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DOCUMENTED
BRIEFING



Health and Medical Research in Singapore

Observatory on
Health Research Systems

Sonja Marjanovic, Siobhán Ní Chonail

Prepared for the Health Research and Development Policy Research Unit,
Department of Health (England)

The research described in this report was conducted with funding support from the Health Research and Development Policy Research Unit of the Department of Health (England).

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Preface

This documented briefing provides an overview of biomedical and health research in Singapore. The report is part of a series of country-specific reports available from RAND Europe's observatory on Health Research Systems, funded by the Department of Health (England).

First, this report will discuss the structure of the health research system in Singapore, presenting the funding sources, sectors performing biomedical and health research and development (R&D) and Singapore's health research priorities. Second, it will look at the processes and performance of the Singapore health research system, providing an overview of the types of funding packages available for building biomedical R&D capacity and competitiveness. It will discuss Singapore's science commercialisation and technology transfer initiatives, with some examples of the system's performance. Finally, this report considers some of the key topics related to the future of Singapore's health research system.

The report comprises a desk-based document review, complemented by three key informant interviews to help validate insights from the document reviews. The report does not attempt to discuss current policy options or make recommendations for future strategy. The report will be of interest to government officials dealing with health and medical research policy, medical research councils, health and medical research charities, public and private institutions engaged in health research and researchers.

All the financial figures in this report are given in Singapore dollars (SGD), unless stated otherwise.

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Contents

Preface.....	ii
Summary.....	iiv
Acknowledgements.....	vii
List of abbreviations.....	viii
Introduction.....	1
Structure of the Singapore health research system.....	2
Processes and performance of the Singapore health research system.....	24
Outlook.....	34
References.....	37

Summary

Summary: key points

- Singapore's goal is to develop the biomedical and health sciences sector as a key pillar of its economy
- Biomedical sciences sector employs more than 10,000 people and contributes 2.3% of GDP (2007)
- Biopolis is a flagship example of investment into building world-class research infrastructure
- 17% of total R&D expenditure is on biomedical sciences; 63% of health-related research is supported by public funders and 37% by the private sector (2007)
- Key R&D actors: public research institutes, universities, hospitals, consortia, public-private partnerships, pharmaceutical and biotech R&D units
- Health research priorities include chronic and infectious diseases, stem cells, regenerative medicine, medical technology and immunology

This report is a documented briefing of the health research system in Singapore. It provides an overview of how biomedical and health research is financed, the key research and development (R&D) actors, health research priorities and various aspects of process and performance, including the types of funding mechanisms used to build and sustain research competitiveness, science commercialisation and technology transfer efforts. In addition, the report addresses some topical issues related to the future of the health research system in Singapore.

Singapore is a small city-state with a population of 4.69 million (2009 estimate). It is a multi-party parliamentary republic with the prime minister as head of state. Singapore is a highly-developed free market economy with an open and corruption-free² environment. Singapore gained independence from Malaysia in 1965 amid concerns as to whether such a small country would be viable. The government addressed these concerns through strategies designed to diversify the economy and a carefully planned approach to economic development. As part of its economic plan, the Singapore government has sought to attract

² Transparency International ranks Singapore as fourth in the world in its annual Corruption Perceptions Index for 2008 (Transparency International, 2008).

foreign investment by providing access to appropriate land and infrastructure, as well as through tax incentives for businesses (particularly for R&D-intensive ones). A number of factors make Singapore an attractive centre for commerce and investment in knowledge-intensive sectors. These include: an excellent infrastructure and geographic position along major trade routes; close proximity to the largest Asian markets; openness to trade; high education standards; the prevalence of English speakers in addition to Mandarin; and government willingness to provide investment and other support for new business.

Between 2004 and 2007, Singapore's economy grew by an average of 7% annually (real gross domestic product (GDP) growth), although it fell in 2008 to 1.1% as a result of the global economic recession (Central Intelligence Agency, 2009). In response to growing competition for manufacturing business from its Asian neighbours, Singapore's government has focused increasingly on investments and strategies to develop Singapore into Asia's premier knowledge-based and high-tech economy. Within this agenda, building up a biomedical and health research hub has been a central concern. Health research priorities have been determined both according to public health needs and opportunities to contribute to the country's economic competitiveness.

