO.

- **With companies from different industries on a project basis:** RTA and Telecom, for example have complementary roles in the development of the traffic monitoring system, Safe-T-Cam. BHP, Metal Manufactures and the University of Wollongong jointly collaborate with CSIRO in a major high-temperature superconductivity program.

- **With companies and other research organisations in Co-operative Research Centres** CSIRO is a major player in a number of CRCs related to manufacturing:
  - Alloy & Solidification Technologies
  - Australian Photonics
  - Cardiac Technology
  - Cellular Growth Factors
  - Eye Research & Technology
  - Industrial Plant Biopolymers
  - Intelligent Manufacturing Systems & Technologies
  - International Food Manufacturing & Packaging Science
  - Materials Welding & Joining
  - Mining Technology & Equipment
  - Molecular Engineering & Technology
  - New Technologies for Disease Diagnosis
  - Polymer Blends

- **With companies and other research organisations in government funded projects:** CSIRO has been a major player in a number of projects funded under the GIRD scheme which frequently involve CSIRO, universities and one or more industrial partners interacting during the course of the project.

- **With other research organisations to facilitate transfer of technology:** CSIRO and the University of Technology, Sydney, established SEMCOR (Sydney Electrical Machines Cooperative Research) in the mid 1980s to exploit complementary skills. Clients have included Filmlab Engineering, Bardak Solar Power, ADI and Transfield Technologies.

- **With technology transfer organisations:** CSIRO is an active participant in the Queensland Manufacturing Institute and the South Australian Centre for Manufacturing. These centres provide a valuable service in bringing together under one roof and one management the resources to provide business and technical assistance to industry. CSIRO is active in these organisations which also draw on resources from NIES and other local tertiary institutions.

d. Working with Industry Associations

Industry Associations are important for professional networking. In some cases they provide opportunities for technology leadership and industry extension. Among the important industry associations with which CSIRO is actively involved are:

- Australian Diecasting Association (ADCA)

- Australian Chemical Specialty Manufacturers Association (ACSMA)
- Australian Diagnostics Manufacturers Association (ADMA)
- Australian Forging Group (AFG)
- Australian Scientific Instruments Association (ASIA)
- Australian Water and Wastewater Association (AWWA)
- Electricity Suppliers Association of Australia (ESAA)
- Environment Management Industries Association of Australia (EMIAA)
- Metals and Trade Industries Association (MTIA)
- Plastics and Chemical Industry Association (PACIA)
- Technology Industries Exporters Group (TIEG)
- Welding Technology Institute of Australia (WTIA)

e. Informal Networking

Informal contacts with industry colleagues are an important outcome of the industrial and scientific networks within which researchers carry out their work.

A recent study of advice and information given by CSIRO researchers to industry through informal networks and contacts showed that the extent of contacts is large and represents a significant investment of time by CSIRO's professional scientists. On the basis of a six month survey period in 1994, Sultech found that each of three CSIRO manufacturing Divisions was involved in over one thousand industry-initiated contacts per year, mainly from SMEs. These resulted in provision of technical advice (65%), referral to other expert sources (20%) and discussion of R&D opportunities (15%). Well-established research groups were involved in upward of 300 contacts per year.

As the report concluded, the contacts were an important mechanism for information and expertise transfer to companies:

> "Participating scientists all expressed the view that this informal (and free-of-charge) assistance to companies was appropriate for a largely publicly-funded research organisation, and that their investment of time in providing assistance of this nature was an important aspect of their role as CSIRO scientists. While subsidiary to their main tasks of performing research and transferring the results of that research to industry and other users, the making available of expertise associated with performance of these main tasks was regarded as an important ancillary responsibility."

> "... a number of scientists commented that, while the purpose of the industry contact was the solicitation of advice, in numerous instances the explanation of the problem provided them with valuable information also. They therefore tended to regard the outcome of the contact as being more in the nature of an 'information exchange' of benefit to both parties." (CSIRO, 1995)

3.3 Launching new companies

A number of new businesses have been established over the past decade, either arising from or critically dependent on CSIRO manufacturing research. These include:

