



A★STAR

20 Years of Science
and Technology
in Singapore

This electronic version of the
A*STAR Commemorative Publication
contains minor edits.

A ★ S T A R

20 Years of Science
and Technology
in Singapore

_Foreword 6

-Preface 8

_Introduction 11

1_The Beginning 13

2_The Turning Point 41

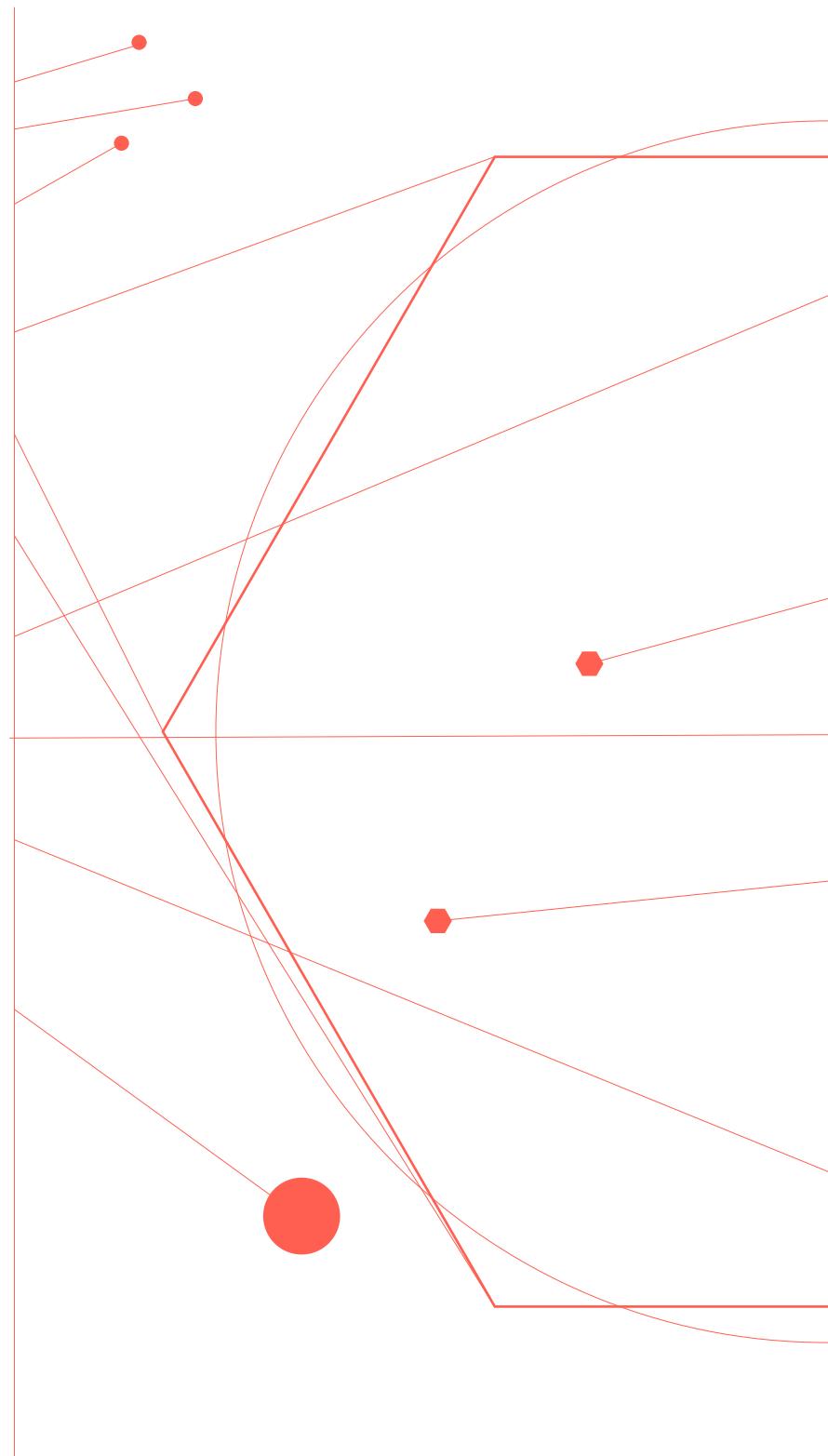
3_A*STAR is Born 63

4_Talent is Key 89

5_Measures of Success 125

6_Asia's Innovation Capital 149

_Research Institutes 153





+32 Early Breakthroughs & Innovations

+48 Battling Global Diseases

+64 Science and Engineering Solutions

+112 Advancing Healthcare

+136 Leading The World

185 [_Timeline](#)
196 [_Abbreviations](#)
198 [_Selected Bibliography](#)
200 [_Acknowledgements](#)



Foreword

Singapore has transformed itself from an entrepôt economy to one driven by knowledge and innovation. One important strategy was investing in science and technology (S&T). It enabled us to overcome our limitations of size, move up the value chain and provide good jobs for all.

This was a national effort. We built a strong foundation in Science and Mathematics by making these subjects compulsory for students up to lower secondary level, and upgrading our S&T-related faculties in ITEs, polytechnics and universities. We focused on manufacturing and attracted multinational firms, especially those with a strong base in manufacturing and technology, to improve our skills and competitiveness.

As our economy developed, we invested significantly in research and development (R&D). Our universities established Research Centres of Excellence, while our Campus for Research Excellence and Technological Enterprise (CREATE) hosts research groups from MIT, UC Berkeley, ETH Zurich and the Technical University of Munich. World-class companies have established corporate laboratories here to tap our vibrant R&D eco-system.

Locally developed breakthroughs in medical technology have advanced treatments for many diseases, while green innovations have contributed to sustainable development. Besides improving ordinary lives, these innovations inspire the human spirit, and show what is possible with creativity and ingenuity.

The Agency for Science, Technology and Research (A*STAR) and its predecessor, the National Science and Technology Board, have played an important role in this transformation. A*STAR alone has 20 research entities in biomedical sciences, physical sciences and engineering, all of which enhance our competitiveness by promulgating new knowledge and innovations. A*STAR has also played an important role in nurturing local scientific talent: its scholars now helm laboratories, occupy leadership positions and mentor the next generation of scientists.

As we celebrate 20 years of S&T, I commend our pioneering scientists, researchers, educators and administrators for their hard work and resolve. Special praise goes to A*STAR for compiling this remarkable record of our S&T journey. Let us continue working together to transform Singapore into Asia's Innovation Capital and a global R&D hub.

Lee Hsien Loong
Prime Minister of Singapore

Preface

This project started with a desire to commemorate A*STAR's 20th anniversary with the publication of a coffee-table book, with glossy photographs that would make for easy browsing. After some preliminary deliberation, we recognized that we needed to delve deeper as there was more to A*STAR's history than meets the eye. A photograph or two of Biopolis or Fusionopolis, for example, would not fully convey the strategic intent behind our investment in R&D; the exciting growth of our research institutes; or more significantly, the many committed people who have worked very hard to bring A*STAR to where it is today.

More than a collection of vignettes and anecdotes, it was hoped that this commemorative publication would document the history of A*STAR which dates back to its early days as the National Science and Technology Board (NSTB). The definitive milestone that would open our book, it was initially assumed, would be the launch of the first National Technology Plan (NTP) in 1991.

Our research, however, uncovered the early history of Singapore's S&T journey that predated NSTB. The scope of the book was thus expanded to provide the historical backdrop and context of the subsequent R&D endeavours. This book evolved into one that includes the journey of Singapore's S&T.

One major challenge for this project was to capture this more than 46-year-long effort in a 200-page publication. A good many individuals and agencies were part of this national S&T effort and a great deal has been achieved in a relatively short time. We apologise for not being able to fully recognize all these remarkable efforts. However, it is our hope that some of the unused reference materials would one day be resurfaced in other future publications.

This book is our first attempt at producing a detailed account of S&T in Singapore, taking us back to 1965 when Singapore gained independence till today. The first few chapters largely follow chronological order. The first chapter outlines our very early efforts in S&T. It introduces Lee Kum Tatt who established the Science Council that shaped initiatives such as outreach programmes (the 1972 Science Quiz) and awards for scientists (the 1969 Gold Medal Award for Applied Research).

The second chapter discloses how a meeting with Nobel Laureate Sydney Brenner in the 1980s inspired then Deputy Prime Minister Goh Keng Swee to push for the formation of the Institute of Molecular and Cell Biology (IMCB), a move which represented our first foray into life sciences R&D. It also details the formation of NSTB in the 1990s, and the formulation of the landmark NTP, the first in a series of 5-year S&T plans. Inaugural Chairman Lam Chuan Leong shared how our mission-oriented approach was already evident then. The chapter also chronicles an exciting period in our economic development as Singapore actively courted MNCs to base their investments and set up corporate laboratories here. Early research institutes were established and incubated within universities to support these burgeoning industry clusters.

The reorganisation of NSTB into A*STAR under my predecessor, Philip Yeo, and subsequent milestones achieved in A*STAR's corporate history forms the bulk of Chapter 3. It also features how Biopolis was born from a bold vision to establish the biomedical sciences (BMS) as a key pillar of the economy which also catapulted Singapore onto the world R&D stage. The chapter puts on record the mergers of early research institutes and the formation of new research institutes which broadened the spectrum of R&D capabilities. It also traces how A*STAR fostered synergies across different research disciplines in order to better tackle the increasingly complex challenges facing us today and in the future.

Chapter 4 veers away from the chronological narrative to take a more thematic approach, telling of the development of human capital. The two-pronged strategy of attracting and nurturing talent underpins much of our S&T journey and it necessitated a unique treatment. Research, after all, is a human enterprise. Chapter 5 and 6, respectively, takes stock of where we are today and gives us a glimpse of the future.

As the publication takes us behind the scenes, it reaffirms how our achievements in R&D today are largely the result of the vision, planning and execution of a team of very dedicated people. As A*STAR Chairman since 2007, it is therefore especially rewarding for me to sponsor this publication in order to highlight the efforts of this team of very dedicated people. In the process of producing this book, I have seen history come alive in the pages through charismatic personalities, colourful sound bites and interesting nuggets of information. I trust that the book will leave a similar impression on you as you leaf through the pages.

Singapore's R&D story is not just an interesting one to tell; it is also an important one. My wish is that the publication will give you a better appreciation of the strategic thinking behind Singapore's push into R&D. More importantly, I hope that you are enthused and excited by the R&D journey that we have covered so far and will continue to support us in the years ahead.

Lim Chuan Poh
Chairman, A*STAR

Introduction

A*STAR – the Agency for Science, Technology and Research – leads the fostering of world-class scientific research and talent in Singapore.

Most of its 14 biomedical, physical sciences and engineering research institutes, and six consortia and centre, are located in one-north, a wooded yet modern complex anchored by Biopolis and Fusionopolis. Here, research facilities, business parks and educational institutions stand among residences and recreational areas – an environment where the creative and talented can meet, share and discover.

A*STAR's research councils – Science and Engineering Research Council (SERC) and Biomedical Sciences Research Council (BMRC), umbrella bodies for their respective research institutes, are linked by a Joint Council that promotes and supports inter-disciplinary research programmes.

Some 2,500 international research scientists and engineers form A*STAR's diverse community. It also supports extramural research in universities, hospitals, and with other national and global partners, while A*GA, the A*STAR Graduate Academy, develops talent through scholarships, fellowships and collaborations with universities in Singapore and elite colleges abroad.

A*STAR is managed through operational departments; the research community is assisted by a scientific services group, and a cluster works to help bring research to market.

In 2011, Singapore celebrates 20 years of S&T planning and investments via A*STAR.

1_

The Beginning



I believe our future depends upon our ability to mobilise the qualities in our population to maximum advantage. It is the one thing we have which makes up for our lack of size and numbers, and it is of the utmost importance that, in the field of science and technology, we should lead the field in this part of the world.

THEN PRIME MINISTER LEE KUAN YEW
at the opening of the Science Tower
in the University of Singapore, 1966.

To truly appreciate the accomplishments of A★STAR and how far it has come, one needs to step back in time to the newly independent Singapore of 1965. It was a nation rich in its people but poor in its capabilities in research and development and science and technology.



»

The tiny new nation of some 1.9 million people, of whom more than a million were under 19 years of age, gave urgent priority to mapping out its own fate as a newly industrialising nation. The serious doubts about its economic and political survival reflected the pre-independence issues faced by the People's Action Party (PAP) when it gained self-government in 1959. Then, the PAP government made a quick start with the economic issues by asking for advice from the United Nations on developing the colonial economy that had thrived on entrepôt trade.

In 1961, a United Nations Development Programme mission, led by noted Dutch economist Dr Albert Winsemius, came to advise Singapore on industrialisation. Labour was cheap and plentiful and industrialisation on the strategy of import substitution was the economic goal. The Economic Development Board (EDB) was formed in 1961 to draw foreign investors to Singapore and develop domestic industries. Its budget of \$100 million included provisions for technical and financial assistance to Singaporean entrepreneurs. The task to help industries upgrade and improve their products rested with the Industrial Research Unit (IRU) under the EDB. Attractive pioneer manufacturing certificates that carried tax breaks were also issued to draw investment and enterprise. During the nearly 23 months when Singapore was part of Malaysia from 16 September 1963, there was the potential of an enlarged domestic base of the Malaysian hinterland to absorb factory output. However, this disappeared after Singapore became fully independent on 9 August 1965.



Dr Albert Winsemius (LEFT), Dutch economist and Singapore's chief economic advisor, with Minister of Finance Dr Goh Keng Swee (SECOND LEFT) and other guests at a reception.



Seamstresses at the Ocean
Garment factory working on sewing
machines which, in 1963, were
considered state of the art.

»

The solution was to shift from import substitution as the economic rationale to one that focused on industrialising for export. The world was going to be Singapore's market. However, producing for the world meant making products of higher standards and better quality to better compete with goods of the established industrialised nations. The technology to produce such high-quality goods was plainly non-existent in Singapore. Ngiam Tong Dow, a pioneer of the EDB, recalled in his book, *A Mandarin and the Making of Public Policy: Reflections*, "In the first 10 years of economic development, 1960 to 1970, labour-intensive industries, garments, hair wigs, transistor radio assembly, and ship breaking, saw us through. The labels 'high tech, low tech' never entered our vocabulary. Any 'tech' which could provide our young school-leavers with jobs would do."

The national response to the challenge of creating jobs and developing the economy was multi-faceted: investors had to be drawn in, appropriate manpower developed, the education system revamped as part of the bigger picture of manpower development, and infrastructure put in place. It also meant raising industrial standards and exploring industry-linked R&D.

Already in operation were the IRU that was renamed the Singapore Institute of Standards and Industrial Research (SISIR) in 1969, and the Light Industries Services (LIS). The purpose of LIS was to help the 2,000 or more light industries in Singapore to expand and to achieve greater efficiency. Among the functions of IRU and LIS were developing production technique, product design and standardisation. The IRU also had the facilities to repair instruments and carry out tests on products and raw materials. This section of the IRU would one day evolve into the National Metrology Centre.

There was evidence of some success in the efforts of IRU and LIS. By 1983, SISIR had issued over 350 standards for industrial and consumer products made in Singapore. Starting by tapping science and engineering staff at the Singapore Polytechnic and the University of Singapore, it built up a core of science and engineering manpower. SISIR's inaugural Chairman Dr Lee Kum Tatt, one of Singapore's earliest home-grown PhDs, said of SISIR, "Its strength lies in the highly trained, experienced professional men and women who provide a corps of technological and managerial expertise from which the Institute provides practical solutions to problems confronting our industries." Indeed, Singapore was the recipient of international standards sent on by the international organisations. However, technology transfer, S&T education and training, and dissemination of scientific information were still at a very low level. At best, Singapore was working at training technicians.

Thus, there was a clearly felt need to promote the importance of S&T in industry and in education. So enthused was the scientific community about raising public consciousness on the importance of S&T that several scientific associations were formed in the immediate years following independence: The National Academy of Science, the Science Teachers' Association, and even a National Academy of Chemistry. The key one was the Science Council.





1.1 THE SCIENCE COUNCIL

»

As early as 1967, the Science Council had been created to push for the national advancement of S&T and to build up human resources in scientific research and development. As defined by the Science Council Act of 1967, the function of the Council was to make reports and recommendations to the Minister on scientific and technological research and development, including the training and utilisation of manpower, and the establishment of official relations with other scientific organisations. The Council was inaugurated on 30 October 1967, with a meeting presided over by Dr Toh Chin Chye, then the Deputy Prime Minister. Dr Toh was the one member of the Cabinet with a PhD in Science and he would become the first Minister for Science and Technology in 1968. The inaugural Chairman of the Science Council was Dr Lee Kum Tatt who received his doctorate in chemistry from the University of Malaya in 1955. The Council hoped to get "cooperation between industries and the Government and training institutes in planning an integrated approach to problems relating to scientific, technical and technological education".

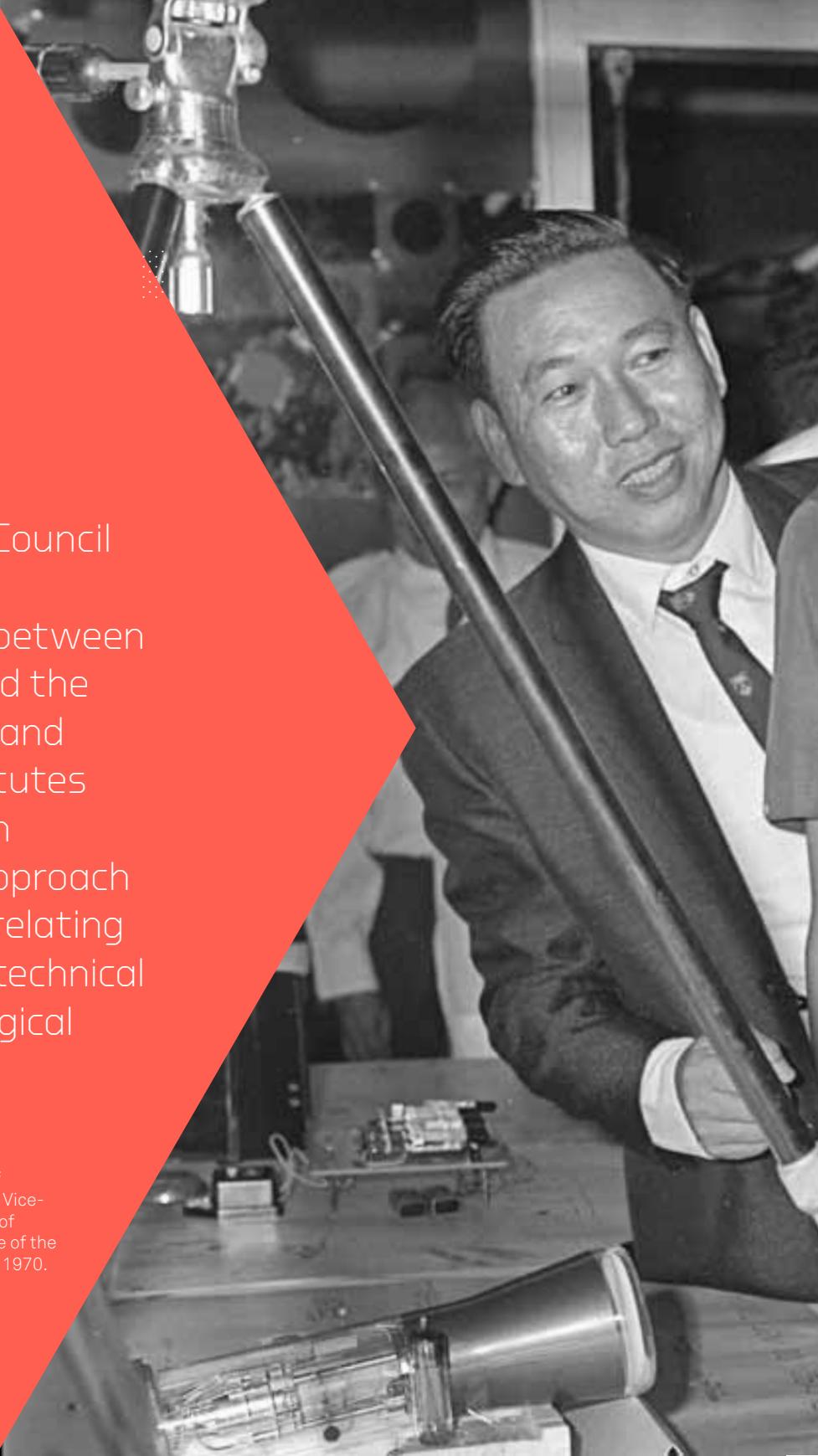
The Council took one of the first steps to get the big picture in 1967 by inviting a UNESCO team to spend six weeks in Singapore to give advice on the building up of technical expertise, standardisation and documentation. The beginning of serious R&D was still over the horizon.

Another step that the Science Council took was the creation of four standing sub-committees: Engineering, Physical Sciences, Social Sciences, and Natural Resources and their Utilisation. The committees were told that their activities should relate the needs to the interests of the nation so that the research would be purposeful and largely applied in nature. The members of these different standing committees were made up of academics from the tertiary institutions as well as representatives from industry. Building links between industry players and the scientific community was considered important even then, as was building links with the international scientific community.



The Science Council hoped to get cooperation between industries and the Government and training institutes in planning an integrated approach to problems relating to scientific, technical and technological education.

Dr Toh Chin Chye, Minister of Science and Technology and Vice-Chancellor of the University of Singapore, at the open house of the university's Science Faculty, 1970.





THE SCIENCE COUNCIL

1.2 PROMOTING SCIENCE AND TECHNOLOGY



In 1968, a proposal was made for the creation of an R&D agency, but the Science Council reported in its 1969/70 annual report that its efforts towards that end at this stage were just exploratory. As part of the exploration, the Council set up a Research Grants Committee to vet proposals of research projects submitted by academic staff in tertiary institutions to the Ministry of Science and Technology. The annual report listed seven research projects all in the agro-fisheries sector. The one that would become a Singapore icon was a project to find a local plant material for the tourist souvenir industry.

A survey of R&D activities in the public sector was conducted in 1970. This first survey of its kind resulted in "A Preliminary Report on R&D Activities in Singapore" that was submitted to the Ministry of Science and Technology. The report recommended, as an immediate plan, attracting foreign science-based industries to set up in Singapore; encouraging big government agencies such as the Ministry of Defence, Public Utilities Board, and the Port of Singapore Authority to start their own R&D units; importing talented and experienced personnel to guide and lead R&D projects; and giving financial grants to private or public sector agencies with feasible R&D projects. The long-term plan was to develop a sufficient number of qualified and experienced scientific and engineering personnel. One strategy would be to send young graduates on two- to three-year attachments with industrial establishments overseas.



Minister for Science and Technology, Dr Toh Chin Chye (SECOND LEFT), at the inauguration of Singapore's Science Centre. Dr Toh announced that a time capsule recording the technological and social progress of Singapore in 1973 was to be buried at the Science Centre in Jurong.



»

Another plan to generate interest in S&T was to establish a popular science centre to bring S&T to the people, particularly the younger generation. The idea of a science museum had come up in the 1963 "Commission of Inquiry Into Education, Singapore: Final Report". The idea was again mooted in the Science Council's 1968 annual report. In September 1969, Miss M K Weston, a UNESCO expert from the London Science Museum, arrived in Singapore to advise the Council on the proposed centre. A detailed report was put up near the end of the three-month assignment, and in August 1970 the Science Centre Act came into operation. The development of the Science Centre was spearheaded by the second Science Council Chairman, Prof Choo Seok Cheow, and the Centre was officially opened in December 1977 by Dr Toh Chin Chye. Appropriately, the Science Centre was sited in Jurong, right in the heart of Singapore's first industrial estate.

1.3 MINISTRY OF SCIENCE AND TECHNOLOGY



During the review of the Science Council's operations in 1967, it was hoped that a Ministry of Science and Technology would be created to coordinate and provide infrastructure for the scientific activities being conducted in Singapore. This hope was realised following the 1968 General Election, for the new Cabinet sworn in soon after included the first Minister for Science and Technology, Dr Toh Chin Chye.



The development of relevant manpower being the top priority, Dr Toh's first task was the restructuring of S&T education particularly at the professional level. As part of manpower planning, the Ministry published its first Directory of Scientific and Technical Research and Consultancy Establishments in Singapore in 1971. Compiled by Wong Hoi Kit and Wee Sin Tho, it was a national survey of S&T activities covering both public and private sectors excluding Medicine, Architecture and Social Sciences. Of the 98 establishments and departments listed, the bulk was in the public sector. Of the 13 listed in the private sector, 10 were engineering consultancies and three were laboratories offering services such as assays, analysis and testing of products ranging from oil to ores to foodstuffs.

To stimulate research, the Ministry introduced an Applied Research Fellowship Scheme and a Research Grant Scheme, both of which were run by the Science Council. The Applied Research Fellowship Scheme would award part-time study fellowships to graduate scientists and technologists in industry, while the Research Grant Scheme was intended for researchers in tertiary institutions. Modifications to the schemes made in 1975 noted that the Research Grant Scheme should fund projects that were more applied in nature "since they arise from government ministries interested in using the results".

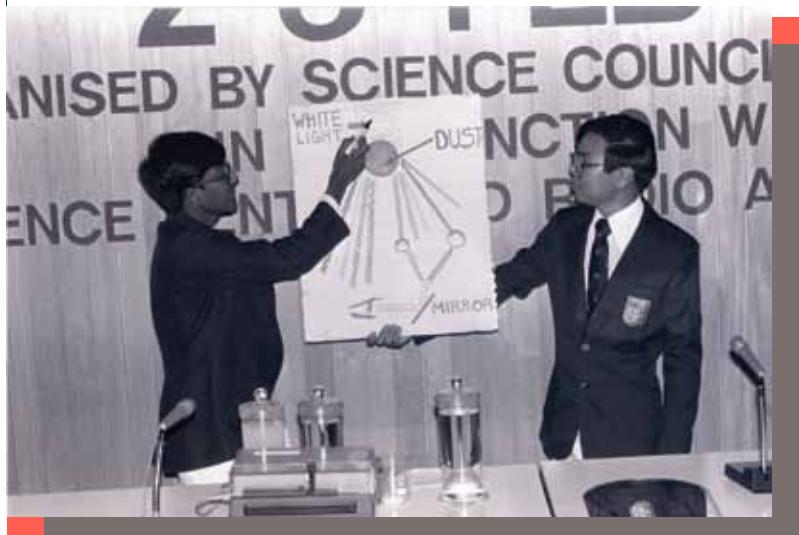
(TOP) Open House at the new science laboratory of Anderson Secondary School, 1967. (BOTTOM) Technical classes in a school workshop, 1970.



»

The Ministry's report in the 1975 *Singapore Yearbook* noted, "Major constraints faced by the Chemistry Department in meeting the objectives have been the lack of manpower and equipment in the Medicines, Narcotics, Toxicology, Food, Radiation Protection and Microbiology divisions and lack of staff and manpower in the Information and Advisory Services." The Science Council's report for the same year, too, acknowledged that a "lack of manpower poses the major constraint."

Aside from manpower, the Ministry needed a strong technical arm as the Science Council had no technical facilities of its own. To meet this need, the Ministry started the Applied Research Corporation (ARC) in 1973 to offer small and medium enterprises (SMEs) a wide range of services in economic science, business management, engineering systems and industrial R&D. The Corporation could draw on the expertise of the tertiary institutions' scientists, engineers, economists and architects, among others. Barring the business management and economics services, the Applied Research Corporation's activities overlapped with the technical and R&D services offered by SISIR.





At the end of 1975, in a review of the civil service chaired by then Prime Minister Lee Kuan Yew on how best to use the limited number of talented civil servants at its disposal, a close look was taken at the role of the Ministry of Science and Technology. The report on the Ministry said, "The role of the Science and Technology Ministry is generally to formulate policies which would decide the optimal use of national resources through the application of science and technology. In the case of developed countries with the means, the Science and Technology Ministry has the added responsibility of deciding policies governing fundamental and pure research. Ours is a nation with no natural resources. Neither can we afford the means to carry out fundamental research. At this stage of development, even applied research is not carried out on a scale that requires major policy guidance. With manpower as our only resource, the Science and Technology Ministry is therefore charged with the responsibilities of tertiary technical manpower development, the provision of science and technical services and the promotion of science and technological activities. Even in the area of policy formulation for industrial development, the Ministry plays a very limited role as these functions are largely dominated by the Ministry traditionally in charge. The role and size of the Ministry is such that it inhibits the full development and utilisation of administrative officers appointed to operate it. In the light of the above, it is considered that the Ministry came into existence somewhat prematurely as much of its portfolio could rationally be absorbed by a number of other Ministries." It was then suggested, that if the Ministry was to be retained, then its technical arm could be strengthened by adding SISIR to its portfolio.



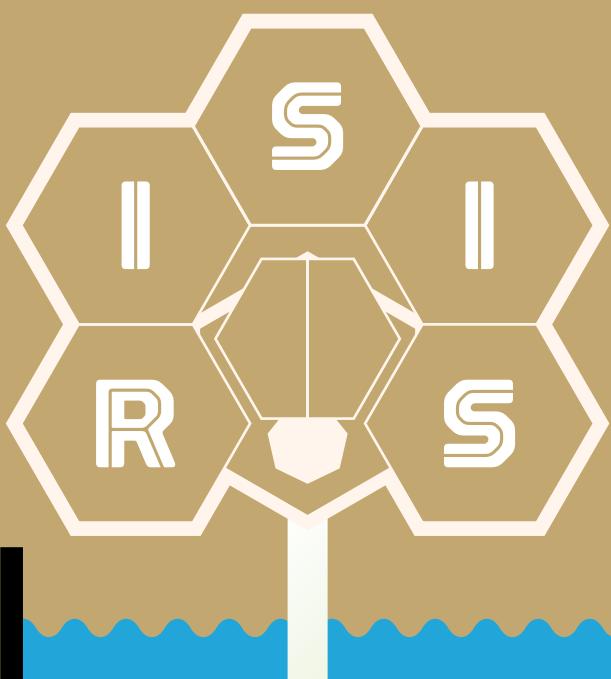
1.4 TESTING THE WATERS OF R&D

As Chairman of SISIR from 1969, Dr Lee Kum Tatt had the tools to execute its R&D mission more effectively than he could as the Chairman of the Science Council. In SISIR's first published annual report in 1973, Dr Lee noted, "Virtually all contract R&D and technical investigations undertaken during the last fiscal year arose from specific needs of business and governmental clients." Nevertheless, he could see a more sophisticated kind of R&D being developed and floated the idea of SISIR making use of "its expertise and facilities to engage in original scientific research, hopefully to make some startling discoveries which may one day prove useful to man." Being pragmatic, he also said, "SISIR has chosen for the next five years a middle-of-the-line course which is to mobilise scientific and technological knowledge to stimulate and cultivate the indigenous technological base of our industries."

SISIR mapped out its ten-year Development and Orientation Plan for the 1980s. The emphasis was on industrial R&D with product/process design and development. The R&D group was expanded, with 50 engineers, chemists, food technologists, physicists and metallurgists besides technical support staff. In March 1978, the EDB's Product Development Assistance Scheme was launched with a budget of \$1 million and a maximum grant of \$100,000 for each project. That year, the Government also introduced the R&D Block Vote which in 1983 became the Research and Development Assistance Scheme.



Dr Lee Kum Tatt, Chairman of Science Council and creator of the RISIS orchid.



Dr Lee Kum Tat, who created the iconic and popular souvenir, wrote about its genesis. "Many people tried to create a truly Singapore souvenir soon after Singapore's independence. Many attempts were made but none succeeded.... I initiated the gold orchid project to fulfill a promise I made to my wife during our courting days in 1955. This started off as a hobby after my return from a trade mission to East European countries in 1967. Our European lady guides were so delighted to receive the live orchids we gave them. I felt that if I could preserve the orchids in gold many ladies would be mesmerized by them.

"One of my ex-staff members offered to give me some metal forming solutions to experiment on in 1973. The hobby and experiments produced some very interesting

The patent for the gold-plated orchid is one of the first patents to originate from Singapore and the company making RISIS – SISIR in reverse – orchids is probably Singapore's first successful commercial spin-off from the laboratory.

and promising results after 1½ years. With this I persuaded SISIR to set aside \$25,000 from its reserve fund to carry on the research to produce the prototypes using better facilities instead of make-shift plastic tanks and rectifiers I used at home.

"We presented one of the first gold-formed orchids to Mrs Benjamin Sheares, Singapore's First Lady, in 1975... Although we had no experience in marketing souvenir products we decided to launch the product ourselves. We stepped up the prototype production... The number of rejects was frighteningly high. We deferred our launch date twice over a period of eight months because of difficulties encountered.

"The launch day, 19 April 1976, came. My gut feel and sixth sense were proven right."

Ironically, this increasing emphasis on R&D came at a time when the Ministry of Science and Technology was slated for closure. When it closed in 1981, the Science Council then came under the purview of the Ministry of Trade and Industry, its statutory role of advising the Government on S&T matters having narrowed to mainly promotional activities, establishing links with the international S&T community and agencies, and organising seminars and conferences.



Things really began to change in the mid-1980s. As part of a re-orientation of the R&D environment, the Science Council, under the chairmanship of Prof Choo Seok Cheow, took over responsibility for two major sets of activities: The administration and promotion of the Research and Development Assistance Scheme, and the administration of the Science Park at Kent Ridge. With its manpower beefed up, the Science Council was buzzing. In 1986, out of about \$2.1 million granted to seven projects, over \$1.2 million were given to four engineering-related projects undertaken by private and public companies. Mentor Graphics, Singapore Electronic and Engineering, and Singapore Test Services, received a grant to research chip-design, non-contact measuring instruments, communications and monitoring systems. The other three projects involving fertility, fish farming, and cancer research were to be carried out by the National University of Singapore. In 1987, the Science Council organised its first Technology Month to showcase S&T activities.



Technician in the food technology laboratory at SISIR,
Science Park, 1988.

1.5 R&D AS AN ENGINE OF GROWTH



From the late 1970s, the Economic Development Board (EDB) introduced a number of measures to promote R&D as an engine of growth. It had begun trying to attract pioneering high-tech companies to invest in Singapore. It created a new section for Advanced Technology/R&D tasked with encouraging small and medium enterprises (SMEs) to invest in R&D to raise the quality of products and to get multinational corporations (MNCs) to set up R&D facilities here.

The semiconductor and disk drive MNCs such as Seagate, Motorola and Fairchild Semiconductor, all high-tech manufacturers, made their entrance in the early 1980s. In 1981, Apple Computer had become the first company to manufacture PCs in Singapore for world markets starting with printed circuit board assembly, its second offshore facility after Ireland. A year later, Seagate Technology, inventor of the hard disk drive in 1980, had been the first disk drive manufacturer to set up manufacturing facilities in Singapore. EDB had persuaded Seagate to also carry out some product and design capability in Singapore and so in 1984, Seagate set up in Science Park to do development work. Seagate has been acknowledged as the catalyst for the development of the disk drive industry in Singapore after it established itself here. It has also been recognised for moving Singapore manufacturing up the value chain by spurring industry sectors like precision machining, die-casting, electronic components and surface mount technology, printed circuit board assemblies, semiconductors and other electronic components designing, and manufacturing.



By 1984, Singapore also had the first wafer fabrication plant in Asia outside of Japan when SGS Singapore, then a subsidiary of the Italian electronics company SGS Microelettronica, began production in Ang Mo Kio Industrial Park 2. Semiconductor wafer fabrication had been one of the capital-intensive and high-tech industries that Singapore had been pursuing with little success for a number of years until Pasquale Pistorio decided to set up SGS Microelettronica's wafer fabrication plant here.

By the late 1980s, semiconductors, data storage, consumer electronics and communications were increasingly important to Singapore's economy.

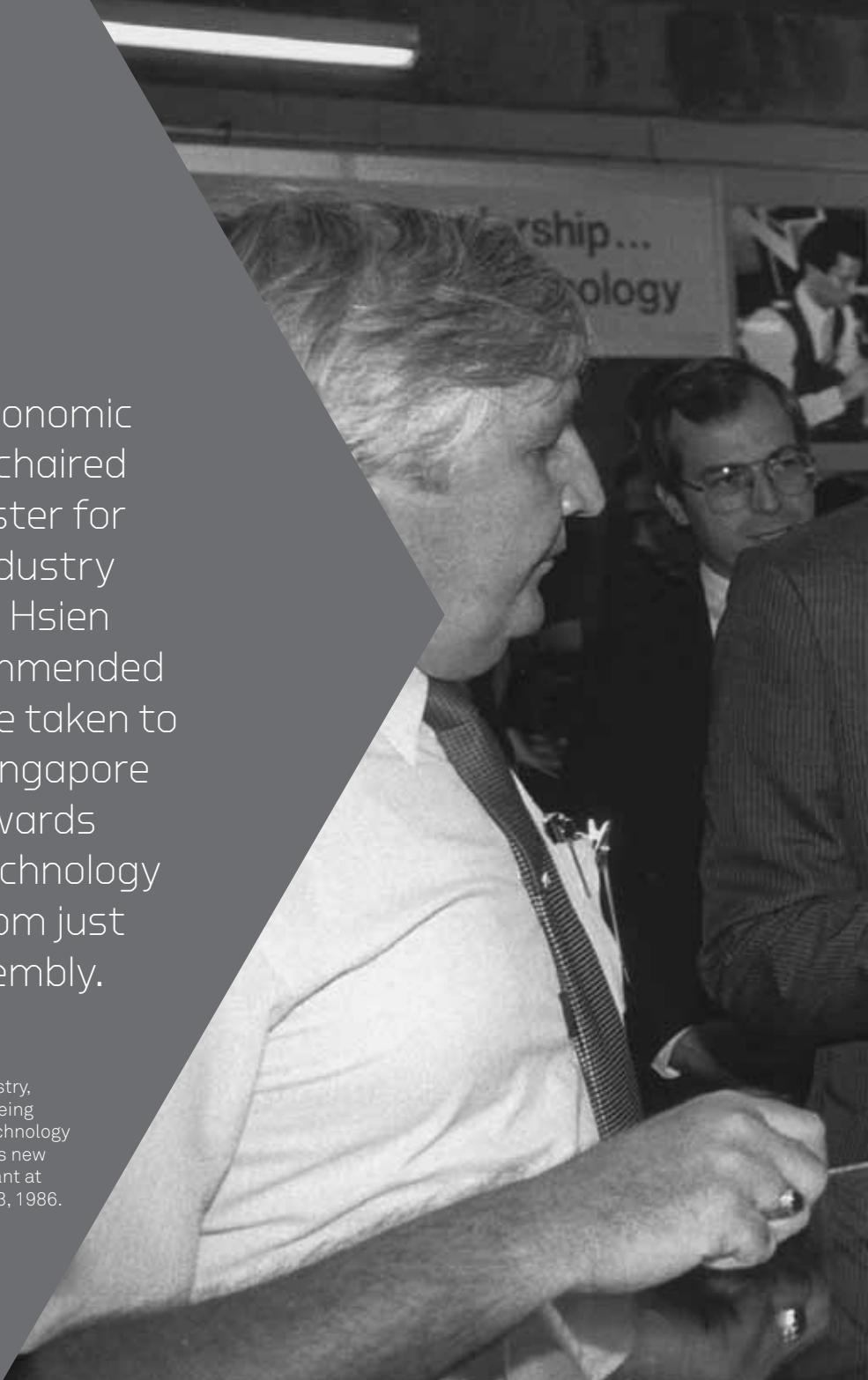
The trigger point for a change in the economic and S&T plans was the mid-1980s recession, the most severe downturn that Singapore had encountered since independence. The 1985 slump prompted an intense review of the economy. The rise of China, India and the region with their vast pools of cheap labour at that time also meant that Singapore could no longer compete on the basis of cheaper costs as it had done in the 1960s and 1970s. However, the recession revealed an interesting trend: companies that were innovative and which had invested in R&D did not fare as badly as the more traditional ones.

Following on the recommendations of the 1986 Report by the Economic Committee, chaired by then Minister for Trade and Industry BG (Res) Lee Hsien Loong, steps were taken to evolve the Singapore economy towards more high technology and away from just product assembly.

»

The 1986 Economic Committee, chaired by then Minister for Trade and Industry BG (Res) Lee Hsien Loong, recommended that steps be taken to evolve the Singapore economy towards more high technology and away from just product assembly.

Minister for Trade and Industry, BG (Res) Lee Hsien Loong being briefed on mobile phone technology during his tour of Motorola's new Communications Sector plant at Ang Mo Kio Industrial Park 3, 1986.

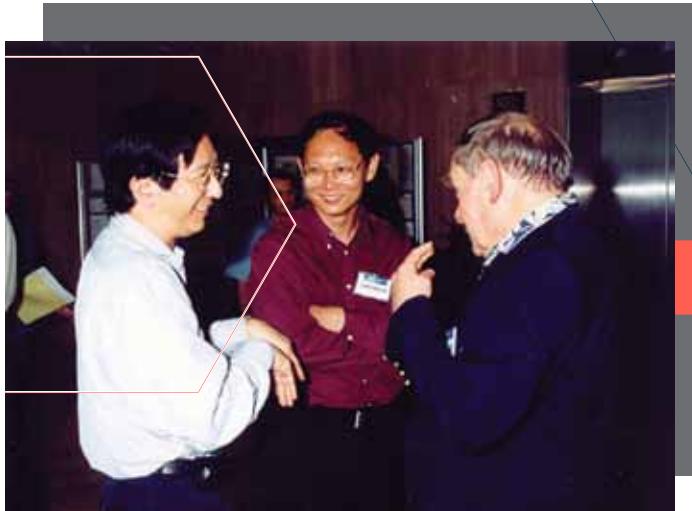




R & D AS AN ENGINE OF GROWTH

» Philip Yeo became the Chairman of EDB in 1986. He was previously the Permanent Secretary at the Ministry of Defence. In 1987, as an Eisenhower Fellow, he spent 11 weeks zipping through 54 US cities visiting laboratories, universities and innovative companies well-known for their R&D, including 3M and AT&T Bell, famed for its seminal work on silicon transistors, solar cells and the laser. Yeo strongly felt that Singapore should go beyond product assembly to making component parts and engaging in R&D. He recalled, "Singapore was making TVs, radios, irons – Philips irons – making products, assembling it. So I said, No. The focus for us will be components – disk drives, semiconductors, chemicals, pharmaceutical chemicals – which can be exported anywhere. I decided we must do R&D or product development. I was trying to get the economy going in the 1985-86 recession when a lot of people had lost faith in manufacturing."