Singapore's government has supported aggressive biomedical R&D infrastructure development, including Biopolis – a purpose-built biomedical research hub consisting of a seven-building complex linked by sky-bridges and covering more than 200,000 square meters, where scientists from the public and private sectors are co-located. Biopolis is located strategically, close to the National University of Singapore, National University Hospital and Institute of Molecular and Cell Biology. The research community at Biopolis is supported by state-of-the-art infrastructure and services catering to the R&D activities of all the institutes located there, as well as to education and training.

The health research system in Singapore is sustained by diverse funding sources across the public and private sectors. These include government agencies, charities and not-for profit foundations, local and international corporations, foreign governments and international organisations. Since 2006, investment in translational and clinical research in particular has become a priority for various national funding agencies. This includes the National Medical Research Council, National Research Foundation and the Biomedical Research Council of the Singapore Agency for Science, Technology and Research. In addition, the government has established a National Framework for Innovation and Enterprise to support and facilitate the growth of an innovation culture and conducive conditions for science commercialisation in Singapore.

Biomedical and health R&D actors in Singapore are equally diverse. Key public sector R&D actors are public research institutes, universities and hospitals. Consortia between various public institutions and public-private collaborations are encouraged by central government. Private sector R&D takes place in multinational pharmaceutical and biotechnology R&D units and in local biotechnology and medical technology small and medium-sized enterprises.

As a well-established and credible intellectual property environment with favourable business conditions (for the past three years, Singapore has been ranked as the best place in the world to do business by the World Bank; see World Bank Group, 2009), incentives such as low corporation tax, 10-year tax exemptions for strategic research in priority areas

and open immigration policies have all helped to attract a high number of foreign investors and multinational companies to the region.

Singapore's health research priorities include the disease-specific areas of R&D (i.e. cancer, eye diseases, neurological disorders, infectious diseases, metabolic disease such as diabetes), as well as functional research areas (i.e. stem cells, regenerative medicine, medical technology, immunology and others).

In terms of performance, Singapore's output in top medical journals is higher than that of most regional competitors, and publishing output has doubled in comparison to the 1990s (Sandström, 2009). The country's largest university, the National University of Singapore, was ranked 17th in the world for life sciences and biomedicine by the Times Higher Education Supplement – Quacquarelli Symonds (THES-QS) university rankings for 2008 (THES-QS, 2008).

One of the key issues facing the future of the health research system is how to attract, retain and grow a critical mass of biomedical and health researchers (including clinician scientists) in the country. Diverse non-competitive and competitive funding packages are available to help build biomedical R&D capacity (e.g. grants, scholarships, fellowships and strategic programmes). However, whether Singapore will achieve and sustain critical mass in the long term and effectively manage 'brain circulation', remains to be seen. Other important issues relate to: strengthening capacity in health policy research (for example, Singapore is disadvantaged by not having a public health graduate school); improving the e-health system; managing competitive threats from neighbours such as China; and building capacity to ensure a competitive niche in stem cell research and related product development.

Acknowledgements

We would like to thank Charlene Rohr and Jonathan Grant for their rigorous quality assurance of this report.

List of abbreviations

Abbreviation	Term
A*STAR	Agency for Science, Technology and Research
BMRC	Biomedical Research Council
BMSG	Biomedical Sciences Group
CREATE	Campus for Research Excellence and Technological Enterprise
EDB	Economic Development Board
EDBVM	EDVB Management Pte Ltd
ETC	Experimental Therapeutics Centre
GDP	Gross Domestic Product
GERD	Gross Domestic Expenditure on R&D
ILO	Industry Liaison Office
NHG	National Healthcare Group
NMRC	National Medical Research Council
NRF	National Research Foundation
NUS	National University of Singapore
R&D	Research and development
SGD	Singapore Dollar
SMEs	Small and medium-sized enterprises
SPRING	Standards, Productivity and Innovation Board
SSCC	Singapore Stem Cell Consortium
TCR	Translational and clinical research