- **ActionLaser,** a company based on laser drilling technology from the Division of Manufacturing Technology to make fine metal screens, sieves, and filters which are key components in a range of industrial equipment.
- **Australian Magnet Technology,** a company established to manufacture rare-earth magnets based on research from the Division of Applied Physics.
- **Bioclone,** established to develop monoclonal antibodies developed by CSIRO and the Garvan Institute
- **Bioquest,** involved in monoclonal antibody production and biotechnology processing
- **Biota,** founded in a public offer in 1985 with its leading project being the collaborative flu research with CSIRO
- **Castec,** based on research in the Division of Manufacturing Technology to market Castflow/-Castherm software for the diecasting industry with adaptation to PC-based computers
- **Ceramic Fuel Cells Limited,** a company established to develop and market solid oxide fuel cell technology, based on work by the Division of Materials Science and Technology. (The company was established by a consortium including CSIRO, BHP, SIRF, ERDC, and five State power agencies)
- **Dunlena,** a joint venture company established by DuPont, the AIDC and CSIRO to develop and test crop protection chemicals for international markets.
- **Nilcra,** a company formed by Nilsen Sintered Products and CRA to manufacture and market partially stabilised zirconia (PSZ)
- **Peptide Technology,** which was established to

Advanced welding technology

Working with the Welding Industry

CSIRO'S early involvement with the welding industry was work on hardfacing processes and alloys. By the early 1980s it expanded to address the needs of the more economically significant joining sector of the industry. Work was directed at the optimisation of existing processes and the development of new processes and welding consumables. Without this activity it was recognised that Australia's welding industries would suffer increasingly from import competition. CSIRO thus took on a R&D technology leadership role for the industry. Key research outcomes have included:

- a novel pulsed-arc welding power supply which gives the operator greater control over the welding process and which virtually eliminates spatter;
- a new narrow-gap welding process for joining thick sections which employs a very simple mechanical design making the hardware much less expensive than imported systems and therefore more accessible to SMEs;
- an innovative variant of the gas-tungsten arc welding process which is capable of joining aluminium sections up to 25 mm thick in just two passes without the need for any edge preparation or filler material;
- new formulations of flux-cored arc welding consumables which offer improved properties in completed joints and which, in conjunction with the pulsed welding power supply, provide a superior welding process for the latest types of high strength steel.

Particularly important has been work involving the Welding Technology Institute of Australia. The WTIA is an industry association which addresses the interests of the welding community in Australia. It has some 1930 members spread throughout the country, including approximately 370 company members. It runs an active program of monthly lectures and plant visits through its State-based divisions, and it organises a very well attended national conference each year. It also produces a respected quarterly magazine, *Australasian Welding Journal,* and a series of Technical Notes, some of which have formed the basis for new Australian Standards.

CSIRO's Division of Manufacturing Technology has been very closely involved in WTIA notably through its Technical Panels which cover different aspects of welding technology, publish technical papers and provide influential technical guidance to the industry.

The welding industry is one of several cases, others being diecasting and forging, where work with industry associations has been a highly effective way for CSIRO to assist a large number of small companies within an industry.

develop enzymatic peptide synthesis technology and is now redirected as a pharmaceutical discovery company

- **The Preston Group,** which had its origins in a breakthrough in computer software simulation technology in the Division of Manufacturing Technology. TPG is now an international leader in its field: Qantas, the Federal Airports Corporation, ANL, Manchester and Schiphol Airports are among the users of its interactive simulation and scheduling computer software
- **SRL Plasma,** a company based on the Plascon waste treatment technology developed by the Division of Manufacturing Technology in collaboration with Siddons Ramset
- **Test Technologies,** a company based on Battery Tester technologies developed by the Division of Manufacturing Technology.

CSIRO's experience over the past decade with start up companies[2] provides a number of lessons including: the need for patient capital and access to emergency reserves to cover operational cash flow problems that may arise; the need for a senior experienced management and Board with international perspective and manufacturing experience; and the ability to attract highly motivated people with strong marketing and market access experience.

[2] The examples above are drawn from current Divisions of the Institute of Industrial Technologies. Other start-up companies arising from research elsewhere in CSIRO include Ausmelt, Ausonics, Austek Microsystems, Innoculo, Interscan, Mineral Control Instrumentation, and Savant Systems.

RESEARCH TO BENEFIT AUSTRALIA

Some prominent recent examples of CSIRO's contribution to wealth creation include:

4.1 Processing

The **diecasting** industry has had a long association with CSIRO. The Division of Manufacturing Technology's concern has been to introduce structured science and engineering principles into Australian diecasting practices which had largely relied on the subjective judgement of operators in the workplace. Research into pressure diecasting has led to significant changes in the design of diecasting machines, dies and diecast products. In addition the Division has assisted training in the die casting industry with bodies such as the Australian Die Casting Association and RMIT. Work for the diecasting industry has included development of software to assist in the design of more effective dies. The first version, **'Metflow',** was designed to run on a mainframe computer and was marketed by **Moldflow.** This was restructured to meet the needs of SME diecasters who mainly operate on a PC-based platform, as the PC-based **'Castflow'.** A companion package 'Castherm' was developed for thermal analysis in diecasting and launched commercially after trialing with several Australian and American diecasters. The packages optimise the way the molten metal is introduced into the die and allow for investigation, at the design stage, of the effect of die sprays, materials of construction and die geometry under normal operating conditions without expensive trial and error.