Meanwhile, Singapore companies, generally, were striving to climb the technology ladder with tried and tested methods rather than going into cutting-edge R&D. There was little need to invest in R&D as most of industrial companies were multinationals which transferred advanced technologies to their Singapore operations and key domestic components and service suppliers.



It was becoming more and more apparent that to sustain economic growth, Singapore had to develop a credible R&D ecosystem consisting of a pool of high-calibre researchers and research institutes linked to industry which would add value to Singapore manufacturing to keep MNC plants – and jobs – here. Such an ecosystem was necessary to move Singaporean SMEs up the technology ladder and make them relevant to the market. Without this environment, the MNCs could just as easily set themselves up elsewhere where production costs were cheaper.

Against this backdrop, the Science Council was not equipped for the task of leading the S&T community into the next era. The economic imperatives and the quickening pace of S&T in the late 1980s provided the added impetus to replace the Science Council with an agency with more clout to drive R&D as Singapore's key engine of growth. Said Lam Chuan Leong, the inaugural Chairman of this new agency, "The Science Council did what it was intended to do given the prevailing policies then. However, the new R&D vision envisaged a much heavier emphasis on R&D and a stronger link with economic development policies."

A major development was about to unfold that would make this small island a key player in global R&D.

Philip Yeo, Prof Hong Wanjin and Dr Sydney Brenner celebrating the completion of the draft sequence of the Fugu genome conducted by the International Fugu Genome Consortium led by IMCB and the Joint Genome Institute of the United States.



2_

The Turning Point

There were few known models for us to follow. The search for directions and for people with the right knowledge and background in this field – and able to apply it to Singapore – was the major challenge. We were all novices at the beginning and were casting about for practical ways to implement the new R&D vision.

LAM CHUAN LEONG

inaugural Chairman of the National Science and Technology Board in 2011.



In 1989, while in Tokyo for a meeting and over a dinner of porridge with then Minister of Trade and Industry BG (Res) Lee Hsien Loong, then Chairman of EDB Philip Yeo suggested replacing the Science Council with a National Science and Technology Board (NSTB).

Yeo recounted the points he made: “If we just had manufacturing alone without R&D, we would not be able to develop new products. So I said, ‘we must co-locate R&D and manufacturing under one umbrella.’”



Former NSTB Chairman, Teo Ming Kian, elaborated,

»

"For Singapore, it was imperative for us to do so or we would lose our competitive edge to be a place for companies, both Singaporean and foreign, to start up, stay and grow. And this required a capability and capacity for knowledge creation and innovation to translate the new knowledge for the marketplace. Having a growing pool of researchers and a credible research capability in our economy, both in the private and public sector, was therefore crucial to fire up the creation of a vibrant and sustaining science and technology environment for an ecosystem of large, small, local and foreign enterprises to develop."

On 31 October 1989, a meeting was held to discuss ways and means of promoting and developing R&D and the role of the NSTB.

The meeting was chaired by then Minister of Education, Dr Tony Tan, a scientist by training and a long-time supporter of university research. Present also were representatives from the Ministry of Trade and Industry, National University of Singapore (NUS), Nanyang Technological Institute (NTI) and the EDB. The meeting's agenda was wide-ranging, covering aspects such as manpower training, staffing of the institutes, and ways to accelerate R&D activities in Singapore.



Following the meeting, a Development Project Committee Paper was submitted to the Ministry of Finance outlining the following goals for the institutes of advanced engineering:

- ─ To undertake R&D and develop Centres of Excellence in selected areas of advanced engineering research relevant to the critical needs of Singapore industry;
- ─ To train and develop a pool of industry-oriented researchers because the universities do not always train industry-ready researchers;
- ─ To participate in joint research programmes and provide technical assistance and consultancy to help Singapore firms to develop;
- ─ To develop effective mechanisms for rapid transfer to industry of research findings and technology generated in the Institutes.



»

The paper also proposed the setting up of a separate Council for Engineering Research to oversee the implementation and progress of the institutes of advanced engineering.

In June 1990, the Ministry of Finance approved the plan with a three-year budget of \$81.56 million for Phase I development of the Institute of Microelectronics and the Institute of Manufacturing Technology. These institutes of advanced engineering were to report to a National Council for Science and Technology, which was later formally named as the National Science and Technology Board, to be set up under the Ministry of Trade and Industry.

The plans for NSTB were announced in August 1990 by BG (Res) Lee Hsien Loong. The Science Council was to be made into a statutory board with a projected initial budget of \$100 million to develop Singapore into a research hub in selected fields of S&T to boost competitiveness in industry and the service sector. The mission of the new board was to identify promising new fields of research while strengthening existing R&D activities, and to identify and nurture manpower needs to meet not just the demands of R&D work in Singapore but also that of industry for higher skill levels. NSTB began operations on 11 January 1991.

2.1 MAPPING THE ECONOMIC GUIDE TO R&D



NSTB framed the first five-year National Technology Plan that had an allocated budget of \$2 billion to set the directions for the development of S&T in Singapore. The Plan was produced in consultation with 200 experts grouped into nine subcommittees from both the private and public sectors. Published in August 1991, within a year of the formation of NSTB in January, the National Technology Plan took as its base the 1978 National R&D Survey done by the Science Council.

The Plan stated that Singapore would concentrate on that part of research directed towards economic upgrading. "Thus, our science and technology research must be results-driven, i.e. it must produce results eventually relevant to our economic competitiveness. Our target areas of excellence must be carefully selected in niches that are relevant to our strengths. Government must work in close collaboration with industry, and government's research institutes must support and complement industries' efforts in working towards a common end."

In 1991, a number of fields were already obvious: Manufacturing technology, information technology, electronics, materials technology, energy, water, environment and resources, food and agrotechnology, biotechnology, and medical sciences. Yet, the initial plans were broad, to serve as a guide and to give latitude for development. The next National Science and Technology Plan for 1996-2000 had a budget of \$4 billion and focused on supporting manufacturing and services industries.

Given the high cost of cutting-edge research and the risks involved, Singapore, like other newly industrialised countries, chose to focus on niche research areas where, by the turn of the century, their R&D efforts might begin to have an impact on the global economy and society.



2.2 DRAWING IN CORPORATE R&D CENTRES



The top priority then was to draw in corporate R&D centres. It was no easy task as companies would ask why they should conduct R&D in Singapore when there was no resident talent. Eventually, it was the "follow the sun" strategy for R&D efficiency that convinced some of them. Progressive companies saw the world as their market, and they recognised that Singapore was the only logical gateway to Asia – China and India not being competitors at that time.

The advantages for MNCs to base their R&D centres in Singapore then became obvious. Pairing R&D and pilot production produces a competitive advantage by shortening the time between research, mass production and market. The presence of a viable R&D community speeds up the ironing out of problems in product design, production processes, and all the little things that can go wrong when an innovation is being commercialised. Shortening the time in bringing an innovation to market is critical given the rapid turnover of product innovation and new products. Every day counts and for an MNC to have to send a product thousands of miles to sort out a glitch is time wasted. A product that enters the market place without all its glitches ironed out can prove to be very costly because of the usual warranty extended to most consumer electronics, however limited.



In the late 1990s, with patient cultivation and imaginative marketing, companies began to set up their research centres here, and the R&D capacity and capability in Singapore was gradually built up, turning a vicious cycle into a virtuous one. It helped when companies such as Panasonic revealed how their R&D presence transformed their production capability from, for example, designing and producing cassette recorders to DVD recorders, and how, as a result, they not only stayed on despite lower costs elsewhere, but grew their investments in Singapore with increasingly more sophisticated products.

In addition, a number of schemes were put in place to promote private sector investment in R&D. One was the Research Incentives Scheme for Companies (RISC). Said former NSTB chairman Teo Ming Kian, "I was often referred to as the Billion Dollar Man as the NSTB was allocated \$2 billion for its first five-year S&T plan. Even though funding support was often not the most critical factor for a company's decision to locate their R&D centre to Singapore – since it would still have to bear the bulk of R&D expenditure – the scheme signalled the commitment of Singapore in R&D and helped the companies draw in researchers to their laboratories. This scheme was responsible for building up private sector R&D capability quickly. An illustration of sustainability was that in the depth of the Asian financial crisis from 1997 to 1999, the RISC programme was still able to attract \$1 billion of private sector R&D investments in each of those years."



2.3 INVESTING IN INSTITUTES OF SCIENCE AND ENGINEERING



While multinational manufacturers were being wooed to establish R&D centres in Singapore, the advanced engineering institutes, proposed in 1989 to enhance industry-research institute collaboration, were being formed, expanded or made over.

NSTB's inaugural Chairman Lam Chuan Leong said, "The broad direction of harnessing R&D to serve economic growth was reasonably clear. The sectoral emphasis was also reasonably clear. The key issue was where to position precisely the R&D effort along the spectrum from more upstream to more downstream. Another issue was how to justify the money to be put into R&D and how to measure the benefits and over what period of time. Over time, the faith in R&D has increased but in the initial phases, such questions were frequently posed and I think we did not know exactly how to go about answering them."

His successor, Teo Ming Kian, Chairman of NSTB from 1993-2001, said, "It was mandated by the Ministry of Trade and Industry and the Ministry of Finance for NSTB to support and fund applied research with economic payoff. Given this direction, it was quite obvious that the fields of R&D focus were in our industry sectors like electronics, engineering, petrochemicals and info-communication. To ensure good alignment with this focus, NSTB was reorganised with departments specifically looking after these sectors with a clear objective of enhancing our economic competitiveness."

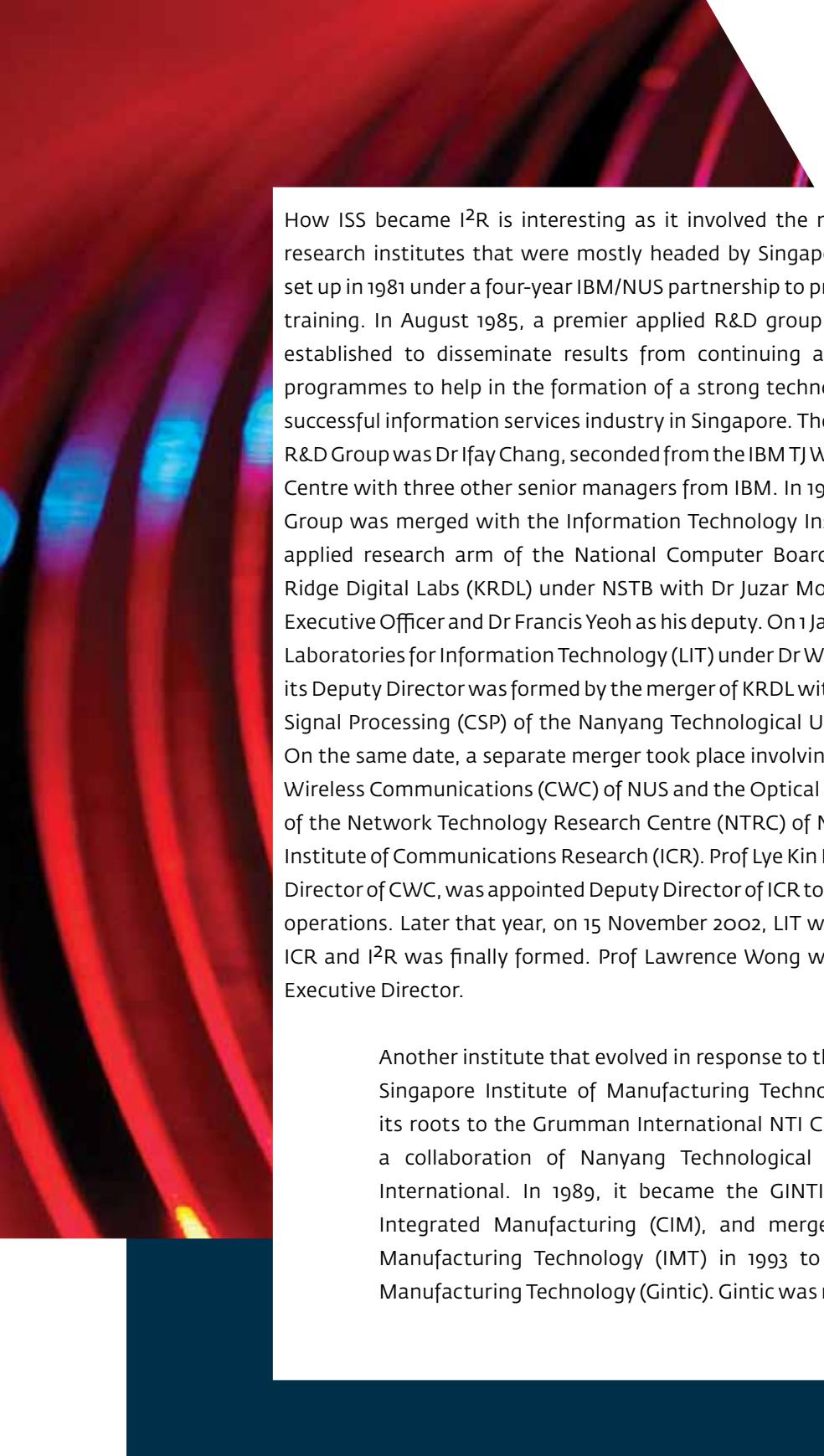
"The objective was three-fold. Firstly, to leverage on R&D to strengthen the capabilities of companies and help move them up the value-added curve so they could be more competitive. Secondly, to help transform the industry. Thirdly, to pre-position ourselves to take advantage of opportunities when they arise even though the industry had not yet been developed."



In setting up the institutes, it was natural to first tap on the universities which already had engineering research centres run by Singaporean academic staff. Said Prof Lim Pin, Vice-Chancellor National University of Singapore in his convocation address in August 1992, "Joint research with industry has always featured prominently in the University's research agenda. Three major projects have recently been approved with substantial funding support from the National Science and Technology Board. They are the Magnetics Technology Centre, the Centre for Wireless Communications, and the Centre for Remote Imaging, Sensing and Processing. They have been selected for support by NSTB on account of their potential strategic impact on key sectors of our nation's economy through collaborative R&D with industry."

The Magnetics Technology Centre was founded by Prof Low Teck Seng within NUS in June 1992 to undertake R&D in magnetics technology for hard disk drives. This research institute expanded to become the Data Storage Institute (DSI) in April 1996.

Likewise, what is now called the Institute for Infocomm Research (I²R, pronounced as i-squared-r), had its early beginnings in the university as the Research Division of the Institute of Systems Science (ISS).



How ISS became I²R is interesting as it involved the merger of many research institutes that were mostly headed by Singaporeans. ISS was set up in 1981 under a four-year IBM/NUS partnership to provide executive training. In August 1985, a premier applied R&D group within ISS was established to disseminate results from continuing applied research programmes to help in the formation of a strong technology base for a successful information services industry in Singapore. The director of this R&D Group was Dr Ifay Chang, seconded from the IBM TJ Watson Research Centre with three other senior managers from IBM. In 1998, the ISS R&D Group was merged with the Information Technology Institute (ITI), the applied research arm of the National Computer Board, to form Kent Ridge Digital Labs (KSDL) under NSTB with Dr Juzar Motiwala as Chief Executive Officer and Dr Francis Yeoh as his deputy. On 1 January 2002, the Laboratories for Information Technology (LIT) under Dr Wong Lim Soon as its Deputy Director was formed by the merger of KSDL with the Centre for Signal Processing (CSP) of the Nanyang Technological University (NTU). On the same date, a separate merger took place involving the Centre for Wireless Communications (CWC) of NUS and the Optical Research Group of the Network Technology Research Centre (NTRC) of NTU to form the Institute of Communications Research (ICR). Prof Lye Kin Mun, the former Director of CWC, was appointed Deputy Director of ICR to oversee its daily operations. Later that year, on 15 November 2002, LIT was merged with ICR and I²R was finally formed. Prof Lawrence Wong was its inaugural Executive Director.

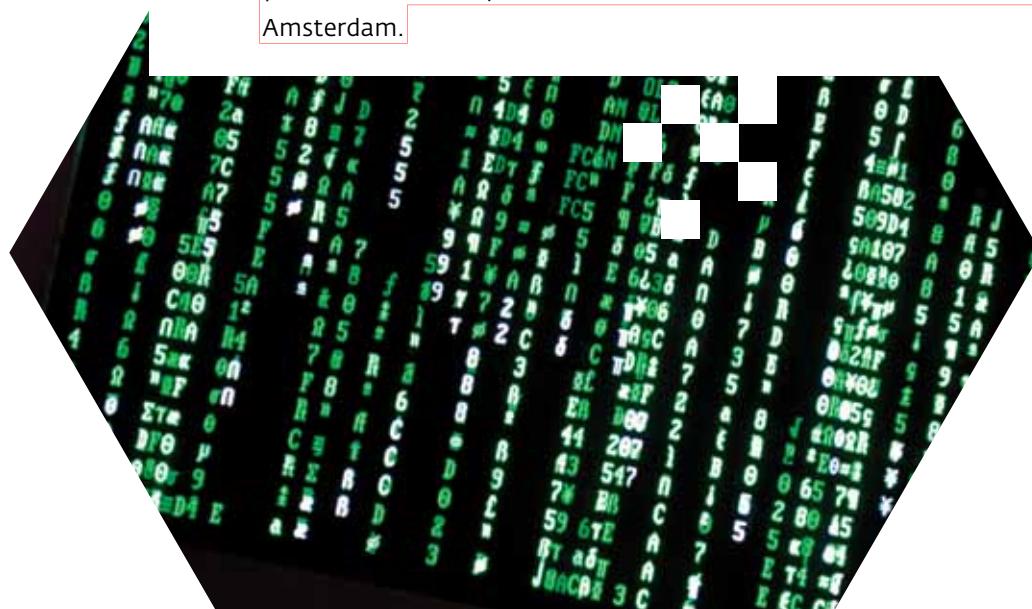


Another institute that evolved in response to the needs of industry is the Singapore Institute of Manufacturing Technology (SIMTech). It traces its roots to the Grumman International NTI CAD/CAM Centre (GINTIC), a collaboration of Nanyang Technological Institute and Grumman International. In 1989, it became the GINTIC Institute of Computer Integrated Manufacturing (CIM), and merged with the Institute of Manufacturing Technology (IMT) in 1993 to form Gintec Institute of Manufacturing Technology (Gintec). Gintec was renamed SIMTech in 2002.

- ▶ Although the Institute of Microelectronics (IME) was funded by NSTB and supported by the EDB, its facilities were hosted by NUS. It was established in 1991 to add value to Singapore's semiconductor industry by developing strategic competencies, innovative technologies and intellectual property.

The industry relevance of Singapore's research institutes is nowhere more apparent than that of the Institute of Chemical and Engineering Sciences (ICES) located on Jurong Island in the heart of the petrochemical industry. It had its start in the late 1990s as a small research centre in the Chemical Engineering Department of NUS at a time when the petrochemical industry was expanding. Jurong Island is now the centrepiece of Singapore's chemicals industry with more than 100 leading petroleum, petrochemicals and specialty chemicals manufacturing companies from all over the world based there.

The chemical industry is an R&D-driven industry with tremendous potential. Prof Hang Chang Chieh, whose first job had been with Shell before he switched to academia, recalled there was no R&D for the chemical industry in the 1980s. "All along this disturbed me and I kept thinking about it. But Singapore was not ready for a centre like ICES yet. I used to work for Shell, so I know Shell has 2,000 researchers in Amsterdam.



ExxonMobil has a few thousand in the US. If you start an institute with one or two hundred people, no one will look at you. Also research in this area is highly centralised, and the oil companies didn't set up and tap talent from all over the world, unlike the electronics industry. The chemical industry is very conservative, very protected, and they didn't want to set up R&D outside of their traditional bases."

It was the emergence of specialty chemicals that prompted the petrochemical giants to look harder at their conservative approach to R&D. Explained Prof Hang, "Speciality chemicals are produced by small start-ups. The small companies came up with new formulae, new compounds and so on. The big companies sat up and said, 'They are more innovative than us; we are too big and too conventional. These are the guys who left us to form their own companies.' And so the big companies became interested in collaborating with these small ones. It was then that they realised that some of these companies are in Asia."

At about the time that the petrochemical giants were sitting up and taking notice of what the small fry were up to, Philip Yeo in pursuit of his Jurong Island idea was invited to the Chemical Engineering Department to see what its little research centre was doing. According to Prof Hang, Yeo said during the visit, "Very good! What do you need?" Prof Hang replied, "We need to upgrade." And Philip Yeo's response was, "Very good! By the way, I am building the petrochemical industry on Jurong Island. This institute should be there." So, in 1998, the Chemical & Process Engineering Centre took shape with NSTB approved funding. It would take two changes of name, from the Institute for Chemical Sciences to the Institute of Chemical and Engineering Sciences (ICES) before it moved to Jurong Island in 2002. Dr Keith Carpenter, who had worked for 25 years with ICI, was the founding Director of ICES, the first such institute in the region.



»

The early focus on application-oriented institutes in Singapore started to veer away as materials science gained prominence. Prof Low Teck Seng recalled, "In the mid-90s we started to talk about a research institute for materials. We had to have the applications-oriented institutes first before we could think about a research institute for materials. Once we have the applications, centralised materials research to do the basic research to feed into the more application-oriented institutes is more efficient. At the time when the paper for forming the materials research institute was accepted, Prof Shih Choon Fong, an ex-Singaporean who had worked for a long time in the US, came to Singapore as a visiting professor and was soon made the first Director of the Institute of Materials Research and Engineering."

International manufacturers with a base in Singapore continued, indeed still continue, to move their R&D facilities here and the list of institutes grew. The Institute of High Performance Computing (IHPC) was launched in September 1998 from the merger of the National Super-Computing Research Centre and the NUS Centre for Computational Mechanics to undertake upstream and industry-driven research and simulation using advanced computation techniques. The Environment Technology Institute (ETI) was launched in June 1996 to position Singapore as a regional hub for environmental technology, and the Institute of Molecular Agrobiology was established in April 1995. The collaborations of the research institutes and centres together with industry partners paid rich dividends in innovations and economic impact. However, exciting developments in biomedical sciences made Singapore look at another direction for economic inspiration.

2.4 CULTURING BIOMEDICAL SCIENCES R&D



The story of the development of biotechnology is also the story of the right people coming together at the right time, in this case Nobel Laureate Dr Sydney Brenner; Dr Chris Y H Tan, a naturalised Canadian; Dr Goh Keng Swee, architect of Singapore's economy; and Glaxo, the British pharmaceutical company.

In the biomedical and biotechnology field at that time, there were the two big pharmaceutical companies – Beechams, which came to Singapore in 1972, and Glaxo in 1979. There were also a number of biotech pioneers who came later in the 1980s. One of these was Singapore Biotech Pte Ltd. Incorporated in 1983 with Temasek Holdings, US Summit Corporation and DBS Bank as stakeholders. Its research division, Singapore Biotech Research Laboratories, focussed on diseases prevalent in Southeast Asia. Another was Diagnostic Biotechnology Pte Ltd, incorporated in 1984, an offshoot of Biotech Research Laboratories, Rockville, Maryland, USA, whose principal activity was in research involving immunochemistry, biochemistry, microbiology and biology. The third was Scitech Medical Products incorporated in 1987. With its focus on biotechnology, the company was working towards the goal of becoming the anti-viral centre of East Asia. At the same time, Singapore had already become well-known in the region for its medical services.

The shift into the biotechnology sector was an obvious one for Singapore but it was to be one that would blossom only after a long haul. While it requires highly-qualified research scientists and engineers (RSEs), it needs few natural resources but adds high value to, and takes advantage of, Singapore's well-established global distribution network.



(TOP) Nobel Laureate Dr Sydney Brenner was genuinely interested in helping Singapore go in the right direction in developing biomedical research.
(RIGHT) Sir Paul Girolami, Executive Chairman of Glaxo and Dr Chris Tan at the signing ceremony of the Glaxo-IMCB Research Venture in 1987.



The EDB had excelled itself in getting Glaxo to invest in a plant in Singapore to produce a newly-discovered drug, Zantac. By late 1982, sales of the new drug had pushed Glaxo up from 25th position to being one of the top pharmaceutical companies in the world by sales. Thus began Glaxo's role in seeding the biotechnology industry in Singapore.

Dr Brenner was invited in 1983 to Singapore to give a lecture on an overview of biotechnology in industry at which time he met then Prime Minister Lee Kuan Yew and then Deputy Prime Minister Dr Goh Keng Swee. Dr Brenner proposed the setting up of the Institute of Molecular and Cell Biology (IMCB) to be hosted by NUS as a start to developing research capability and research manpower in the field of biotechnology.

In a biography by Errol Friedberg, Dr Brenner was quoted as saying: "I was genuinely interested in helping a young country motivated to go in the right direction... This was to be an experiment in developing state-of the-art biomedical research at a national level in what was a third world country not too many years before. I viewed it as an exciting venture and an exciting opportunity."





- ▶ Despite the almost pioneering nature of biotechnology – or perhaps because of it – planning for the Institute begun almost as soon as Dr Brenner had proposed it, with Dr Chris Y H Tan recruited that same year. Dr Tan recalled that Dr Goh had been the one who called him to ask him to consider the job. A professor of medical biology and medical biochemistry at the University of Calgary and well-known for his research on interferon – considered a wonder substance that scientists were then trying to harness for the treatment of cancer – Dr Tan began sending out feelers for researchers to join him at the yet-to-be-built institute. Planning for the new institute had reached such a stage that the \$20.5 million contract for building IMCB was given out in January 1986, before the February release of the Report of the Economic Committee which had recommended a focus on new opportunities of economic growth such as the biotechnology sector.

Singapore clearly wanted to be quick off the mark. Yet as Dr Tan realised, "It was a major challenge – the country was very mercantile at the time, and it took a lot of soul searching for the government to put funding into basic research."

The IMCB was considered a "proof of principle" that Singapore could conduct credible biomedical research in spite of its small population pool. Outside Japan, and to some extent in China, there was very little culture of basic research in Asia. In the EDB's perspective, the IMCB was a compelling promotional tool for attracting life science and pharmaceutical companies to Singapore.

Singapore thus began exploring the possibility of developing a viable biotechnology industry to diversify the economy. In 1988, then EDB Chairman Philip Yeo set up the National Biotechnology Programme (NBP) within the EDB, as well as the National Biotechnology Committee to spearhead the venture into biotechnology. The NBP was headed by Teoh Yong Sea who was also General Manager of Singapore Bio-Innovations Pte Ltd, Singapore's first biotechnology investment fund. A budget of \$40 million was allocated to start the programme.

»

Recalling his stint as the director of NBP, Teoh, currently A*STAR Deputy Managing Director, said, "As Biotechnology was identified as a key strategic interest for priority development, the NBP was formed to develop the capabilities and manpower necessary for the industry. The NBP initiated the setting up of the Bioprocessing Technology Unit and provided funding for bioscience research in NUS and food research at SISIR. The first Diploma in Biotechnology Course was introduced in Ngee Ann Polytechnic with the help of NBP. We also began a long-term plan to cultivate pharmaceutical companies to come here."

By then, IMCB was up and running with Dr Chris Tan as the founding Director and Dr Brenner as Chairman of its advisory board. The Institute gained further research credibility when it entered into research collaboration with Glaxo on the central nervous system. The genesis of this industry-funded research programme can be traced to a meeting between IMCB advisory board member Dr Louis Lim and Glaxo's research group arranged by the EDB's London office. With the EDB's encouragement and active support, Dr Lim who hailed from the Institute of Neurology London (INL) sent Glaxo a research proposal on the central nervous system which fitted well with Glaxo's interest in drugs for treating brain diseases. Glaxo responded with a \$50 million grant spread over 15 years to fund the programme in IMCB and its collaborative researchers in INL.

»

The research collaboration boosted not only Glaxo's reputation in the biomedical research community but also IMCB's international visibility. It was Singapore's first major industry-academia R&D collaboration. All the parties were very pleased with the progress and wanted to explore more of such collaborative projects. "When Dr Richard Sykes*, then President of Glaxo Research, led a team to Singapore in 1992 to discuss a project on high throughput screening for active molecules in natural products, we were able to conclude an agreement on the project parameters in one meeting because of the tremendous goodwill that existed among the parties," recalled Teoh Yong Sea who negotiated the deal. Glaxo put up \$20 million for the research, IMCB provided research and infrastructure support worth \$10 million and the EDB stumped up \$10 million from its NBP. It was a textbook case of productive industry-research institute collaboration, and an example of effective cross-border research collaboration. The Centre for Natural Products research was spun off as Merlion Pharmaceuticals ten years later.

Recognising the significance of IMCB, Prof Lim Pin said at the opening of the Conference on Biotechnology in the Pacific Rim on 5 September 1988, "As a global city plugged into the world's economic system, Singapore has long recognised the need to keep pace with technological developments. The potential of biotechnology is too great for Singapore to ignore. In preparing for the biotechnology era, the Singapore Government has already taken several measures since the early 1980s. The most significant of these was the establishment of the Institute of Molecular and Cell Biology within the National University of Singapore."

★

Dr Sykes would later become Chairman of the Glaxo Group and Rector of Imperial College when he retired from Glaxo. In subsequent years, he became deeply involved with biomedical science development in Singapore, serving as the country's Chairman of International Advisory Panel for Biomedical Science since 2000.



IMCB's abilities did not go unnoticed. In 2000, it was conferred the 5th Nikkei Asia Prize in the category of Technology Innovation for its work towards improving the quality of life in Asia through its outstanding contribution to biotechnology. The award also recognised IMCB's impressive development into "the first major centre of research in Asia". However, while IMCB was producing good research publications, questions arose as to how its relevance to the biomedical sciences industry cluster could be strengthened.

Singapore was about to embark on yet another exciting phase in its S&T development.



3_

A[★]STAR is born



We want to be an agent of change... to be a STAR, to provide the guiding direction for knowledge, change and upgrading in Singapore's economy. A[★]STAR aspires to be a leading star that guides and inspires our young people, and galvanises our local scientific and engineering community to pursue knowledge for the continued prosperity of Singapore.

In the late 1990s, to spur Singapore into a knowledge and innovation-driven economy following the 1997 Asian financial crisis, the biomedical sciences (BMS) sector was identified as one with tremendous growth potential. On the advice of Dr Brenner, NSTB looked at all the top biomedical research laboratories especially in the UK.

George Radda, who was then Chief Executive of the UK Medical Research Council, remembered the study tour from Singapore. "A high-powered delegation including Dr Tony Tan, EDB Chairman Philip Yeo, and Sydney Brenner visited the UK Medical Research Council in 1999 to see how we organize the support for medical research, spanning from basic science to translational and applied research."

It quickly became clear that what was needed was not one institute but a whole spectrum of capabilities that included highly qualified R&D manpower and first-rate research facilities. This need to diversify spawned the Biomedical Sciences Initiative, a plan masterminded by Philip Yeo. A committed and passionate team that Yeo has variously called the "BMS Mafia", "the Gang of Four", and "three doctors and a misemployed engineer", formulated the BMSI together with Sydney Brenner. The doctors were Prof Tan Chorh Chuan, then Dean of the NUS Medical Faculty; oncologist and subsequently Dean of the Medical Faculty Dr John Wong; and then-BMRC Executive Director Dr Kong Hwai Loong; and the "misemployed" engineer – Yeo himself.



Then Minister for Trade and Industry George Yeo launched the Biomedical Sciences Initiative on June 2000 as a major drive to establish BMS as one of the key pillars of the Singapore economy, alongside electronics, engineering and chemicals. Fortuitously, that same day, the US and UK governments announced the results of the first draft of the 15-year, US\$3 billion human genome sequencing project. The efforts of BMS were directed at building industrial capital, human capital and intellectual capital. Beyond BMS manufacturing, Singapore aimed to establish a strong base in R&D, to attract corporate R&D activities and anchor manufacturing activities in Singapore. A budget of \$1.48 billion was allocated for Phase I of the Biomedical Science Initiative.

In August 2000, Philip Yeo became concurrently Co-Chairman of NSTB. It was also announced that he would take over as Executive Chairman of NSTB in February 2001 and become Co-Chairman of EDB, swapping positions with NSTB Chairman Teo Ming Kian who then became EDB Chairman and Co-Chairman of NSTB. Recalling the leadership change, Yeo said, "From 1993 to 2000 I was not involved with NSTB. Then I started to think of trying to promote the biomedical sciences. In 1999 I told Minister George Yeo who was then taking over as Minister of Trade and Industry that we needed to do something about biomedical sciences. I said, 'We need to do research. The only biomedical research institute is IMCB.' I said this was not good enough. I volunteered to take over NSTB and restructure it."

» The resulting re-organisation of NSTB was massive, culminating in the grouping of the research institutes under two councils – and under one roof – for a more targeted R&D approach. Thus, the Science and Engineering Research Council (SERC) was formed as the overarching group for the physical sciences and engineering institutes in 2000. SERC would support manufacturing particularly in the electronics, communications, chemicals and general engineering sectors. Also formed at the same time was the Biomedical Research Council (BMRC) to focus on developing public sector research and talent development in the biomedical sciences, an integral part of the broader national plan to establish and grow the fledgling biomedical sciences industry into the fourth pillar of the manufacturing sector.

In January 2002, NSTB was renamed the Agency for Science, Technology and Research or A*STAR with Philip Yeo at the helm. Together with SERC and BMRC, two further organisational units were added in 2002: A*STAR Graduate Academy (A*GA) to implement A*STAR's scholarship programmes, and Exploit Technologies Pte Ltd, a wholly-owned subsidiary of A*STAR to manage intellectual property and facilitate technology transfer.

Thus, related research institutes were brought together in one space to generate collaboration and to avoid duplication. Rather than grow out of university research and disparate research institutes, Singapore's R&D agenda was now clearly set out by a single agency.

WHY THE NAME A*STAR?

Philip Yeo who came up with the acronym explained:



"Every Primary Six kid knows what an 'A-Star' is. It's not just 'A', it's an A-PLUS. It means you can go to the top schools. So I used 'A*STAR' and worked backwards to form 'Agency for Science, Technology and Research'. I want the kids to be A-plus students, not just A alone because, of the 12,000 A-level kids, 4,000 will get four As but only 400, maximum 500, are really the cream. From these, I select 50 of them for my National Science Scholarships because a nation with that top talent can pull the whole engine along. We do not neglect the rest but if we just focus on the average, Singapore will never be a great nation. It will be an average nation. And the key to being a great nation is there in the top 10 percent. I focused on A-Star to emphasise human talent. And it is true that the scholars who come for our scholarships got all perfect scores at Primary Six. Literally perfect scores. From primary school, you can see they are consistent. Their A-Stars are not flukes. These kids are bright all the way through. From primary school to secondary school to A-levels, their results were perfect."

3.1 HARNESSING BIOMEDICAL SCIENCES



The first five years of the Biomedical Sciences Initiative was focussed on building Singapore's BMS capabilities – which led to the growth in the biomedical sciences institutes. Spearheading the effort was the Genome Institute of Singapore (GIS), the national flagship programme for the genomic sciences that was launched in 2000 as the Singapore Genomics Programme (SGP). In March 2001, Prof Edison T Liu was appointed the first Executive Director of GIS. Liu was wooed from the US National Cancer Institute to lead the GIS and was tasked with developing genomic research, infrastructure, scientific human capital, and attracting R&D ventures in biomedicine into Singapore. Under his leadership, GIS grew from an initial three-man staff into a major international research institute comprising 27 laboratory groups and a staff of 270, all within a short span of 10 years. Today, GIS is recognised internationally as a leader in functional genomics, computational biology, population genetics and genome-to-systems biology.

Other research institutes with specific capabilities soon followed.

Said Prof Lee Eng Hin, the current Executive Director of BMRC, in hindsight in 2011: "Within a short span of ten years A*STAR was able to build up its core capabilities in biomedical research and attract a critical mass of excellent researchers from all over the world."

The Bioinformatics Institute (BII), headed by Dr Gunaretnam Rajagopal, was set up by A*STAR in July 2001. The Bioprocessing Technology Centre was upgraded to a full Institute – the Bioprocessing Technology Institute (BTI) under Professor Miranda Yap in 2003 when its research activities increased in scale and scope. The institute's Bioprocessing Manufacturing Technology Centre (BMTC) was spun off to A-Bio, a local biologics contract manufacturing company, in 2002. In 2003, the Institute of Bioengineering and Nanotechnology (IBN) under the leadership of Professor Jackie Ying was set up to research the interface between biology and technology. Together with IMCB, they form the five core biomedical research institutes.





A*STAR also established the Centre for Molecular Medicine, which eventually became the Institute of Medical Biology in 2007, focusing on translational research to bridge the gap between laboratory research and clinical applications, and to develop closer engagement with the hospitals and disease centres. The areas of focus include regenerative medicine, oncogenomics, immunology and epithelial biology. In 2004, BMRC and the Ministry of Health's National Medical Research Council (NMRC) established joint grant calls for research Proposals. In 2008, the so-called Bedside-and-Bench grants, a new grant co-funded by BMRC and NMRC, helped to foster closer links across the spectrum from basic to translational and clinical research.

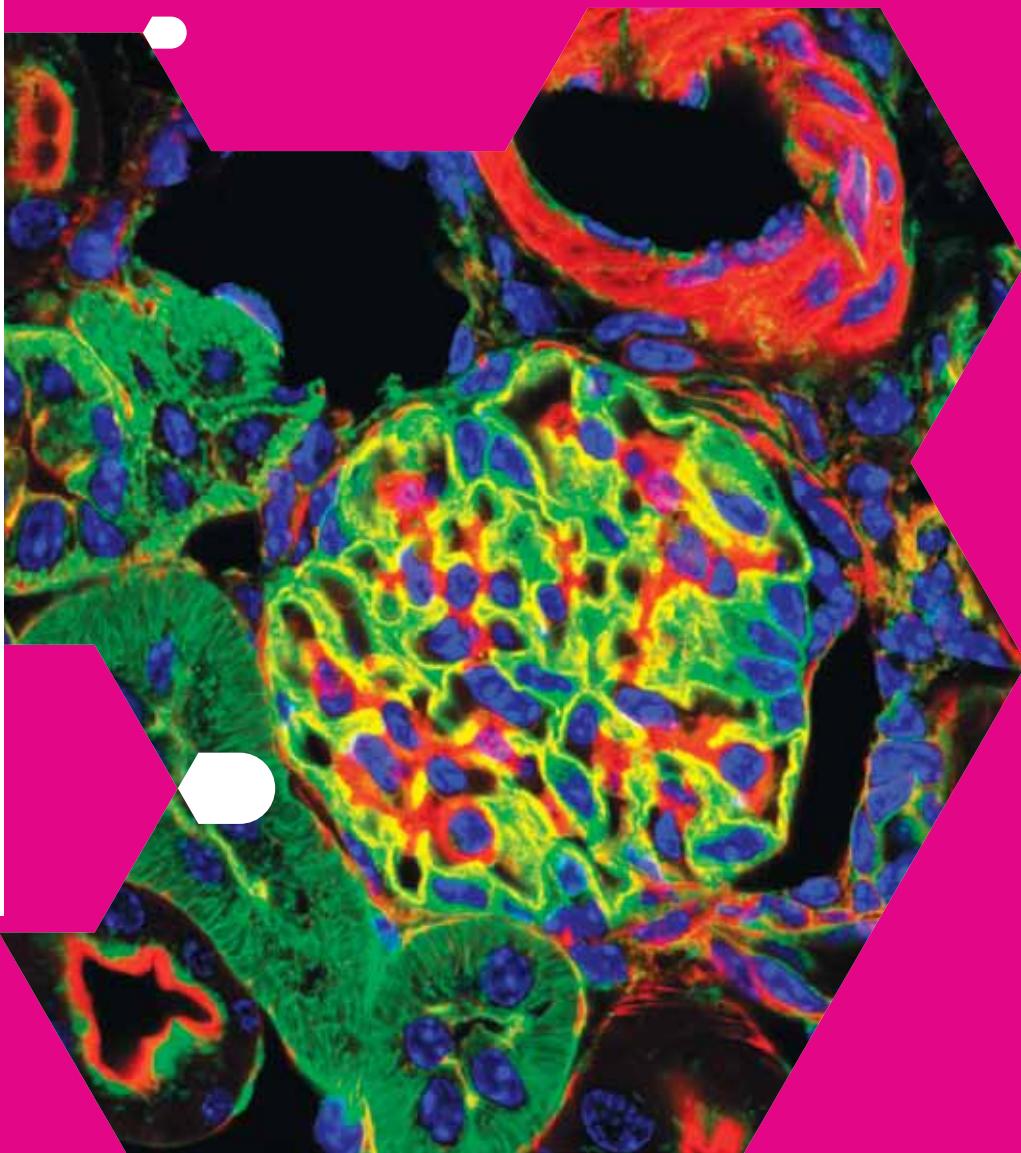
»

This was also the period of leadership change in A*STAR. With Philip Yeo moving on to become Chairman of SPRING Singapore, Lim Chuan Poh was appointed A*STAR's Chairman on 1 April 2007.

Lim was no stranger to A*STAR having been a board member of the Biomedical Research Council since January 2004 and Deputy Chairman A*STAR since November 2006. Well versed on the Biomedical Sciences Initiative, he held the view that Singapore should build on its intrinsic advantages that make it an attractive site for translational and clinical research. In an interview in July 2007 for the Singapore Medical Association Newsletter, Lim said, "We are geographically compact with an ethnically diverse population and a world-class, easily accessible and fairly integrated healthcare system. We also have a robust regulatory environment with sound ethical frameworks and a reputation for quality and safety. As such, we are well-suited to carry out early phase clinical trials and first-in-man studies which rely on small numbers of carefully selected patients who are closely monitored in an appropriate clinical setting."

TRANSLATIONAL & CLINICAL RESEARCH

Prof Tan Chorh Chuan, former Chairman of the Biomedical Sciences Executive Committee Intellectual Property Working Group explains Translational and Clinical Research. “Translational and Clinical Research is about how you apply science to learn about human health and disease. You are taking discoveries made in the lab to see how they can help you make better diagnoses or treatments. Conversely, insights gained from clinical practice and research often generate important basic science research ideas and insights.” Describing the need for high-calibre people to do TCR, he also pointed out the critical link between excellent people and the right environment. He said, “We are also building up the environment that allows this type of research to be done in an effective and efficient way. This includes vibrant academic medicine programmes in our hospitals, strong links between the clinical and basic science research communities, excellent infrastructure for investigational medicine and early phase trials, and a regulatory framework that gives the public confidence that the research that is carried out is ethically responsible and sound.”