Introduction

Health and Medical Research in Singapore

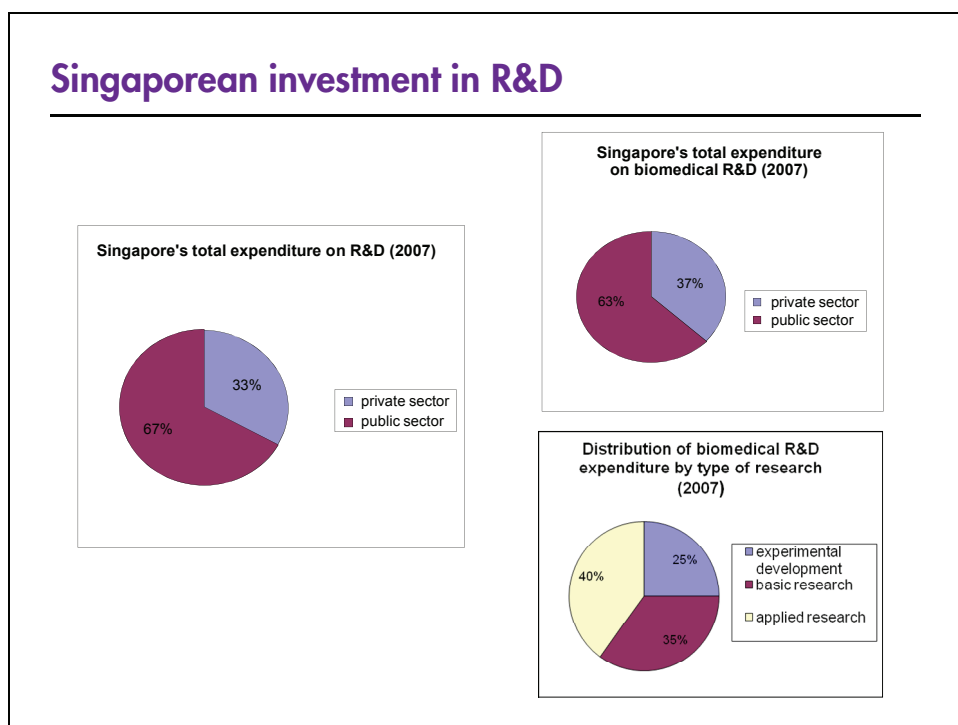


Observatory on Health Research Systems

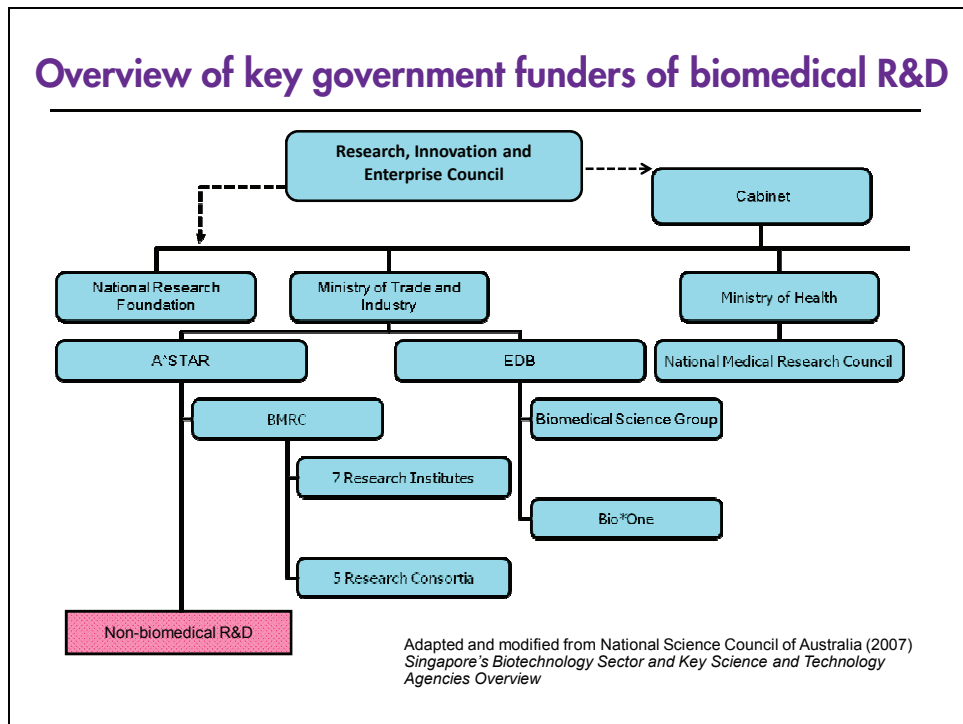
Singapore is a small and densely populated city-state which has witnessed a dramatic increase in wealth since it became an independent republic in the 1960s. Since that time, Singapore's prosperity has been attributed to successful strategic investment in building up chemical industries, electronic manufacturing, port activities and a strong financial services sector. Singapore's economy depends heavily on exports and refining imports, particularly in the context of manufacturing (i.e. electronics, petroleum refining, chemicals, mechanical engineering and biomedical sciences-related manufacturing). However, since 2000, cost competition in the manufacturing industries from regional neighbours offering cheaper labour (such as China) has led Singapore's government to focus increasingly on creating and strengthening competitiveness in knowledge-based industries. Biomedical and health R&D has been high on the list of priorities within this agenda.