Automotive components: Diecasting is a key technology for the Australian automotive industry which exports products worth more than a billion dollars each year. Many companies are using CSIRO's casting and solidification software in the manufacture of aluminium components. Solidification modelling, also developed in the Division of Manufacturing Technology, is another example of computer technology applied to industrial processes. The Division's interests have expanded to include low-pressure diecasting. A significant outcome in ongoing research has been the coming together of four of the major Australian-based automotive companies, **Ford, Toyota, Mitsubishi** and **Nissan,** along with **Castalloy, Southern Aluminium** and CSIRO in a $2.2 million venture to improve the quality and competitiveness of Australian low-pressure aluminium die casting. CSIRO's low pressure die-casting equipment is central to the project as it is to the CRC for Alloy and Solidification Technology (CAST) which has funding of $4 million per annum from the leading participants. A related development arising out of the Division's work with **Boeing** has been a new joint venture between **Aluvic** and a US-based casting company to manufacture and export high-precision cast automotive components.

Olex Cables, Australia's only producer of extra-high-voltage cables, has been supported by the Division of Applied Physics through developing computer models for predicting heat flows and heat transfer in manufacturing processes. This has enabled Olex to compete successfully with overseas manufacturers for major underground cable contracts.

New diecasting technique

OVD Technology displayed in a postage stamp released by Australia Post in 1995.

The **welding** industry's interaction with CSIRO has been described. One notable product of research in this area has been the CDT Synchropulse welder, a top-of-the-range welding unit developed with the SME, **Welding Industries of Australia.** The welder has been widely used in Australia with significant productivity benefits and export sales. It was estimated by the BIE in a 1991 analysis to have public benefit: cost ratio of about 3.6:1.

The **SIROFLOC** process from the Division of Chemicals and Polymers is equipment for water and waste water treatment. SIROFLOC was designed to use reactive magnetic particles for preparation of potable water. Licensed to **Davy John Brown,** a number of plants have been installed in Australia and overseas. It also has provided a basis for CSIRO contacts and collaboration with companies in and exporting overseas, principally East Asia. A modified version of the equipment **SIROFLOC II** has been developed for sewage treatment with a 5 megalitre a day pilot plant being tested by the **Water Board** at Sydney's Malabar facility. Full-scale operation at Cronulla is under consideration.

4.2 Systems

Cellular manufacturing developed in the Division of Manufacturing Technology has proven to be a significant advance for manufacturers looking for a competitive edge. The research began with small projects in robotics and analysis of work-cell efficiency. The first complete cellular manufacturing unit designed by CSIRO was incorporated into the **GMH** plant at Elizabeth between 1986 and 1989 yielding annual savings of some $2M, or double the cost of installation. Other projects have included reorganisation at **Hardie Irrigation** at Murray Bridge in which the company has reduced inventory holdings to just over 20% of original levels. Introduction of cellular manufacturing software at Boeing Commercial Airplanes' Wichita plant as a Beta-test site has allowed demonstration of the versatility and superior performance of the CSIRO software. The first trial cell under way at Boeing involved relocation of 13 large manufacturing machines involved in the production of 7000 different parts for Boeing aircraft models – the 737, 747, 757, 767 and 777. The short payback period for Boeing is indicative of the potential benefits of this expertise within Australian industry.

Machine Vision Systems for monitoring and control applications using equipment ranging from simple, stand-alone video monitoring units to intelligent robotic systems with real-time data processing and response capabilities have been developed by the Division of Manufacturing Technology. Based on a proprietary CSIRO algorithm, specialised chips designed by the Division are now being used in a number of commercial applications. These enabled the **Machine Vision** firm to provide customised systems based on high-speed processing hardware. Clients include the **NSW Road Traffic Authority,** the **Australian Road Research Board,** the **Melbourne Water Corporation, Telecom, BHP** and a number of SMEs. Applications range from monitoring of road use for traffic safety, inspection of water and sewerage pipes to detection of defective food and defective whitegoods surfaces on production lines. The vision systems research builds on earlier development of a high-speed vision processor in collaboration with **Atlantek Microsystems** of Adelaide.