The first steps into Translational and Clinical Research (TCR) promised greater things to come. In the second phase of the Biomedical Sciences Initiative, Singapore was able to move into building new capabilities in TCR to bring scientific discoveries from the bench to the bedside, to improve human health and healthcare delivery, and ultimately contribute to the economy and bring benefits to society. For this phase, from 2006 to 2010, A*STAR's BMRC managed a budget of \$2 billion. Of this amount, \$648 million was set aside to support programmes related to translational and clinical research. By 2007, other TCR research institutes and consortia had come into being: Experimental Therapeutics Centre (ETC), Singapore Institute for Clinical Sciences (SICS), Institute of Medical Biology (IMB), Singapore Bioimaging Consortium (SBIC), Singapore Immunology Network (SIgN), A*STAR-Duke-NUS Graduate Medical School Neuroscience Research Partnership (NRP), and Singapore Stem Cell Consortium (SCCC) among others. Five TCR flagship programmes were also established, including the Gastric Cancer TCR Flagship Programme which has since presented new findings that could potentially impact early detection and treatment of gastric cancer.

To secure the human capital necessary to further Singapore's TCR efforts, the Biomedical Sciences Executive Committee, a multi-agency effort comprising entities such as A*STAR, the Ministry of Health, the Ministry of Trade and Industry and the Ministry of Education, announced initiatives to support and nurture clinician-scientists. The Singapore Translational Research (STaR) Investigatorship Award, for example, provides grants to world-class clinician-scientists to conduct research here.



In the development of biomedical research, A*STAR Chairman Lim Chuan Poh said, "In the case of the biomedical sciences, unlike the physical sciences, you need a spectrum of capabilities, and that spectrum is so wide-ranging that we couldn't build it in one five-year plan. From the point of investing in research, it's actually a very big investment for a particular sector. It's a long-term one because you don't get this in three years. You only get this after close to 10 years or more."

"But we have made remarkable progress. When the third five-year plan is completed in 2015, we will have a complete suite of capabilities from basic research in the laboratory, working with cells and molecules, to be able to take this all the way through to humans, to be able to do clinical trials for a small population and then a larger population."

In 2010, the Biomedical Sciences International Advisory Council (BMS IAC), a council comprising eminent scientists and key leaders in the international biomedical community, commended Singapore for its efforts in basic research and TCR in the first two phases of the Biomedical Sciences Initiative. Said Sir Richard Sykes, Chairman, BMS IAC, "Now, having got that integrated system working, Singapore is well-poised to enter into the third phase with the greater emphasis on economic and social outcomes."

To accelerate these outcomes, the Biomedical Sciences Executive Committee, co-chaired by Chairman A*STAR and the Permanent Secretary of the Ministry of Health, announced the formation of the BMS Industry Partnership Office. This multi-agency office made up of A*STAR, the National Medical Research Council (NMRC) and EDB would serve as a one-stop shop for industry players wishing to engage multiple Singapore agencies in research collaborations. This, it was hoped, would contribute to greater efficiency in the drug discovery and development process.

3.2 LOCATED AT BIOPOLIS

»

Environment has been identified by business gurus as a big contributor to creativity and productivity. Thus, to put R&D talent in close proximity with each other is to generate buzz and synergy. Witness the sparks that fly when a large group of like-minded people are in the same room. At the same time, a creative environment must have quiet spaces for reflection and formal and informal spaces for interaction. In other words, a work-live-play-learn environment.

In 2003, such an ideal environment was realised with the launch of Biopolis. Construction of Phase I of Biopolis, a name suggested by Sydney Brenner, had started in 2001 and gone on almost day and night driven by Philip Yeo in his capacity as A*STAR Chairman. It was completed in double-quick time and opened in 2003, ready to receive the new BMS institutes that joined IMCB. Biopolis also houses corporate laboratories of international and Singaporean pharmaceutical and biotechnology companies. Through this co-location of private and public sector research it is hoped that scientists from A*STAR and industry would exchange ideas and explore collaborations, thus facilitating the commercialisation of research outputs. Strategically located in one-north, near the National University of Singapore and the National University Hospital and Singapore Science Parks, Biopolis also encourages multi-disciplinary collaboration and partnerships between academia and industry.



ONE-NORTH: BIOPOLIS, FUSIONOPOLIS

In 1998, then Deputy Prime Minister Dr Tony Tan announced plans for a Science Hub in the Buona Vista area. Renamed one-north, it would comprise Biopolis, Fusionopolis, and Mediapolis upon completion. The master developer of the 200-hectare plot is JTC Corporation.

Conceived by then A*STAR Chairman Philip Yeo and Dr Sydney Brenner, Biopolis – named by Dr Brenner – is the cornerstone of a vision to build the biomedical sciences as a key pillar of the Singapore economy.

The architect of Biopolis was Zaha Hadid. Seah

Chee Kien, chief architect of JTC, was responsible for its construction. Conception and planning started in February 2001. Construction began in early December 2001 and the project, managed by JTC's chief executive Lim Neo Chian, was completed in record time with work going on seven days a week and late into the night. By October 2003, five research entities, namely GIS, BII, BTI, IBN and IMCB, had moved in.

At the launch of Biopolis Phase 1, Dr Tony Tan said, "Biopolis represents a vision to establish the entire value chain of Biomedical Sciences



Fusionopolis was conceptualised as the science and engineering hub. The Phase 1 cluster, identified by the impressive two-tower complex designed by Kisho Kurokawa, is an architectural marvel. However, according to A*Star Chairman Lim Chuan Poh, who chaired the Fusionopolis Steering Committee, "Fusionopolis is more than just mortar and bricks. To us, it is really an emblem of community, collaboration and cooperation."

Prof Chong Tow Chong, then Executive Director of the Science and Engineering Council, who played a key role as the Chair of the Fusionopolis Working Committee, said: "Fusionopolis is conceived as a "world-within-a-city", a living

laboratory environment for researchers to work, live and play and where creativity and innovation have grounds to foster into world-class solutions and applications."

The hub is Singapore's icon for R&D in the interactive media, physical sciences, engineering and technology. Housing private sector facilities, and public sector agencies in a single location, Fusionopolis was designed to encourage spontaneous interactions among its tenants.

Equally important, Fusionopolis is in close proximity to Biopolis, thus opening up opportunities for multi-disciplinary research,





activities in Singapore – from research and development to manufacturing and healthcare delivery... ”

Biopolis helped to boost Singapore’s reputation as a biomedical research hub. In April 2005, *The Independent* declared: “Globally, it would be hard to find a location with a more new, concentrated pharmaceutical industry investment than of Singapore.”

Biopolis has attracted companies such as GlaxoSmithKline, Novartis Institute for Tropical Diseases, Vanda Pharmaceuticals, Paradigm

Therapeutics and Olympus to set up R&D facilities here. They are co-located with A*STAR’s biomedical research entities which better facilitates public-private collaboration.

Biopolis Phase 1 is a cluster of seven buildings linked by skybridges. Phase 2, comprising Neuros and Immunos to reflect a new emphasis on research in neurosciences and immunology, was launched three years later. Phase 3 was completed in early 2011 and is intended to extend basic research activities into translational and clinical research as well as medical technology.

leveraging on the broad-spectrum capabilities of the science and engineering and biomedical research entities. A*STAR established the Joint Council Office in 2008 to drive this effort to integrate research capabilities across communities.

Prime Minister Lee Hsien Loong said at the opening of Fusionopolis in 2008: “Fusionopolis and Biopolis are the anchors of the one-north development, which is designed as an entire integrated innovation eco-system.... The Government remains fully committed to investing in R&D, in order to develop a key capability that will keep our economy competitive in the long term. Our steady commitment will

continue to draw researchers to set up and root their research activities in Singapore, and give investors the confidence to establish high-tech industries and corporate R&D centres here.”

The 30-hectare Fusionopolis will be developed over six phases. A*STAR’s I2R and IHPC, are located at Phase 1. Phase 2A, when completed, will eventually house four other A*STAR science and engineering research institutes, bringing almost all of A*STAR’s science and engineering research institutes into one compact location. Fusionopolis is also home to private companies such as Nitto Denko Asia Technical Centre, Seiko Instruments Inc and HP Labs.

3.3 CONSOLIDATING SCIENCE AND ENGINEERING INSTITUTES



While biomedical sciences were being developed in the early 2000s, the science and engineering research institutes were at the same time being encouraged to consolidate and come under SERC. The integration of institutes was more easily said than done. To appreciate the constraints, one needs to understand their history and their organisation.

Before 1997, when the research institutes and centres became autonomous, with financing from and responsibility to NSTB, they were organised as part of the universities that also provided administrative support and branding. The research institutes were physically scattered and each had its own advisory panel made up of international researchers. In its first decade, NSTB served essentially as a funding agency. The advantage of this particular structure was that with the universities hiring the researchers for the institutes, the researchers had a greater sense of security; in the unlikelihood that the institutes should close, the universities could absorb them. There were other reasons. Teo Ming Kian explained, "The decision to host them in either NUS or NTU was to facilitate collaboration and networking with the existing research community which was primarily in the universities. Another reason was to encourage the universities to increase their impetus to strengthen their research capability."



Prof Hang Chang Chieh, then Deputy Chairman of A*STAR, was given the heavy responsibility of bringing the research institutes under one roof. He was asked by Philip Yeo to consolidate the science and engineering research institutes “ideally into five”. Prof Hang bargained for six or seven. He said, “We had smaller ones which we were supposed to incubate. At that time NSTB funded a Centre for Wireless Communication at NUS, and a Centre for Signal Processing in NTU. We also had Kent Ridge Digital Labs. I looked at them and proposed that all these merge to form the Institute for Infocomm Research. But I had a tough time convincing people to give up their small territories and join forces to do something bigger. Without all these mergers, not only are we unable to achieve our mission, there was the risk of duplicated efforts. I had to convince them to come under one wing so that we would have hardware, software, communication, everything, and then you don’t worry about funding.”

With the merger, the boards of the original research institutes were dissolved and their research programmes were reviewed. In some instances, founding and early directors had completed their terms and new directors had to be appointed to the merged entities. SERC now managed its research institutes directly. Collaboration with industry was strengthened.

Prof Hang Chang Chieh, popularly known to his peers as C C Hang

3.4 SUCCESSES IN SCIENCE AND ENGINEERING

»

A*STAR continued to work with the EDB to attract major private R&D activities to Singapore through its strategy of holistically integrating SERC's research capabilities to serve industry needs. In the early 2000s, the research institutes developed relevant technologies and capabilities for the key manufacturing industry sectors of electronics, infocomms and media, chemicals, and engineering. The Institute of Microelectronics, for instance, consolidated its 6- and 8-inch Deep Sub-micron Integrated Circuit facilities to better meet industry requirements. It was also at this time that ICES was established to add chemicals research to the spectrum of core capabilities and the Institute for Infocomm Research was formed.



SERC research institutes also enjoyed success in the form of collaborations with MNCs. A case in point was the joint projects on engine modelling between the Institute of High Performance Computing and Rolls-Royce in 2002. The collaboration resulted in Rolls-Royce setting up an Advanced Technology Research Centre in Singapore in 2004.

By 2009, SERC had seven research institutes and one centre. It had built up strengths in several key areas including chemistry; computational and device technologies; information, communications and media; materials; manufacturing technology; mechatronics and automation; and metrology. Data storage and semiconductors continued to be the brightest stars of the Singapore economy in the latter half of 2000s. SERC's research areas were also aligned with Singapore's four main industry sectors: Electronics, infocomm, chemicals, and engineering. The main challenge for the electronics and engineering industries, with their long history in Singapore, was to continue to innovate in order to keep strengthening the manufacturing processes and thus stay ahead of the crowd. Thus, the SERC research institutes supporting the engineering industry cluster started to adopt a more institutional approach and began to make inroads into broad-based technologies that cut across various clusters – computational technology, material technology, nanotechnology and microelectronics. This approach was to become the new calling card for A*STAR.



3.5 CREATING SYNERGIES IN R&D



A*STAR Chairman Lim Chuan Poh explained how the research landscape had evolved, "In the first five-year plan, the way R&D created impact was to create institutes to serve the whole cluster of manufacturing. We were not at a stage to create or look for synergy among the various research institutes to generate a much bigger impact. Later on, such as in the biomedical effort, we began building a suite of capabilities for one big industry cluster. This was a fresh approach, a new strategy. This was how the research landscape changed, not in terms of entities, but conceptually."

The new concept was multidisciplinary research that leveraged on the entire spectrum of research capabilities in A*STAR. This was intended when A*STAR was created but to make it work and work well was the challenge and the opportunity. The first step towards this integral approach was to bring the diverse communities of researchers working in different fields together. Mooted by Lim Chuan Poh, the Joint Council was formed in 2008 to facilitate this, including running grant calls for multidisciplinary research projects and organising an annual scientific conference to bring the scientific community together.

Lim elaborated, "The first annual scientific conference was organised in 2008. This provided a rare opportunity for scientists from the biomedical community to meet the scientists and engineers from the physical science community. Senior scientists told me, 'I didn't know A*STAR had so many different capabilities.' These initiatives were designed to encourage cross-council multidisciplinary collaborations. For instance, in the field of medical diagnostic, collaboration between the Genome Institute of Singapore and the Institute for Microelectronics led to the development of very powerful diagnostic devices."

"The Joint Council is a very impactful instrument in another way. If there is a new area of research we want to go into that needs to draw on research capabilities from both the research councils, such as in the biomass conversion space or Medical Technology, the Joint Council can invite proposals in that space from the entire A*STAR research community. The researchers will then self-organise to put forward their proposals. We have the flexibility to convene a fit-for-purpose panel to review the proposals with an integrative and holistic perspective. If it's competitive, relevant and impactful, we'll support it."

"By harnessing the synergies of private-public research collaboration in the precompetitive space, Singapore is laying the ground for innovation through Singapore-made technologies. By supporting and working with consortium partners, Singapore companies get a head start through manpower training and access to the R&D results to prepare them for new technologies and advances."

A*STAR had a natural advantage in promoting multi-disciplinary research as Singapore's small size encourages co-location of research institutions. In 2008, A*STAR officially opened Phase I of Fusionopolis at one-north. Just as Biopolis was built as the hub for the biomedical sciences, Fusionopolis was conceptualised as the science and engineering hub. Conceived as early as 2001, the project was initially known as 'Techpolis', but underwent a series of name changes from 'Technopolis' to 'Fusionopolis', before it was finally re-christened 'Fusionopolis' by Philip Yeo. Prof Chong Tow Chong, then Executive Director of the Science and Engineering Council was tasked by Yeo to bring all the SERC research institutes, with the exception of ICES, under one roof in Fusionopolis.



» By harnessing the synergies of private-public research collaboration in the precompetitive space, Singapore is laying the ground for innovation through Singapore-made technologies.





CREATING SYNERGIES IN R&D

Fusionopolis was designed to facilitate the coming together of talent from different scientific disciplines and sectors, and to create opportunities for them to contribute their capabilities as a vibrant and collaborative community. This close proximity of Fusionopolis and Biopolis – only 600 metres apart – encourages cross-council research collaboration both from the ground up and top down. The ability to integrate diverse research capabilities from the two councils is A*STAR's one significant value proposition to industry.

On the eventual completion of the hub in 2014, Lim Chuan Poh who chaired the Fusionopolis Phase 2 Steering Committee had this to say, "It will be a fantastic environment for researchers. You can just walk down the corridor or you can just meet for a meal in a nearby restaurant, and you can start talking about collaboration. That, in itself, is valuable."

However, the proximity and intensity of research in one location has greater strategic significance for Singapore vis-à-vis other nations.

"Many visitors have commented that they like what they see here. This is intense... A country may look like it has a lot of research dollars but when you spread that over a big geographical area, the effort dissipates. In a large country, they have this challenge because they cannot concentrate everything only in their capital city. So, when you start giving everyone a little bit, it ends up that everyone has nothing substantial. We are fortunate because of our compactness. We can be very concentrated. One location."

Fusionopolis marks the beginning of another chapter in A*STAR's R&D landscape where collaboration and cooperation across the agencies and sectors are encouraged as part of the drive towards a knowledge-based, innovation-driven economy.

*

Fusionopolis currently houses two of SERC's RIs. By 2014, all of SERC's RIs, with the exception of the Institute of Chemical and Engineering Sciences will be co-located together in Fusionopolis.



4_

Talent is Key

Our small physical size need not be a handicap in R&D... What matters is whether we have the right talent to do research, or can attract them here, and whether we succeed in plugging ourselves into the global community of technical specialists and scientists.

LEE HSIEN LOONG, 1990
then Deputy Prime Minister,
and Minister of Trade and Industry



Notwithstanding Singapore's limited native talent pool and its physical smallness, creating a knowledge-based economy is not impossible. In 1990, Lee Hsien Loong, then Minister for Trade and Industry and Second Minister for Defence, suggested that Singapore could look to the Massachusetts Institute of Technology (MIT) and Switzerland for inspiration.

» He said, "Our small physical size need not be a handicap in R&D. MIT in the US is one of the major sources of innovation in the US economy. The whole of MIT covers less than two square miles, although of course its catchment consists of the best and brightest young men and women from the whole of the US, and indeed from many countries all over the world. Similarly, Switzerland is a relatively small country with a small population. Yet Swiss pharmaceutical companies are major players in world markets. They keep ahead of the pack by investing more on quality research, innovation and market development."

According to former A*STAR Chairman Philip Yeo, "two-legged assets" are the key resources for developing a knowledge-based economy. He said at every turn, "The foundation of good scientific research and innovation is talented people. The creative power of the human spirit and the inventiveness of the human mind are the propelling fuel for scientific advancement and technological progress."



(LEFT) Dr Bill Chen was the founding Executive Director of the Institute of Microelectronics.

4.1 EARLY EFFORTS WITH TALENT

»

In the 1990s, the biggest challenge for Singapore R&D was convincing the right people to come to Singapore and being attractive enough to keep them here long enough to develop a core capability and ensure continuity. Singapore tapped the ties built up in the past decades by agencies such as the EDB and the Science Council as well as the networks made by university academics.

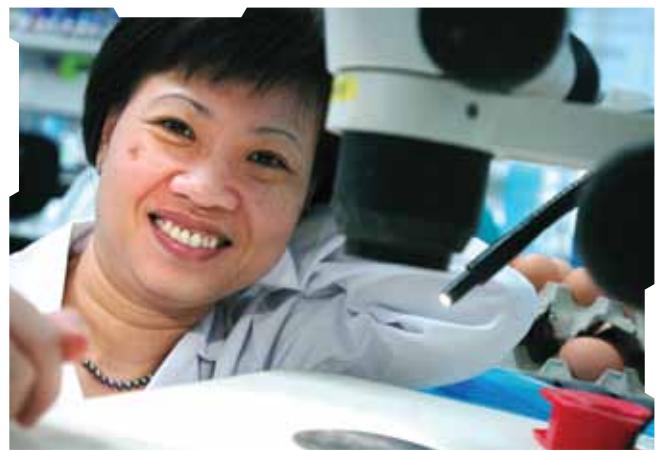
For instance, the founding executive director of the Institute of Microelectronics (IME) was Dr Bill Chen, an AT&T Bell Lab scientist in his mid-50s who had many years of experience not only in the laboratory but also in manufacturing and R&D management. In fact, he was one of the international advisers who had helped Taiwan to build up its semiconductor industry.

Philip Yeo, who knew the AT&T Chairman, went to him and asked to borrow a research scientist. When the Singapore offer came along, Bill Chen decided to commit to a three-year term. Eventually, he stayed for 12 years.

As director of IME, Dr Chen recruited 15 to 20 RSEs, all expatriates with many years' experience in industry. They knew Chen's reputation and track record, and they were drawn to Singapore because he was here. Prof Hang Chang Chieh acknowledges that without Bill Chen, he would have been unable to grow the institutes so quickly. The founding directors as well as many of the senior RSEs that helmed the research institutes were sometimes "loans" extended to these institutes when Singapore had little S&T credibility of its own to make R&D work here worthwhile.

(RIGHT TOP) Prof Birgitte Lane and Prof David Lane. (RIGHT BOTTOM) Dr Lim Sai Kiang.

EARLY EFFORTS WITH TALENT





»

Dr Frans Carpay who was instrumental in developing SIMTech also arrived as a result of networking. James Boyd, the founding director of GINTIC (Grumman International NTI CAD/CAM Centre) – a predecessor of SIMTech – had been on “loan” from Grumman International. Boyd had strong links with the Dutch network, among them Carpay who had been with the Philips R&D centre in Eindhoven and was experienced in the whole R&D cycle from research to commercialisation. Boyd recommended Carpay and the latter arrived with his family in 1993. Instead of staying the agreed three years, he remained involved with Singapore’s R&D evolution from helping to prepare the 1996 and 2001 National Technology Plans to serving on various advisory committees, an involvement of more than 12 years.

As early institutes were incubated in the universities, NSTB could also draw on resources from them. As a result, many of the pioneers who provided scientific leadership for the nascent research entities were from Singapore’s two universities. The Data Storage Institute (DSI), then known as the Magnetics Technology Centre, was one such institute. Prof Low Teck Seng was an academic staff of the Department of Electrical Engineering in NUS when he was approached by Philip Yeo. He recalled, “Philip Yeo sent his young officers to come and see me, and I made a presentation to him in EDB, and in his usual style he said, ‘Yes, yes, let’s do it.’”



Prof Low became the Founding Executive Director of DSI and grew the 20-man R&D team to a 180-strong institute with world class research capabilities. Under his leadership, the institute also expanded its scope from an initial focus on mechatronics and electronics to encompass magnetic read sensors, magnetic media and optical programmes. Prof Low recalled his initial difficulty in starting the institute: "Building the institute from scratch was tough. It was difficult, but along the way there was great excitement."



Prof Low credits Philip Yeo and the EDB for being the driving force behind the institute's founding, "I'm a university professor, if there wasn't this support for me from outside campus, on what basis would I be able to establish a programme and plan to drive in that direction? Having got that impetus, I was able to articulate a vision and, hence, together we were able to build DSI."

The research entities that eventually merged into I2R also had a string of leaders drawn from universities. In 1989, Dr Juzar Motiwalla from NUS took over the reins of the R&D Group of the Institute of Systems Science from Dr Ifay Chang, and would eventually become its longest-serving head. The Centre for Wireless Communication and the Centre for Signal Processing were also helmed by professors from NUS and NTU respectively, such as Prof Tjhung Tjeng Thieng and Prof Lye Kin Mun from the former, and Prof Er Meng Hwa and Assoc Prof Ser Wee from the latter. In 2002, when I2R was formed, Prof Lawrence Wong of NUS was identified by a search committee to head the new institute as its Executive Director.

(TOP) Lim Chuan Poh, Chairman, A*Star
(BOTTOM) Prof Low Teck Seng, founding Executive Director of Data Storage Institute.



4.2 LURING WHALES

»

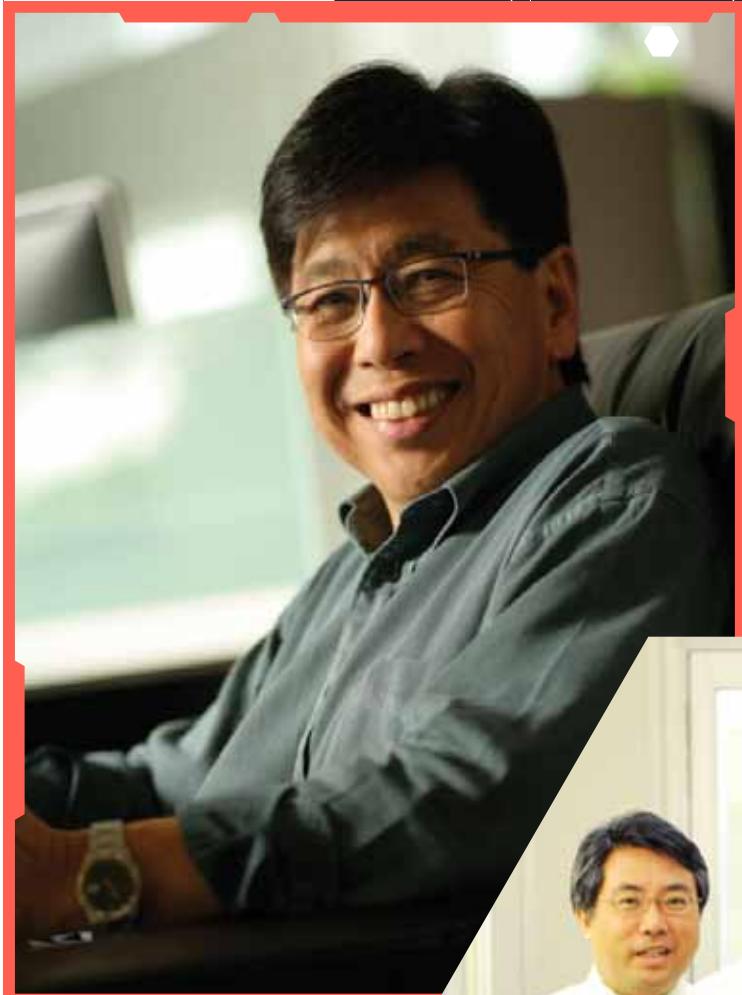
There was, however, a shortage of PhD talent in Singapore necessary to jumpstart the Biomedical Science Initiative. Knowing the length of time it takes to nurture home-grown scientific talent to realise Singapore's ambition of becoming a world-class scientific hub, Philip Yeo looked overseas for RSEs to complement the Singaporean core.

Philip Yeo embarked on his programme of "kidnapping" experienced scientists to nurture young scientific talent. Speaking at the Okinawa Institute of Science and Technology International Symposium in 2010, he recounted what he did to set up the growth of the PhD population:

"The key to research and development is not know-how. It's people. And, for Singapore, we have actually no history of Science, unlike Japan and America. We started by building. So I came up with a list of a hundred scientists in the world that I wanted to kidnap. I use the word 'kidnap' to mean 'hire them'. I drew up the list with the help of Dr Sydney Brenner, went around the world, and kidnapped about a hundred of them."

Philip Yeo called these RSE heavyweights "whales" whose role was to nurse the "guppies" or young Singaporean talent. Philip Yeo's first whale was Prof Edison Liu, then scientific director of the National Cancer Institute's Division of Clinical Sciences in Bethesda, Maryland.

(TOP) Prof Edison Liu.
(BOTTOM, FROM LEFT) Dr Patrick Lo
Guo-Qiang, Dr Yu Mingbin, Dr Liow
Tsung-Yang, and Dr Ang Kah Wee
from the Institute of Microelectronics
were awarded the 2010 President's
Technology Award.





Dr Jackie Ying (LEFT FOREGROUND)
with Prof Edward Holmes.



In 2001, Prof Liu was appointed as the founding Executive Director of the Singapore Genomic Programme which was subsequently renamed the Genome Institute of Singapore (GIS). During his years in Singapore, Prof Liu helped to grow GIS into a top genomic research institute from a staff of three to one with 27 laboratory groups and a staff of 270. Prof Liu was followed closely by Prof David Lane and his spouse, Prof Birgitte Lane, formerly from the University of Dundee, Scotland, to head the Institute of Molecular and Cell Biology (IMCB) and the Institute of Medical Biology (IMB) respectively.

Related Yeo in 2007: "More whales followed and I was soon labelled a 'serial kidnapper' by *Time* magazine. David Lane was 'deputised' to recruit whales of the likes of Dr Neal Copeland and Dr Nancy Copeland from the US National Institutes of Health's Mouse Genomics Center." Philip Yeo also enticed Jackie Ying who was then, at age 34, among the youngest fully tenured professors at MIT to come to Singapore with his vision of Biopolis. Prof Ying would go on to helm the Institute of Bioengineering and Nanotechnology. During phase 2 of the Biomedical Science Initiative, two eminent physician-scientists, Prof Edward W Holmes and Prof Judith L Swain were recruited to help drive translational medical research.

Said Philip Yeo in a 2007 interview, "These scientists of international stature are role models for the younger generation of Singapore scientists. They have helped Singapore to catch up with established R&D centres.... Now, bringing in these international scientists is only one approach. The second way is to train our own people."

4.3 NURTURING GUPPIES

»

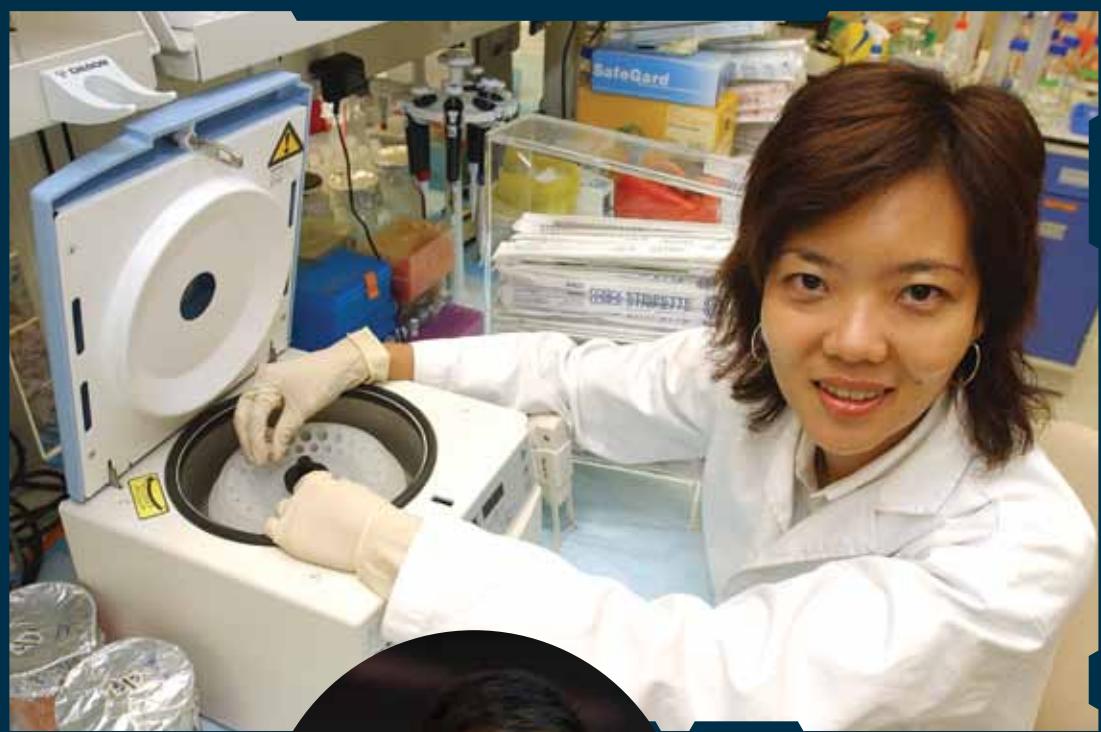
Philip Yeo came up with a plan in 2001 to train 1,000 PhDs, and provide them eight years of funding which would take them from bachelor degree all the way to PhD. It was in March 2001, at about the time that Yeo was surveying the barren land opposite the Ministry of Education building with Dr Sydney Brenner for the construction of Biopolis, that Yeo advertised the National Science PhD scholarship in *The Straits Times*.

A*STAR National Science Scholarships (NSS) were launched on 13 July 2001. Said Philip Yeo, "I invited the Minister of Trade and Industry then, George Yeo, to hand out the first awards to the 2001 batch of scholars on 13 July 2001. There were 27 BS (Bachelor of Science), seven MBBS-PhD, and 10 PhDs for the BMS sector and one PhD for Electronic Engineering. George Yeo was curious and asked me where I got the funds. I replied that I merely robbed the A*STAR research institutes of 10 percent of their five-year budgets. He had a good laugh and kindly did the honours of handing out the 45 scholarship certificates that day."

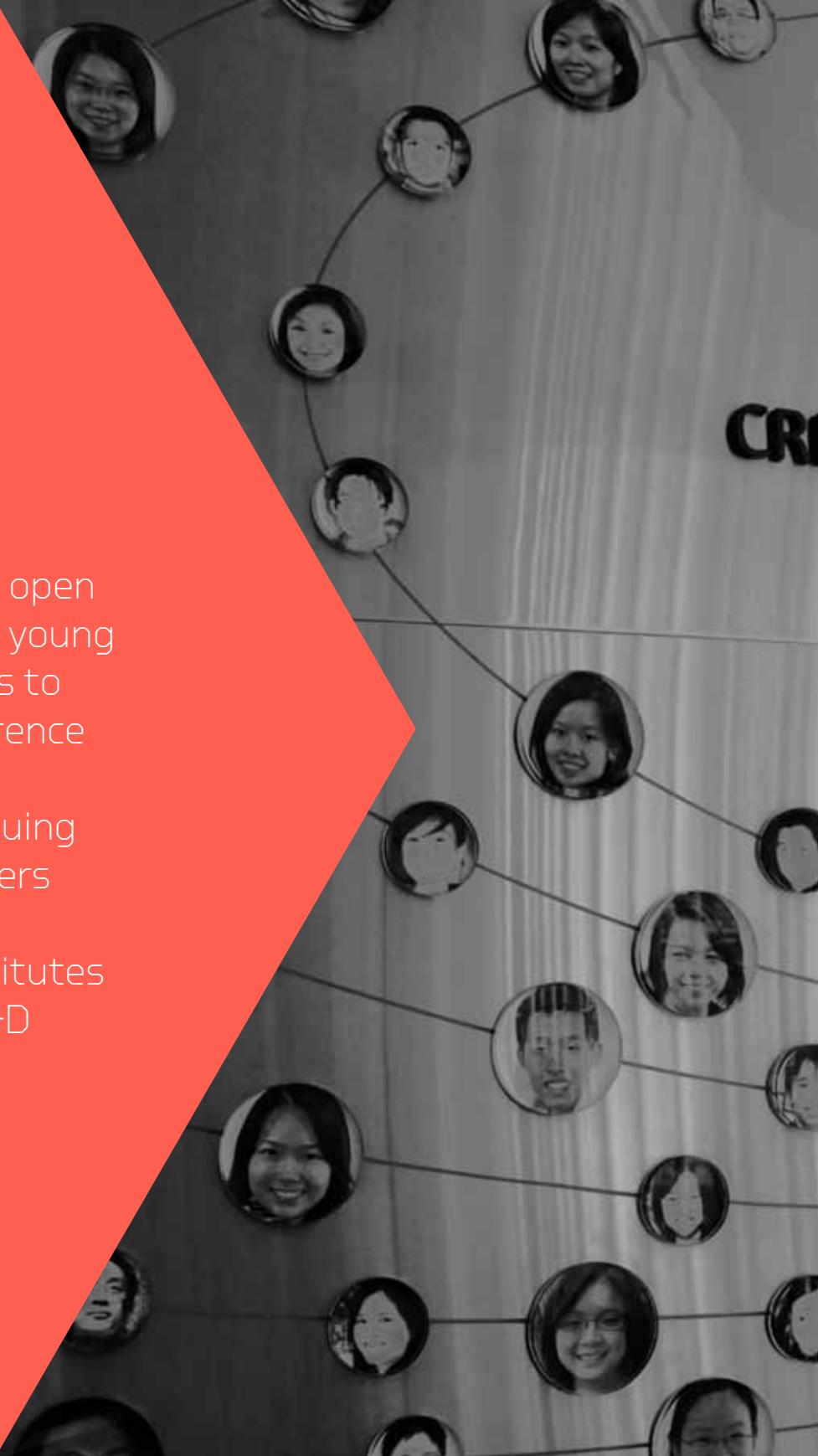
Philip Yeo continued to reflect, "The Singapore government had never given PhD scholarships. In my generation, the graduates came home with just a bachelor's degree... Korea invested in PhDs, Taiwan invested in PhDs – but not Singapore. Singapore was a nation of technicians, screwdriver guys, making washing machines, making TVs and radios. So I said, 'This is not a future for Singapore. We need to do product development.'" To do that, the country needed research scientists and engineers. Said Yeo, "I wanted, at the end of the day, 50 percent of the researchers, PhDs, to be Singaporean." Not only did Yeo introduce PhD scholarships, he also shortened the bond period to a mere six years to make the scholarships doubly attractive.

(TOP)Dr Lisa Ng, who was a polytechnic student, won the ASEAN Young Scientist and Technologist Award 2008.

(INSET, BOTTOM) Dr Victor Tong, winner of TR35 Award from MIT's *Technology Review* in 2008

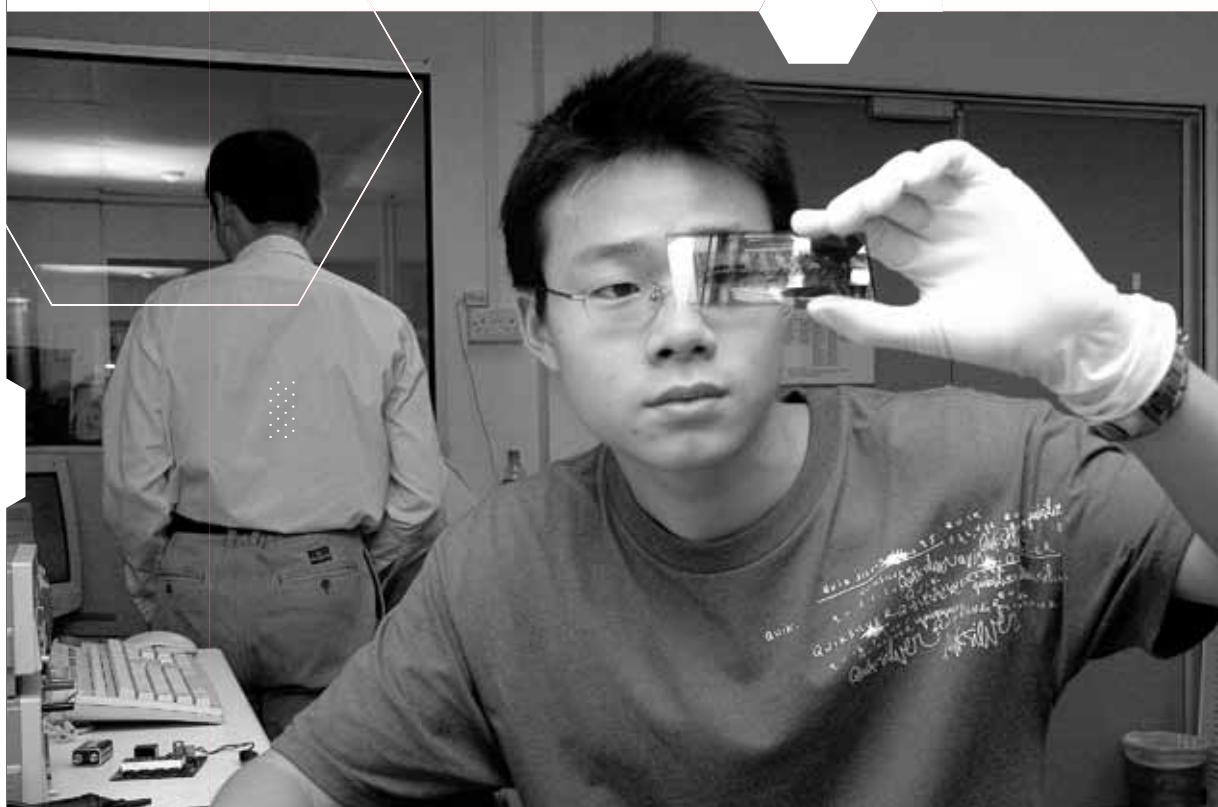


» A★STAR programmes open the doors for young Singaporeans to make a difference to Singapore through pursuing fulfilling careers within public research institutes or private R&D laboratories.





OUR SCHOLARS
CREATING THE FUTURE. IMPACTING THE WORLD.



4.4 A*STAR'S TWO-PRONGED TALENT STRATEGY

»

Committed to the pursuit of top and mid-level international talent as well as the development of young Singaporean talent so as to build a pool of world-class scientific talent in Singapore, A*STAR has built on early efforts and continues to invest in R&D talent.

Since 2001, A*STAR has helped nurture a pipeline of Singaporean talent through the offering of scholarship programmes. Today, students who have the passion or develop enough interest to want to make a career as RSEs may apply to a number of scholarship and fellowship programmes that take scientific talent down the road to a doctorate and beyond doctoral studies to fellowships at well-known R&D institutions and laboratories to enhance their research experience.

A*STAR Graduate Academy (A*GA) programmes, many of which are aimed at identifying and grooming Singapore's scientific talent to its full potential, have funded more than 1,000 scholars and fellows in the best universities in Singapore and abroad. To speed up the development of RSEs, NUS and NTU introduced fast-track programmes that allow the gifted to move faster through the S&T pipeline to a Master's or a PhD in Science and Engineering. Some of the Masters scholarships that EDB had given out in the 1990s were also converted into A*STAR PhD scholarships to add to the biomedical research talent pool more rapidly.

Together, these programmes opened the doors for young Singaporeans to make a difference to Singapore through pursuing fulfilling careers within the public research institutes or private R&D laboratories; in academia; in the commercialisation of cutting-edge technologies; or in the wider public or private sector.

PROGRAMMES FOR TALENT

- A*STAR Science Awards
- A*STAR Talent Search
- Singapore Science & Engineering Fair

- A*STAR Undergrad Scholarship (AUS)

- National Science Scholarships (BS-Phd)
- National Science Scholarships (MBBS-Phd)

- A*STAR Graduate Scholarship (AGS)

- National Science Scholarship (PhD)

SINGAPOREAN TALENT

Secondary School Junior Colleges/ Polytechnics

Bachelor

PhD

The A*STAR Investigatorship Awards (AI), initiated for the Biomedical Research Council in 2006, then extended to the Science and Engineering Research Council the next year, was designed to attract the most promising young researchers from around the world to do independent research at one of A*STAR's institutes. Conceptualised by Dr Tadataka Yamada, an A*STAR board member who was also President of Global Health Programme at the Bill and Melinda Gates Foundation, and former Chairman of Research and Development of GlaxoSmithKline, the AI are modelled after the prestigious Howard Hughes Medical Institute Investigatorship Award known for selecting the very best from the scientific community in the US.

The first AI selection panel was chaired by Dr Yamada who, at the announcement of the inaugural award,

said he was impressed by the depth of talent displayed by those who responded to AI calls.