This report provides an overview of the Singaporean biomedical and health research system. First, it discusses the major health-related research funders across the public and private sectors and their remits, key biomedical and health R&D players and national health research priorities. Second, the report presents an overview of how the R&D system carries out its activities, providing examples of the types of funding mechanisms available to build and nurture research capacity, discussing science commercialisation efforts and reflecting on some examples of the health research system's performance. Finally, the report concludes with a discussion of some enduring and emerging hot topics related to Singapore's health research system.

Structure of the Singapore health research system



Funding for health and medical research in Singapore comes from a number of sources across the public and private sector nationally, as well as from foreign-based companies, foreign governments and international organisations (Agency for Science, Technology and Research Singapore, 2007). According to 2007 data, annual expenditure on R&D across sectors amounted to SGD 6,339 million (2.61% of gross domestic product; GDP), of which 67% was public sector expenditure and 33% private sector expenditure (Agency for Science, Technology and Research Singapore, 2007). Singapore currently invests more than 2.5% of GDP in biosciences and total biomedical R&D expenditure has grown at an average annual rate of 38.2% (Sandström, 2009). Singapore's government aims to create Asia's leading biosciences hub across the entire value chain: basic, translational and clinical R&D, product and technology development, manufacturing and healthcare provision (Sandström, 2009). In 2007, 17% of total R&D expenditure was in biomedical sciences, of which 35% was on basic research, 40% on applied research and 25% on experimental development (Agency for Science, Technology and Research Singapore, 2007). Of the overall biomedical R&D expenditure (SGD 1077.63 million), 63% was from public funders and 37% came from the private sector. Since 2000, the government has invested more than SGD 5 billion in building industrial, human and intellectual capital for the biomedical sciences sector (Singapore Economic Development Board, 2009a). Biomedical and health R&D in Singapore is supported by government funding, charities and not-for-profit organisations, industry and international research organisations.



Major government funders of biomedical and health research in the country include: the National Medical Research Council (NMRC) of the Ministry of Health; the Biomedical Research Council (BMRC) of the Agency for Science, Technology and Research (A*STAR); the National Research Foundation (NRF); the Health Research Endowment Fund; the Singapore Economic Development Board (EDB); and Standards, Productivity and Innovation Board (SPRING) Enterprise Development Agency.

Various charities and not-for-profit foundations also provide funding and focus generally on specific diseases. Moreover, there is investment in biomedical R&D from industry (pharmaceutical and biotechnology firms), from private equity and international research organisations.

The Research, Innovation and Enterprise Council advises the government on national research, innovation and enterprise strategies. The council is chaired by the prime minister and comprises government ministers, prominent captains of industry and internationally renowned figures from the scientific and academic communities.