Optically Variable Devices: OVD technology, from the Division of Materials Science and Technology, finds its major use in high-value processing and in anti-counterfeiting devices such as those on banknotes. Indeed CSIRO has become a world leader in this field following its pioneering work with the Australian ten dollar banknote. (CSIRO also was involved in other technologies for this banknote.) The OVD technology was the subject of a recent court action involving an Australian company which has

Modified atmosphere packaging in use to maintain quality of produce in transit.

been successfully resolved and is now on-track to generate significant export earnings and royalties for Australia. The technology is further displayed in a postage stamp released in April 1995 by **Australia Post.**

4.3 Advanced Materials

Active Packaging has been the focus of joint research involving the Division of Materials Science & Technology, **ANL** and packaging companies. Other CSIRO Divisions (Food Science & Technology, Horticulture) were involved. Products of this research are improved packaging which extend the shelf-life and permit increased exports of fresh fruit, vegetables, cut flowers, and other products. Patented technologies involve new materials for atmosphere and condensation control, ethylene removal and for other purposes. Trials with cut flowers and selected products have been successful and the technology opens possibilities for horticultural producers to access counter-seasonal northern hemisphere markets. The technology is expected to enable doubling of horticultural exports within a decade. This research has been recently incorporated into a new CRC for International Food Manufacture and Packaging Science.

Advanced Composites: Building on its polymer expertise, the Division of Chemicals and Polymers has developed a strong intellectual property position in advanced composites. It is to establish production in Australia through an Australian firm, **Teckcorp.** Prototype projects have included racing-car spoilers for **Holden Special Vehicles,** rudders for a trimaran which won the world speed sailing record in Victoria in 1993, and advanced composite bodies for solar cars which have taken part in a trans-Australian race. Negotiations are in progress with companies in fire retardant panelling, vehicle armour plating and boat building.

Partially stabilised zirconia (PSZ) was a major research breakthrough by the Division of Materials Science and Technology. It dates back to 1974 when researchers discovered a process for making a new, extremely strong ceramic. This exceedingly tough ceramic material was patented and became known as PSZ. The product has multiple uses including metal shaping and bearings for mining, valves in the chemical processing and mining industries, and tooling for sealing in the canning industry. It provides for higher productivity and savings in maintenance costs. Today, **ICI Advanced Ceramics** produces and sells millions of dollars worth of PSZ products each year for a variety of applications. By the year 2000 the PSZ business has been projected to have an annual turnover of about $100 million. The PSZ work has been critical to the development of the SIRO2 oxygen sensor and solid oxide fuel cell technology. The latter technology is the focus of a major new consortium **Ceramic Fuel Cells Limited** (CFCL) which is currently undertaking an R&D program, costing in the order of $30M over 5 years, with a view to production of multi-kilowatt solid oxide fuel cell stacks and commercial applications.

Work on **rare earth magnets** in the Division of Applied Physics has had a number of beneficial results in terms of industry and research. A start-up company, **Australian Magnet Technology** was involved in the manufacture of rare-earth magnets from neodymium iron boron alloys. Meanwhile research in the Division led to the development of electric motors with a 15% increase in efficiency through the use of rare-earth magnets. Applications of these motors include film processing equipment manufactured by the SME **Filmlab Engineering** and sold overseas. Solar water pumps manufactured by the SME **Bardak Solar Power** which uses brushless permanent magnet motors for submersible pumps in remote areas was another. Further applications are expected in the automotive and white goods industries.

4.4 Equipment and Instruments

The **PLASCON™** technology provides a means for destruction of hazardous chemicals by plasma arc. The Division of Manufacturing Technology and **SRL Plasma,** a subsidiary of Siddons Ramset, began work on the development in the early 1980s to destroy toxic chemicals on-site by means of a plasma arc at temperatures at more than 10,000 degrees C. The large agricultural chemicals manufacturer, **Nufarm,** has installed PLASCON at its Laverton site and has invested about $2M in further development and marketing of the technology. PLASCON won the 1993 ACIC Environment Award and a 1994 Australian Institution of Engineers Engineering Excellence award. The Halon Bank has recommended PLASCON for destruction of halons which are being withdrawn from industrial use in equipment such as fire extinguishers. The technology is expected to be engineered to a number of future demands for waste destruction.