“Their ability to compete internationally is evidenced by the offers that they are also receiving from world-class institutions in the US and Europe. The fact that some of the best have chosen to come to Singapore and to invest the prime years of their scientific careers with A*STAR speaks volumes for the attractiveness of the research opportunities at Biopolis.” The inaugural award went to Dr Bruno Reversade who is now a Principal Investigator at the Human Embryology Lab of A*STAR's Institute of Medical Biology (IMB). The awards expanded to include science and engineering research talent. There are now nine AI recipients including exceptional Singaporean scientists such as Joel Yang at IMRE and Jonathan Low at IMB.

— A*STAR
International
Fellowship

To develop a pipeline of local talent, A*STAR launched a spectrum of scholarships and awards that offer bright young talent with the opportunity to embark on a career in science at different junctures in their lives.

To build an international R&D community at the heart of Asia, a series of programmes were launched to draw in top- and mid-level talent from around the world.

Post-doctorate

While the AI drew young doctorates to do research in Singapore's research institutes, the Singapore International Graduate Award (SINGA) encourages international students to pursue a PhD education in Singapore's universities as a way of fostering a vibrant and culturally diverse research community here. Under SINGA – a collaboration among A*STAR, NUS and NTU – students receive PhD training at their chosen A*STAR research institute or in one of the top two universities in Asia. This positions the graduates to establish global links that will take their research career to greater heights.

The A*STAR International Fellowship (A*IF) provides PhD graduates with two years of fully funded post-doctoral training at top overseas laboratories to expand their research experience and learn new skills to advance their research careers, thus connecting

them with the global research community.

A different fellowship programme open to A*STAR Graduate Scholars (A*GS) allows such scholars to conduct post-doctoral research for up to two years at a leading overseas laboratory of their choice.

Another programme is the A*STAR Research Attachment Programme (ARAP), a collaboration between A*STAR and overseas universities to provide research opportunities at A*STAR research institutes and consortia. Under this programme, PhD students may spend one to two years at an A*STAR research institute under the supervision of the institute and the university. Nomination to this programme is open only to students whose home university supervisor has a collaboration with an A*STAR researcher.

4.5 GROOMING THE NEXT GENERATION OF SCIENTIFIC LEADERS



Some ten years after the National Science Scholarships were first introduced, the first batch of A*STAR scholars are returning into the system and contributing actively to S&T in Singapore. Dr Cheok Chit Fang, one of the first recipients of a National Science Scholarship in 2001, for example, was appointed to head the IFOM-P53Lab Joint Research Laboratory in 2011.

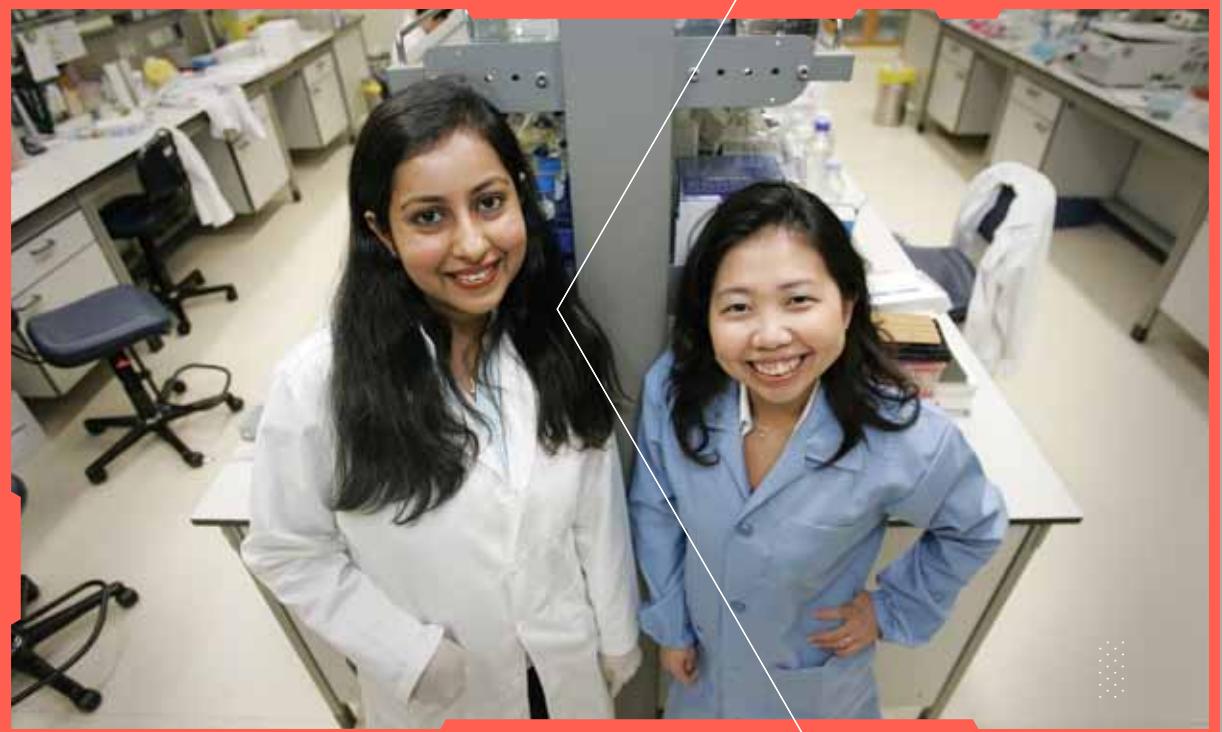


In the words of A*STAR Chairman Lim Chuan Poh, "Singapore will be in a good position when there is a strong core of Singaporeans in leadership positions with a vibrant and diverse international wraparound the Singaporean core."

In 2011, it was announced that Dr Ng Huck Hui who had joined GIS in 2003, will take over from Prof Edison Liu to form the next-generation scientific leadership of GIS. Prof Liu noted that the appointment was a coming-of-age of sorts for the R&D scene in Singapore: "It is symbolic that at this juncture, I, as someone brought in from the outside, can pass the leadership baton to a son of Singapore. Singapore has reached an important milestone in the path to being a hub for research excellence."

As an indication of the maturity of the biomedical sciences R&D scene, Dr Ng joins the ranks of other prominent Singaporeans, such as Prof Lam Kong Peng and Prof Hong Wan Jin who hold key leadership positions in BTI and IMCB respectively.

(TOP RIGHT) Dr Cheok Chit Fang
(right) helms the IFOM-p53Lab Joint
Research Laboratory.(BOTTOM)
Prof Lam Kong Peng.

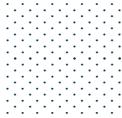


4.6 OUTREACH EFFORTS



"We continue to look for the most capable and committed young Singaporeans, with a passion for science and research, whom we can groom to become future leaders in Singapore's research landscape", said A*STAR Chairman Lim Chuan Poh.

In a bid to inspire this next generation of future leaders to undertake a career in Science, a series of outreach efforts targeted at youths were initiated from as early as the Science Council era. Even in the nascent years of Singapore's S&T development predating the National Technology Plan, the Science Council organised its first Technology Month to showcase S&T activities and introduce several pioneers in the biomedical sciences field. The inaugural Technology Month on the theme Towards Excellence with Science and Technology was opened with a technology symposium at which the Council's first International Panel of Advisers set up in 1985 spoke. NSTB grew TechMonth through the 1990s and involved the wider scientific community in outreach efforts.

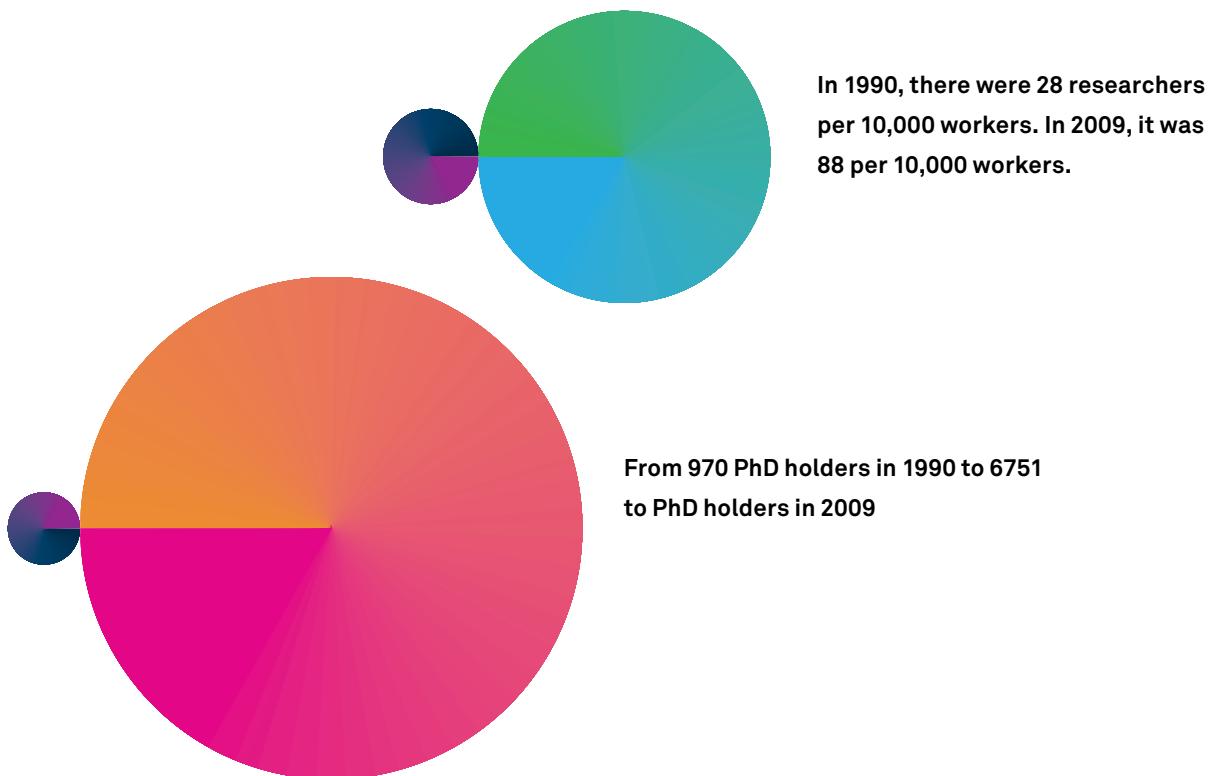


In 2001, A*STAR brought outreach to a new level with Science.01 – a month of science, technology and biomedicine. A*STAR also launched X-periment! that year at Tampines Central, rallying the research community to showcase science to the public in such an accessible manner for the first time. In close partnership with the Ministry of Education and the Singapore Science Centre, A*STAR continues its outreach efforts in earnest to convince young Singaporeans of the importance and relevance of science in their daily lives and help get them excited about science.

4.7 GROWTH OF RSES OVER TWO DECADES

Between 1991 and 2009, Singapore enlarged its RSE talent pool from fewer than 5,000 to more than 26,000. Of these, almost 7,000 are PhD holders. This critical mass of top scientific talent has helped the city-state become a vibrant, world-class international research hub and has also helped to anchor foreign investments here as well as create high-value jobs.

To date, A*STAR has more than 2,500 researchers, more than 50 percent of which come from 60 different countries. These world-class international scientists will continue to attract like-minded and similarly excellent scientists to anchor their research activities here – including Singaporeans who had been working overseas for long periods of time.



»

Said A*STAR Chairman Lim Chuan Poh, "In addition to Singaporean scientific talent, the presence of world-class international scientists in A*STAR has definitely generated significant mindshare for Singapore's R&D effort globally. These scientists have expanded Singapore's global network and reinforced our position as a critical node in the network of world-class research hubs. This international R&D community that we are in the process of building in the heart of Asia will be A*STAR's and Singapore's differentiating advantage."

Prof Low Teck Seng believes that the task of recruiting talent may become easier as Singapore matures as an R&D hub. He said, "With A*STAR's Biopolis and Fusionopolis, the research environment here is radically different from the one we had 20 years ago. However, having state-of-the-art infrastructure for R&D is not the only thing that attracts people to Singapore. It's Singapore as a country, Singapore as a location to bring up a family, Singapore as a location to develop a career. Diversity is very, very critical as well. That's why Singapore thrives – because we are open and we welcome all people."



4.8 A VIBRANT COMMUNITY FOR R&D

» Today, an international mix of high-level, mid-level and young talent co-exist in the thriving R&D ecosystem in Singapore. Dr Sydney Brenner for example, is currently mentoring several PhD scholars who have returned to Singapore, including Dr Shawn Hoon. Similarly, Prof David Lane takes an active role in mentoring PhD students and post-docs in his lab, an endeavour he finds extremely rewarding. He said, "To be part of these developments, to see the buildings grow and the young scientists mature and become established has been an exciting privilege."

According to Lim Chuan Poh, "When the scholars and fellows complete their training, they will have the opportunity of working in an ideal research environment with eminent scientists as their mentors. They also have the rare chance of working in an international community of top talent bound by a common goal to make a difference and contribute to Singapore and the world."

He also revealed that A*STAR is continually working to enhance the research environment here so that Singapore will become the "best place" for promising talent to begin their research career. In his words, "The target is for A*STAR to be one of the top destinations for top PhD students and post-docs, both Singaporean and foreign, within the next five years."



AN AWARD FOR EXCELLENCE

The President's Science and Technology Awards (PSTA), formerly known as the National Science and Technology Awards since 1987, are given to top individual or teams of scientist and engineers for outstanding achievements in Singapore R&D. Renamed in 2009, PSTA comprise three separate awards.

The President's Science Award is presented to research scientists and engineers in Singapore who have made outstanding contributions in basic research leading to the discovery of new knowledge or the pioneering development of scientific or engineering techniques and methods.

The President's Technology Award gives recognition to research scientists and engineers in Singapore who have made outstanding contributions to R&D resulting in significant new technology or innovative use of established technology.

The most prestigious President's Science and Technology Medal is awarded to outstanding individuals who have made distinguished, sustained and exceptional contributions and played a strategic role in the development of Singapore through the promotion and management of R&D.

Over the years, the NSTA/PSTA has awarded exemplary RSEs for their contributions to science and technology.

Said then President SR Nathan in a message for the 2010 PSTA Awards, "...These research scientists have consistently demonstrated a spirit of innovation, an admirable degree of commitment and a relentless pursuit of excellence. For their efforts, they have made breakthrough discoveries that have not only been personally satisfying for them as researchers, but have also benefited the wider society."

Winners of the PSTA Medal include:

Professor Chong Tow Chong, Provost, Singapore University of Technology and Design

"For his distinguished, strategic and far-sighted contributions to Singapore's science and engineering landscape, particularly in spearheading the development of the data storage industry, driving research integration in Fusionopolis, and shaping R&D in Singapore."

Professor Miranda Yap, Executive Director, Bioprocessing Technology Institute, A*STAR

"For her sustained, distinguished and strategic contributions to Singapore's Biomedical Sciences landscape particularly in the areas of developing the biologics industry sector, building the research culture and nurturing young talent."

Professor Tan Chorh Chuan, President, National University of Singapore

"For his outstanding contribution, initiation and expansion of high value R&D activities in Singapore."

GET-UP & T-UP

In 2003, A*STAR organised Growing Enterprises through Technology Upgrade (GET-Up), and its corollary, Technology for Enterprise Capability Upgrading (T-Up).

GET-Up has a variety of schemes designed to encourage SMEs to enhance their competitiveness through R&D activities. Since its launch, more than 300 local companies have participated.

T-up is an initiative that sends A*STAR's researchers to Singaporean enterprises to help them upgrade their technical capabilities. Under the scheme, SMEs specify the criteria for proposed research projects and RSEs with the relevant skills and interests are matched accordingly.

According to a 2009 survey conducted by NUS Entrepreneurship Centre, 95 per cent of companies on the T-Up scheme stated that it helped them to achieve their overall objectives. Anecdotal evidence also suggests that the scheme helped SMEs to develop new products and processes, set up in-house R&D departments, expand their range of services or products and even penetrate international markets.

In 2011, during the first T-Up Excellence Awards organised by A*STAR, several SMEs paid tribute to outstanding secondees for services rendered under the scheme.

A representative from Seidensha shared how his company was given a new lease of life as a result of T-Up. Prior to T-Up, Seidensha was in the field of manufacturing and marketing of Cathode Ray Tubes testing equipments and found itself becoming obsolete when liquid crystal display monitors became increasingly the norm. Dr An Chengwu, a scientist from A*STAR's Data Storage Institute, was seconded to Seidensha in 2003 to lead a four-man research team to develop new technologies for the company. The hard disk media testing systems that Dr An helped to develop, were adopted exclusively by a leading hard disk manufacturer in Singapore, and went on to net Seidensha more than ten million dollars in sales. It also helped the company break into a new industry. At the award ceremony, Seidensha's grateful general manager told *The Straits Times*, "Without him, we would have gone bust."



4.9 INTERNATIONAL RECOGNITION

A*STAR is now home to a large number of research talent. Among them are some of the eminent names in research who came to set up and lead our research institutes such as Prof Miranda Yap, Prof David Lane, Prof Philippe Kourilsky, Prof Paola Castagnoli, Prof Dim-Lee Kwong and Prof Jackie Ying.

- Prof Miranda Yap, Executive Director of the Bioprocessing Technology Institute and the inaugural President's Science and Technology Medalist, was named a Foreign Associate of the US National Academy of Engineers in 2006, becoming the first female scientist in Singapore to be so honoured. This is the highest honour accorded to an engineer by the Academy, in recognition of a non-US researcher's contributions to engineering research, education and management.
- Prof David Lane, currently Chief Scientist of A*STAR, received in 2008 the Royal Gold Medal from the Royal Society of Edinburgh, one of its highest accolades given to individuals whose intellectual endeavours made an impact on people's lives worldwide.
- Prof Philippe Kourilsky, Chairman of the Singapore Immunology Network (SIgN), was conferred one the highest French honours – Commander of the Legion of Honour – in 2009 for his work in science at both national and international levels.

(TOP) Prof Miranda Yap.
(BOTTOM) Prof Philippe Kourilsky.





- Prof Paola Castagnoli, Scientific Director of the Singapore Immunology Network, was elected to the German Academy for Sciences Leopoldina, which is the world's oldest academy for medicine and traditional sciences.
- Prof Jackie Ying, Executive Director of the Institute of Bioengineering and Nanotechnology, was named as one of the "One Hundred Engineers of the Modern Era" in 2008 by the American Institute of Chemical Engineers and was appointed by the US National Academy of Engineering to the "Grand Challenges for Engineering" committee in 2007.
- Prof Dim-Lee Kwong received the 2011 IEEE Frederik Philips Award for his strategic leadership at A*STAR's Institute of Microelectronics.
- A*STAR research institutes today also boast of young Singaporean talent such as Prof Lam Kong Peng, Dr Li Haizhou, Dr Lisa Ng, Dr Ng Huck Hui, Dr Lim Sai Kiang and Dr Victor Tong who have made their mark as scientists in their respective fields.



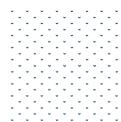
(BOTTOM) Dr Ng Huck Hui

» Prof Lam Kong Peng, Scientific Director of Bioprocessing Technology Institute, was the first Singaporean to be honoured with the prestigious Arthur Kornberg Memorial Award by the Asia Pacific International Molecular Biology Network (A-IMBN), one of Asia's key organisations for research in molecular biology and biotechnology based in Korea. The award is given to promising scientists who demonstrate excellence in research relevant to the needs of humanity.

» Dr Li Haizhou, Head, Human Language Technology at the Institute for Infocomm Research was awarded the prestigious Nokia Visiting Professor Award 2009 in recognition of his contributions to speaker and language recognition research. Dr Li's eminence in this field was recognised again when he was elected to the Board of the International Speech Communication Association, which is the largest professional organisation in the areas of speech communication, science and technology. Its board members are all globally acknowledged experts in this field.

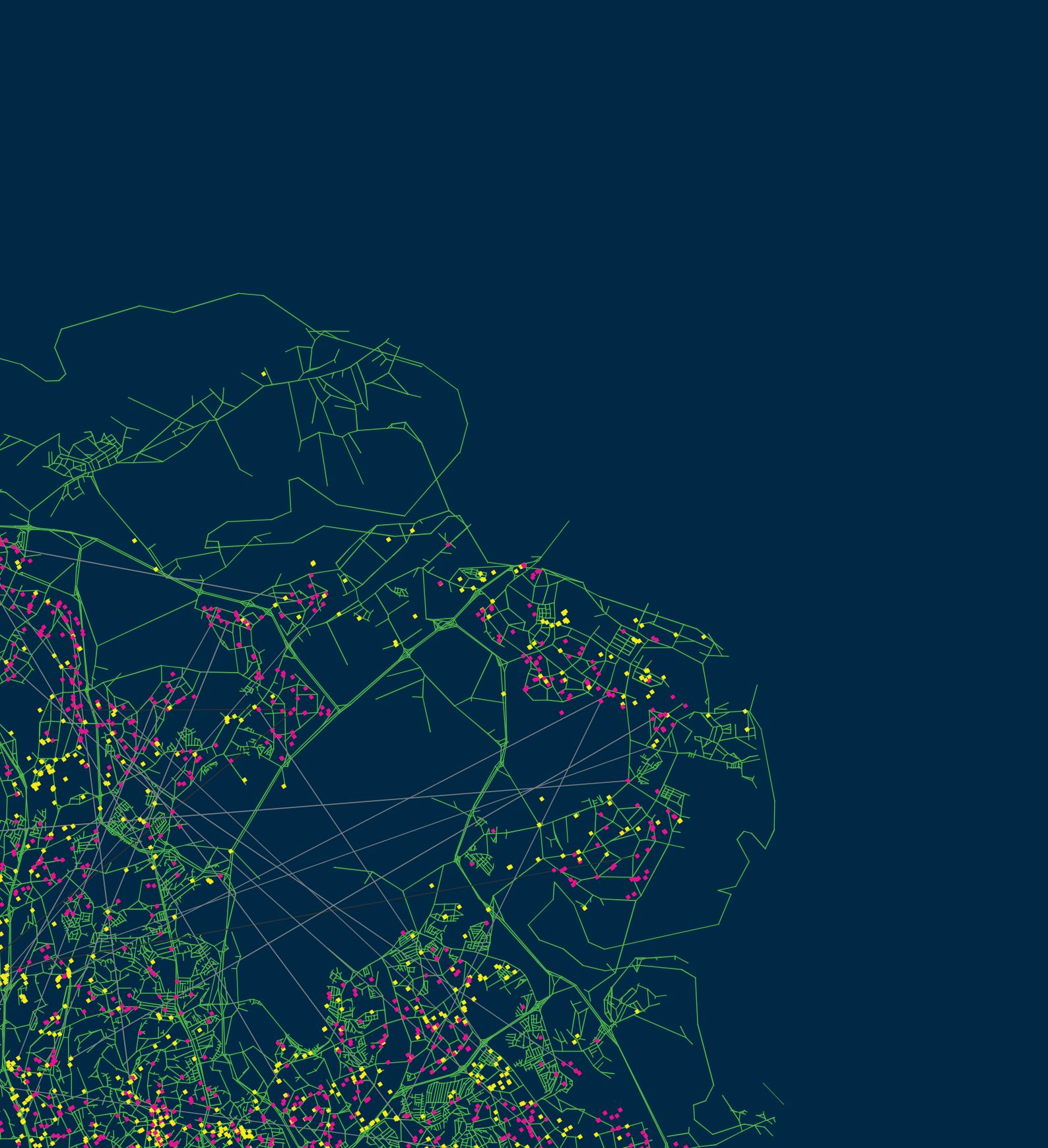
» Dr Victor Tong Joo Chuan, another researcher from Institute of Infocomm Research, was conferred the TR35 Award for his research work on Personalized Vaccine Design by MIT's *Technology Review* in 2008. He was the first staff member of A*STAR to win the annual award which recognises the outstanding achievements of researchers under the age of 35.

» Dr Lisa Ng, from the Singapore Immunology Network won the ASEAN Young Scientist and Technologist Award 2008 for her work on infectious diseases, particularly in the development of diagnostic kits for the SARS-CoV and avian influenza H5N1 viruses.





(TOP) Prof Judith Swain
(BOTTOM) Dr Li Haizhou



5_

Measures of Success

A*STAR has developed a unique spectrum of deep capabilities across biomedical sciences, and physical sciences and engineering. It has nurtured R&D programmes that are of high-quality and industry-relevant, and is engaged in a wide range of industry collaborations to add value to Singapore's economic clusters.

LIM CHUAN POH,
Chairman A*STAR

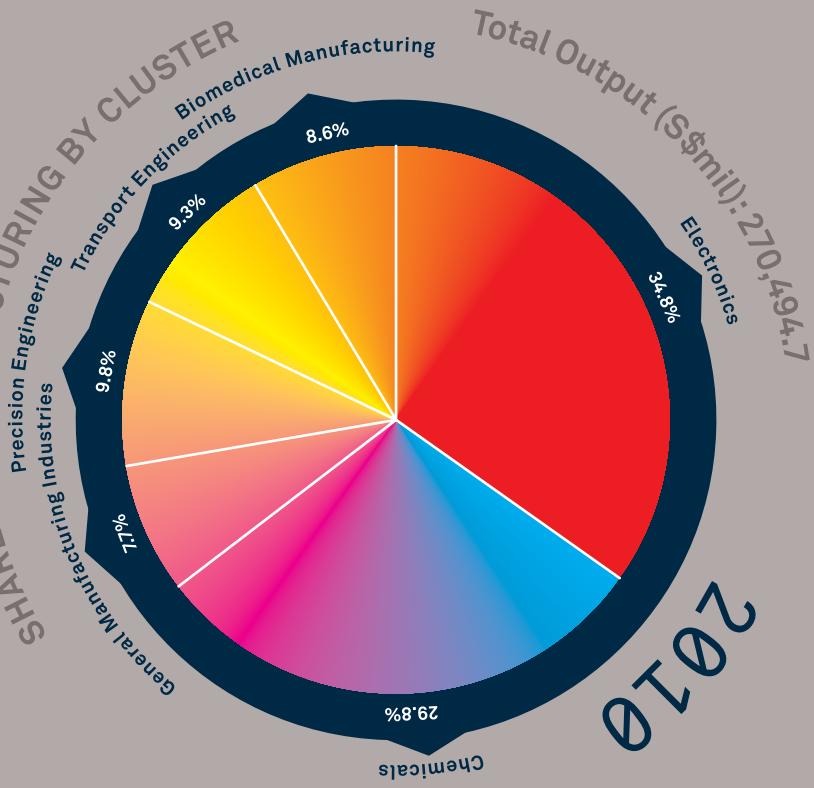
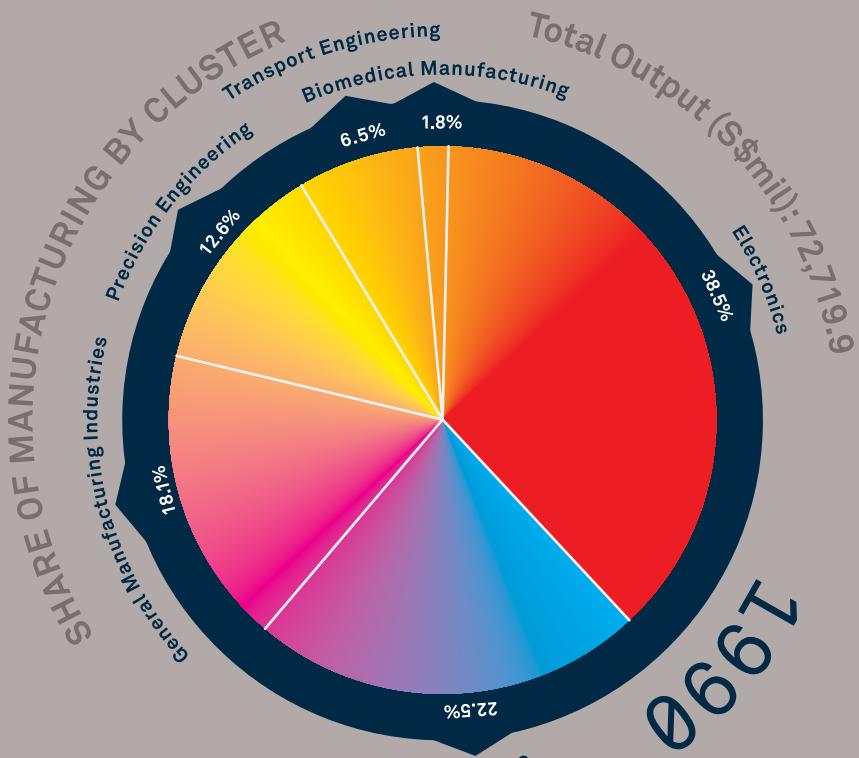
As a result of the Government's sustained efforts to transform Singapore into a knowledge-based and innovation-driven economy, Singapore developed a unique spectrum of deep capabilities across the biomedical sciences, physical sciences and engineering within 20 years.

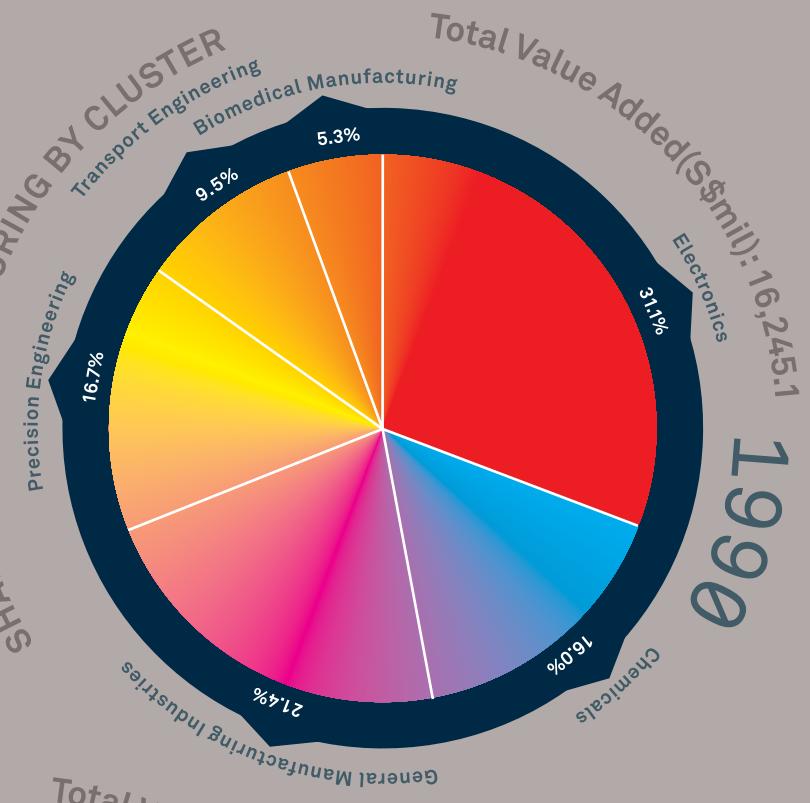
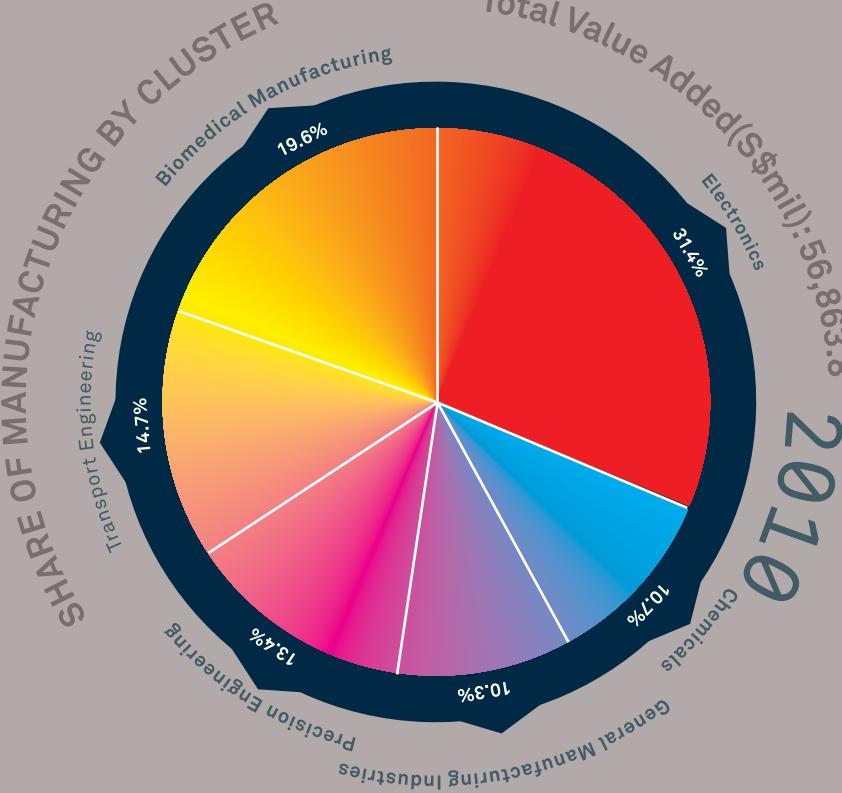


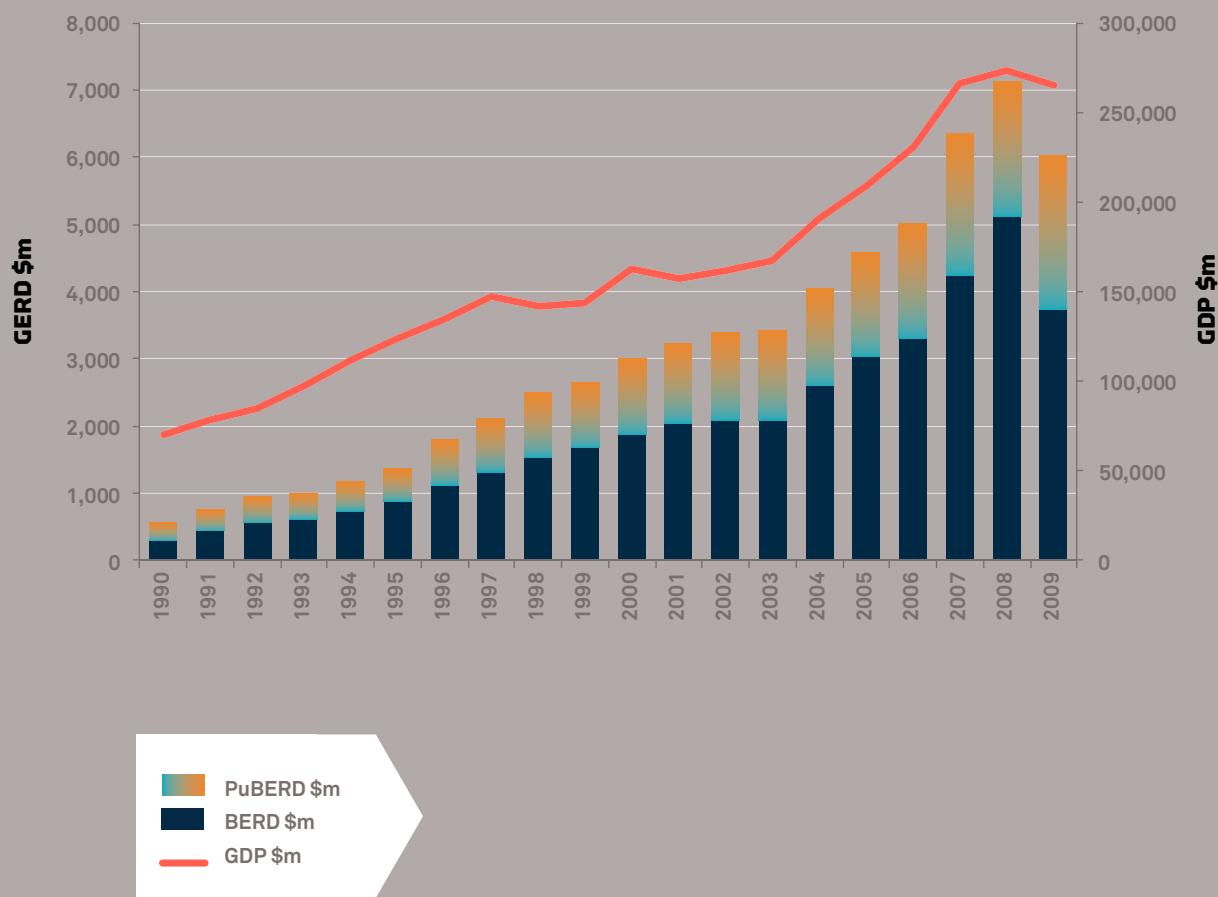


Since 1990, Singapore has shifted towards high-value manufacturing and added new capabilities in areas such as semiconductors and computer peripherals. This helped to fuel the increase in total output of the electronics cluster in the 1990s. Singapore had also diversified her investments to include the biomedical sciences, with GlaxoSmithKline (GSK) setting up the first biomedical manufacturing plant in 1998. As a result, manufacturing remains a key pillar of the Singapore economy contributing to as much as 22 percent of GDP in 2010. This is exemplified in the following figure which shows Singapore's total output growing from \$73 billion to \$270 billion and total value added growing from \$16 billion to \$57 billion.

The Gross Expenditure on R&D (GERD) rose substantially over the last two decades from \$571.7 million in 1990 to \$6,042.8 million in 2009, with a compound annual growth rate of 13.2 percent. This growth was driven primarily by Business Expenditure on R&D (BERD) which grew from \$309.5 million in 1990 to \$3,724.5 million in 2009. In 1990, BERD accounted for 54.1 percent of GERD whereas in 2009, BERD constituted 61.6 percent of GERD (see overleaf).



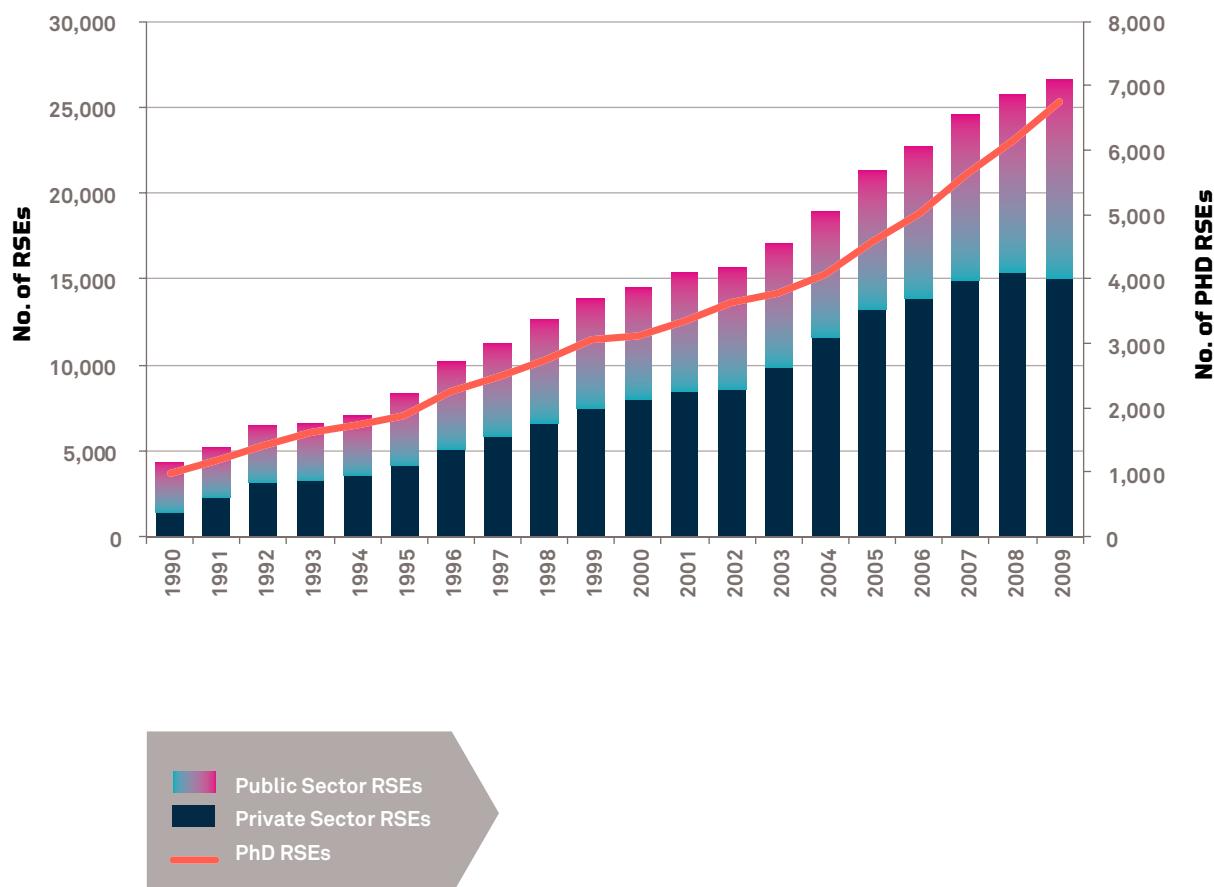




5.1 HUMAN CAPITAL



There was a six-fold increase in the number of RSEs and a seven-fold increase in the number of PhDs from 1990 to 2009. In order to sustain Singapore's R&D drive, A*STAR nurtured a pipeline of more than 1,000 Singaporean PhD candidates through its scholarship and fellowship programmes. Those who have returned were given the opportunity to serve at public sector research institutes, academia or industry.



A*STAR has embarked on various *bilateral collaborations* with companies. In many instances, the collaborations spurred the companies to set up dedicated R&D facilities in Singapore.

Mitsui Chemical

In 2004, Mitsui Chemicals became acquainted with A*STAR, and engaged in research collaborations with three A*STAR research institutes. The successful collaborations led Mitsui to locate its first R&D lab outside of Japan at A*STAR's Institute of Chemical and Engineering Sciences (ICES) in 2006. Within two years, Mitsui and ICES announced a breakthrough development of a catalyst that can produce benzene and hydrogen from methane. Mitsui has since moved from having a lab within a research institute to setting up their own R&D centre in Singapore.

Seiko Instruments

Seiko started its watch manufacturing business in Singapore in 1976, which it diversified over the years. In 2006, Seiko set up its first overseas corporate R&D centre in Fusionopolis. The company is currently engaged in five ongoing research collaborations with A*STAR research institutes and NUS in areas such as next-generation storage technology and packaging technologies.