National Medical Research Council

- Established in 1994
- Total budget of SGD 1.55 billion
- SGD 204.61 million committed to strategic programmes, institutional block grants, competitive individual research grants, awards, scholarships and fellowships (2007)
- Since 2006, there has been an increased focus on translational and clinical research
- Distributes funds, facilitates research collaborations, builds human resource capacity, assists with science commercialisation

The **NMRC** of the Ministry of Health was established in 1994 to provide research funds to healthcare institutions, national disease centres and tertiary public educational institutions. To date, it has funded more than 1,100 individual research projects and 13 national research programmes. Steered by the Biomedical Sciences Initiative Executive Committee (and with a total budget of SGD 1.55 billion funding from the NRF, Ministry of Health and A*STAR), NMRC administers grant calls to help realise the goal of making Singapore an international centre of excellence for translational and clinical research (TCR). NMRC activities go beyond the distribution of funds to promoting and facilitating collaboration between diverse stakeholders in the medical sector, attracting and developing new researchers and assisting with the commercialisation of research findings. In 2006 the Ministry of Health introduced a new directive to support TCR, and NMRC has taken a lead role in funding research in these areas. In the 2007/2008 financial year, NMRC committed SGD 204.61 million to strategic programmes, institutional block grants, competitive individual research grants, awards, scholarships and fellowships (Ministry of Health, 2007a). NMRC administers Singapore's TCR Flagship Programme. With a budget of SGD 125 million over five years, the programme aims to help build up a critical mass of researchers in selected areas and to establish Singapore as a scientific leader in five disease-related areas: cancer, cardiovascular and metabolic research, neuroscience, infectious diseases and eye disease (Ministry of Health, 2007b).

Biomedical Research Council

- Established in 2000
- Supports, oversees and coordinates public sector biomedical R&D
- Promotes translational and interdisciplinary healthcare research
- Funds research staff, supports their training and professional development
- Supports seven public research institutes housed in the Biopolis, and consortia

The **BMRC** of A*STAR was established in 2000. It supports, oversees and coordinates public sector biomedical R&D, both basic and applied (Agency for Science, Technology and Research, 2009a). BMRC actively promotes translational medicine and cross-disciplinary research as part of its efforts to advance human healthcare (although the translational research environment in Singapore is still in its nascency). As part of this agenda, BMRC supports biomedical research in the wider scientific community, such as public universities and hospitals, funds research activities, engages in human capital development in the biomedical sciences and promotes societal awareness of biomedical research through outreach programmes. Seven research institutes are supported by BMRC (bioinformatics, bioprocessing, bioengineering and nanotechnology, genome research, medical biology, molecular and cell biology and clinical sciences). A biomedical sciences executive committee (co-chaired by the chairperson of A*STAR and the secretary of health) orchestrates funding from BMRC.

National Research Foundation

- Set up in 2006
- Oversees the implementation of Singapore's national R&D agenda and its strategic objectives
- Funds biomedical R&D, often administered via NMRC and BMRC
- Supports TCR Flagship Programme:
 - funded programmes in cancer; eye diseases; neuroscience; metabolic diseases; and infectious diseases
 - each programme received SGD 25 million over 5 years
- Oversees Singapore's Biomedical Sciences Initiative
- Other schemes: Competitive Research Programme Funding Scheme, Campus for Research Excellence and Technological Enterprise; Research Centres of Excellence
- Initiatives are designed to build a critical mass of researchers and research activity in the long term

The **NRF** was set up in 2006 as an official government department and oversees the implementation of Singapore's National R&D agenda and its strategic objectives (Government of Singapore, 2007a). It coordinates the research of different agencies within the larger national framework, implementing the strategies approved by the Research, Innovation and Enterprise Council. It also provides biomedical research funding, which often is managed and administered via NMRC and BMRC. Via the NMRC, NRF supports Singapore's TCR Flagship Programme. Five initiatives have been launched within this programme (each receiving SDG 25 million), which are consortia for research in: (i) gastric cancer; (ii) translational research innovations in ocular surgery; (iii) vulnerability, disease progression and treatment in schizophrenia and related psychoses; (iv) developmental pathways to metabolic diseases; and (v) scientific exploration, translational research, operational evaluation of disease prevention and preventive measures through new treatment strategies against Dengue fever.