The **SIRO$_2$ oxygen sensors** stemmed from Division of Materials Science and Technology research into partially stabilised zirconia. The initial metal/ceramic bonded oxygen sensor which assisted industrial process control in smelters between 300 and 600 degrees C (whereas conventional sensors worked above 600 degrees C) worked well and included an electronics unit which is still being used by the licensee for other applications. This unit was upgraded following Divisional research, sponsored by **Novatec** and **MacDhui,** to study the use of fully stabilised zirconia as an electrolyte to measure oxygen in molten copper. The improved durability of the electrolytes made the sensors world-leading technology with benefits to Australian companies through sales and exports of sensors and associated equipment. **Ceramic Oxide Fabricators** at Bendigo has described the development of the oxygen sensor as having been critical to its existence. Benefits of the technology have also accrued through improved efficiency and lower production costs in Australian smelting operations.

The **Optical Surface Profiler** in the Division of Applied Physics has been developed in successful collaboration with the Royal Australian Mint, from a body of knowledge based on holography which was applied to non-destructive testing and quality control. The current application uses these advanced optical technologies as tools for fine dimensional measurement. The project sprang out of a visit by representatives of the Mint interested in hard coatings for coin dies who recognised the potential of optics technology in the manufacture of the dies. The **Royal Australian Mint** has estimated a payback period on the new instrument of about 18 months due to a significant reduction in turnaround time in production.The OSP has been sold to mints in the US and China with further sales in prospect. Marketing is continuing with a view to incorporating the technology into general manufacturing instrumentation affording major savings in production costs.

Liteslice was developed by the Division of Applied Physics in the early 1980s to provide **Hammersley Iron** with a rapid and accurate instrument for measuring rail wear. Liteslice was mounted under a purpose-built carriage to measure wear along Hammersley's 800 km rail link between its iron ore mines and its shipping ports. It has generated major maintenance and inventory cost-savings for the company. The product was commercialised by a Perth company **Aldetec,** since taken over by **Gemco,** and is now the basis of a multimillion dollar rail maintenance system marketed to customers in Japan, the US and Canada.

Advanced composites used in spoilers for motor vehicles.

The development of the **RACOD Meter** came out of broad biological nutrient control research which has been under way in the Division of Chemicals and Polymers aimed at creating environments which remove phosphorus from sewage and water systems. The AAA (Alternating Aerobic and Anaerobic) process was developed from knowledge about the behaviour of bacteria in oxygen-deprived conditions. The RACOD meter built on this process allows for measurement of organics in wastewaters automatically 24 hours a day. The meter is being manufactured in Sydney with further research continuing in this significant area of monitoring of environmental pollution.An allied development by the Division of Materials Science and Technology has been the **Sewer Sentinel** monitoring system now under further development with **Mace Instruments** and **Melbourne Water.** This monitors temperature, conductivity, turbidity, pH, and dissolved oxygen in sewage for rapid identification of spills and discharges of potentially damaging effluents.

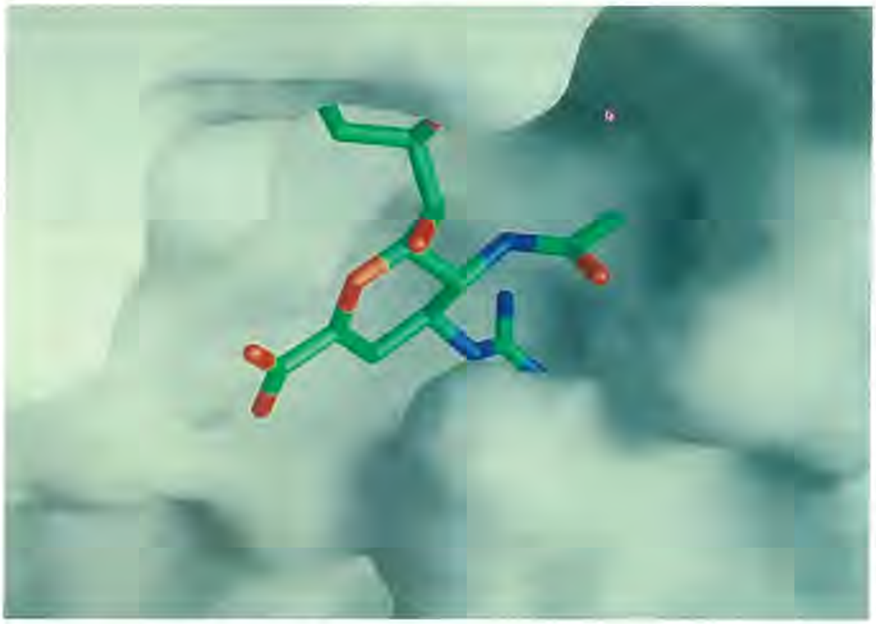
The **dry vacuum pump** was developed in the Division of Materials Science and Technology and finds use in scientific and industrial purposes where a vacuum environment is required. It has provided income from royalties since 1990. Its long-term commercial success, however, has been hindered by complicated licensing arrangements invloving **Repco, Varian Vacuum Products, Vacuum Research Corporation** and (in upgraded version) a Japanese company, **Fuji Seiki Inc.**