HP Labs

Following a joint collaboration with A*STAR in June 2006, HP Labs announced in February 2010 the setting up of a \$50 million full-scale research lab in Fusionopolis. This lab will embark on a range of ambitious projects that will fundamentally re-examine data centre and application design principles to explore how future cloud computing needs will be met. HP Labs is looking to employ more than 70 research scientists and engineers.

Procter & Gamble (P&G)

In September 2010, P&G signed a Master Research Collaboration Agreement with A*STAR involving all 14 A*STAR research institutes. The agreement is to set the stage for collaborations in Transformative Platform Technologies, which include biotechnology, molecular biology, chemistry, high performance computing and materials. It was signed ahead of the opening of P&G's Innovation Center in Singapore that is expected to be completed by late 2013.

A*STAR has played a leadership role in driving the setting up of consortia and partnerships to engage multiple industry partners in R&D.

A*STAR Aerospace Programme

Launched in 2007, the A*STAR Aerospace Programme brings together A*STAR's science and engineering research institutes and 19 companies to engage in pre-competitive R&D. The goal is to grow the aerospace industry, and move it up the value chain, including anchoring manufacturing and design activities in Singapore. The 19 companies include a mix of MNCs and Singaporean enterprises such as Boeing, EADS, Pratt & Whitney, Rolls-Royce, Honeywell, Flight Focus, ST Aerospace, Sunny Instruments, SIA Engineering Company and Tru-Marine. A total of 24 R&D projects are currently underway.

Roche

In January 2010, Roche announced its intention to establish a Translational Medicine Hub in Singapore. Roche will invest \$130 million over five years, and employ around 30 leading scientists. A joint steering committee consisting of members from Roche and Singapore research institutes, including A*STAR, will define the strategic direction of the alliance and oversee research projects.

Fujitsu

Fujitsu and A*STAR have enjoyed long-standing collaborations, and further cemented the relationship with two major announcements in 2010. In January 2010, both entities announced a collaborative partnership to jointly develop advanced applications technologies for the next generation of scientific computing known as petascale computing. In May 2010, Fujitsu launched its first biomedical research facility in Southeast Asia at Biopolis. The facility focuses on the development of aptamers for diagnostics. The lab supports a number of key research initiatives, working in collaboration with A*STAR, its Experimental Therapeutics Centre, NUS, National University Hospital, and the Cancer Science Institute of Singapore.

Bodycote

BOMBARDIER

Honeywell

 **SAFRAN**
AEROSPACE · DEFENCE · SECURITY

 **TruMarine**

EADS

 **Sunny Instruments**

 **GT INDUSTRIAL PTE LTD**
Specialist in Shot Peening and Vibratory Finishing

 **addvalue technologies**

SIA ENGINEERING COMPANY 



Pratt & Whitney
A United Technologies Company



A company of ST Engineering

RÖSLER®
finding a better way ...



Rolls-Royce



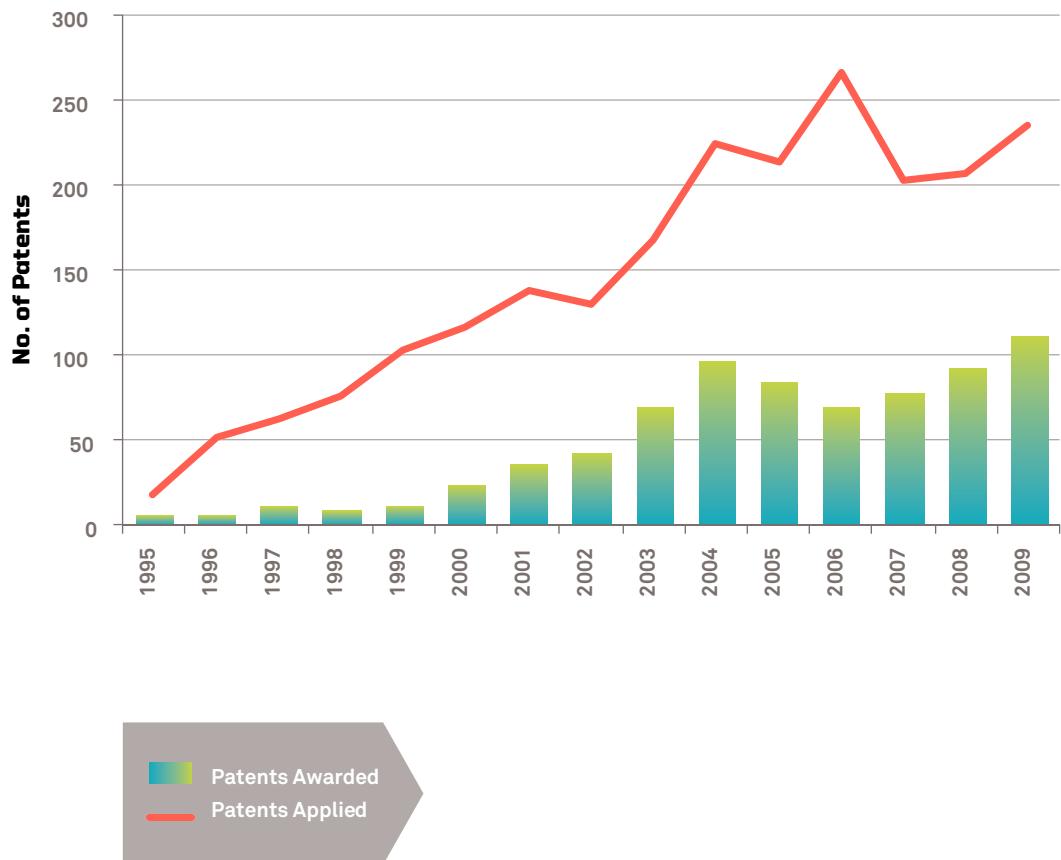
imagination at work



5.2 INTELLECTUAL CAPITAL



In 1995, A*STAR applied for 17 patents and was awarded five. This is in striking contrast to 2009 when A*STAR's patent applications were 236 with 111 awarded. The number of patents awarded grew at a compound annual rate of 20.7 percent from 1995 to 2009, and the number of patents applied grew at a compound annual rate of 24.8 percent from 1995 to 2009.



A*STAR has set up experimental and *testbedding* facilities that offer compelling innovative platforms for public-private sector partnerships.

A*STAR Experimental Power Grid Centre (EPGC)

In July 2010, A*STAR announced the setting up of the EPGC that will support and conduct research, development, and demonstration (RD&D) of technologies for intelligent grids, microgrids and distributed energy resources. The \$38.5 million facility is the first of its kind in Southeast Asia, and will be ready by 2011. Rolls-Royce, Vestas, SP PowerGrid and CEI Contract Manufacturing are among four partners that will collaborate with A*STAR at the facility.

Since 2003, A*STAR has assisted more than 300 Singaporean enterprises to upgrade their capabilities to gain a foothold in new industries and markets.

Nanyang Optical

Nanyang Optical tapped the cutting-edge expertise of A*STAR Singapore Institute of Manufacturing Technology (SIMTech) to successfully develop the world's first range of eyewear frames that are made from nearly 100 percent recycled industrial waste like plastic and steel. This has allowed the company to capture a share of the fast-growing "green products" market in Europe.

Advanpack Solutions

A research scientist from the Institute of Microelectronics was seconded to Advanpack Solutions (APS) Pte Ltd under the T-Up scheme from 2007 to 2009 and helped to develop a proprietary technology called the "Micro Molded Interconnect Substrate". This attracted interest from a company in China, resulting in a total investment of \$6.5 million in APS, including technology transfer and licensing. The technology has since gained very favourable responses and has helped APS to propel itself to the next level of growth.

Seidensha

In 2001, Seidensha manufactured and marketed Cathode Ray Tube testing equipment at a time when the display industry was undergoing a critical change of direction. Liquid Crystal Display (LCD) had arrived, and CRT was being phased out by key players in the display industry. This led to a downturn for the company. Seidensha tapped the capabilities of the Data Storage Institute to develop hard disk media testing systems that were adopted exclusively by a leading hard disk manufacturer in Singapore which brought Seidensha more than \$10 million in sales.



AEROSPACE CONSORTIUM

A*STAR's Aerospace Programme seeks to drive innovation in the aerospace industry and sustain Singapore's standing as a global aviation hub in the long-term with Singapore-made technologies. Launched in January 2007, a cornerstone of the programme is the Aerospace Consortium, through which, for the first time, the in-competition giants, Boeing, EADS, Pratt & Whitney and Rolls-Royce, are collaborating on a common platform to chart the R&D strategy and direction in the aerospace industry. This common platform occurs in what is called the pre-competitive space. Before each company goes into their own proprietary research area, they can benefit from a list of common research agendas in which they share costs.

All the pre-competitive research is conducted in Singapore, spearheaded by A*STAR's seven physical sciences and engineering research institutes. Each of the consortium members have their own scientists working alongside A*STAR scientists either physically in Singapore or virtually.

This would not have been possible if A*STAR's seven physical sciences and engineering research institutes had not developed strong capabilities in the past in diverse areas such as materials research, high-performance computing, infocomm, data storage and manufacturing technologies. Together, they are able to engage in all aspects of aerospace R&D from advanced materials, manufacturing processes and automation, to information and communication, inspection and non-destructive testing, computational modelling and dynamics and industry informatics for rotatable parts management and cargo handling through radio-



frequency identification (RFID) technology.

By harnessing the synergies of public-private research collaboration in the pre-competitive space, Singapore is laying the ground for innovation through Singapore-made technologies. By supporting and working with consortium partners, Singaporean enterprises get a headstart through manpower training and access to the R&D results to prepare them for new technologies and advances.

5.3 INDUSTRIAL CAPITAL



The thriving R&D ecosystem in Singapore has encouraged multinational companies to make the city-state a base for their innovative activities. Many have ramped up their operations, moved into high value-added activities and initiated R&D activities in Singapore.



In 2010, Roche announced the setting up of the Roche-Singapore Translational Medicine Hub as its first Translational and Clinical Research site in the world. This 100-million Swiss francs (\$130 million) investment will tap the expertise of Singaporean BMS scientists and clinicians from the hospitals, universities and research institutes, and enable them to collaborate with Roche's core team of scientists to conduct multi-disciplinary research to accelerate the process of drug discovery and development. Also in 2010, GlaxoSmithKline established the GSK-Singapore Academic Centre of Excellence. Awards went to researchers at the Institute for Clinical Sciences, Duke-NUS Graduate Medical School, NUS School of Medicine, Singapore Eye Research Institute, and the National University Hospital. The awards were to investigate treatments for pressing medical problems prevalent in Singapore and the surrounding region.

Patrick Vallance, Senior Vice-president of Drug Discovery at GSK said, "We really tap into the investment that's been made in basic science and clinical science here in Singapore, which has put it very much on the world stage, and is the reason why we want to be here.... This is catalytic. We're not funding a research programme the way people normally do. We're giving enough to get to a stage to understand whether there is a joint drug discovery programme that we can take forward together."

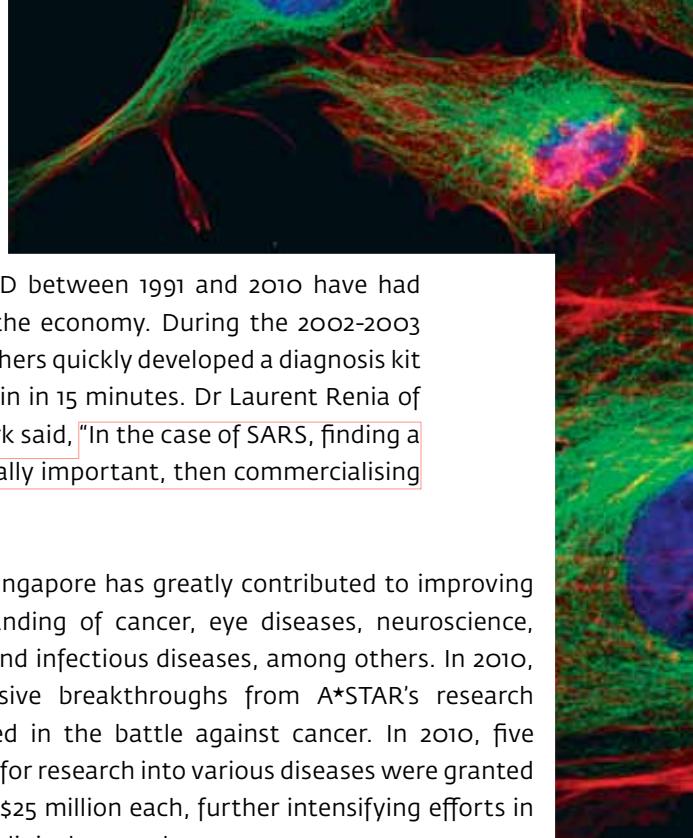
In 2011, Applied Materials signed a research collaboration agreement with A*STAR's Institute of Microelectronics to set up a Centre of Excellence in Advanced Packaging in Singapore.



5.4 ENHANCING LIVES



Singapore's investments in R&D between 1991 and 2010 have had an impact on more than just the economy. During the 2002-2003 SARS outbreak, A*STAR researchers quickly developed a diagnosis kit that could detect the virus strain in 15 minutes. Dr Laurent Renia of Singapore Immunology Network said, **"In the case of SARS, finding a new diagnostic method was really important, then commercialising it right after was a good move."**



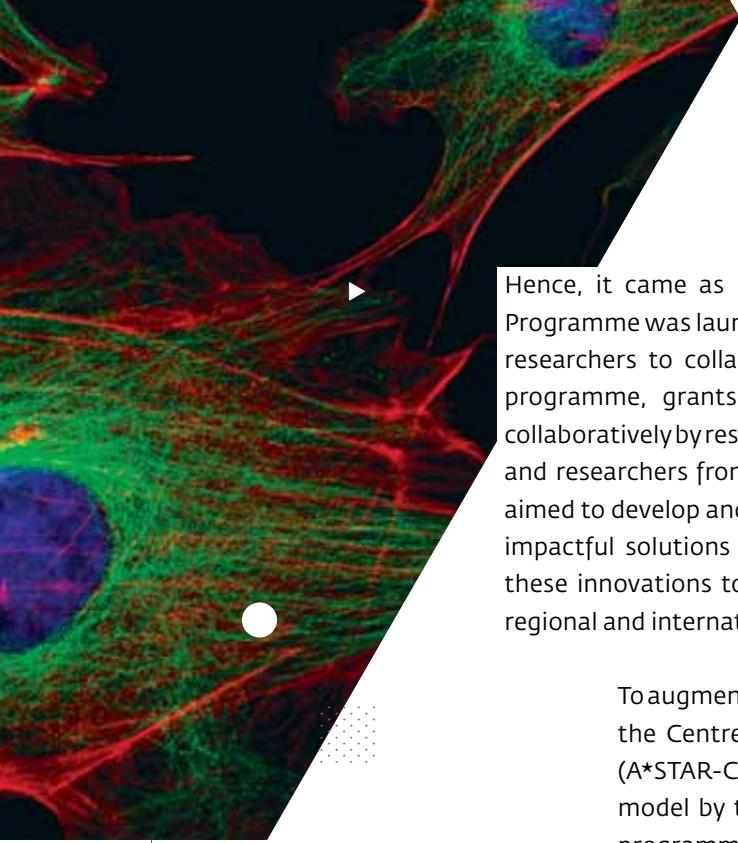
Indeed, research in Singapore has greatly contributed to improving the world's understanding of cancer, eye diseases, neuroscience, metabolic diseases, and infectious diseases, among others. In 2010, for example, successive breakthroughs from A*STAR's research institutes have helped in the battle against cancer. In 2010, five flagship programmes for research into various diseases were granted a five-year budget of \$25 million each, further intensifying efforts in the translational and clinical research space.



By 2008, the BMS landscape in Singapore had evolved greatly. Besides the biologics and pharmaceutical industries, the healthcare services and medical technology industries were also growing. By then, the medical technology industry already had an output of \$3 billion and employed more than 8,000 people in Singapore. There were also early successes in attracting leading MedTech companies such as Hill-Rom and Siemens Medical to invest in R&D in Singapore. The prospect of the medical technology industry looked bright, given the growing Asian market and the need for companies to customise their products and services to this market. A*STAR decided to give this sector a decisive push.

A*STAR has a natural advantage when venturing into medical technology research. Research in this area is characterised by cross-disciplinary collaborations among clinicians, biomedical scientists and engineers, and it is defined by a constant flow of innovation to develop meaningful solutions to address complex medical problems. With a spectrum of capabilities in BMS, physical sciences and engineering research, A*STAR was in a unique position to give the medical technology industry an added push.





Hence, it came as no surprise when the Biomedical Engineering Programme was launched in 2009 to create opportunities for A*STAR researchers to collaborate with clinicians in hospitals. Under this programme, grants were awarded to research projects helmed collaboratively by research engineers at A*STAR, clinicians in hospitals, and researchers from the universities and hospitals. These projects aimed to develop and provide cost-effective, innovative and clinically impactful solutions for healthcare systems. The intention was for these innovations to eventually be developed for the Singaporean, regional and international markets.

To augment the medical technology research, A*STAR also established the Centre for Integration of Medicine and Innovative Technology (A*STAR-CIMIT) programme in 2009, which is an adaptation of the model by the Boston-based research consortium CIMIT. Under this programme, opportunities were created for engineers, clinicians and BMS scientists in Singapore to work with clinicians in Boston to come up with engineering solutions that have clinical and market relevance. This will allow A*STAR to leverage on CIMIT's existing technologies and best practices which will significantly shorten Singapore's own innovation cycles. It will also accelerate the commercialisation of innovative medical technologies and give rise to high-tech start-ups. A*STAR also partnered Stanford University in the Singapore-Stanford Biodesign Programme in 2008 to train teams of young professionals from diverse backgrounds – medical, engineering and business disciplines – to acquire the foundational skills to become medical innovators to address Asia's growing healthcare needs.

By 2009, A*STAR had already scored some successes in MedTech research in collaboration with universities, private sector companies as well as across the research institutes from the BMRC and SERC. One such success story was the The MicroKit, a portable diagnostic kit for fast and accurate detection of infectious diseases such as the H1N1 virus that was developed in a collaborative effort with IBN, Dyamed Biotech and National University Hospital (NUH).

5.5 CHANGES IN THE RESEARCH LANDSCAPE



Over the course of the four national S&T plans the Singapore research landscape has transformed dramatically from basic research confined to specialised areas and needs of specific industries to the current multidisciplinary efforts that span the spectrum of science. During this period, significant strides were also made in building up the scientific and research manpower base. The number of research scientists and engineers in Singapore grew by 60 percent from 1990 to 2009. The two-pronged strategy of developing home-grown talent as well as attracting talent from abroad proved the secret of success.

5.6 EARNING A REPUTATION AS AN INTERNATIONAL R&D HUB



That tiny Singapore can be compared at all with such heavy weights as the US and Europe says something about how concerted and successful the efforts have been to build up R&D here in the last 20 years.

In the 2009 Boston Consulting Group Report entitled "The Innovation Imperative in Manufacturing", Singapore was ranked No. 1 out of 110 countries, ahead of South Korea, Hong Kong and the United States. In "The Atlantic Century: Benchmarking EU and US Innovation Competitiveness" prepared by the European-American Business Council and the Information and Technology and Innovation Foundation in 2009, Singapore was also ranked No. 1 followed by Sweden at No. 2 and South Korea at No. 5 out of 36 countries. In the 2010-2011 Global Competitiveness Report prepared by the World Economic Forum and with 117 variables, Singapore was ranked No. 2 out of 142 major and emerging economies.





Singapore, however, is not about to rest on its laurels. Moving forward, R&D and innovation will play an even bigger role in driving Singapore's economy. Said Chairman Lim Chuan Poh, "In the next tranche, Singapore will accelerate its efforts in R&D and we're working to get even more returns on our investment through strengthening the entire value chain of research, innovation and enterprise."

_5.7 RESEARCH, INNOVATION, ENTERPRISE 2011 - 2015

In 2010, the Government announced that \$16.1 billion would be allocated to support research, innovation and enterprise for the next five years. This will allow Singapore to continue to nurture world-class research-intensive universities and institutions to attract and train top talent for the economy, develop excellent R&D capabilities, and build international recognition. More importantly, the investment is aimed at translating the knowledge creation in the public sector into the marketplace. In the RIE2015, the fifth such S&T plan since the first in 1991, "Enterprise" is the last segment of its foci – "Research, Innovation, Enterprise".

Speaking at the President's Science and Technology Awards dinner in 2010, Trade and Industry Minister Lim Hng Kiang said, "How much we invest in R&D is important – it signals our commitment and enables us to build on what we have achieved to-date. But more important is what we invest it for and where we invest it."

The new plan's \$16.1 billion budget is a marked 20 percent increase from the \$13.6 billion allocated for the last five-year plan, and was designed to promote greater economic outcomes.

Singapore first embarked on patent reform in 1982 when the Science Council set up a study group to look into Singapore's patent system, inviting a four-member World Intellectual Property Organisation Technical Mission to Singapore for consultations. With patents regarded as an enabler of innovation, the push to reform the patent system more actively came after the formation of the NSTB in 1991. The next year, NSTB set up the Patent Application Fund to defray the high cost of patent applications. The fund finances 50 percent of all approved innovations, up to a maximum of \$30,000 per subject of patent application. In 1993, the first three recipients from this fund were Gan Chui Liang, Singapore Computer Systems, and IC Equipment.

At the same time, NSTB also began looking into a revamp of the patent system. In 1995, the Patents Act instituted a patent filing system for Singapore. Prior to the revision in legislation, patents had to be filed in the United Kingdom and re-registered in Singapore. At the same time, Singapore acceded to the Paris Convention and the Patent Cooperation Treaty, thus simplifying

the process of applying for international patents and widening the reach of patent protection. A key feature under these treaties is that patent applications filed in signatory countries and corresponding to subject matter of a Singapore patent application are accorded the same filing date as the Singapore patent application if filed within a year from that Singapore patent application.

The new patent application procedure reduces the cost and time of applying for intellectual property protection, thereby encouraging a greater spirit of innovation and entrepreneurship amongst researchers. Deciding where to seek protection is a commercial decision as not all patents are useful everywhere. The requirements for patent applications vary from country to country but protection is usually specific to the country where patent rights have been granted. There was also the larger issue of the protection of intellectual property and enforcing patent rights. Thus, in 2001, all intellectual property and patent work was taken over by the Intellectual Property Office of Singapore, a statutory body under the Ministry of Law, to facilitate the links between

legal enforcement of intellectual property and corporate filing for protection of intellectual property rights. The Intellectual Property Office of Singapore is a restructuring of the Registry of Trade Marks and Patents and its first chairman was Prof Hang Chang Chieh.

Patent owners have a monopoly of 20 years to exploit the patent commercially. However, few patents can stand alone. It usually requires support from other patents to produce a commercially viable product. The essential connectivity of patents today generates the need for the bundling of relevant patents together if they are to have any impact, a collaborative activity that brings together technology transfer offices from different parts of the world. Such a collaborative technology transfer mechanism helps start-ups to manage and commercialise their intellectual property. Thus, one of the tools that Exploit Technologies Pte Ltd, the commercialisation arm of A*STAR, had to have was a database of patents and linked patents to increase the impact of intellectual capital. That patents and licensing arrangements must cross borders if they are to make any kind of economic

impact are signs of the globalising nature of technology. Such a technology transfer network is a paradigm shift away from the protective national bias of patenting and licensing deals of the 20th century.

As of 2010, Exploit Technologies has managed over 2,000 patents and licensed more than 90 technologies with expected revenues in excess of \$300 million. Its successes include slip-resistant glass, portable diagnosis kits for infectious diseases and software engines for businesses.

Said Boon Swan Foo, the former Executive Chairman of Exploit Technologies, “Invention is just one part of the innovation chain. Obviously, the better the invention or the more significant the breakthrough, the higher the chances of success, and the more markets and alternatives you have. But you must also constantly innovate in terms of use (by coming up with new products), markets (by finding new growth areas), and product development (by making your product better than your competitors). Sometimes the exact placement of a feature is what decides if your product is a winner or not.”

5.8 THE WAY FORWARD: WORKING TOGETHER FOR GREATER IMPACT



One way to work towards more commercial outcomes is through synergy and collaboration. Rather than confine R&D to the traditional internally integrated set-up, even big companies are seeking external partners to share in building up knowledge capital. Such a partnering trend for knowledge creation is being seen in Singapore.

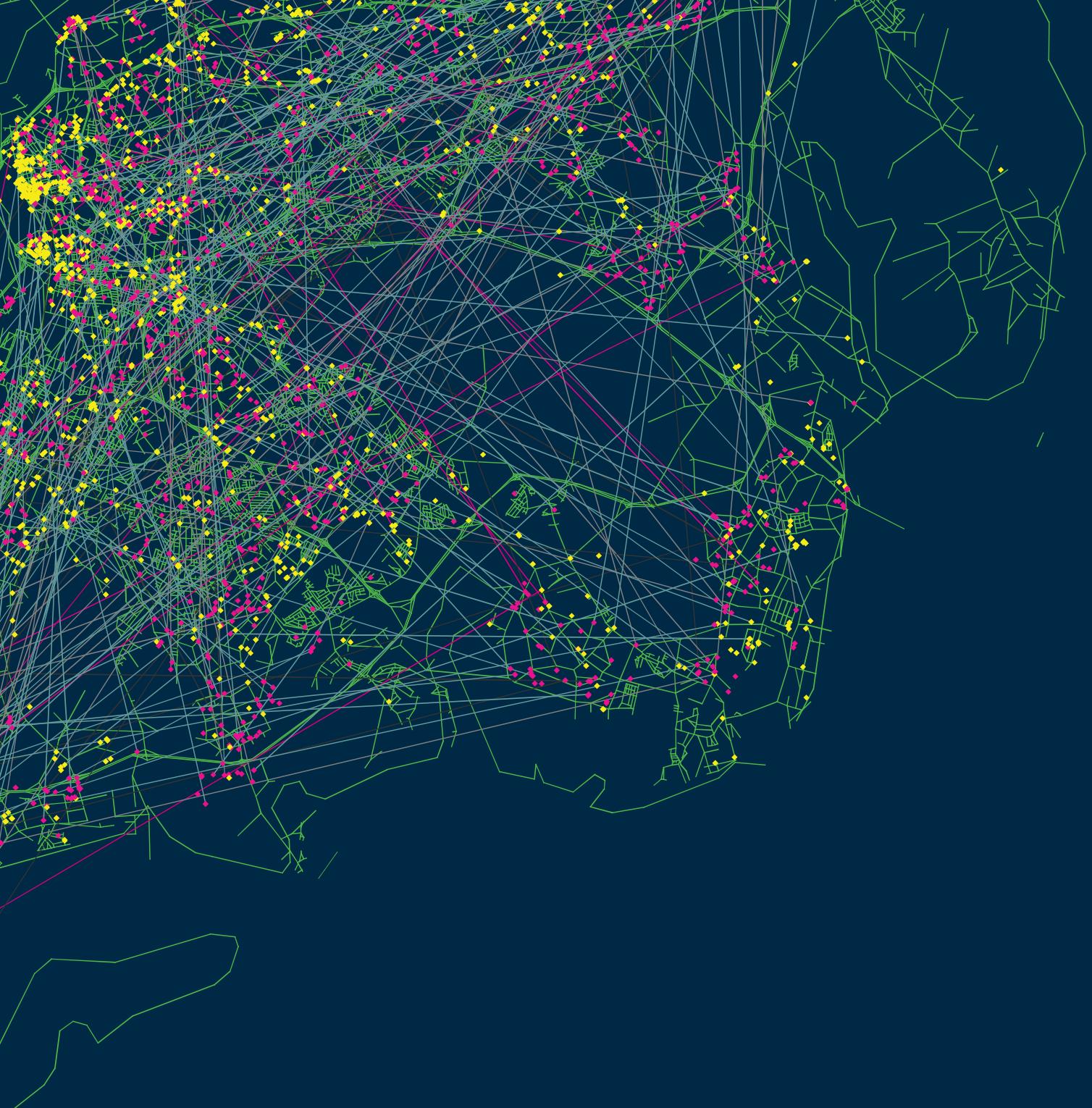
Procter & Gamble, welcoming the ease with which they could partner a diverse range of R&D players, to be among global businesses, and tap on the diverse, cosmopolitan talent here, announced in 2010 that it would build its own R&D facilities in Biopolis. When completed in 2013, the 32,000 square metre facility will house some 500 employees.



Said Lim Chuan Poh, gesturing towards the plot of land, vaguely visible from his office on the 21st floor of Fusionopolis, where construction work for P&G's mega-hub innovation centre is in progress, "Why did Procter & Gamble come here? They could sign just one research collaboration agreement and work with 14 research institutes. They didn't have to knock on doors and chase people all around town. Just that process alone creates value for the company. At the same time, we have people that can do research on formulations for shampoos, epithelial biology for facial and skin products, among many other things. We can integrate high-performance computing, skin biology research, and chemical processes so you can eliminate a lot of the costs in the development by bringing a significant part of that work in silico. This is the high added value we create for Procter & Gamble in one single location."

Lim clarified that Singapore is not competing with big countries such as US but with research-intensive locations at the city-scale like Boston or San Francisco. He points out that in this race towards innovation and enterprise, size does not necessarily equate to might.

Said Lim, "Singapore has compactness that goes beyond geography. We create value through our ability to integrate across scientific disciplines, through our ability to mobilise the public sector research institutes, hospitals, and universities, and through our ability to build meaningful partnerships with the private sector. We create value through synergy and integration, and flow this value to the private sector. And this is Singapore's value proposition. The more Singapore works as Singapore Inc the more competitive we are."



6_

Asia's Innovation Capital

Singapore's long-term aim is to be among the most research-intensive, innovative and entrepreneurial economies in the world in order to create high-value jobs and prosperity for Singaporeans. Research and innovation underpin the competitiveness of our industries, catalyse new growth areas, and transform our economy. Increasingly, intellectual capital will be critical for our next phase of economic development.



Singapore's rapid evolution into a knowledge-creation and innovation centre is the result of the concerted efforts of many – not least of which is Singapore's international network – as befits a global city. Aided by a conducive business and regulatory environment, a largely English-speaking population, and sound intellectual property regulation, Singapore has set itself apart from other R&D centres in the region. The ease in which government entities, public sector research institutes and industry integrate seamlessly under a coordinated "Whole-of-Singapore" approach, has helped the city-state seize opportunities in the rapidly changing world economic landscape and take advantage of growing interest in Asian markets.

In 2010, the Economic Strategies Committee convened to review strategies and chart new directions for the next 10 to 15 years. Minister for Finance Tharman Shanmugaratnam in his 2010 Budget Speech noted, "A vibrant ecosystem is emerging, comprising a diverse range of research facilities, both in the private and public sectors. In the next decade, we must build on our initial investments, especially by expanding private sector R&D, and move decisively to commercialise R&D so as to maximise returns from these investments." This move to create more value from R&D activities was the strategy of the Sub-Committee on Growing Knowledge and Innovation Capital, co-chaired by A*STAR Chairman Lim Chuan Poh and S*BIO CEO Dr Jan-Anders Karlsson. The Sub-Committee's recommendation to enhance the impact of Singapore's Research-Innovation-Enterprise framework was to grow investments in R&D to 3.5 percent of GDP by 2015. Singapore was clearly signalling its intent to stand among the most R&D intensive nations in the world.

This was timely, for by 2011, the research landscape had changed greatly. Singapore's universities had become more research-intensive, with the addition of five new Research Centres of Excellence focusing on a range of basic research subjects.



Meanwhile, the public sector was accelerating innovation capital by collaborating with enterprises through multiple innovation platforms. One such platform is the consortium model, in which MNCs, globally competitive companies (GCCs), SMEs and public sector research entities work together to solve a wide range of technological challenges. The groundbreaking A*STAR Aerospace Programme, for example, is the first-of-its-kind consortium in the world where national public research institutes and major aerospace companies collaborate in research in the pre-competitive space. Aside from consortia, SMEs can also participate in Centres of Innovation and outreach platforms such as the GET-Up Programme to increase their productivity and enhance their competitiveness. With the inclusion of polytechnics in the GET-Up scheme in 2010, SMEs can effectively leverage on a broader spectrum of deep capabilities.

Concerted efforts were also made to attract and develop a wide spectrum of talent along the research, innovation and enterprise value chain, including start-up mentors alongside the scientists and engineers. There is also an ongoing effort to nurture high-tech start-ups through the creation of a vibrant entrepreneurial sector. Singaporean research-intensive universities are taking an active role in training potential entrepreneurial talent and supporting entrepreneurial activities on their campuses. Besides the tertiary institutions, public sector agencies are playing their part to nurture high-tech start-ups by initiating and accelerating multi-disciplinary research. The A*STAR-CIMIT collaboration, for example, enables engineers, clinicians and BMS scientists in Singapore to work with clinicians in Boston to come up with engineering solutions that have clinical and market relevance. Through these initiatives, Singapore is now better able to bring disciplines together to realise the value of its R&D activities, and be better equipped to attract MNCs, develop GCCs and move SMEs up the value chain.

Since the first S&T plan in 1991, NSTB/A*STAR has played a catalytic role in this drive, by developing the necessary human, intellectual and industrial capital to support the R&D industry. Its strategy is paying dividends. Over the past 20 years, the organisation has helped Singapore develop R&D into a major pillar of the economy. As its international reputation has grown, A*STAR has signed an increasing number of collaboration agreements with other national R&D agencies, with universities, institutions and the private sector. Singapore as one of the key hubs of Asia has developed into a significant second home for a growing number of such facilities.

Moving forward, the role of A*STAR will increasingly be about bringing different R&D players together for more targeted results. In the words of A*STAR Chairman Lim Chuan Poh, "A*STAR will be important as a 'neutral integrator', working with universities, medical centres and enterprises. The more partners there are, the more complicated the whole process of management. A*STAR needs to take leadership in this aspect of integration so that Singapore can derive synergy from its R&D investment in creating growth and enhancing lives."

That public sector agencies such as NSTB and A*STAR played such a critical role in the formative years of R&D in Singapore is indicative of the strong and sustained government commitment to R&D. In the last 20 years, guided by a series of S&T plans, Singapore undertook bold moves in order to ensure its transformation into a knowledge-based and innovation-driven economy.

As political leaders, the scientific community and the society at large share the conviction that R&D is the future, Singapore today is moving one step closer to its goal of becoming Asia's innovation capital.



Early Breakthroughs & Innovations

Early Bluetooth Chip

Institute of Microelectronics (IME) successfully demonstrated one of the earliest Bluetooth chip realized by RF CMOS processes in 2000. IME's CMOS RF front-end chip for integrated Bluetooth solution was a key milestone in enabling cost-viable mass production of Bluetooth chips that paved the way for today's prevalent Bluetooth technology in mobile devices for wireless communication.

Better Compression

Institute for Infocomm Research (I²R) developed a state-of-the-art lossless compression algorithm for audio signals called the MPEG-4 Scalable to Lossless System (SLS). In as early as 2002, the technology defeated all other proponents, including Microsoft®, Franhoufer, NTT® and Real Networks®, in an evaluation conducted by the MPEG International Standard committee and was adopted as the reference model. In 2010, a new audio lossless codec developed by I2R was adopted by Audio Video Coding Standard (AVS) Workgroup of China and incorporated into China Blue High-Definition Disc (CBHD) in China, in recognition of its superior lossless compression performance.

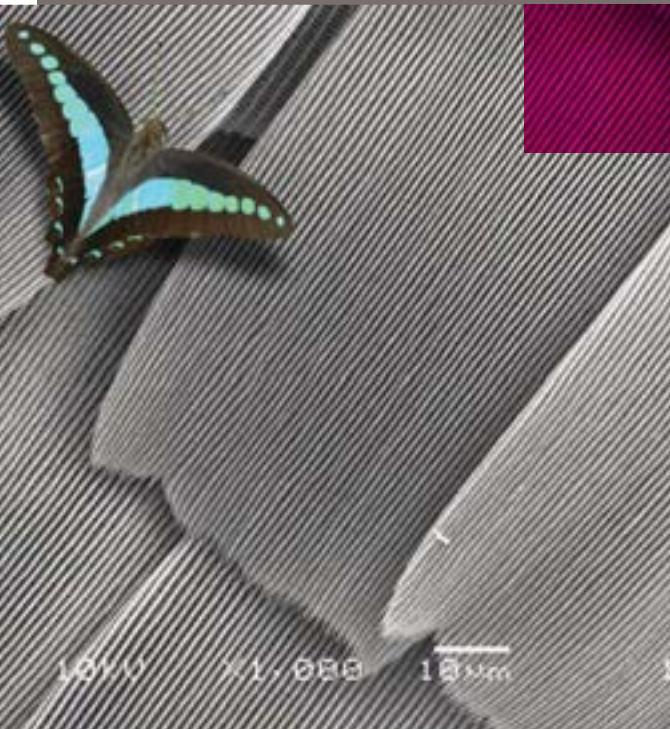
Combating Counterfeit Goods

Using a blend of micro and nanotechnology, Singular ID Pte Ltd, the first spin-off of the Institute of Materials Research and Engineering (IMRE), invented anti-counterfeit tags with nano-sized particles providing unique "fingerprints" to combat counterfeit goods. Practically irreproducible, and yet inexpensive to manufacture, these tags can be used in a wide range of articles including pharmaceutical packaging, luxury goods such as watches and handbags, and automotive and aviation spare parts. Singular ID Pte Ltd received many accolades and technology awards and was acquired by a multinational company, Bilcare Ltd, in December 2007 for some S\$19 million.

From Ink-Jet Cartridges To Next-Generation Data Centre And Grid-Related Technologies

One of the early returns of a long-running collaboration between Institute of High Performance Computing and HP were incorporated into the design of HP's new generation of ink-jet cartridges in 2000. In 2006, a team from the Advanced Computing Programme at IHPC and HP Labs developed technology-based software tools and platform work to provide compute capabilities and software in a shared services delivery model. Following this long-term collaboration, HP established a research lab in Fusionopolis to collaborate with IHPC and other entities in A*Star. IHPC and HP labs are currently pursuing upstream research in cloud computing and shared services.

Useful Surfaces via Nano Imprinting: Anti-Bacterial Surfaces



In 2002, researchers at the Institute of Materials Research and Engineering (IMRE) developed novel nanoimprint processes which can be used to fabricate high anti-reflectivity plastics for displays, anti-bacterial surfaces for medical devices, walls that are as colourful as a butterfly's wing, new non-slip materials, and even adhesives that do not leave sticky residues. The process can fabricate truly 3-D structures by using simple 2-D mold as 'building blocks'. Using IMRE's technique, engineered material can take on properties such as luminescence, adhesiveness, water-proofing and anti-reflectivity.



Battling Global Diseases

Cancer

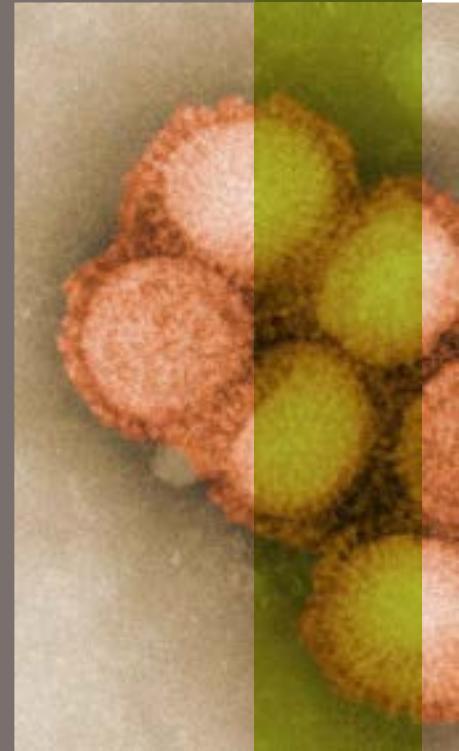
In 2010-11, A*STAR made successive breakthroughs in key areas of cancer research. Published in top scientific journals *Cancer Cell*, *Nature Cell Biology*, *Cancer Research* and *Nature Genetics*, the research sheds light on the mechanism behind cancer metastasis, suggests why breast cancer cells live as long as they do, shows a better way to detect cervical cancer and uncovered the cause of a rare skin cancer. In 2011, for example, the Institute of Medical Biology (IMB) led an international team to identify the genetic basis of a skin cancer that heals itself. The peculiar behaviour of this self-healing cancer, called multiple self-healing squamous epithelioma (MSSE), was discovered to be caused by a failure in the gene, *TGFBR1*.

Neuronal Diseases

An Institute of Molecular and Cellular Biology (IMCB) team investigated 21,000 genes in the entire human genome to find those which regulate the two characteristic properties of hESCs. Their research, the first ever genome-wide study of human stem cells on this scale, published in top scientific journal *Nature* in 2010 is crucial in understanding how stem cells may one day be used to treat debilitating conditions such as Parkinson's disease and traumatic spinal injury. Earlier in 2004, IBN developed a new method to deliver baculoviral vectors via axonal transport to the central nervous system. This can lead to possible treatment in diseases such Parkinson's, Chronic neuropathic pain and Alzheimer's.

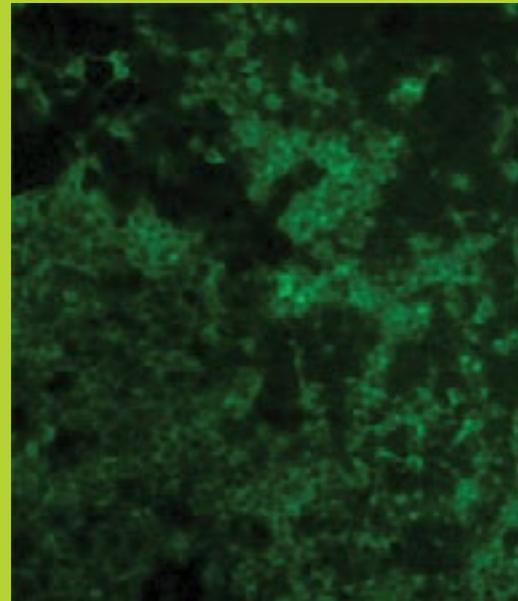
Swine Flu

During the swine flu epidemic in 2009, Bioinformatics Institute (BII) became among the first in the world to publish their complex analysis of the 3-D structural model of the H1N1 virus, a mere two weeks from the time the first patient virus samples were made available. In that same year, researchers from the Genome Institute of Singapore (GIS) and the Institute of Molecular and Cell Biology (IMCB) developed a chip that could sequence or decode the genes of the flu virus and distinguish between the H1N1, seasonal and mutated flu strains within two hours. Since the pandemic, researchers from A*STAR have been working with hospitals and health authorities in Singapore, Mexico, Brazil and the WHO Collaborating Centre in Melbourne to follow the evolution of circulating influenza viruses closely and detect mutations that could alter severity, drug susceptibility or vaccine efficacy.