In addition, NRF has established several initiatives and programmes to attract, develop and nurture a critical mass of researchers and research activity for the long term (although these programmes are not limited to biomedical R&D). These include: (i) the Competitive Research Programme Funding Scheme, which provides funding for high-impact research through periodic calls for proposals; (ii) the Campus for Research Excellence and Technological Enterprise (CREATE), which supports joint research programmes between international research universities and Singapore-based research institutions; and (iii) Research Centres of Excellence, which are long-term investments aimed at attracting world-class academic talent to Singapore in order to develop and build on research excellence in universities.

Economic Development Board

- Established in 1961
- Lead government agency that plans and executes economic strategies to enhance Singapore's position as a global hub for business, investment and talent
- Responsible for designing and delivering solutions that create value for investors and companies in Singapore
- It has a SGD 1.4 billion cluster development fund to invest in key clusters of technology
- Its Biomedical Sciences Group is responsible for the development of the biomedical sciences industry with a budget of SGD 2.1 billion

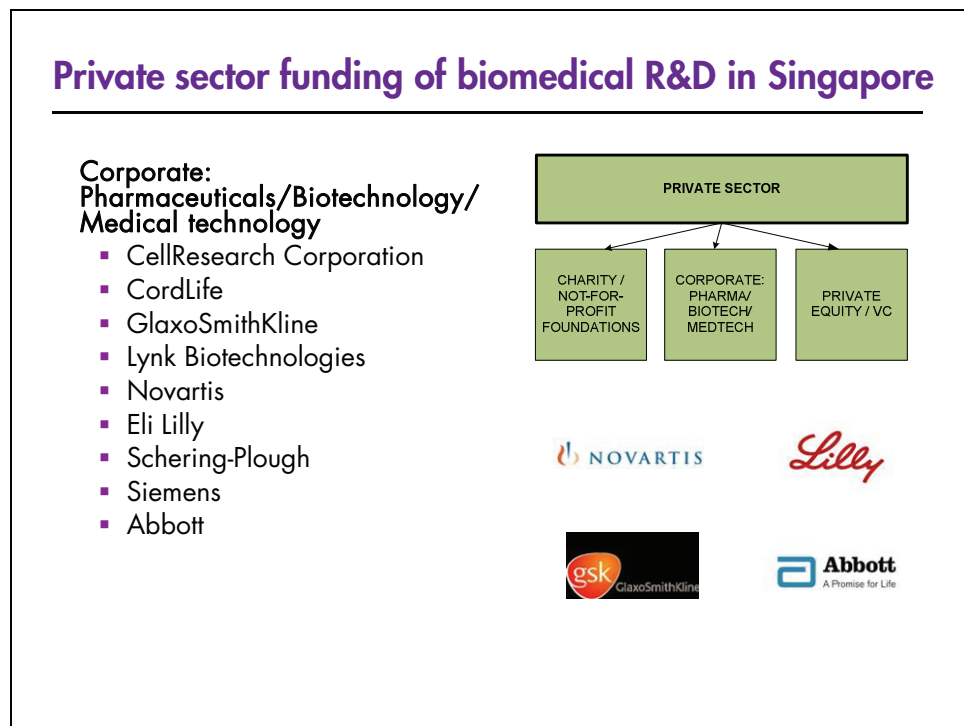
The **EDB** is the lead government agency for planning and executing strategies to enhance Singapore's position as a global business centre. It promotes private sector R&D by attracting multinationals to locate R&D centres and corporate R&D activities in Singapore. EDB works closely with corporate investors to create innovative solutions to meet their business needs, while constantly updating Singapore's long-term strategic plans in order to respond to changing business and industry environments. EDB has a SGD 1.4 billion cluster development fund to invest in key clusters of technology. The EDB Biomedical Sciences Group is responsible for development of the biomedical sciences industry, with a budget of SGD 2.1 billion for the period 2006–2010. EDB is responsible for bringing in investment and generating long-term economic value in the life sciences sector: this is done primarily through its Biomedical Sciences Group, and Bio*One Capital which functions as an investment arm. Together they work to attract companies to establish R&D operations in Singapore and develop the local manufacturing sector in the field.