Paper colorimetry equipment was developed by the Division of Applied Physics over a period of eighteen months for **Australian Newsprint Mills.** A staff member was seconded to the Division to work for a year in developing a prototype instrument. It was installed in the company's Boyer plant in Tasmania in 1989.

4.5 Molecular Design

An **anti-flu drug** based on CSIRO research is now in advanced clinical testing and is on track to generate multimillion dollar royalty returns to Australia. Reported in *Nature* in mid-1993, this is the culmination of about 15 years' team research. In the mid-1970s, researchers sought to understand the way the flu virus changes, necessitating frequent flu vaccinations. The first five years of the project from 1978 were funded by CSIRO as fundamental research. Commercial backing came from the SME, **Biota Holdings Ltd,** which in 1989 formed a partnership with **Glaxo** Australia to develop the research further. The breakthrough came as a result of determining the 3-dimensional structure of a virus protein found in all influenza strains. Researchers discovered that while most of the protein could change shape during the evolution of new influenza strains, one small, important region of the protein remained constant throughout all strains. This region then became a target for a designer drug molecule, rather than a vaccine. The new drug was synthesised in conjunction with the Victorian College of Pharmacy and has the potential to be a major product internationally.

Chemicals for **Crop Protection** are being designed and synthesised by the Division of Chemicals and Polymers in collaboration with **Du Pont.** This collaboration which stems from the mid-1980s and arises out of previous research on insecticides, is an example of exploiting key research capabilitities. It follows the synthesis of a novel rice insecticide, cycloprothrin, which CSIRO has licensed to a Japanese manufacturer, **Nippon Kayaku,** and for which it continues to draw sizeable royalties. The success of that product led the Division to realise its capability for further commercial products. After developing another, GH1213, it advertised for a manufacturer to



A computer graphic simulation of the anit-influenza drug, GG 167, binding to neuraminadase, an influenza surface protein.

become involved in collaborative research. Du Pont's response led to the formation of the joint venture Australian company, **Dunlena,** which also involves CSIRO and the **AIDC.** Du Pont's continued investment in the joint venture over a period of a decade is a sign of the high regard it retains for CSIRO research. The CSIRO team has developed a significant number of specially designed chemicals for testing for food crop protection. Several of these are currently being field-trialed. CSIRO's experience highlights the rewards but also the difficulties in developing new commercially viable pesticides which meet the stringent standards of agriculture now demanded by governments internationally. In its 1991 analysis of this project the BIE estimated an Australian benefit:cost ratio of between 2.1 and 3.8.

Antibody engineering for a range of medical and pharmaceutical applications is a major activity in the Division of Biomolecular Engineering. The technology enables the production of specific binding molecules to detect target proteins which can be used for diagnosis and purification of important proteins for medical science. These antibodies can be made in bacteria. One outcome is the first genetically-engineered diagnostic antibody for HIV currently undergoing production trials. This product is expected to expand the current $3 million sales by the SME collaborator, **AGEN Biomedical,** on the world diagnostics market. Work is also under way to formulate genetically-engineered reagents for a whole range of new diagnostics. Targets include Hepatitis B & C and other viral diseases as well as cardiovascular and Alzheimer's diseases. Further applications are antibody design as immunotoxins and biosensor and biomaterial applications.

The synthesis and production of **squalene** for export as a health tonic to Asia for a local SME, **Squalus,** illustrates the strengths of CSIRO in this area of research. It also illustrates the importance of chemical processing and specialist processing equipment on an industrial scale to support a local industry.