Potential Treatment for Chikungunya

Chikungunya, a disease that currently has no available vaccine or specific treatment, is prevalent in Africa, South Asia, and Southeast Asia and is transmitted by the Aedes mosquito. In 2011, Singapore Immunology Network (SIgN) and VIVALIS, a French biopharmaceutical company, announced the discovery of two new fully human monoclonal antibodies which could battle Chikungunya. Published in the *Journal of Immunology*, the international team of scientists used Humalex®, a VIVALIS technology platform designed to identify and generate fully human monoclonal antibodies, to develop two antibodies that could neutralize several Chikungunya strains in vitro by culturing immune cells from an individual who had developed resistance to Chikungunya.



RESEARCH HIGHLIGHTS



Science and Engineering Solutions

Scratch Proof Irons

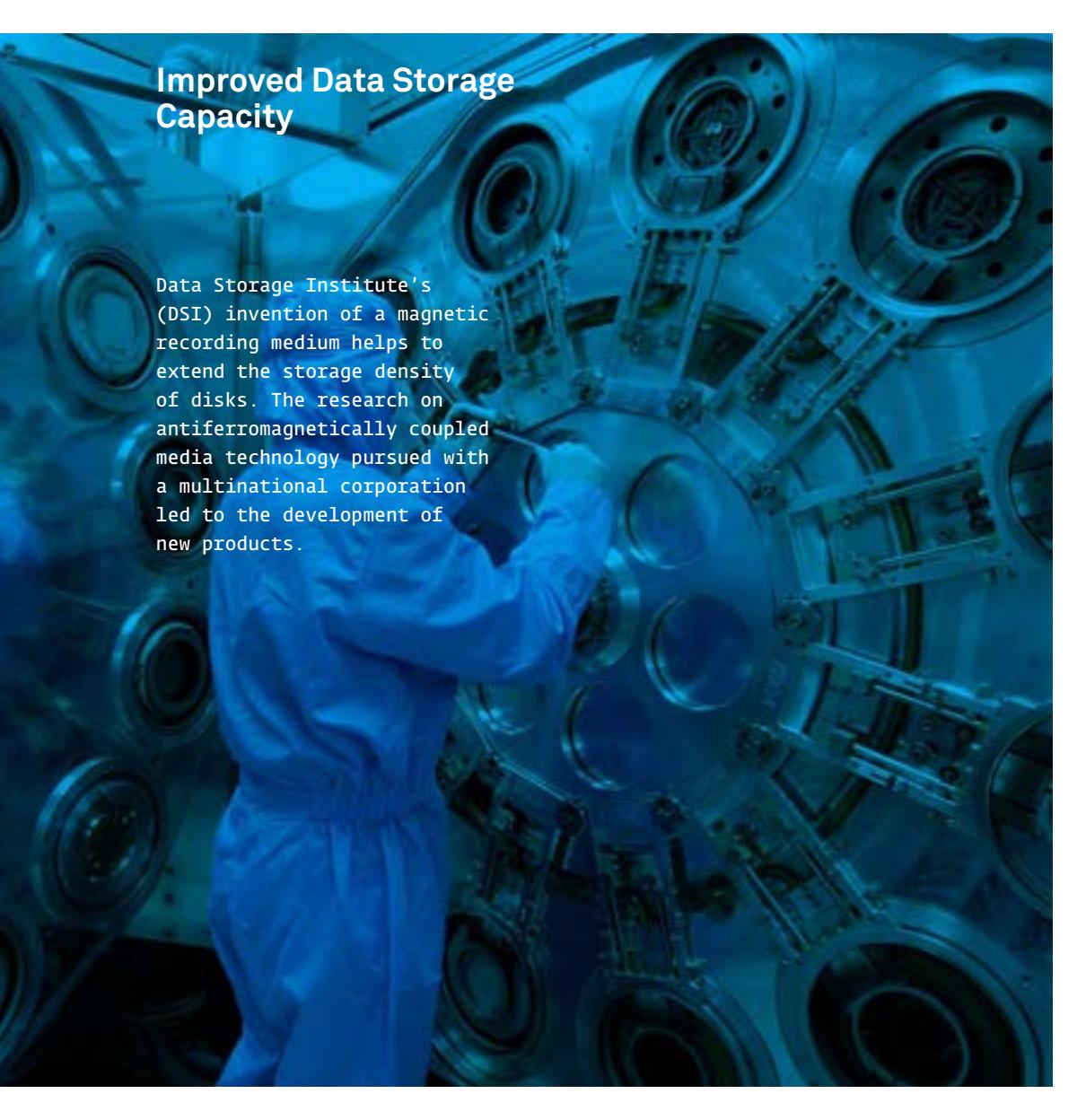
In 1999, the Singapore Institute of Manufacturing Technology (SIMTech) and Philips Domestic Appliances and Personal Care (Philips DAP) collaborated to develop an innovative process to create a sol-gel based multi-layer coating. The novel process has enabled Philips iron products to have excellent scratch resistance and enhanced impact resistance at substantially higher production yields and, consequently, lower costs.

Low Sulfur Diesel

In a patent first filed in 2006, the Institute of Chemical and Engineering Sciences (ICES) developed an alternative process for the removal of sulphur species from diesel fuel to <10ppm levels. This enables a low cost route to low sulphur diesel. In the two-step process, ultra low sulfur diesel (ULSD) can be produced without using hydrogen, contributing to the lower processing costs.



Improved Data Storage Capacity

A photograph showing a person in a blue protective suit and gloves working on a large array of circular disk drives, likely in a data storage facility. The drives are arranged in a grid and are illuminated from below, creating a bright glow. The person is focused on a specific drive in the foreground.

Data Storage Institute's (DSI) invention of a magnetic recording medium helps to extend the storage density of disks. The research on antiferromagnetically coupled media technology pursued with a multinational corporation led to the development of new products.

Miniaturising Electronic Devices

The semiconductor industry has manufactured increasingly complex and miniature devices based on Complementary Metal Oxide Semiconductor (CMOS) devices. A team from the Institute of Microelectronics (IME) developed a novel CMOS-compatible nanowire technology, a breakthrough that potentially advances applications in biosensing, energy harvesting, data storage and optoelectronics, and enables the realisation of the smallest CMOS transistors.



Advancing Healthcare

Brain Control Interface for Stroke Rehabilitation

Using brain control interface technology, the Institute for Infocomm Research (I²R) developed a system for the rehabilitation of stroke victims suffering from upper body paralysis. The non-invasive technology detects brain signals from stroke victims who attempt to move a robotic arm as part of their rehabilitation. Early clinical trials, conducted in collaboration with Tan Tock Seng Hospital and the National Neuroscience Institute, indicate that BCI-driven robotic rehabilitation may be effective in restoring the motor control of stroke victims.

Diseases Diagnostics – microkit

A*STAR developed portable disease diagnostics including a portable MicroKit system that enables mass health screenings to be conducted at strategic locations such as airports, immigration checkpoints and train stations. By facilitating rapid and accurate disease detection at these decentralized places, the Institute of Bioengineering and Nanotechnology (IBN) MicroKit can help to curb the spread of infectious diseases and prevent pandemics.

Reversible 3D Cell Culture Gel

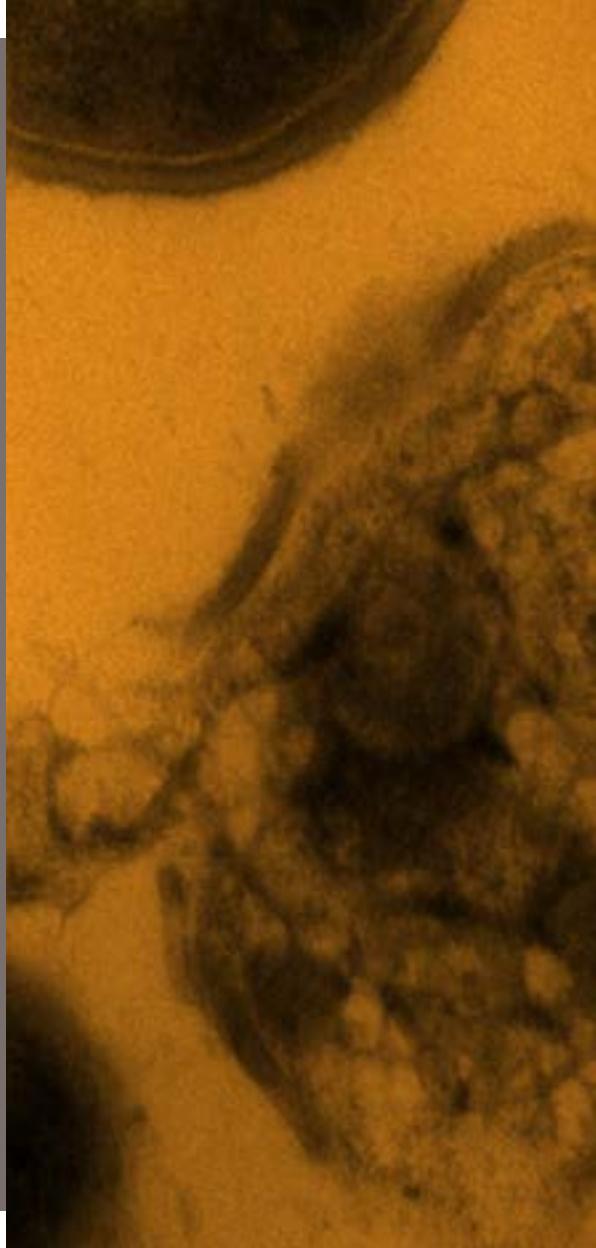
In 2008, scientists from the Institute of Bioengineering and Nanotechnology (IBN) developed a unique gel that can reverse from solid to liquid upon applying mechanical force. This invention may be used for three-dimensional (3D) cell culture and provide new insights for basic research and drug development. Researchers can control the gel's stiffness, directing stem cell differentiation into specific phenotypes. By conjugating specific ligands to the gel, the latter may also be used to investigate the effect of various biological signals on cells in 3D cultures, and to study extracellular matrix production by cells responding to drugs or diseases.

Advancing Stem Cell Therapy - mAb84

The Bioprocessing Technology Institute (BTI) developed a monoclonal antibody, mAb84, that is able to specifically target undifferentiated human embryonic stem cells (hESCs) and cause them to undergo induced cell death. This antibody can be used before transplantation to remove any residual undifferentiated cells and therefore reduce the risk of teratoma formation. This will help address safety concerns when clinical approval for stem cell therapies is required in the future.

New Weapon against Drug-Resistant Superbugs

Scientists at the Institute of Bioengineering and Nanotechnology (IBN) and IBM Research developed the first biodegradable polymer nanoparticles to combat drug-resistant superbugs, such as Methicillin-Resistant *Staphylococcus aureus* (MRSA). Their self-assembled nanoparticles selectively kill bacteria without destroying surrounding healthy red blood cells, and have great potential to treat infectious diseases in the body. Possible applications include the treatment of MRSA skin and blood stream infections, wounds, multidrug-resistant tuberculosis and lung infections. The novel polymers could also be developed into consumer products such as deodorants, table wipes and preservatives.





Leading The World

Sequencing the Pufferfish Genome

The completion of the sequencing of the pufferfish genome made Singapore a significant player in the world of genomics research. A landmark paper published in *Nature* in 1993 showed that the pufferfish genome is the smallest known vertebrate genome, being only one eighth the size of the human genome, but contains the same gene repertoire. Unlike the human genome, the pufferfish genome contains very little 'junk' DNA, and is densely packed with genes. The team's research led to the formation of an international consortium for sequencing the whole genome of the pufferfish in November 2000. The genome sequence of the pufferfish was completed and published in *Science* in August 2002.

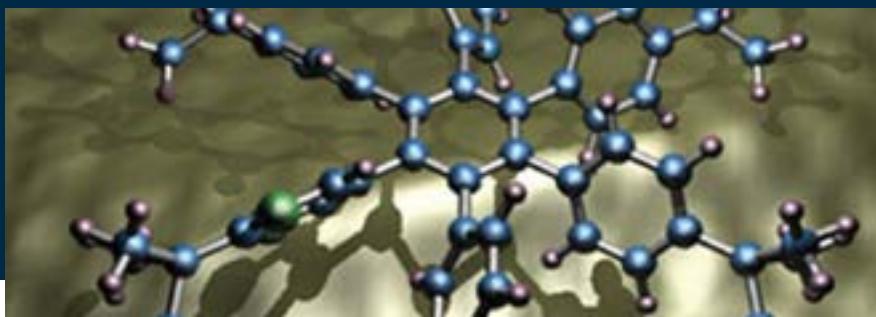


World's Smallest Gear

Researchers at the Institute of Materials Research and Engineering (IMRE) made it into the Guinness Book of World Records by demonstrating the world's first controllable 1.2 nm molecule-gear. The breakthrough, developed in 2009 and published in *Nature Materials*, marks a radical shift in the scientific progress of molecular machines which may lead to innovations like pocket-sized supercomputers, miniature energy harvesting devices and data computing on atomic scale electronic circuits.

Transforming of Carbon Dioxide to Methanol

The Institute of Bioengineering and Nanotechnology (IBN) in 2009 became the first in the world to achieve a green method for sequestration and conversion of carbon dioxide at room temperature. Using organocatalysts, the researchers activated carbon dioxide in a mild and non-toxic process to produce methanol, a widely used industrial feedstock and clean-burning biofuel. Previous attempts to reduce carbon dioxide to more useful products have required more energy input and a much longer reaction time.



Transgenic Rat

IMCB researcher, Zeng Qi, genetically engineered the first transgenic rat in Asia. This breakthrough prompted Fortune magazine (Oct/Nov 1991) to declare "Zeng's success is yet another sign that Asia is no longer merely the home of rows upon rows of women in sewing garments or of machines spewing out VCRs, picture tubes and personal computers." The Institute of Molecular and Cellular Biology (IMCB) became the first research institute to implement and commercialise transgenic rat technology.

A Step Against Premature Ageing

Scientists from the Institute of Medical Biology (IMB) and the University of Hong Kong's Department of Medicine have produced the world's first human cell model of progeria, a disease resulting in severe premature ageing in one in four to eight million children worldwide. Children with progeria suffer symptoms of premature ageing, including growth retardation, baldness, and atherosclerosis (hardened arteries), and all die in their early teens from either heart attack or stroke. The research, published in the scientific journal *Cell Stem Cell* in 2011, also gives insights into the normal ageing process.

THE A★STAR RESEARCH ENTITIES

BIOMEDICAL RESEARCH INSTITUTES



The **BIOINFORMATICS INSTITUTE**, founded by Dr Gunaretnam Rajagopal in 2001 as an IT services and bioinformatics support unit, was transformed into a biological research organization in 2007 with Dr Frank Eisenhaber as its Director. Its mission is in computational-biology-driven life science research aimed at the discovery of biomolecular mechanisms. BII develops appropriate computer-based theoretical research tools and collaborates with experimental and clinical groups from academia as well as with industry.

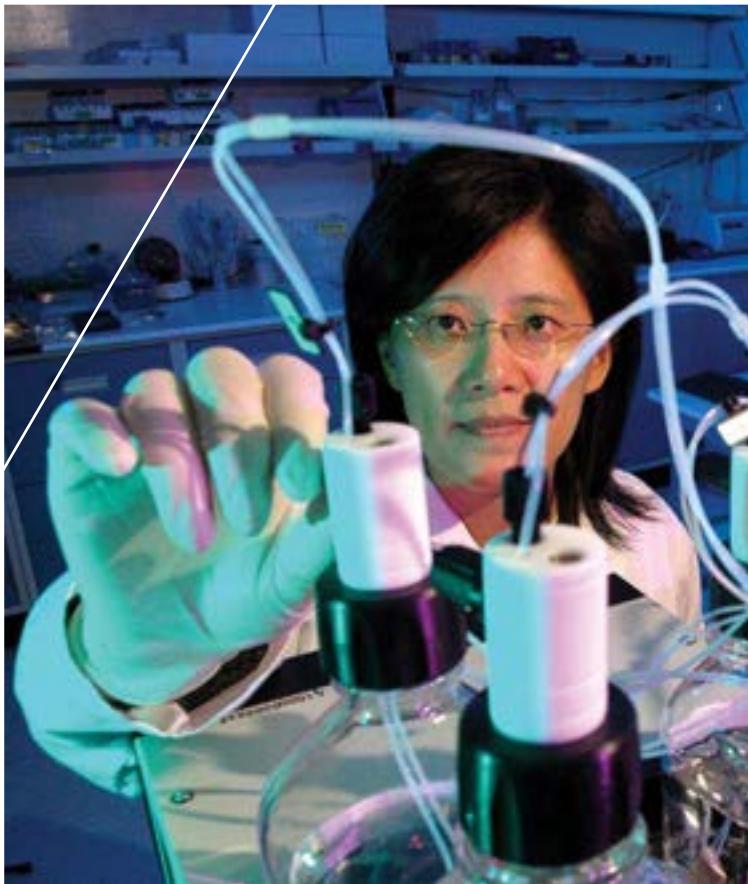
At BII, more than a dozen small and medium-sized independent research teams collaborate in: (i) analysis of genome sequences, gene expression and RNA biology, (ii) protein sequence analysis and function prediction of uncharacterized genes, (iii) protein 3D structure modelling and (iv) computer-supported analysis of microscopic images of cells and tissues with labelled molecules (imaging informatics).

ACHIEVEMENTS

- Produced >350 scientific publications and filed >20 patents as of August 2011.
- Ongoing influenza mutation surveillance with GIS; Ministry of Health; the National Institute of Genomic Medicine, Mexico; and INDRE. "Mapping the sequence mutations of the 2009 H1N1 influenza A virus neuraminidase relative to drug and antibody binding sites" in Biology Direct was downloaded by about 13,000 readers in May 2009.
- Discovered an entropic mechanism of regulating p53 by MDM2 and inhibitory stapled peptides, together with the team led by Prof David Lane. A Review titled "Awakening guardian angels: drugging the p53 pathway" in Nature Reviews Cancer (December 2009).
- Development of novel defensin-based antibiotics for topical application with Singapore Eye Research Institute (Ministry of Health) and BII within SINS, BII's first spin-off biotech company.

The **BIOPROCESSING TECHNOLOGY INSTITUTE** was founded in 1990 as the Bioprocessing Technology Unit within NUS and funded by EDB, the unit facilitated research in biotechnology and the process development needs of the biotechnology industry. In 1994, the Bioprocessing Technology Unit was taken over by NSTB and renamed Bioprocessing Technology Centre. It became the Bioprocessing Technology Institute in 2003 with Prof Miranda Yap as its founding Executive Director.

BTI spearheads bioprocess R&D using its core expertise in expression engineering, animal cell technology, stem cells, microbial fermentation, product characterisation, downstream processing, purification and stability with supporting proteomics and micro-array platform technologies. It bridges the gap between discovery, process development and commercialisation. In 1997, it set up Incubator Units to nurture small- and medium-sized biotechnology companies in Singapore.



ACHIEVEMENTS

- A cell culture media that improved yields of monoclonals which had been successfully tested by companies and laboratories in Europe and the US.
- Second-generation CHO gene-targeted cell lines with enhanced product yield and consistent glycosylation quality.
- Panel of antibodies specific to human embryonic stem cells.
- Microcarrier expansion platform for human embryonic stem cells.





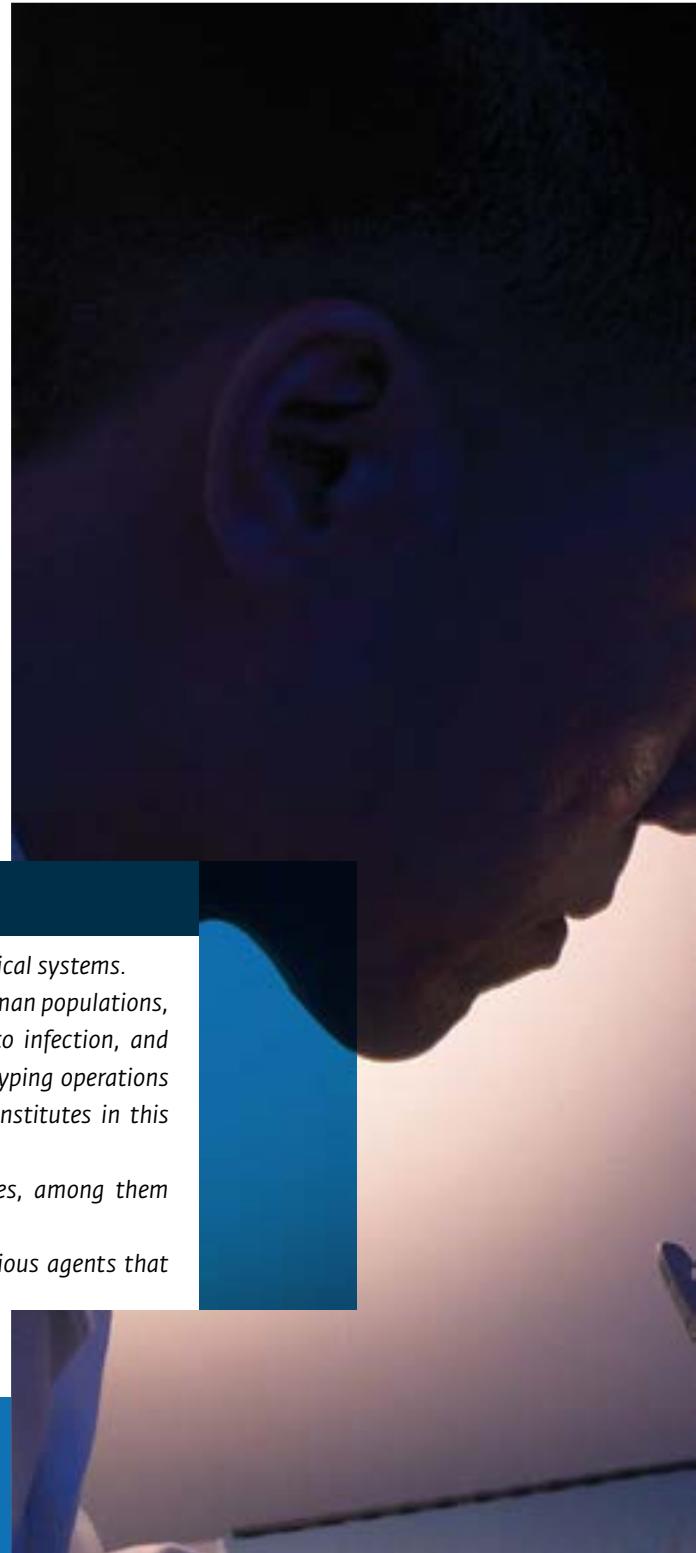
GIS was founded in 2000 as the Singapore Genomics Programme. It was renamed the **GENOME INSTITUTE OF SINGAPORE** in 2001 with Dr Edison Liu as its Executive Director.

A national flagship initiative, the institute seeks to use genomic sciences to improve public health. Its goal is to integrate technology, genetics and biology, and customise medicine to specific illnesses. It focuses on investigating post-sequence genomics to understand the genetic architecture of pan-Asian populations in relation to cancer biology, pharmacogenomics, stem cell biology and infectious diseases. The institute also functions as a training institute for scientific talent and acts as a bridge between academic and industrial research.

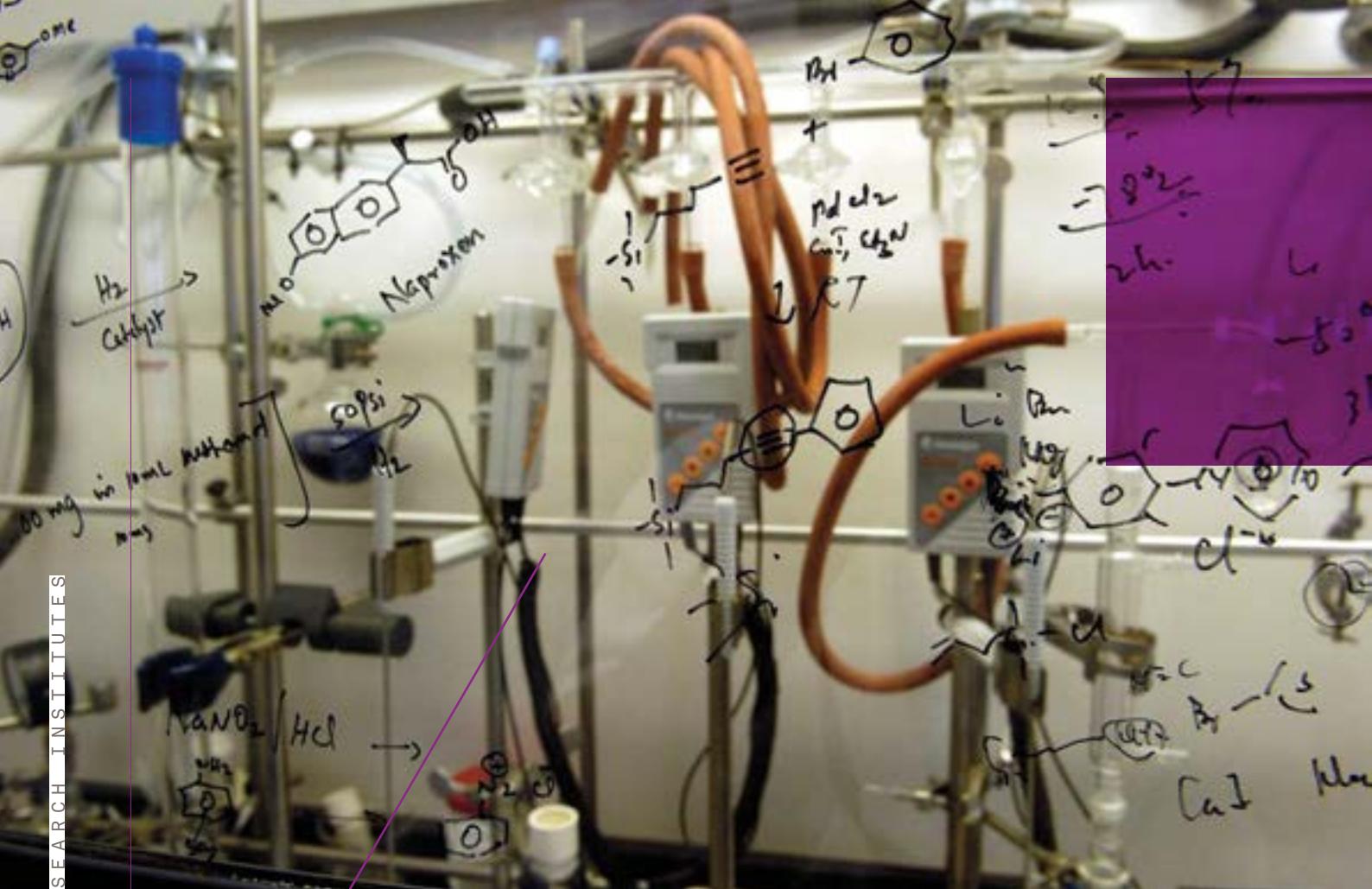
GIS is housed in the Genome, a 7,200 sq metre facility within Biopolis.

ACHIEVEMENTS

- *Elucidation of complex regulatory networks in biological systems.*
- *Identification of genes associated with diseases in human populations, including breast cancer, psoriasis, host responses to infection, and neurological disorders. It has state-of-the-art genotyping operations and has collaborated with other notable research institutes in this field.*
- *Monitoring known and emerging infectious diseases, among them dengue fever, tuberculosis, and flu.*
- *Developing technologies to identify emerging infectious agents that will help mitigate outbreaks such as SARS.*







The **INSTITUTE OF BIOENGINEERING & NANOTECHNOLOGY** was formed in 2003. It is the world's first bioengineering and nanotechnology research

institute, focusing on cutting-edge research at the interface of these two multidisciplinary and highly diversified fields involving Science, Engineering and Medicine. Its founding Executive Director is Prof Jackie Ying.

IBN's multidisciplinary nature and wide diversity presents numerous opportunities for researchers. The potential for improving health and quality of life lies in areas such

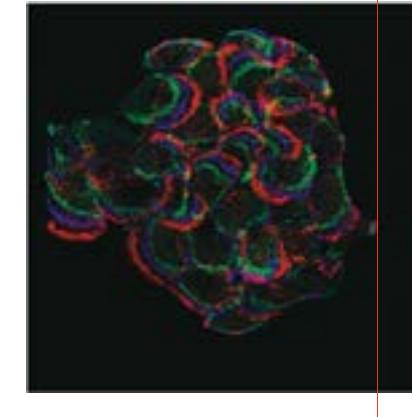
as drug and gene delivery, cell and tissue engineering, biodevices and diagnostics, and pharmaceuticals synthesis and green chemistry.

The institute's goal is to create a critical knowledge base in bioengineering and nanotechnology, and to make significant impact in healthcare through the generation of new materials, devices, instruments, systems and processes.



ACHIEVEMENTS

- Transformed human embryonic stem cells (hESCs) into heart cells using a "decellularized" heart as a scaffold.
- Developed a genetic engineering technique that promises safer stem cell therapy for cancer patients by using an insect virus to insert a therapeutic gene into embryonic stem cells.
- Developed nanocarriers for simultaneous delivery of drugs, genes, and proteins.
- Developed a unique reversible gel for 3D cell culture based on a polyethylene glycol (PEG)-silica nanocomposite which mimics natural body conditions better than conventional 2D cultures on flat surfaces.
- Invented an all-in-one droplet-based technology, Virtual Reaction Chamber, to radically reduce the time and costs associated with laboratory testing.
- Developed environmentally friendly catalysts for pharmaceutical synthesis.
- Won 65 international and Singapore research awards between 2003 and 2010
- BN's Youth Research Program has reached out to more than 48,000 students and teachers since 2003.



The **INSTITUTE OF MEDICAL BIOLOGY** was founded as the Centre for Molecular Medicine in 2004 before it was relaunched in 2007 as the Institute of Medical Biology with Prof Birgitte Lane as its founding Executive Director. The institute focuses on issues at the interface between basic science and medicine to facilitate the development of translational research. Its current programme is concerned with different aspects of human disease. Its role is to work closely with scientists and clinicians to support, inform and refine each other's strengths and specialisations to improve the translational process, and ultimately help improve the quality of life. IMB's researchers were early founders of Singapore Stem Cell Club (now the Singapore Stem Cell Society), the Singapore Skin Club and BMRC's first Postdoctoral Society, three important networking structures that foster dialogue between Singapore's clinicians and scientists.

ACHIEVEMENTS

- Discovery with University of Dundee that mutations in the *TGFBR1* gene cause a rare skin cancer that heals itself.
- Production of the first human cell model of progeria, a severe premature-aging disease with Department of Medicine, University of Hong Kong.
- Identification of key cells of oesophagus as candidates for the evolution of oesophageal cancer with the Genome Institute of Singapore, National University of Singapore, Harvard Medical School and the Bingham and Women's Hospital.
- Discovery of a crucial interaction between the protein kinase PAK1 (important for synapse formation in the brain), and the fragile-X-related protein FXR1, shedding light on the mechanisms underlying fragile X syndrome, the most common cause of inherited male mental retardation and a leading genetic determinant of autism.
- Discovery that mutations in *PYCR1* gene cause a rare genetic condition with premature skin ageing, known as wrinkly skin syndrome.
- Discovery that the human papillomavirus (HPV16) protein E2 can be used for the early detection of HPV infections that predispose to cervical cancer.
- Discovery that stem cell secretions improve blood flow after a heart attack, and establishment of a scalable manufacturing process for the active components with the Leiden University Medical Centre.
- Identification of genetic differences between Asian and European populations in mutations predisposing to eczema with University of Dundee and National Skin Centre, Singapore.
- Identification of further kinases whose mutation leads to cancer formation – promising candidates for cancer therapy.



The **SINGAPORE INSTITUTE FOR CLINICAL SCIENCES** was established in 2007 with the mission to accelerate the translation of basic discoveries into new diagnostics and therapeutics.

It focuses its research on clinical applications; the use of innovative approaches and technologies that enable the study of human health and disease, especially in infectious diseases, metabolic diseases and cognitive development.

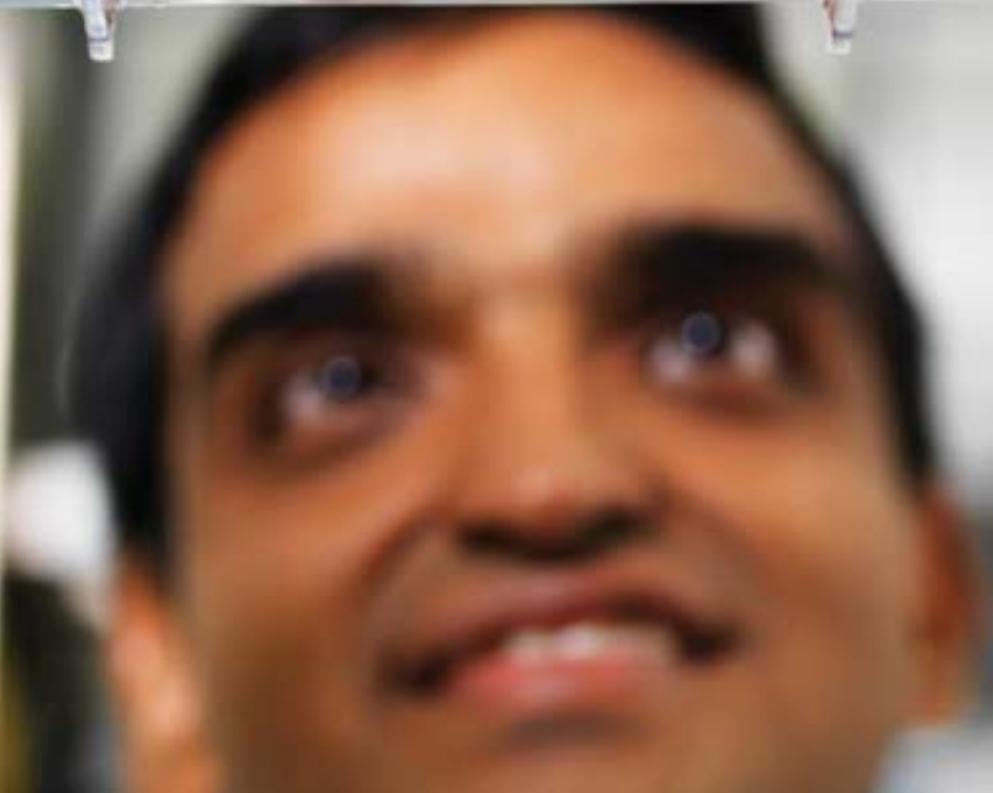
Housed in the Brenner Centre for Molecular Medicine within NUS, SICS collaborates with most of the public hospitals, as well as with the Singapore Bioimaging Consortium, Bioprocessing Technology Institute, Institute for Molecular and Cell Biology and the Singapore Immunology network.



The **INSTITUTE OF MOLECULAR AND CELLULAR BIOLOGY** was officially opened in 1987 within

the National University of Singapore. Its founding Director was Prof Chris Y H Tan, and its international Scientific Advisory Board, chaired by Dr Sydney Brenner, included Professors Louis Lim, Chua Nam Hai and Alice Huang. In August 2002, the Institute of Molecular Agrobiology (IMA) joined IMCB, bringing with it core capabilities of structural biology and zebrafish research. As evidence of IMCB's success, the institute won the Nikkei 2000 Award.

When Prof Tan retired in 2001, Prof Hong Wanjin served as Acting Director from 2001-2004. Thereafter, Prof Sir David Lane and Prof Neal Copeland took leadership as Executive Directors from 2004-2007 and 2008-2010 respectively. Under their leadership, IMCB sharpened its relevance to industry while strengthening its capabilities in basic Science. Since its inception, the research institute has trained more than 300 post-doctoral fellows and 130 PhD graduates who are active in the worldwide academic and industrial research community. Prof Stephen Cohen served as Acting Executive Director from 2010. Under its fourth Executive Director Prof Hong Wanjin (appointed in November 2011) IMCB continues to focus on research in cell and developmental biology with relevance to human disease.





ACHIEVEMENTS

- IMCB formed an R&D partnership with Glaxo in 1989 to research on degenerative brain diseases. The team, led by Prof Louis Lim, included Drs Thomas Leong and Ed Manser.
- IMCB formed a joint venture with Glaxo and the EDB in 1993 to discover bioactive compounds via the Center for Natural Product Research. This venture was spun off in 2002 as MerLion Pharmaceuticals.
- Prof Wanjin Hong discovered GS28 and other SNAREs in 1990, making Singapore the place of discovery of about half of mammalian SNAREs.
- IMCB formed a consortium with the Joint Genome Institute of the United States Department of Energy to sequence the pufferfish genome. This was an important milestone in the Human Genome Project, which contributed significantly to the complete annotation of the Human Genome.
- IMCB developed technologies that proved instrumental in providing two rapid and accurate diagnostic kits to detect the SARS virus. These kits were developed in collaboration with Genelabs Diagnostics Pte Ltd.
- A PCR-based Malaria diagnostic kit, jointly developed by the IMCB team led by Dr Robert Ting and the NUS team led by Dr Ursula Kara, was licensed by Veredus laboratories.
- A novel mechanism for regulating the protein levels of metastasis-associated PRL-3 in human cancer was defined by Dr Zeng Qi which provided insight into PRL-3's role in cancer progression.

- Dr Wang Yue and his team discovered the transport proteins of *Candida albicans*, the most prevalent fungal pathogen of immunocompromised patients.
- Dr Lianhui Zhang received the National Science Award (NSA) for his pioneering research on bacterial quorum sensing as a target in the control and treatment of infection. Zhang's studies on how bacteria communicate with one another has led to discovery of potential new antibiotic drugs, currently in development at IMCB.
- Dr Uttam Surana's work on control of cell division and genome stability was recognized with an NSA. His studies using yeast as a genetic model has uncovered novel mechanisms that regulate division in human cells. Surana has built on these studies to identify new anti-cancer drugs, which currently show promise in preclinical testing.
- Research by IMCB's Haiwei Song and Wanjin Hong provided a detailed understanding of the interaction between proteins called TAZ/YAP and TEAD. These proteins are overactivated in many cancers. IMCB's pioneering analysis of how these proteins touch each other has set the stage for the design of anti-cancer drugs.

SCIENCE & ENGINEERING RESEARCH INSTITUTES



The **DATA STORAGE INSTITUTE** was originally set up in 1992 at the National University of Singapore as the Magnetics Technology Centre. Its aim

was to acquire core competencies in technologies related to data storage, enabling an increase in the value-added potential of Singapore's industries, and to provide access to technology for existing industry and spin-offs. The Magnetics Technology Centre was renamed Data Storage Institute in 1996, the year it filed a patent for its fluid film bearing motor prototype. DSI was the one pioneer research institute to be developed by Singaporean talent – Prof Low Teck Seng, its founding Executive Director.

ACHIEVEMENTS

- DSI researchers awarded the Information Storage Industry Consortium Technical Achievement Award 2009 in recognition of outstanding work in the development of Extremely High Density Recording Software Channel simulator for standard and two-dimensional magnetic recording in the INSIC-EHDR Program.
- Tan Kah Kee Silver Award 2008 to researcher Tan Chun Chia for his contributions to improving phase-change random access memory (PCRAM) performance, bringing PCRAM one step closer to commercialisation.
- National Technology Award 2006 for DSI's spindle motor team for contributions to advanced micro-motor technologies used in hard disk drives and miniaturised mechatronic systems.

- DSI's nano-mechanics and nano-tribology research team awarded 2005 National Technology Award for contribution towards ultra-low flying height technology at sub-3nm to make extremely high density storage possible.
- In 1996, Laser Research Pte Ltd was spun off to support the media manufacturing industry. It signed a contract with Topometrix, an AFM manufacturer, for the company to develop new instruments using two patents filed by the Magnetics Technology Centre.

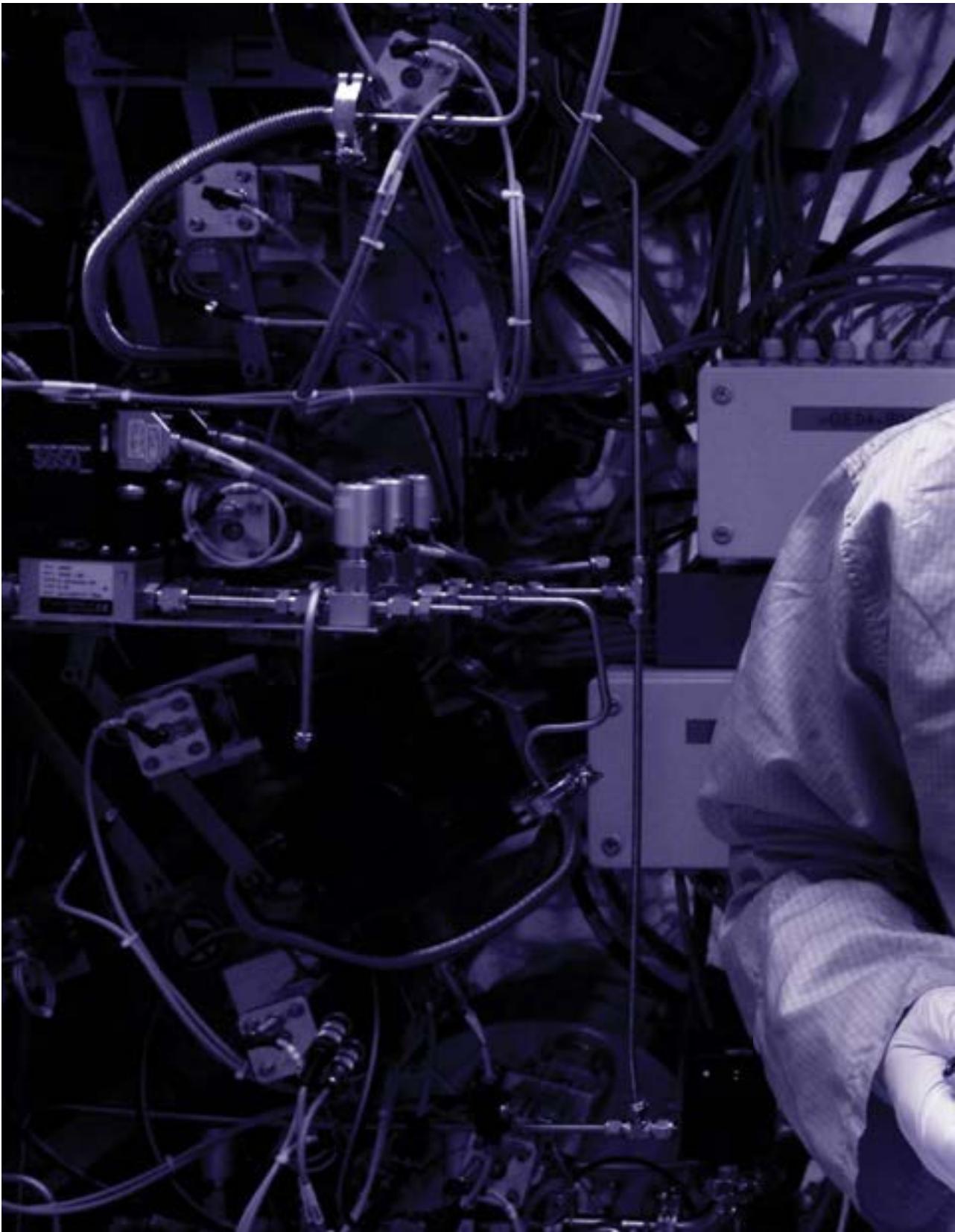


The **INSTITUTE FOR CHEMICAL AND ENGINEERING SCIENCES**

began as the Chemical & Process Engineering Centre in NUS's Chemical Engineering Department in 1998. When EDB embarked on Jurong Island for the petrochemical industry, it was decided that the centre would become its research anchor. In 2006, the Chemical & Process Engineering Centre moved to Jurong Island as ICES with Dr Keith Carpenter as its founding Executive Director. In 2009, ICES opened Kilo Laboratory, the first pilot-scale research facility in Southeast Asia to develop new process research techniques and solve the problems of scale-up and manufacturing in the pharmaceutical and petrochemical industries.