Veterinary vaccines: The potential of genetic engineering in controlling diseases in animals was recognised early by researchers in what is now the Division of Biomolecular Engineering. From 1983-1990 the Division used genetic engineering techniques in the development of veterinary vaccines. (More recently the focus has shifted to pharmaceutical products). Major developments in veterinary vaccines were:

- an **IBDV Vaccine** for the infectious bursal disease virus for chickens with **Websters** as commercial collaborator. IBDV is a major worldwide poultry pathogen. The vaccine is in the final stages of development prior to commercial launching.
- a **footrot vaccine** developed in collaboration with **Websters** and **Biotechnology Australia.** The product is registered and scheduled for future release.
- a **worm vaccine** (anti-parasitic nematodes) is still under commercial development by **Biotechnology Australia,** a process extended by the complexity of the parasitic organism and the necessity for lengthy sheep trialing.

Biomolecular Research Institute: The Institute, a joint initiative between CSIRO and the Victorian Government's Strategic Industry Research Foundation, conducts a virology program which includes research into HIV, Hepatitis B and Hepatitis C using targeted organic synthesis and biological studies to develop new antiviral drugs. This includes the "rational drug design" approach employed in the flu drug development. An understanding of the structure of a target protein can enable researchers to design a chemical to inhibit the protein's function and prevent the virus from spreading. Improved understanding of biomolecular structures is expected to yield results in a number of other areas of medical and pharmaceutical research.

4.6 Standards

CSIRO's legislative responsibilities to maintain physical standards through the National Measurement Laboratory (NML) mesh with its wider industry role. NML activities complement other research in the Division of Applied Physics. In evaluating NML's activities in 1991 the BIE noted:

> "The social value of the National Measurement System ... is such that the benefit of the essential contribution to it by the NML far outweighs the cost of the NML... the NML's performance has been in world-leading class eg Australian contributions include the calculable capacitor, the redefinition of the volt and ohm and participation in the IPTS-68 and ITS-90 programs. Apart from 'national pride', benefits from a unified NML are access to leading edge intellectual property, and an appropriate structure for using new measurement technology entering Australia in the form of equipment purchases". (BIE, 1991, p. 10).

More recently the Kean Report on Australia's Standards and Conformance Infrastructure paid tribute to NML's key role in the measurement infrastructure and recommended the Commonwealth assign it responsibility for providing leadership to and coordination of Australia's measurement system" *(Kean Report, 1995, p. xix)* and *inter alia* recommended that NML's role be expanded to include responsibility for chemical metrology.

CSIRO's measurement activities are an important component in moves to facilitate trade within the APEC region. (See box). Other outcomes have included:

- **electromagnetic interference and compatibility** (EMI/EMC) **testing.** Electro-magnetic "pollution" is an increasing problem for people using computers, television and radio as well as other electrical devices, with the possibility of interference from substandard products imported into Australia. The measurement of EMC parameters of imported goods must be traceable to national physical standards at NML if the result is to have international credibility, particularly against strict compatibility and compliance standards being enforced by the European Union after January 1996.

- **FA18 Radar Contract:** NML assisted local-based contractor **Philips Defence** fulfil its role in manufacturing radar under the FA18 fighter aircraft contract. The equivalence of NML-maintained Australian primary standards with those of the US national standards laboratory provided a crucial link between Philips measurement standards and those of McDonnell Douglas. Philips Defence also supplied this radar system to overseas purchasers of the FA18 in support of Australia's offset-related commitments.

- the **Coordinate Measuring Machines** (CMM) User Group provides a national focus for CMM usage, which is critical to monitoring traceability and ensuring quality assurance. More than one hundred companies network with the group to ensure they keep abreast of international developments and get full value from their high tech instrumentation. Individual users of CSIRO's CMM facilities include **A E Bishop,** an automotive components design company. It has carried out intensive measurement for prototype designs of power steering systems that have been sold to domestic and overseas markets.

- **Radiation pyrometry** research from the Division of Applied Physics improved product quality and process efficiency in projects in the steel and aluminium industries, with installations in **BHP** and **Comalco.** Specialised radiation pyrometers were designed to measure temperature during processing by non-contact means, for example, for Comalco in the hot and warm rolling mills at Yennora in NSW, in steel strip in BHP's galvanising line at Westernport in Victoria, and in painted steel strip at Port Kembla.

OTHER RESEARCH

Research by CSIRO Divisions other than those in this Institute of Industrial Technologies has also contributed significantly to wealth creation by manufacturing and related industries.