ACHIEVEMENTS

- Invention of dehydration catalyst for bio-alcohols such as ethanol, butanol and mixtures. This catalyst has extremely high selectivity and stability.
- Invention of a two-step process for biodiesel production from waste oils and fats. The steps are enzymatic hydrolysis of the feedstock and esterification of the free fatty acid produced in the hydrolysis step.
- Invention of innovative synthetic routes to access novel chemical entities with potential as chemotherapeutics in the treatment of cancer and infectious diseases.
- Invention of a new delivery system for amorphous active materials using mesoporous nanomaterials to enhance the bio-availability and delivery of active ingredients by improving both aqueous solubility and long-term stability. It has potential applications in the pharmaceutical and specialty chemicals industries.
- Invention of a sugar-based surfactant micro-emulsion containing essential oils for cosmetic and pharmaceutical use. It is a good agent for topical treatment that has excellent thermodynamic stability and biodegradability.
- Invention of a process leading to polymeric ketones which may be used as derivatives in industrially important novel materials.







The **INSTITUTE FOR INFOCOMM RESEARCH** was formed in 2002 from the mergers of Laboratories for Information Technology (LIT) and Institute for Communications Research (ICR). LIT itself was formed from the merger of Kent Ridge Digital Labs (KRDL) and Centre for Signal Processing (CSP), while ICR was formed from the merger of Centre for Wireless Communications (CWC) and the Optical group of Network Technology Research Centre (NTRC).

I2R incorporates the R&D activities of its constituents but focuses on creating next generation technologies in the areas of information technology, wireless and optical communication networks, interactive and digital media, signal processing and computing. The Institute is an effective conduit for technology transfer to the IT and other industries because it works closely with industry partners



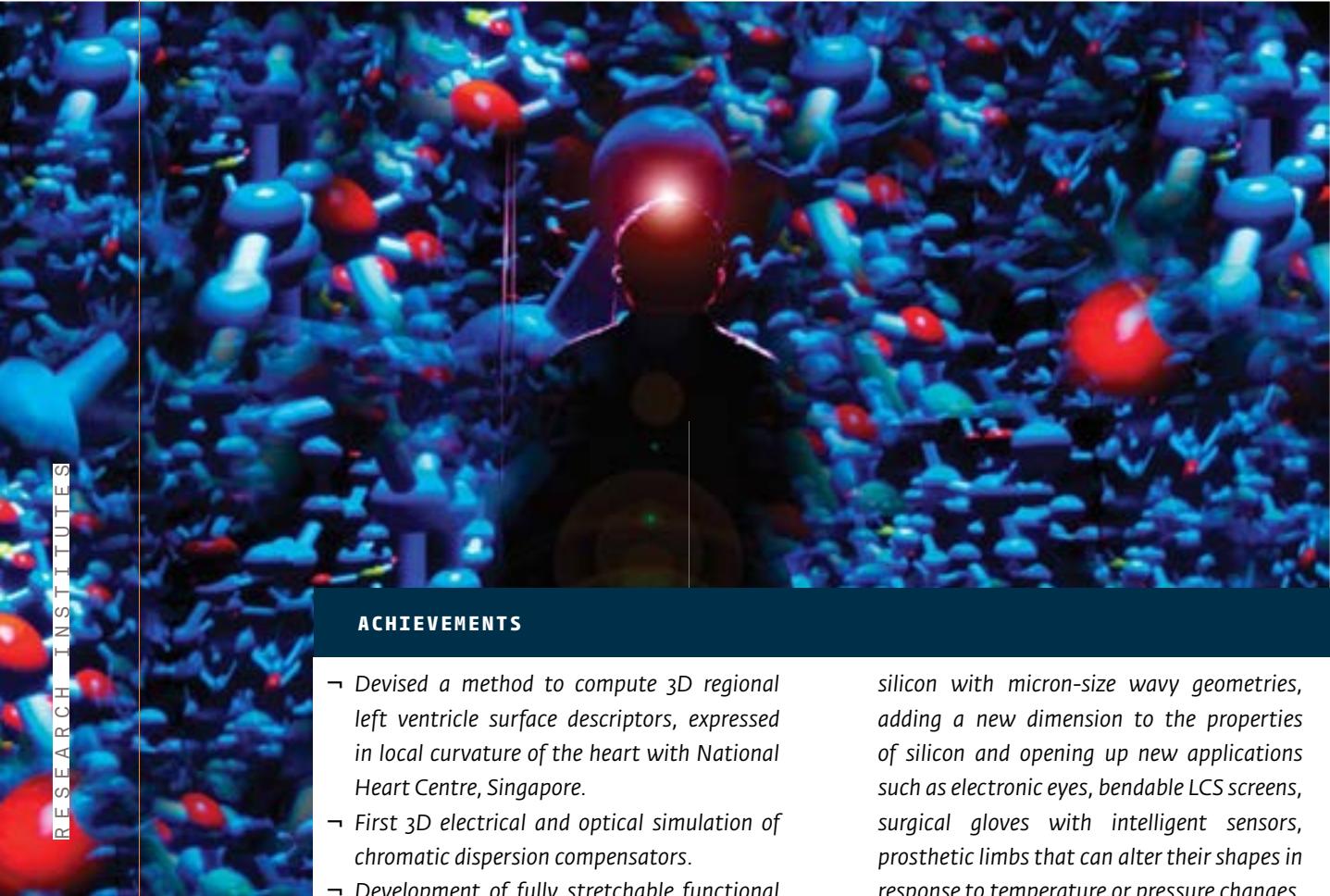
ACHIEVEMENTS

- Advanced Audio Zip (AAZ) – 1st “made-by-Singapore” technology adopted by normative MPEG international standards. AAZ is capable of packing any music file into a compressed file less than half its original size with no loss (lossless) in quality during playback. AAZ was adopted as the reference model in MPEG scalable to lossless audio workgroup and published by ISO as an international standard in June 2006.
- Licensed its Perimeter Intrusion Detection System based on Fibre Bragg Grating technology to ST Electronics (Satcom & Sensor Systems), who co-invested with Changi Airport Group to deploy it around Changi Airport’s 22km perimeter.
- MIMO-WLAN was adopted in IEEE 802.11n Joint Proposal Technical Specification. This scheme enables data transmission at 162 Mbps, which was 3x the current WLAN data rate, and with longer WLAN range. This technology garnered multi-million dollar funding support from a European MNC.
- Was overall 1st in National Institute of Standards and Technology 2008 Speaker Recognition Evaluation (Core Test Condition).
- Won BCI Research Award 2010 for “Motor imagery-based Brain-Computer Interface robotic rehabilitation for stroke”, with Tan Tock Seng Hospital and National Neuroscience Institute.
- I2R’s spin-off company, Muvee Technologies Pte Ltd, won the National Infocomm Award, and was recognised in the Most Innovative Product or Service category.
- Jointly developed advanced algorithms with Addvalue Communications Pte Ltd, resulting in a multi-million dollar contract to design, develop and supply pocket-sized BGAN satellite terminals.



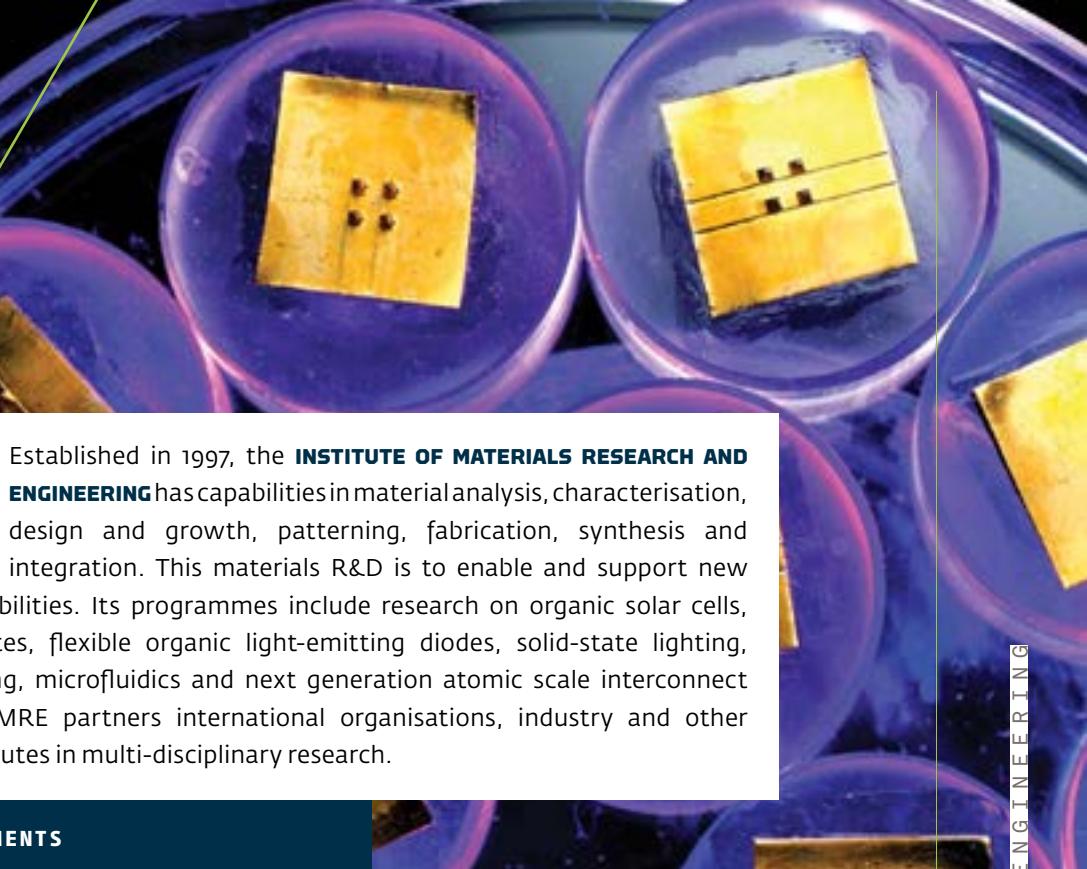


The **INSTITUTE OF HIGH PERFORMANCE COMPUTING** grew out of the National Supercomputing Research Centre founded in 1993. Its aim was to promote and provide support for the use of high-performance computer applications and undertake research in parallel computing, high speed networks and interfaces and scientific visualisation. It became the Institute of High Performance Computing in 1998 with Prof Lam Khin Yong as its founding Executive Director. The institute researches solid and fluid computational mechanics, computational chemistry, digital modelling and visualisation, cognitive science and artificial intelligence, and advanced computing technologies such as cloud computing.



ACHIEVEMENTS

- Devised a method to compute 3D regional left ventricle surface descriptors, expressed in local curvature of the heart with National Heart Centre, Singapore.
- First 3D electrical and optical simulation of chromatic dispersion compensators.
- Development of fully stretchable functional circuits with researchers at the University of Illinois at Urbana-Champaign and the Northwestern University in Chicago.
- Improvements in water filtration membrane technology using computational fluid dynamics tools and simulations to provide insights into a complex and large-scale multiphase flow phenomena with membrane filtration effects and to arrive at an optimal system that increases productivity and efficiency.
- Simulations to provide new insights into the mechanical characteristics of stretchable silicon with micron-size wavy geometries, adding a new dimension to the properties of silicon and opening up new applications such as electronic eyes, bendable LCS screens, surgical gloves with intelligent sensors, prosthetic limbs that can alter their shapes in response to temperature or pressure changes, and wireless medical devices.
- Photonics crystals with light reflection for all angles and all polarisations with applications such as ultraviolet filters for sunglasses, safety glasses, visible light blocking for security and defence applications, and infrared and UV photography filters.
- Electronic package system simulator that is able to numerically solve the electrical property of a complex electronic package system with multilayered structure and multiple vias and signal traces. It is 10 times faster than the previous system.



Established in 1997, the **INSTITUTE OF MATERIALS RESEARCH AND ENGINEERING** has capabilities in material analysis, characterisation, design and growth, patterning, fabrication, synthesis and integration. This materials R&D is to enable and support new industry capabilities. Its programmes include research on organic solar cells, nanocomposites, flexible organic light-emitting diodes, solid-state lighting, nanoimprinting, microfluidics and next generation atomic scale interconnect technology. IMRE partners international organisations, industry and other research institutes in multi-disciplinary research.

ACHIEVEMENTS

- Developed Ultra-high Flexible Barrier Film which protects sensitive devices such as organic light-emitting diodes and solar cells from moisture 1,000 times more effectively than any other technology available. The inventors have spun off Tera-Barrier Films Pte Ltd to develop the technology further.
- Developed Translucent Organic Solar Cells which are flexible materials with a wide range of applications from energy-generating tinted windows to powering portable electronics. The material allows light to pass through yet absorbs enough light to generate electricity.
- Perfected a new range of patented micro-needles that can be mass produced more readily and at a lower cost than current microneedle technologies. Micropoint Technologies Pte Ltd, an investment of Japanese conglomerate Sumitomo Corporation Asia, was formed to exploit the technology.
- Together with Data Storage Institute and Singaporean precision equipment manufacturer Solves Innovative Technology, IMRE built a machine capable of producing nanometer-size components and in wafer-scale volumes for applications in consumer electronics such as hard disk and optical storage media. This first made-in-Singapore mass-production nanoimprinter is a significant improvement on conventional nanoimprinting processes. Its double-sided imprinting reduces processing time and allows a customised dosing system. It also allows imprinting in a vacuum which prevents air bubbles and thus achieves more accurate patterning.
- Colloidal synthesis of nanodisk heterostructures consisting of $Cu_{1.94}S$ and wurtzite CdS .
- Innovation of a technique for making hydrogels that is biocompatible, biodegradable and can be easily moulded into different shapes and sizes.





The **INSTITUTE OF MICROELECTRONICS** was founded in 1991 with a mission of adding value to Singapore's microelectronics industry by developing strategic competencies, innovative technologies and intellectual property; enabling enterprises to be technologically competitive; and cultivating a talent pool to inject new knowledge to the industry.

IME has developed strengths in integrated circuit and system design, process technologies, advanced packaging and reliability testing. These capabilities provide the core infrastructure to support research programmes in multi-disciplinary fields such as 3D IC and Through Silicon Via (TSV) technology, bioelectronics and miniaturized medical devices, MEMS, nanoelectronics and silicon photonics. Numerous innovative technologies were developed through these programmes and were transferred to industry. Since 2003, more than 40 IME researchers were seconded to 33 Singaporean companies on a full- or part-time basis.

IME provides Singapore universities and polytechnics with student attachment opportunities. Numerous research collaborations have been established among IME, universities and industry to train and develop the next generation of microelectronic scientists.

ACHIEVEMENTS

- ¬ Demonstrated one of the earliest bluetooth chip realized by RF CMOS processes.
- ¬ Developed CMOS-compatible nanowire technology for advancing applications in biosensing, energy harvesting, data storage and optoelectronics.
- ¬ Developed a Radio Frequency Identification (RFID) reader chip that extended identification-tracking applications.
- ¬ Developed one of the faster and smaller multichannel avalanche photo detector arrays with wavelength multiplexing that enabled ultra fast data communications.
- ¬ Developed a bedside tool for fast and sensitive detection of rare cardiac biomarker cells to enable efficient prescription of treatment to heart patients.



The **SINGAPORE INSTITUTE OF MANUFACTURING TECHNOLOGY** develops high value manufacturing technology and human capital to enhance the competitiveness of Singapore's manufacturing industry. It is made up of two constituent institutes: Grumman International-Nanyang Technological Institute Centre for CAD/CAM, started in 1985, and the Institute of Manufacturing Technology set up in 1991. These institutes were merged in 1993 to become GINTIC Institute of Manufacturing Technology with Dr Frans Carpay as its founding Executive Director. The name of the institute was changed to SIMTech in 2002.

The institute currently has three divisions; focusing on manufacturing process, manufacturing automation and manufacturing system.



ACHIEVEMENTS

- *Applied the developed ultrasonic vibration-assisted cutting method to directly cut steel-based alloys to produce high-precision components for use in various industries.*
- *Developed an intelligent and automated control system for SATS Airport Services airfreight terminal. This system provides accurate real-time information and automated decision-making, full audit trail, and intelligent self-recovery that can re-route cargo with minimal human intervention.*
- *Produced magnesium disk drive parts with wall-thickness of 0.38mm, believed to be the thinnest magnesium die-cast part in the world.*
- *Developed a positioning system that has a novel decoupled motion axes configuration and a control scheme for tightly synchronised motion of dual linear motor drives.*
- *Collaborated with Nanyang Optical to produce the world's first spectacle frames made from recycled materials. Nanyang Optical received international recognition at the 2008 Milan International Optics, Optometry and Ophthalmology Exhibition.*



BIOMEDICAL & ENGINEERING CONSORTIA & THE NATIONAL METROLOGY CENTRE



EXPERIMENTAL THERAPEUTICS

CENTRE was founded by A*STAR in December 2006. Its promoter and founder was Prof David Lane who

was also its first CEO. The present CEO is Alex Matter, formerly Director of Novartis Institute for Tropical Diseases in Singapore. ETC's work is also overseen by a Project Review Committee chaired by Prof Tadataka Yamada, former President of the Global Health Program of the Bill & Melinda Gates Foundation. ETC is located in Biopolis and has some 80 full-time employees.

ETC's mission is to guide early-stage drug discoveries towards proof-of-concept in man. It complements the existing biomedical research infrastructure and expertise that Singapore has built up over the past decade, and serves to bridge the gap from basic to clinical research in Singapore.

ETC brings a compound to the stage of a Preclinical Development Candidate, after which Contract Manufacturing Organizations and Contract Research Organizations are engaged to execute the required preclinical development activities before entering early clinical trials.

ETC partners with Singapore Clinical Research Institute and Investigational Medicine Units in conducting proof-of-concept studies, to assess a compound or a biologic in a small, targeted number of patients in a well-understood disease with a known molecular pathway, to determine early evidence of clinical efficacy consistent with the purported effect of the drug, at well-tolerated doses.

ETC has ramped up its technologies and headcount to a level where it can undertake all the necessary drug discovery activities at a state-of-the-art level. It has also established



a diverse project portfolio addressing a wide range of medical needs, and is able, mainly via its partnerships, to draw on deep biological understanding of the model systems to be employed.

Current projects include a collaboration with Duke University and the National University of Singapore Graduate Medical School to screen for novel gastric cancer medicines; another with DSO National Laboratories and the Genome Institute of Singapore to discover anti-bacterial drugs using a novel whole animal screening platform; and one with Fujitsu to develop an aptamer technology for disease diagnosis.

ETC is actively involved in the establishment of technology platforms to serve the greater Singapore scientific community. In 2011, it opened the new Singapore Screening Center with an automated, versatile platform for biochemical and cell-based screens, and a chemical library of 300,000 compounds, many of which are proprietary.



A*STAR DUKE-NUS GMS NEUROSCIENCE RESEARCH PARTNERSHIP. Neuroscience is one of the most widely supported research areas of modern biology. While some mysteries about the inner workings of the brain and the nervous system have been answered, many remain to be solved. Neuroscientists throughout the world continue to be fascinated by the complexities of neuronal organization and function, as well as the array of neuropathologies responsible for the morbidity and mortality of so many people.

In 2007, Duke-NUS and A*STAR recognised the potential of neuroscience research and the need for Singapore to embrace and participate in its ongoing growth by entering into a Neuroscience Research Partnership (NRP). Professor Colin Blakemore was NRP's founding Chairman.

The partnership's main objectives are to facilitate the overall growth of outstanding neuroscience and increase the number of neuroscientists in Singapore, rather than at a single institution.

Another goal is to promote collaborations across research institutions, with industry, and with the clinical community.

The NRP allows for the cost-effective sharing of material and intellectual resources between Duke-NUS at Outram Road and A*STAR Institutes at Biopolis. Key areas of investigation include the effects of aging, cognitive neuroscience, neural plasticity, neurogenetics, stem cells, brain tumors, and sleep disorders. All these areas are relevant to the wider neuroscience community and can be further developed for both health and industry-related impact.

Still in a phase of growth, NRP plans to recruit several neuroscientists into the program each year for the next five years till the number of investigators at the Biopolis is similar to those at Duke-NUS.



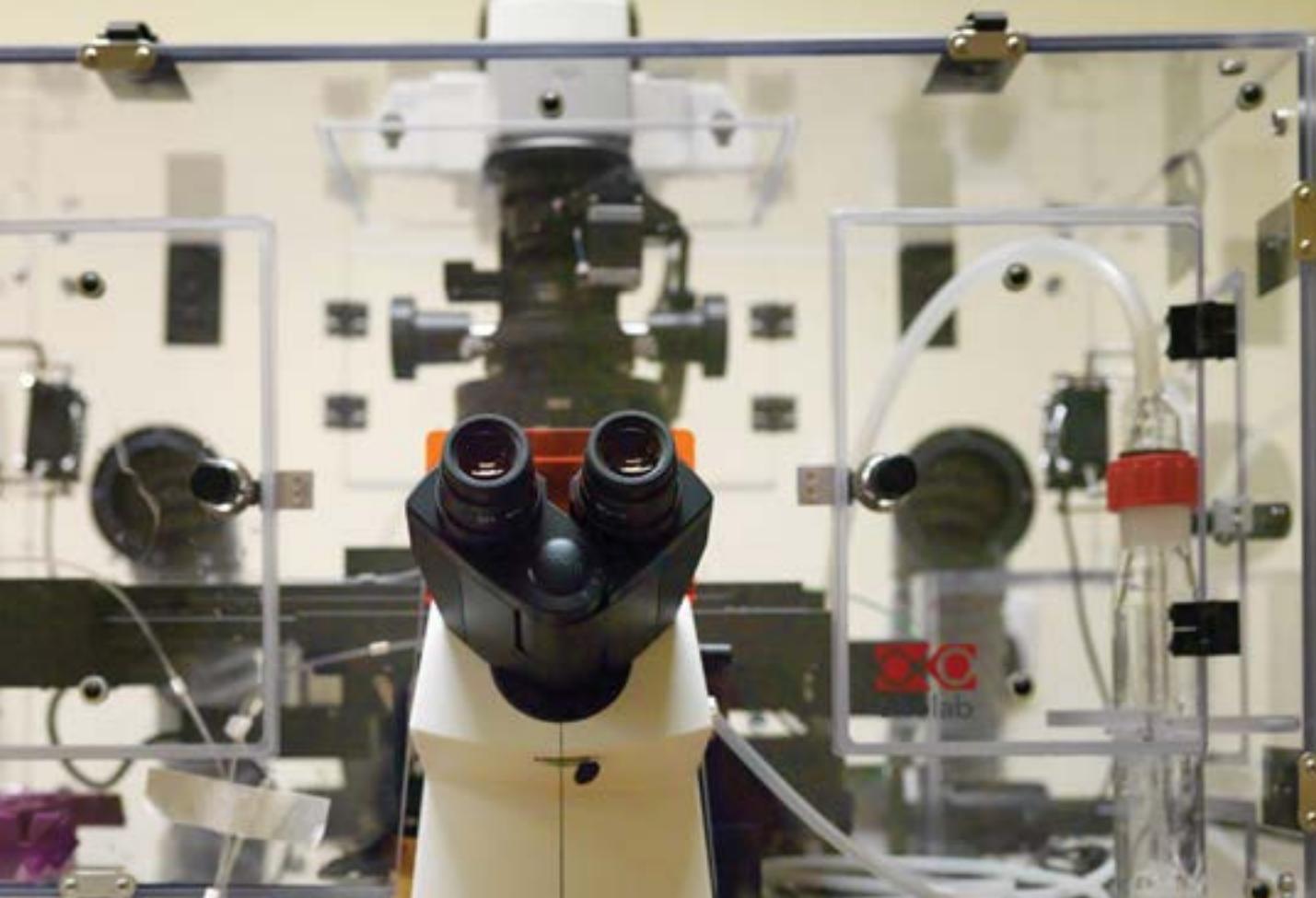
The **SINGAPORE BIOIMAGING CONSORTIUM** was officially inaugurated on 6 April 2006. It consisted of three laboratories:

The Lab of Molecular Imaging (LMI), the Lab of Metabolic Medicine (LMM), and the Biomedical Imaging Lab (BIL). LMI and LMM are new laboratories located within SBIC's premises in Helios Building in Biopolis while BIL, which was transferred to SBIC from the Bioinformatics Institute, is located in the Matrix Building. The consortium currently has 13 research units.

SBIC's roots can be traced to a Bioimaging Workshop organised by BMRC in 2004. The follow-up Bioimaging Task Force chaired by Prof George Radda identified four technology platforms for coordinated research programmes: Optical imaging; image processing and management; small animal imaging with Magnetic Resonance (MRI and MRS); and the development of chemical/biological probes.

Three areas of biology – cancer, metabolic medicine, and regenerative medicine – integrated across the four technology platforms, were also highlighted as possible main drivers of SBIC. In addition, the task force recommended that micro-CT and micro-Ultrasound imaging be set up for the rapid phenotyping of mice. The proposal for SBIC was formally presented to, and approved by, the BMRC Board on 10 August 2004, and was subsequently endorsed by the Life Sciences Ministerial Committee Meeting on 21 August 2004 and the Biomedical Sciences International Advisory Council on 11 October 2004.

SBIC's main vision is to build a coordinated national programme of imaging research and bring together the substantial strengths in engineering and physical sciences with those in biomedical sciences. SBIC seeks to identify and consolidate the various bioimaging capabilities across research institutes, universities and hospitals. It also aims to foster closer collaboration



in bioimaging amongst researchers and medical practitioners. SBIC therefore serves as a focal point for stimulating, funding, coordinating and reporting on the various aspects of bio-imaging activities in Singapore.

In 2007, SBIC spearheaded the formation of the NUS-A*STAR Clinical Imaging Research Centre (CIRC) jointly with NUS and Siemens as the industry partner. CIRC aims to become a national resource for research imaging in humans open to all biomedical researchers in Singapore via the use of state-of-the-art instruments.

In early 2011, SBIC and Maccline Pte Ltd, a contract research organisation, established a collaboration to set up the unique "Translational

Imaging Industrial Lab" (TIIL) which will provide global biopharma companies with a one-stop solution for all the preclinical imaging challenges faced by the drug discovery and development industry.

The collaboration will combine Maccline's highly advanced large animal imaging capabilities with SBIC's cutting edge research and state-of-the-art biomedical imaging expertise. Thus, SBIC in collaboration with CIRC and Maccline will offer the clinical and pharmaceutical community a comprehensive suite of imaging services from small animals to humans.





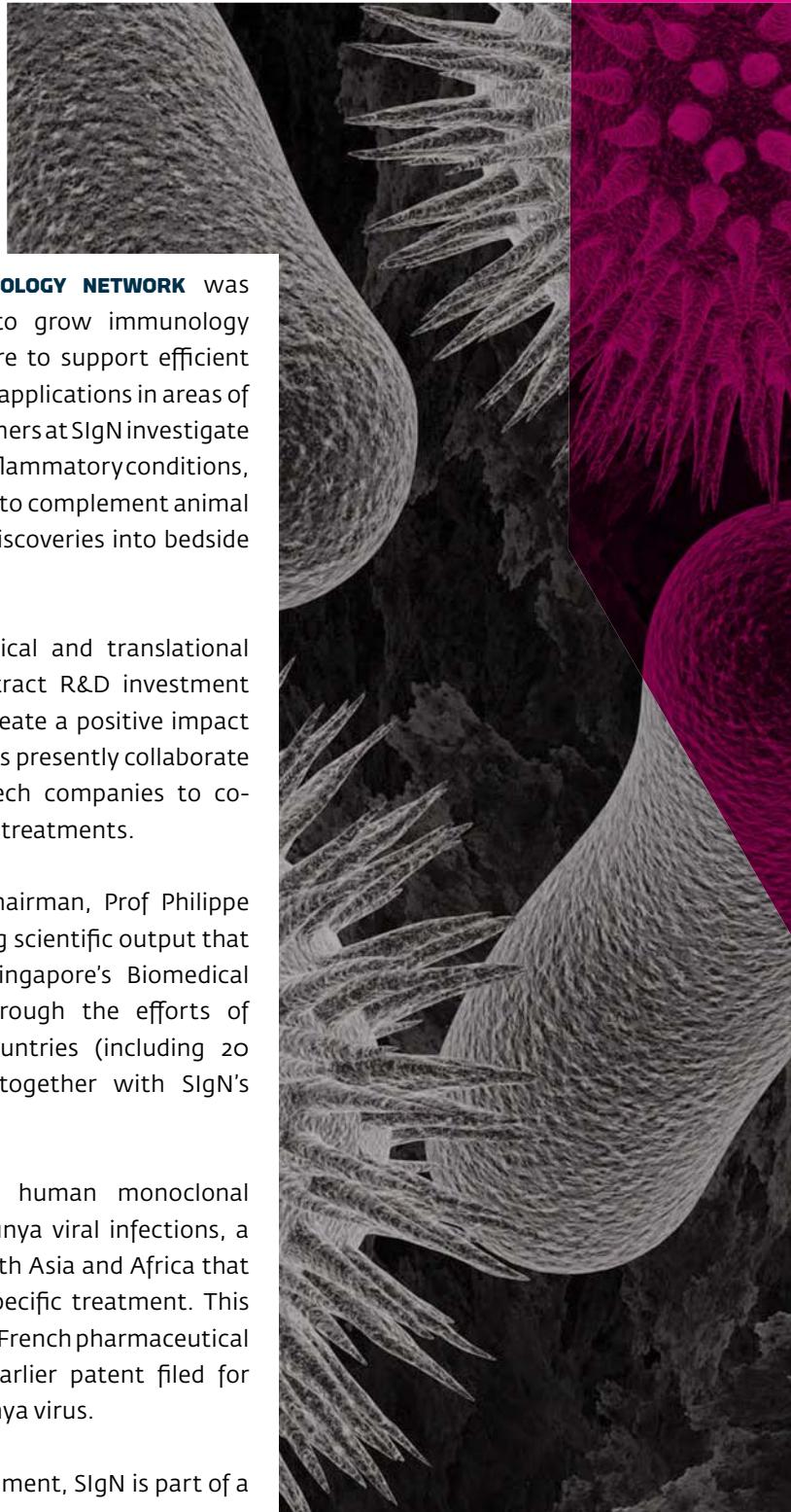
The **SINGAPORE IMMUNOLOGY NETWORK** was established in 2008 to grow immunology capabilities in Singapore to support efficient translation into clinical applications in areas of medical needs. Researchers at SlgN investigate human immunity during infections and inflammatory conditions, including cancer, by using human tissues to complement animal models in an effort to translate bench discoveries into bedside medical treatments.

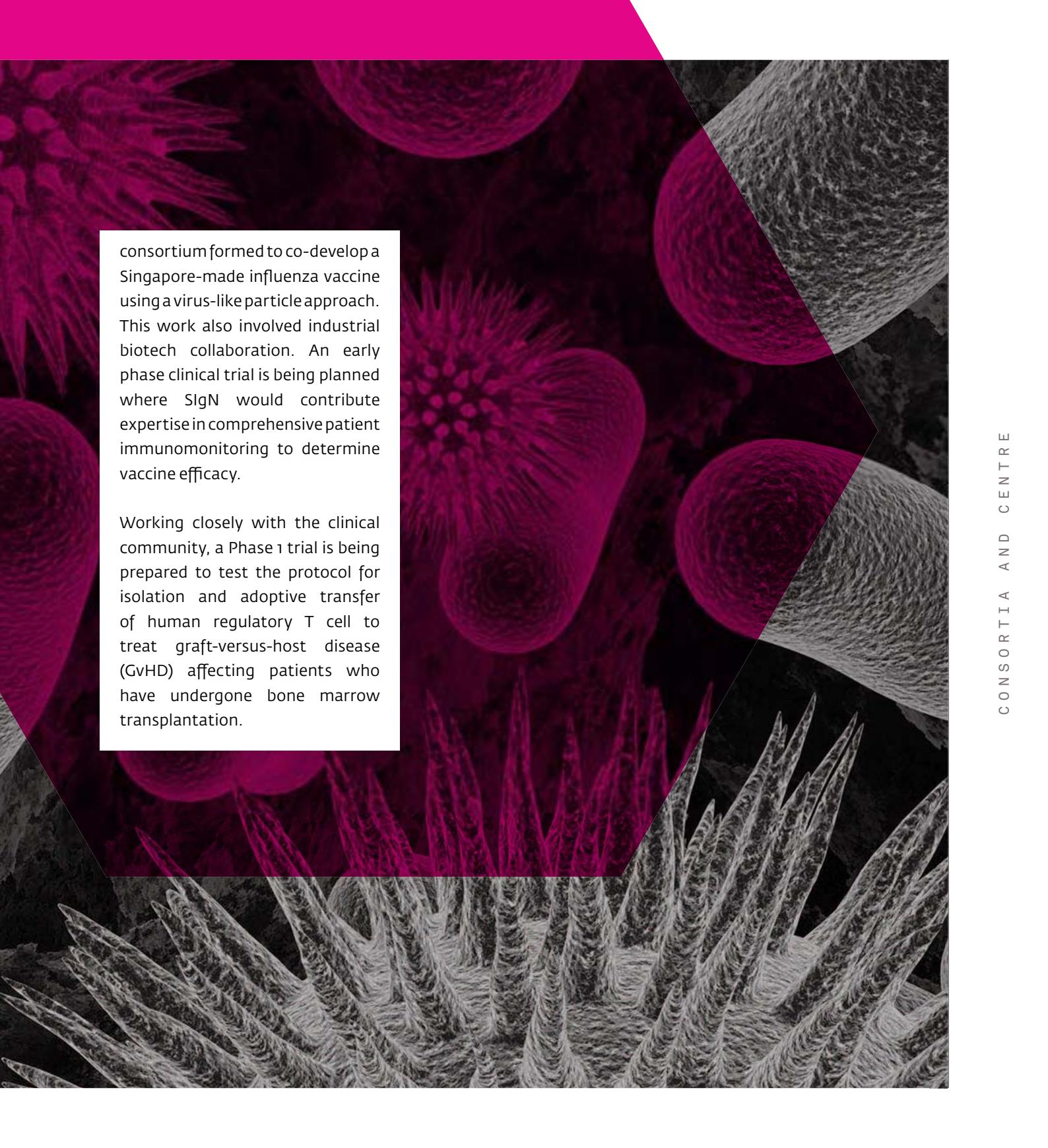
In addition to serving Singapore's clinical and translational efforts, SlgN was also designed to attract R&D investment from industrial companies in order to create a positive impact on Singapore's economy. SlgN researchers presently collaborate with over 12 pharmaceutical and biotech companies to co-develop new products and novel medical treatments.

Since its establishment by founding Chairman, Prof Philippe Kourilsky, SlgN has delivered outstanding scientific output that gained international recognition for Singapore's Biomedical Sciences. This was made possible through the efforts of 200 researchers from 25 different countries (including 20 international principal investigators), together with SlgN's clinical and industrial collaborators.

SlgN has discovered two new fully human monoclonal antibodies which could battle Chikungunya viral infections, a disease prevalent in Southeast Asia, South Asia and Africa that currently does not have a vaccine or specific treatment. This discovery, made in collaboration with the French pharmaceutical company, Vivalis, stemmed from an earlier patent filed for binding molecules against the Chikungunya virus.

In the area of vaccine design and development, SlgN is part of a



The background of the page features a complex, abstract image of biological cells and fibers. Some cells are shown in a vibrant red/pink hue, while others are in grayscale, creating a high-contrast, textured pattern. The fibers appear as delicate, radiating lines, suggesting a network or structural framework.

consortium formed to co-develop a Singapore-made influenza vaccine using a virus-like particle approach. This work also involved industrial biotech collaboration. An early phase clinical trial is being planned where SlgN would contribute expertise in comprehensive patient immunomonitoring to determine vaccine efficacy.

Working closely with the clinical community, a Phase 1 trial is being prepared to test the protocol for isolation and adoptive transfer of human regulatory T cell to treat graft-versus-host disease (GvHD) affecting patients who have undergone bone marrow transplantation.



The **SINGAPORE STEM CELL CONSORTIUM** was set up in 2006 under the leadership of Prof Roger Pederson to exploit the potential of stem cell research.

In July 2007, Dr Alan Colman took over as the first SSCC Executive Director.

SSCC aims to establish a coordinated and focused translational research and development programme in stem cells. Its research focuses on catalysing the translation of basic stem cell research into clinically viable stem cell therapies for chronic debilitating diseases. It also has an interest in using stem cells to create models of mammalian development and disease states, as well as providing cellular assays for the identification of novel signalling molecules, pathways, and the development of new drugs. In addition to supporting intramural stem cell research within the Institute of Medical Biology, it has co-ordinated diverse stem cell research activities in Singapore by funding collaborative grant calls and developing key resources for the stem cell research community. SSCC participated in negotiations with Lonza to build and staff a new facility to grow cells for clinical applications.

From 2006 to 2010, SSCC issued five grant calls. In total, 32 awards were made, committing \$21,942,137 to date. SSCC also contributed a further \$5M in grant support for stem cell applications under an A*STAR Translation and Clinical Research in eye research. These grant supports have been acknowledged in 46 publications.



Established in 1975, the **NATIONAL METROLOGY CENTRE** serves as the custodian of the national measurement standards in Singapore.

NMC participates actively in international comparisons with other national metrology institutes and is a signatory of the International Committee for Weights and Measures Mutual Recognition Arrangement. NMC provides technical expertise and support in measurement and calibration technologies to the industry, research, government organisations and other end users.

NMC is responsible for the establishment and maintenance of Singapore's highest metrology reference standards traceable to the International System of Units (SI) established under the Metre Convention. It provides calibration and measurement services to, and training and consultancy for, industry. NMC undertakes R&D to develop measurement technology and solutions for industry; and participates in international negotiations and standards-setting relating to metrology.

NMC aims to enhance the quality of measurements in industry by providing an internationally recognised national measurement infrastructure.



CONSORTIA AND CENTRE

ACHIEVEMENTS

- One of the 38 signatories of the International Committee for Weights and Measures Mutual Recognition Arrangement in 1999, removing the barrier for Singapore companies in global markets.
- Participated in the international comparison of the 10 V Josephson voltage standard led by the International Bureau of Weights and Measures, making NMC one of the top performers among leading national metrology institutes.
- Set up a primary ozone standard, designated Standard Reference Photometer (SRP) 46 for the

calibration of ozone meters. SRP46 is the first and only traceable primary ozone standard in Southeast Asia.

- Since 1997, NMC has contributed the readings of five atomic clocks to the International Bureau of Weights and Measures which derives the Coordinated Universal Time by averaging the inputs from about 400 atomic clocks.



1981: Institute of Systems Science was formed primarily as a teaching institute to help organisations with computerisation.

1985: Setting up of an R&D Group in the Institute of Systems Science as part of the push into R&D.

1985: GINTIC was formed as a result of a collaboration between Nanyang Technological Institute and Grumman International

1986: The Information Technology Institute set up as part of the National Computer Board.

1987: Singapore's first life sciences institute, the Institute of Molecular and Cell Biology, was opened. Its founding director was Prof Christopher Tan. The institute was a 'proof of principle' that Singapore, in spite of its size and limited manpower, could replicate the research culture in the US.

1987: The Science Council initiated the National Science & Technology Awards which give recognition to Singapore scientists and engineers who have made significant contributions to R&D and innovation.

1988: The National Young Scientist & Engineer Award was launched to give recognition to researchers aged 35 and below.

1988: The National Biotechnology Programme was established by the Economic Development Board to spearhead the development of biotechnology.

1989: The Institute of Molecular and Cell Biology entered into a 15-year partnership with Glaxo, to undertake research in the field of mechanisms and diseases in the central nervous system. Glaxo agreed to invest \$50 million in the institute in exchange for rights to the commercialisation of any intellectual property derived from this project and royalties.

1989: GINTIC was transformed into the GINTIC Institute of Computer Integrated Manufacturing. The centre coordinated national R&D in Computer Integrated Manufacturing.

1990: The Institute of Manufacturing Technology was formed to enhance the competitiveness of Singapore's manufacturing.

1990: The Bioprocessing Technology Unit was formed under the Biotechnology Competence Enhancement Programme administered by the Economic Development Board. It would provide manpower training in bioprocessing - fermentation and cell culture, and purification technologies. It was a central facility for multi-disciplinary R&D.

1991: The National Science and Technology Board set up with Lam Chuan Leong as its inaugural Chairman.

1991: Publication of the first five-year National Technology Plan entitled Science and Technology: Window of Opportunities. The report recommended a \$2 billion Research & Development Fund to support industry-driven R&D over the next five years.

1991: The National Science and Technology Board set up an International Advisory Panel on Science and Technology comprising nine eminent researchers, scientists and industrialists from top institutes and private companies in the US, Europe and Japan.

1991: Singapore Institute of Standards and Industrial Research convened the inaugural meeting of its International Panel of Advisors on Technology to help map its Technology Master Plan.

1991: Simon Tan Lian Chye of Hewlett-Packard became the first from industry to win the National Young Scientist and Engineer award for his contribution to the development of the 'One Pen Colour Inkjet Printer' technology.

1991: Formation of the Institute of Microelectronics with Dr Bill Chen from Bell Laboratories as its Executive Director.

1991: Technet, a joint National University of Singapore and National Science and Technology Board project, was launched, marking the beginning of the Internet in Singapore.

1992: The Magnetics Technology Centre headed by Prof Low Teck Seng was set up to support Singapore's storage manufacturing industry with research capabilities.

1992: The Apple-ISS Research Centre, a collaboration with Apple Computer Inc and the Institute of Systems Science, was officially launched to develop technology in computing processing of Asian languages.

1992: The R&D Group of the Institute of Systems Science with IBM Singapore set up Singalab Pte Ltd, the group's first spin-off.

1992: The National University of Singapore Medical Faculty initiated the Advanced Specialty Training programme for post-MMed doctors. In 1995, more than 230 doctors from 15 countries were pursuing the MMed degree in 11 disciplines, with another 100 doctors doing the Advanced Specialty Training Programme.

1992: The National Science and Technology Board launched the Patent Application Fund which allowed Singapore inventors to defray the costs of patent applications.

1992: The first National Science and Technology Medal, launched by the National Science and Technology Board, was presented to Frank Cloutier, the manager of Hewlett-Packard's Asia Peripherals Division.

1992: The National Science and Technology Board set up the Centre for Wireless Communications.

1993: The Institute of Molecular and Cell Biology undertook a \$60-million joint venture with Glaxo and the Economic Development Board to discover novel bioactive compounds from natural resources such as plants, micro-organisms and marine organisms. This drug discovery venture was the first of this sort of collaboration between a large drug company and a research institute.

1993: Teo Ming Kian took over as Chairman of the National Science and Technology Board.

1993: Formation of the GINTIC Institute

of Manufacturing Technology from the merger of the GINTIC Institute of Computer Integrated Manufacturing and the Institute of Manufacturing Technology. Its founding Executive Director was Dr Frans Carpay.

1993: The Research Incentive Scheme for Companies was launched to support companies wanting to invest in R&D or facilities to build core technological capabilities.

1993: The World Competitiveness Report ranked Singapore, for the first time, top in science and technology amongst non-OECD countries, overtaking Taiwan for the first time.

1993: The National Computer Board formed ITI Holdings Pte Ltd to coordinate the commercialisation of research by the Information Technology Institute and oversee its investments in spin-off companies.

1994: The Innovators Club was inaugurated to facilitate interaction, sharing of ideas and experiences, and networking.

1994: The Innovations Support Framework programme was initiated by the National Science and Technology Board to create an environment for innovation through ideas, facilitation, information provision and funding.

1995: The National Science and Technology Board and the National University of Singapore launched the Bachelor of Technology Programme to provide polytechnic graduates with opportunities to earn a degree in Singapore.

1995: The Cooperative Research Programme was launched by the National Science and Technology Board to help SMEs develop and apply technological expertise to raise their competitiveness by linking them with public sector research organisations.

1995: The setting up of the Institute of Molecular Agrobiology to focus on research at the genetic and molecular levels was announced. The Institute of Molecular Agrobiology was later reorganised and its biomedical-related research groups were merged

with the Institute of Molecular and Cell Biology while its agrobiology-related groups were spun off as the Temasek Life Sciences Laboratory.

1995: GeneSing, the Institute of Molecular and Cell Biology's first spin-off company, was incorporated. The company develops human health care products for the Asian market.

1995: The Bioprocessing Technology Unit became the Bioprocessing Technology Centre.

1995: The National Technology Databank was set up by a collaboration between the National Science and Technology Board and the National University of Singapore. The organisation acts as a centralised source of technology information and a gateway to international technology markets, providing critical information on subjects such as patents, invention disclosures and technology offers.

1995: The Patents Bill came into force allowing the filing of patents in Singapore.

1996: The Singapore Institute of Standards and Industrial Research set up the National Patent Information Centre as a one-stop patent information resource centre to support R&D.

1996: The Centre for Signal Processing of the Nanyang Technological University was launched.

1996: The \$27-million, three-year Aerospace Technology Programme was launched to boost the capabilities of Singapore's aerospace industry and position as an aerospace hub.

1996: The second five-year National Science and Technology Plan was announced. The \$4-billion budget was double that of the first five-year plan.

1996: The Magnetics Technology Centre expanded the scope of its R&D efforts and was renamed the Data Storage Institute.

1996: The National Science and Technology Board launched the Innovation Centre to provide a supportive working environment for budding technopreneurs.



1996: Institute of Microelectronics initiated first Electronic Packaging Research Consortium, a resource and cost-sharing R&D platform.

1997: The Institute of Materials Research and Engineering was launched to focus on optoelectronics, nanomaterials, and polymers. Its director was Prof Shih Choon Fong.

1997: The Bioprocessing Technology Centre launched its Incubator Units to nurture biotechnology SMEs.

1998: The Institute of High Performance Computing was formed through the merger of the National Supercomputing Research Centre and the National University of Singapore's Centre for Computational Mechanics. The institute was positioned as a one-stop provider of large-scale, high performance computing resources and capabilities in computational science and engineering. Prof Lam Khin Yong was appointed its Executive Director.

1998: The Information Technology Institute and the R&D Group of the Institute of Systems Science was merged as Kent Ridge Digital Labs.

1998: The Centre for Drug Evaluation, a collaboration between the National Science and Technology Board and the Ministry of Health, was started to provide the expertise necessary for the testing of new drugs.

1998: Clinical trial centres such as the Cancer Therapeutics Research Group and the National University of Singapore Drug Study Centre to enhance the clinical trials infrastructure were set up.

1998: A Technology Incubator Programme was launched to provide a mentor system to guide high-tech start-ups in translating their innovation into commercially viable ventures.

1998: Deputy Prime Minister Dr Tony Tan announced plans to build a Science Hub in Buona Vista to be completed in five years.

1998: ITI Holdings Pte Ltd was renamed KRD Holdings Pte Ltd. It held all the shares in the various KRD spin-off companies.

1999: The National Science and Technology Board launched Technopreneurship 21 with a \$1 billion Technopreneurship Investment Fund to intensify Singapore's efforts in building a conducive environment to support start-up companies. The Technopreneurship 21 framework of education, financing, regulation and facilities was designed to reinforce, promote and sustain a culture of creativity and innovation. In 2001, Technopreneurship 21 was transferred to the Economic Development Board, and the Technopreneurship Investment Fund to grow venture capital funds was corporatised.

1999: The Genetic Modification Advisory Committee was set up under the Ministry of Trade and Industry to oversee and provide scientifically-sound advice on the R&D, production, release, use and handling of genetically modified organisms in Singapore.

2000: Launch of the Biomedical Sciences initiative to develop the Biomedical Sciences as a key pillar of the economy.

2000: Establishment of the Biomedical Sciences International Advisory Council chaired by Sir Richard Sykes. Its 12 members recommended the establishment of the Biomedical Research Council, Bioethics Committee and the Biomedical Sciences Investment Fund.

2000: Formation of the Biomedical Research Council; formation of Science and Engineering Research Council.

2000: The Institute of Molecular and Cell Biology was conferred the 5th Nikkei Asia Prize in the category of Technology Innovation for its work towards improving the quality of life in Asia through outstanding contribution to biotechnology and the institute's development into the first major centre of biological science research in Asia.

2000: The Ministerial Committee for the Life Sciences chaired by Dr Tony Tan, was established to oversee development of the biomedical sciences. Its Executive Committee was chaired by Philip Yeo.

2000: The Singapore Genomics Programme was

formed to bring together state-of-the-art technologies such as microarray, high throughput sequencing, and proteomics to identify novel genes and molecular targets in strategic diseases in Asia for diagnostic and therapeutic applications.

2000: The National Science and Technology Board and the Economic Development Board released their first joint survey on the venture capital community. By end-1999, Singapore was managing a total of \$10.2 billion in venture capital funds.

2000: A Bioethics Advisory Committee was appointed by the Cabinet to examine the legal, ethical and social issues arising from biomedical sciences research.

2000: The National Science and Technology Board and the Intellectual Property Office of Singapore jointly announced initiatives to build an intellectual property framework.

2000: The Science & Technology Plan 2005, covering the years 2000-2005 was unveiled. It had a \$6 billion budget.

2000: Singapore embarked on Phase 1 of the Biomedical sciences Initiative (2000-2005) which focused on building a strong foundation in basic biomedical research.

2001: In February, the Economic Development Board Chairman, Philip Yeo, took over as the Chairman of the National Science and Technology Board from Teo Ming Kian and concurrently became Co-Chairman of the Economic Development Board; Teo Ming Kian became the Chairman of the Economic Development Board and concurrently Co-Chairman of the National Science and Technology Board.

2001: The Bioinformatics Institute was formed to use computing systems in biomedical research. Dr Gunaretnam Rajagopal was its founding Director.

2001: The Singapore Genomics Programme was renamed the Genome Institute of Singapore to reflect its status as a research institute. Dr Edison Liu was its Executive Director.

2001: The first National Science Scholarships were given out by then Minister for Trade and Industry, BG George Yeo, at the Economic Development Board-National Science and Technology Board Scholarship Award Ceremony.

2002: The National Science and Technology Board was renamed A*STAR or Agency for Science, Technology and Research.

2002: Gintic Institute of Manufacturing Technology was renamed SIMTech or Singapore Institute of Manufacturing Technology.

2002: The Institute for Infocomm Research was formed by the merger of the Institute for Communication Research and the Laboratories for Information Technology. Its Executive Director was Prof Lawrence Wong Wai Choong.

2002: The Institute of Chemical and Engineering Sciences was formed to support Singapore's chemical, biomedical and process engineering industries, with Dr Keith Carpenter as its Director.

2002: Exploit Technologies Pte Ltd was formed to commercialise the outcome of A*STAR's research institutes and to consolidate the patent portfolio of these institutes under A*STAR's ownership.

2002: The A*STAR Graduate Academy was started to manage the A*STAR scholarships and talent development programme.

2002: The A*STAR Pre-Graduate Scholarship was launched to provide a headstart for undergraduates keen to pursue their PhD studies and embark on a research career. Awardees from the National University of Singapore and the Nanyang Technological University can look forward to attachments at A*STAR's Research Institutes and be part of its community of scientists and researchers.

2002: Muvee Technologies Pte Ltd was spun-off. It revolutionised the concept of PC video editing by radically simplifying the process and making it up to 1,000 times faster than any other technique. The technology, developed at the Kent Ridge Digital Labs, enables a user

to quickly transform raw footage into videos complete with music, effects and transitions.

2002: KRD Holdings Pte Ltd was brought under Exploit Technologies Pte Ltd as a wholly owned subsidiary and was rebranded ETPL Investments Pte Ltd. It holds the shares of A*STAR spin-off companies.

2003: The National Advisory Committee on Laboratory Animal Research was set up to develop national guidelines for the care and use of animals for scientific purposes.

2003: Biopolis, the biomedical sciences research and development hub comprising a seven-building complex, linked by skybridges, was officially opened.

2003: The Bioprocessing Technology Centre was renamed Bioprocessing Technology Institute with Dr Miranda Yap as its Director.

2003: The Bioprocessing Technology Institute's Biopharmaceutical Manufacturing Technology Centre was spun-off as A-Bio, a contract biologics manufacturer. A-Bio secured six major investments in its first three years to manufacture biologics for the global market.

2003: The Institute of Bioengineering and Nanotechnology was formed with Prof Jackie Ying as its Executive Director.

2003: Growing Enterprises with Technology Upgrade was launched. The four initiatives under it are: (a) The Technology for Enterprise Capability Upgrading scheme where researchers are seconded to SMEs for up to two years to provide them with R&D and technology expertise; (b) The Operation & Technology Roadmapping scheme where researchers work with SMEs to help them develop long-term plans to help its products or services meet the needs of businesses and markets; (c) The Technical Advisors Support scheme where researchers provide in-depth technical consultancy to SMEs on technology matters and business challenges; and (d) The Facility Sharing Programme where A*STAR provides SMEs with access to its world-class laboratories and facilities to help SMEs intensify their R&D activities.

2003: AGS (NUS/NTU) was launched as part of the A*STAR Graduate Scholarship. It funds PhD studies in Singapore at the National University of Singapore, Nanyang Technological University or A*STAR. Many AGS (NUS/NTU) scholars also receive the AGS Post-Doctoral Fellowship that supports two years of post-PhD experience at choice international labs.

2003: XID Technologies Pte Ltd was spun-off from the Institute for Infocomm Research. It commercialised a facial synthesis software solution that creates unique identification through face recognition.

2003: Veredus Laboratories Pte Ltd, a life sciences company, was spun-off. Its Lab-on-Chip technology integrates PCR and microarray, allowing simultaneous detection of multiple targets with high sensitivity and specificity for faster, more accurate early detection and diagnosis of diseases.

2003: Merlion Pharmaceuticals was spun-off from the Centre for Natural Products Research. The company provides access to one of the world's largest and most diverse natural product collections by offering sample/extract supply services, extract profiling and standardisation, assay development, high throughput screening, compound purification and structural identification, biocatalyst isolation and strain improvement.

2003: iDimension Systems Pte Ltd, an e-manufacturing solutions provider, signed a licensing agreement with Exploit Technologies to license the Gintic Scheduling Software developed by SIMTech. The technology is an advanced planning and scheduling software.

2003: iCognitive Pte Ltd, a provider of supply chain management consulting services, was spun off. The company obtained licenses of technologies developed by the Singapore Institute of Manufacturing Technology, namely the Supply Chain Information Portal (SCIPo) software and SIMForecaster technology to develop demand forecasting solutions.

2003: Molecular Connections (India), a dry lab solutions provider for drug discovery process

was established as a joint venture between Idea2solutions, India and the Institute for Infocomm Research. It uses the institute's text-mining technology for biomedical informatics to enable drug discovery companies to reduce the discovery cycle time and the resources spent on drug discovery.

2004: Formed in late 2004, the Singapore Bioimaging Consortium aims to serve as a focal point for stimulating, funding, coordinating and reporting on the various aspects of bioimaging activities. The consortium also creates a platform for multidisciplinary research for biologists, chemists, physicists, electrical/electronics engineers, computer scientists and clinicians to work together on strategic bioimaging projects.

2004: A PCR-based Malaria diagnostic kit jointly developed by the Institute of Molecular and Cell Biology and the National University of Singapore was licensed by Veredus laboratories.

2004: The Centre for Molecular Medicine was set up to bring advances in regenerative medicine, oncogenomics, immunology and epithelial biology to the clinic with part-time involvement of Dr Alan Colman as senior scientist.

2004: AGS (Overseas) Singapore was launched as part of the A*STAR Graduate Scholarship. It comprises two years of PhD studies at an A*STAR research institute and another two years at a select top overseas university. Mentored by a professor from the selected university and a senior member of an A*STAR research institute, successful students will be conferred a PhD degree by the university.

2004: BLC Solutions Pte Ltd, a home-grown company, was spun-off to commercialise the enterprise process-centric IT or Epcit software developed by the Singapore Institute of Manufacturing Technology. Now known as TrueOrders, the technology helps SMEs organise, plan and control the entire design-to-manufacturing process over the Internet.

2004: SiMEMS Pte Ltd, providing low cost, point of care diagnostic projects based on

chip platforms, was spun-off. It developed a system that accelerates DNA analysis.

2004: iDNA Biotech Pte Ltd was spun-off. The company develops, manufactures, markets and distributes innovative products and services in the areas of life sciences, biotechnology and laboratory medical diagnosis.

2005: Delta-Optics Pte Ltd was spun-off. It provides ultra-precision machining of optical mold inserts.

2005: Wholetree Technologies Pte Ltd, a company that specialises in multilingual and multimodal computing technology licensed the voice-enabling technology of the Institute for Infocomm Research.

2005: Using a blend of micro and nano-technology, Singular ID Pte Ltd, the Institute of Materials Research and Engineering's first spin-off, invented anti-counterfeit nano-sized tags containing unique "fingerprints" that help combat counterfeiting.

2006: The National Research Foundation was established by the Government to boost research in universities and nurture new strategic areas of economic development. The Research, Innovation and Enterprise Council, chaired by the Prime Minister, was convened.

2006: The 5-year, \$13.55 billion Science and Technology 2010 Plan was unveiled. The plan builds R&D capabilities with an emphasis on developing human capital, industrial capital and intellectual capital.

2006: Phase 2 of the Biomedical sciences Initiative (2006-2010) was launched, focusing on building up translational and clinical research capabilities while continuing to strengthen the foundation in basic research.

2006: The Singapore Stem Cell Consortium set up with Dr Alan Colman as Executive Director.

2006: The Experimental Therapeutics Centre was formed to incubate new technologies for commercialisation and mentor young scientists for careers in pharmaceutical and biotech

industries. Its promoter and founder was Prof David Lane.

2006: Biopolis Phase 2, comprising the Neuros and Immunos buildings, was completed. Its 37,000 sq m (400,000 sq ft) houses A*STAR biomedical research institutes as well as private research organisations.

2006: The Singapore Bioimaging Consortium, founded by Sir George Radda, was officially opened to identify and consolidate the various bioimaging capabilities across research institutes, universities and hospitals.

2006: The A*STAR Investigatorship was launched. This programme was designed to attract a small number of the most competitive international young scientists to Singapore as first-time group leaders.

2006: Nothacker Pte Ltd (now Aksaas Pte Ltd), a Singapore-based Software as a Service provider was spun-off. It uses the capabilities of the Institute for Infocomm Research to develop its software solutions.

2006: D-SIMLAB Technologies Pte Ltd was spun-off. Researchers from the Singapore Institute of Manufacturing Technology developed a simulation-based decision support software that analyses and predicts the performance of manufacturing or logistics network.

2007: The SERC Aerospace Programme, later rebranded as the A*STAR Aerospace Programme, was launched. The consortium was the first in the world to bring together Boeing, EADS, Pratt & Whitney, and Rolls-Royce as founding members and collaborators to chart R&D strategy in the aerospace industry.

2007: Lim Chuan Poh became Chairman of A*STAR.

2007: The Singapore Institute for Clinical Sciences was officially opened with Prof Judith Swain as the Executive Director. The institute serves the critical link between the biomedical research institutes in Biopolis and the translational, clinical and health-outcomes research in hospitals and medical schools.

2007: The Clinical Imaging Research Centre, a partnership between SBIC and NUHS, was set up.

2007: The Singapore International Graduate Award in partnership with National University of Singapore and Nanyang Technological University, was launched to attract international PhD students so as to build a robust and cosmopolitan research community and to better position Singapore as the destination of choice for graduate education and scientific careers.

2007: The Singapore Initiative in New Energy Technologies Centre was formed to focus on green energy research with an emphasis on marrying infocomms and energy. It was renamed the Experimental Power Grid Centre in 2009.

2007: A*STAR Joint Council was formed to generate interaction between the Biomedical Research Council and the Science and Engineering Research Council, and to use the capabilities of A*STAR to further encourage knowledge creation, innovation and opportunities for more industry collaboration.

2007: The A*STAR/Duke-NUS Graduate Medical School Neuroscience Research Partnership was established with the aim of capitalising on the complementary research strengths and resources available at A*STAR and Duke-NUS Graduate Medical School to promote an integrated, multidisciplinary programme in neuroscience with a strong focus on translational research. Its Chairman was Prof Colin Blakemore.

2007: The Institute of Medical Biology, formerly the Centre for Molecular Medicine, was opened with Prof Birgitte Lane as Executive Director. Its focus: to develop research on the mechanisms of human disease at the interface of Science and Medicine, focusing on stem cells, skin biology, cancer and genetic diseases.

2008: Singapore Immunology Network was launched to advance Human Immunology research with the aim of translating discoveries into useful clinical applications to combat major health problems. Researchers at Singapore

Immunology Network investigate immunity during infections and inflammatory conditions, including cancer. Its Chairman was Prof Philippe Kourilsky.

2008: The Singapore Translational Research Investigator Award (STaR) and the Clinician Scientist Award (CSA) were introduced to build up a talent pool to bridge the gap between basic research and clinical applications.

2008: Phase 1 Fusionopolis was opened. Integrating capabilities and facilities in the physical sciences and engineering, Phase 1 Fusionopolis covers 120,000 sq m (1.3 million sq ft) and costs S\$600 million to develop. The Institute for Infocomm Research, the Institute of High Performance Computing and part of the Data Storage Institute were already located there. They would be joined by corporate laboratories including Vestas, the world's leading wind turbine company; Ubisoft, one of Europe's largest game publishers; Linden Lab, the creator of Second Life; and Nitto Denko, a premier electronics and advanced materials company. The Advanced Digital Sciences Centre set up by the University of Illinois Urbana-Champaign would also be tenanted there.

2008: Precision Engineering Centre of Innovation, jointly established by A*STAR and SPRING Singapore, was officially launched to assist domestic PE SMEs adopt technology innovation as enablers of growth.

2008: A*STAR was the first Singapore public research agency to receive the 2009 Frost & Sullivan Asia Pacific Aerospace & Defence Award for Aerospace R&D Institution of the Year. This award recognised its outstanding contribution to Aerospace R&D in Asia-Pacific through the Science and Engineering Research Council's Aerospace Program.

2008: The A*STAR Research Attachment Programme was launched. It allows international PhD students from partner universities to spend up to two years in Singapore.

2008: The Singapore International Pre-Graduate Award was launched to support short-term research attachments for international

students at A*STAR. It provides a unique opportunity for top overseas students to work with distinguished and world-renowned researchers in A*STAR labs.

2008: A*STAR International Fellowship was launched to provide PhD graduates with two years of fully funded post-doctoral training at top overseas laboratories.

2008: The A*STAR Capabilities in Automotive Research Consortium was launched with Bosch, Dou Yee, Infineon and Th!nk Global to bring together automotive OEMs, suppliers and the R&D community to address key research areas in automotive technology.

2008: CurioX Pte Ltd was spun-off from the Institute of Bioengineering and Nanotechnology. The company enables the miniaturisation and automation of bioassays for the acceleration of research in life sciences, drug discovery, and diagnostics.

2008: MicroPoint Technologies Pte Ltd, a spin-off from the Institute of Materials Research and Engineering, signed an agreement with Exploit Technologies to commercialise a cost-effective microneedle technology which can be used in biomedical applications such as transdermal drug delivery, body fluid extraction and skin penetration detection.

2009: A*STAR and Singapore universities signed an MOU to create multiple career pathways in academia and research for young PhDs. Under the Joint Appointment Scheme (Research and Academic Dual Career Track), the Secondment Scheme (Academic Track) and the Adjunct Appointment Scheme, scholars who have completed their PhD education and who have a passion for teaching can further their careers at Nanyang Technological University or National University of Singapore.

2009: The Kilo Laboratory opened at Jurong Island. Under the Institute of Chemical and Engineering Sciences, it is the first research facility in Southeast Asia to develop techniques and solve the problems of scale-up and manufacturing for the pharmaceutical and specialty chemicals industry.

2009: A*STAR and the Economic Development Board launched the 3-Dimensional Through-Silicon Via Consortium to boost next-generation wafer manufacturing capability for Singapore's semiconductor industry.

2009: The MedTech Manufacturing Consortium, spearheaded by the Singapore Institute of Manufacturing Technology, was launched as a medical technology R&D platform for technology transfer and knowledge sharing.

2009: The National Science and Technology Awards were elevated to the President's Science and Technology Awards.

2009: Researchers from the Institute of Materials Research & Engineering developed a special barrier which protects sensitive devices like solar cells from moisture 1,000 times more effectively than any other technology. This was spun-off into Tera Barrier Films Pte Ltd.

2009: Signature Music Pte Ltd spun-off from the Institute for Infocomm Research. The company develops software that uses the Scratune technology which turns short spoken phrases into personalised music.

2009: A researcher from the Institute for Infocomm Research founded Niometrics Pte Ltd, a company that delivers tailored security and traffic analysis solutions. Its products and services support network traffic analysis with applications in enterprise network audit, policy enforcement, traffic management, and data leakage prevention.

2009: Knorex Pte Ltd was formed after it licensed a knowledge discovery software from the Institute for Infocomm Research designed to enable easy aggregation, mining, and integration of data from multiple platforms.

2009: A*STAR's Medical Technology Initiatives were launched to help Singapore become the leading generator of MedTech Innovators and Innovations in Asia.

2010: An MOU between A*STAR and the Centre of Integration of Medicine and Innovative

Technology, a consortium of Boston-based hospitals and engineering schools was signed as part of the broader Medical Technology Initiative. The A*STAR-CIMIT Collaboration enables engineers, clinicians and BMS scientists in Singapore to work with clinicians in Boston to find solutions that have clinical and market relevance.

2010: The Singapore-Stanford Biodesign Program was launched to nurture and train the next generation of Asian medical device innovators. The programme, modelled on the Stanford Biodesign Program, is a joint partnership between A*STAR, the Economic Development Board and Stanford University.

2010: The first Biomedical Engineering Programme grants were awarded to eight new projects helmed collaboratively by research engineers at A*STAR, clinicians in Singapore hospitals and researchers from the universities and hospitals. The grant funds projects that stem from a clinical need or problem identified by the clinical community and would lead to the development of cost-effective and relevant MedTech innovations.

2010: Four Centres of Innovation in Singapore polytechnics joined the GET-Up programme. These are the Food Innovation Resource Centre at Singapore Polytechnic, the Centre of Innovation for Electronics at Nanyang Polytechnic, and the Marine & Offshore Technology Centre of Excellence, and the Environment & Water Technology Centre at Ngee Ann Polytechnic.

2010: The launch of the Micro-Electro-Mechanical-Systems (MEMS) Consortium brought together eight MNCs and Singaporean enterprises from the MEMS supply chain in public-private sector research collaboration.

2010: Groundbreaking of the Experimental Power Grid Centre on Jurong Island. Working with the Economic Development Board, Energy Market Authority, JTC Corporation and the National Environment Agency, the centre aims to make Singapore a 'living laboratory' to develop and implement new energy technologies.

2010: Singapore's first nanotechnology consortium was launched by the Institute of Materials Research and Engineering and Institute of High Performance Computing, together with the Economic Development Board, International Enterprise Singapore and SPRING. The new Industrial Consortium On Nanoimprint would gain access to the advanced nanoimprint developments in A*STAR and work on joint, shared-cost projects, resulting in potentially huge savings in R&D costs and resources.

2010: A*STAR was ranked the seventh most prolific institution for the number of research papers published according to Nature Asia-Pacific Publishing Index. A*STAR was placed ahead of top universities in China and Australia in the number of research papers published in the Nature Publishing Group's portfolio of Nature-branded journals in 2009.

2010: The A*STAR Aerospace Programme Consortium launched in 2007 grew into an 18-member consortium with the addition of industry giants Bombardier, Bodycote, Rosler and Addvalue Technologies.

2010: Fusionopolis Phase 2B completed in October.

2010: The A*STAR Undergraduate Scholarship was launched to support individuals with a keen interest in research for a Bachelor's degree in science or engineering at Nanyang Technological University, National University of Singapore or the Singapore University of Technology and Design. Students can apply for the scholarship after 'A'-Levels, IB, National University of Singapore High School Diploma or during Year 2-4 in the universities.

2010: Prime Minister Lee Hsien Loong announced that the Government will invest \$16.1 billion in R&D under the Research, Innovation and Enterprise 2015 plan.

2010: The Biomedical Science EXCO established the BMS Industry Partnership Office, a one-stop shop for BMS companies that wish to engage multiple agencies in research collaborations.

2010: VeriStem Technologies licensed from Bioprocessing Technology Institute a

proprietary platform technology which caters to stem cell therapeutic companies concerned with ensuring that stem cell products are free from unwanted undifferentiated stem cells.

2010: Pfliq Pte Ltd spun-off utilising Snap2tell technologies developed at the Institute for Infocomm Research. The technology is an Image Recognition Engine that recognises scenes and objects and associates it with relevant information.

2010: iTwin Pte Ltd commercialised an innovative device that allows remote editing of any shared file from any location by connecting two computers through plugging one half of the device into each of the two computers. Once connected, each computer can then remotely access data from the other.

2010: XYZ Wave Pte Ltd developed gesture-based interaction solutions for the game industry based on technologies from the Institute for Infocomm Research.

2010: Sg Austria Pte Ltd, a life-science, service-based company supported by the Bioprocessing Technology Institute, commercialised a proprietary cell packaging material, Gel8, used for the Cell-in-a-Box™ technology, which is derived from a naturally occurring material.

2010: Clearbridge Vitalsigns Pte Ltd licensed technologies from A*STAR to develop a novel, ultra-low powered electrocardiogram chip, which is primarily used to monitor patients with heart problems.

2011: Biopolis Phase 3 completed in January.

2011: JTC Corporation commenced the development of Fusionopolis Phase 2A @ one-north. Phase 2A will include a business park, wet/dry laboratories and offices built on a 1.04 ha (2.5 acres) site with a gross floor area of about 84,000 sq m (904,168 sq ft).

2011: In March, JTC Corporation launched the site for Phase 3 of Fusionopolis for sale by public tender.

2011: A*STAR commemorates its 20th anniversary. 195

A
B
B
R
E
V
I
A
T
I
O
N
S

A*GA A*STAR Graduate Academy
AI A*STAR Investigatorship Awards
A*IF A*STAR International Fellowship
A*STAR Agency for Science, Technology and Research
A*STAR-CIMIT Centre for Integration of Medicine and Innovative Technology
ARAP A*STAR Research Attachment Programme
ARC Applied Research Corporation
BERD Business Expenditure on R&D
BII Bioinformatics Institute
BMRC Biomedical Research Council
BMS Biomedical sciences
BMS IAC Biomedical Sciences International Advisory Council
BMTC Bioprocessing Manufacturing Technology Centre
BTI Bioprocessing Technology Institute
CIM GINTIC Institute of Computer Integrated Manufacturing
CSP Centre for Signal Processing
CWC Centre for Wireless Communications
DSI Data Storage Institute
DSO Defence Science Organisation
EDB Economic Development Board
ETI Environment Technology Institute
GCCs Globally Competitive Companies
GERD Gross Expenditure of R&D
GET-Up Growing Enterprise Through Technology Upgrading
Gintic Gintic Institute of Manufacturing Technology
GINTIC Grumman International NTI CAD/CAM Centre
GIS Genome Institute of Singapore
I²R Institute for Infocomm Research
IBN Institute of Bioengineering and Nanotechnology
ICES Institute of Chemical and Engineering Sciences
ICR Institute of Communications Research
IMB Institute of Medical Biology
IMCB Institute of Molecular and Cell Biology
IME Institute of Microelectronics

IMRE Institute of Materials Research and Engineering
IMT Institute of Manufacturing Technology
INDRE National Institute of Epidemiological Diagnosis and Reference Extension
INL Institute of Neurology London
IRU Industrial Research Unit
ISS Institute of Systems Science
ITI Information Technology Institute
KSDL Kent Ridge Digital Labs
LIS Light Industries Services
LIT Laboratories for Information Technology
MedTech Medical Technology
MNCs Multinational Corporations
MOF Ministry of Finance
MTC Magnetics Technology Centre
MTI Ministry of Trade and Industry
NMRC National Medical Research Council
NBP National Biotechnology Programme
NSS National Science Scholarships
NSTB National Science and Technology Board
NTI Nanyang Technological Institute
NTRC Network Technology Research Centre
NTU Nanyang Technological University
NUS National University of Singapore
PAP Peoples' Action Party
R&D research and development
RISC Research Incentives Scheme for Companies
RSEs Research Scientists and Engineers
S&T science and technology
SERC Science and Engineering Research Council
SGP Singapore Genomics Programme
SIMTech Singapore Institute of Manufacturing Technology
SINGA Singapore International Graduate Award
SISIR Singapore Institute of Standards and Industrial Research
SMEs Small and Medium Enterprises
STaR Singapore Translational Research (STaR) Investigatorship Award
TCR Translational Clinical Research
T-Up Technology for Enterprise Capability Upgrading



Chan Chin Bok (lead author) **Heart Work: Stories of How EDB Steered the Singapore Economy from 1961 into the 21st Century.** Singapore, Singapore Economic Development Board and EDB Society, 2002.

Chew, Melanie and Tan, Bernard **Creating the Technology Edge: DSO National Laboratories, Singapore, 1972-2002.** Singapore, Epigram Pte Ltd, 2002.

Chiang, Mickey **From Economic Debacle to Economic Miracle: The History and Development of Technical Education Education in Singapore.** Singapore, Times Editions, 1998.

Fredberg, Tobias, Elmquist, Maria, and Ollila, Susanne **Managing Open Innovation: Present Findings and Future Directions.** Chalmers University of Technology. VINNOVA Report VR 2008:02 [Stockholm], VINNOVA - Verket för Innovationssystem/Swedish Governmental Agency for Innovation Systems, 2008.

Lee, Edwin and Tan Tai Yong **Beyond Degrees: The Making of the National University of Singapore.** Singapore, Singapore University Press, 1996.

Lim Swee Say and Chang, Ifay F. **National Computerization and Road Map to Information Technology Research and Development.** Paper prepared by Lim Swee Say (Information Technology Institute) and Ifay F. Chang (Institute of Systems Science) for Institute of Electronic Engineers publication, 1987.

Nature, 11 Aug 2005 **The tale of two tigers; An irresistible force**

New Scientist, 22 October 2005 **Asian star shoots for the moon**

Ngiam Tong Dow **A Mandarin and the Making of Public Policy: Reflections by Ngiam Tong Dow.** Introduced and edited by Simon C.S. Tay. Singapore, NUS Press, 2006.

Singapore, TTC Publications Board, 1969.

Quek Chwee Geok **A National Study of Scientific Talent Development in Singapore.** A dissertation presented to Faculty of the School of Education, College of William and Mary in partial fulfillment of the requirements for degree of Doctor of Philosophy. 2005.

Singapore. Agency for Science, Technology and Research **Annual report, 2001-**

Singapore. Dept of Statistics **Economic & Social Statistics Singapore 1960-1982.** Singapore, 1983.

Singapore. Government Gazette. Acts Supplement No. 1, 2 Jan 1991: The National Science and Technology Board Act 1990 (No. 24 of 1990). Singapore, Government Printers, 1991

Singapore Institute of Standards and Industrial Research **Annual report, 1973/74 - 1995/96**

Singapore. Ministry of Science and Technology Economics and Statistics Unit **Directory of Scientific and Technical Research and Consultancy Establishments in Singapore.** Singapore, 1971.

Singapore. Ministry of Trade and Industry **The Singapore Economy: New Directions. Report of the Economic Committee.** Singapore, 1986.

Singapore. National Science and Technology Board **National Survey of R&D in Singapore 1990 - Annual.**

Singapore. National Science and Technology Board. **Annual report, 1991 - 2001.**

Singapore National Academy of Science **Trends in Science Education, Proceedings of seminar.** Eds: Kuok, M.H. and Das, N.P. Singapore, 1989.

Singapore Science Council **Annual report 1967 - 1990**

Singapore Science Council
National Survey of R&D in Singapore 1978 - 1987. Triennial.

Singapore Science Council
Proposals for the Setting Up of a Scientific-Technical Information Centre in Singapore. Report by Dr H. Bauer. Singapore, 1969.

Singapore Science Council
Windows on the Future: A Status Report of the Singapore Science Park. Written by: Guo Yee Leng and Dr Mohand Narendran. Singapore, 1987.

Singapore Science Council
Who's Who in R&D in Singapore. Singapore, 1983.

Singapore Statutes
The Science Council of Singapore Act (Act 13 of 1967) and The Science Centre Act (Act 33 of 1970). Rev. ed. Vol. VIII

The Straits Times

Conference and Seminar Papers

INTERNET SOURCES
(Dates in brackets indicate when website was found.)

BioITWorld.com <<http://www.bio-itworld.com/2010/10/08/gsk-ace.html>> (20 May 2010)

Cyranoski, David. Singapore's salad days are over in Nature 468, 731, 9 Dec 2010; published online 8 Dec 2010 <<http://www.nature.com/nature/journal/v468/n7325/full/468731a.html>> (24 May 2011)

Darden, Lindley and Tabery, James. Molecular Biology in The Stanford Encyclopedia of Philosophy (Fall 2010 Edition), Edward N. Zalta (ed.). URL = <<http://plato.stanford.edu/archives/fall2010/entries/molecular-biology/>> (10 May 2011)

Boyer, Herbert /Genentech <http://library.thinkquest.org/24355/data/details/profiles/boyer.html> (2 May 2011)

Demand for partnering increases in high risk industry in partneringNEWS, March 2011 <<http://ebdgroup.com/partneringnews/2011/03/demand-for-partnering-increases-in-high-risk-industry/>> (24 May 2011)

Genentech Singapore: <http://www.pharmaceutical-technology.com/projects/lonza-singapore/> (15 May 2011)

Cheetham, Andrew
Growing a Research Culture. Address to Academic Senate of University of Western Australia. 2007. <www.uws.edu.au/_.../Item_3.6_Building_a_Research_Culture_Tabled_Doc.pdf> (20 May 2011)

Chesbrough, Henry. Everything You Need to Know About Open Innovation in Forbes, March 2011 <<http://blogs.forbes.com/henrychesbrough/2011/03/21/everything-you-need-to-know-about-open-innovation/>> (20 May 2011)

National Human Genome Research Institute <<http://www.genome.gov/10005139>> (7 May 2011)

National Library Board SearchPlus <nlbsearchplus.nlb.gov.sg> (1 April 2011)

National University of Singapore <http://www.nus.edu.sg/president/past_presidents/tohchinchye.php> (14 Jan 2011)

Ngee Ann Polytechnic <<http://www.np.edu.sg/ba/aboutus/Pages/history.aspx>> (21 Feb 2011)

OpenInnovation.eu <<http://www.openinnovation.eu/artikelen.php>> (20 May 2011)

INSEAD The Business School for the World with Confederation of Indian Industry Global Innovation Index <<http://www.globalinnovationindex.org/gii/main/GII2009-2010.cfm>> (17 May 2011)

Richardson, Mike. Covering all the Bases in Aerospace Manufacturing, March 2011. <<http://www.aero-mag.com/features/40/20113/840/>> (20 May 2011)

Sarewitz, Daniel. Science agencies must bite innovation bullet in the online Nature News, March 2011

<<http://www.nature.com/news/author/Daniel+Sarewitz/index.html>>

Sousa, Milton. Open innovation models and knowledge brokers. Case study. <www.openinnovation.eu/.../LowResIKMarch08Case%20Study.pdf> (19 May 2011)

White House Briefing with the Information Technology Industry Council on 30 March 2011 <<http://www.youtube.com/watch?v=bLvzB3asrzg>> (19 May 2011)

Yeo, Philip. Speech at OIST Symposium 2010 in YouTube <<http://www.youtube.com/watch?v=rQeiVP5LRrc&NR=1>>

INTERVIEWS IN 2011

Prof Hang Chang Chieh
Lim Chuan Poh, A*STAR Chairman, 2007-
Prof Low Teck Seng, A*STAR Managing Director
Philip Yeo, A*STAR Chairman, 2001-2007

EMAIL INTERVIEWS

Dr Horst Flotow, ETC
Dr Kripesh Vaidyanathan, IME
Dr Sebastian Maurer-Stroh, BII
Lam Chuan Leong, NSTB Chairman (1991-1993)
Prof Lam Kong Peng, BTI
Dr Randall Law Yaozhang, DSI
Dr Lim Sai Kiang, IMB
Dr Manfred Raida, ETC
Dr Laurent Renia, SITeN
Dr Fatida Rugrungruang, SIMTech
Dr Michael Sullivan, IHPC
Dr Uttam Surana, IMCB
Teo Ming Kian, NSTB Chairman (1993-2001)
Dr Peili Teo, ICES

ORAL HISTORY CENTRE INTERVIEW

Dr Lee Kum Tatt. Acc. No. A000821/10.
Interviewed by Dr Daniel Chew for Civil Servants Project in 1993

ACKNOWLEDGEMENTS

The production of this book is supported by the A*STAR 20th Anniversary Steering Committee and the Commemorative Publication Sub-Committee.

The A*STAR Commemorative Publication Sub-Committee wishes to acknowledge the contribution of the following individuals and organizations in the publication of this book:

Mr Lim Chuan Poh, Chairman A*STAR for his active support and guidance

Prof Hang Chang Chieh

Mr Lam Chuan Leong

Mr Teo Ming Kian

Mr Philip Yeo

Ministry of Information, Communication and the Arts
National Archives Singapore for photographs

National Library Board

National University of Singapore

Singapore Press Holdings for photographs

Steering Committee Chairman

Prof Low Teck Seng, Managing Director, A*STAR

Commemorative Publication Sub-committee Chairman

Mr Teoh Yong Sea, Deputy Managing Director,
Corporate Planning & Administration Division

Members

Mr Anand Raghavan, Deputy Director, Corporate Communications, SERC Shared Service

Mrs Tay-Png Hong Lan, Deputy Director, Special Projects, BMSI Business Centre

Mr Ho Cheng Huat, Executive Vice-President,
Exploit Technologies Pte Ltd

Dr Konstantinos Repanas, Project Manager, A*STAR Joint Council Office

Edward Manser, Principal Investigator, IMB and A*STAR Neuroscience Research Partnership

A*STAR Corporate Communications Department

Commemorative Publication Secretariat

Ms Choong Ket Che, Director

Ms Evelyn Ho, former Deputy Director

Ms Umadevi Kanagalingam, Assistant Head

Ms Loh Xiu Hui, Senior Officer, Book Project Coordinator

Mr Joshua Tan, Senior Officer

Production

Author: Lee Geok Boi

Research Associate: Erik Holmberg

Design: Relay Room (www.relayroom.com)

Produced by Landmark Books Pte Ltd

Printed by KHL Printing Pte Ltd