- wool processing technologies such as **Sirospun,** a wool spinning technology particularly suited for fine wools, and **Sirocard** which is now in wide use
- the **multibeam earth station antennas** for satellite communication. About 25 have now been built, mainly for **Telstra,** with export revenues flowing from overseas contracts
- a genetically engineered vaccine, **Tickguard,** which is being marketed by **Biotech Australia** to address the costly problem of cattle tick in Australia's beef industry
- smelting technologies for the minerals industry, including **Hismelt** direct iron making process developed in collaboration with **CRA, Sirosmelt** bath smelting technology licensed to **MIM Holdings,** and **Ausmelt**
- replacement of asbestos fibre in cement sheeting, wood adhesives and preservatives for the forest products industry.

MEASUREMENT STANDARDS

CSIRO, via its National Measurement Laboratory (NML), has a legislative responsibility to establish, maintain and disseminate physical standards of measurement which are compatible with international standards for traceability and integrity of measurement. NML's role is paramount in Australia's measurement infrastructure in underpinning much of the quality movement, industrial process control, equipment performance certification and trade and commerce-related measurement. The NML is considered to be in the top echelon of national standards laboratories, ranked alongside Germany, Britain and the United States and has formal 'statements of equivalence' with the national laboratories of Britain, the USA, Canada and New Zealand.

In late 1994 APEC member countries resolved to make regional compatibility in standards one of their first initiatives. CSIRO has had a leading role in measurement standards in the region, based on NML's international standing in metrology over more than 50 years. Australia is regional coordinator for the Asia/Pacific Metrology Programme (APMP) which enables national measurement laboratories to exchange information on measurement capabilities, train scientists from member countries in a range of fields of metrology, and to advise and assess measurement standards and calibration facilities through international intercomparison. This underpins international compliance to specifications for traded manufactured products and services. CSIRO has had extensive interaction with each of NML's counterpart laboratories in the APEC region and has conducted significant training programs for a number of these laboratories.

Measurement standards are a critical building block in expanding trade in the APEC region. Common agreement on measurement is critical to trade, in that a refusal of governments to accept one another's measurement capabilities causes inefficiencies and de facto barriers to trade.

One of the major recommendations of the Kean Report on Standards and Conformance Infrastructure is that Australia should

> *"... continue to accord high priority in APEC to the development of closer cooperation on standards and conformance issues, with a view to the long term development of harmonised regulatory requirements and comprehensive mutual recognition agreements within the region..."* (Kean, 1995, p. 193).

Traceability, Calibration, and Quality Systems: The NML has a full-time staff of 90 and spends about $10M a year on the provision of measurement standards and calibration, with an income of almost $1M from industry calibration fees, training and intercomparisons. With an increasing recognition of the importance of quality systems in Australian industry, the NML emphasises the need for measurement traceability as the basis for a system of documentary standards. This ensures quality of goods and services within Australia and facilitates international acceptance of Australian exports.

5. LOOKING AHEAD

Three things mark CSIRO's experience in research related to manufacturing over the past decade - change, achievement and demonstrated potential to play a major role in Australia's manufacturing future.

The change is ongoing and is marked by the increased importance of private sector research funding, by the new commercial focus in research management, and by a concern to deliver not just world-class science but outcomes which generate wealth in the manufacturing sector. As part of the Continous Improvement approach a greater level of interaction with SMEs and staff exchanges with private companies will occur. At the same time performance indicators will need to be linked to appropriate expectations, based on CSIRO's strengths and ability to deliver benefits to Australia.

The achievements are associated with CSIRO's central strengths - excellence and leadership in science and technology, notably in a wide range of core capabilties. CSIRO endeavours to maintain a progressive world-class scientific working environment, with internationally renowned scientific opinion leaders, and the flexibility to form high-quality teams to address major issues.

The potential for the future is underlined by the critical role R&D will continue to have in maximising Australia's opportunities. Examples include:

- exploiting the full downstream promise of Australia's light metal resources - aluminium and magnesium - through enhancing Australia's component supplier role in the international automotive industry vendor pyramid
- facilitating trade in the APEC region by taking a leading role in establishing mutually accepted measurement standards and reducing the scope for non-tariff trade barriers
- CSIRO's role in the international **Intelligent Manufacturing Systems** program, now run for Australia by the Department of Industry, Science and Technology which will give Australia's manufacturers an important window on the latest developments in manufacturing systems design
- application of modern software engineering practices to a wide range of manufacturing operations; simulation of discrete manufacturing processes and product-design optimisation
- finally, CSIRO's important role in helping Australian companies and agencies as informed buyers of overseas research and technology. This is a key issue for a country that performs just 2% of the world's R&D but seeks to have access to the other 98%.

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