SPRING Singapore

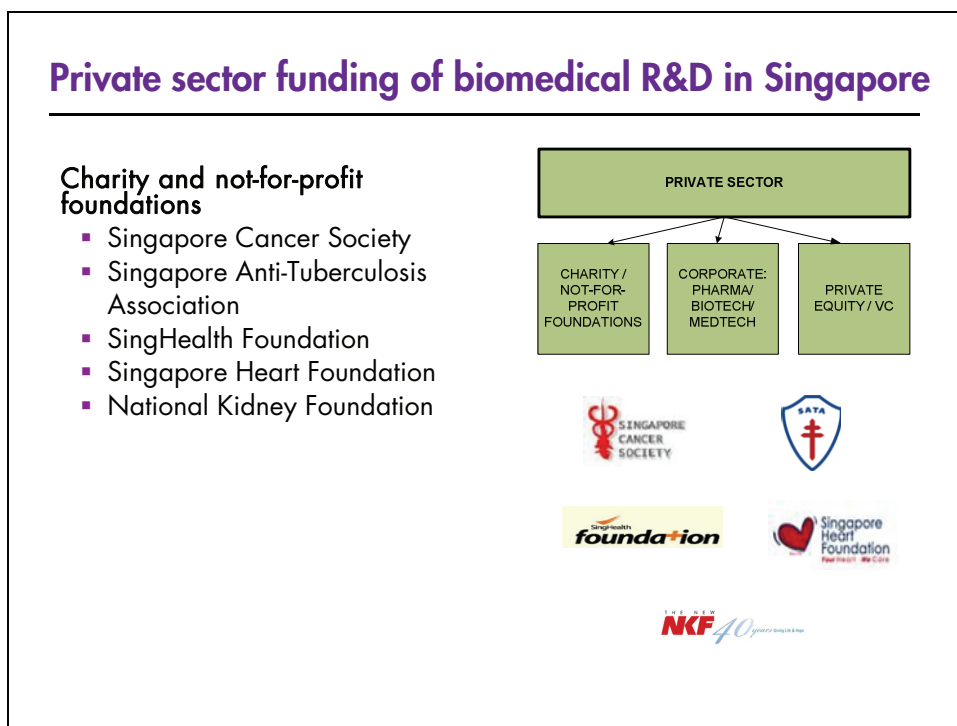
- Enterprise development agency
- Is a statutory board under the Ministry of Trade and Industry
- Dedicated to the promotion of Singapore's economic growth and productivity
- Works with partners to help companies raise finance (equity, loans)
- Is the national standards and accreditation body
- Runs the Technology Enterprise Commercialisation Scheme

SPRING Singapore is the government's main agency for enterprise development. It has three areas of focus: productivity and innovation, standards and quality, and small and medium-sized enterprises (SMEs) and the domestic sector. Although not dedicated exclusively to the biomedical and health sector, establishing companies in this sector is one of the agency's key priorities. SPRING works with partners to help companies raise finance and to access and build business development capabilities. SPRING provides a number of financing options, including: a business angels scheme; enterprise investment incentive scheme; the Start-up Enterprise Development Scheme; a young entrepreneurs' scheme for start-ups; and Deal Flow Connection, a service that matches entrepreneurs with funders. One of the flagship programmes is the Technology Enterprise Commercialisation Scheme, which helps enterprises to access grants to develop technology ideas at the conceptualisation stage and develop a working prototype. As the national standards and accreditation body, SPRING also develops and promotes internationally recognised standards and quality assurance in order to enhance competitiveness and facilitate trade.

Other notable sources of government funding include the Ministry of Health's Health Research Endowment Fund, which complements other sources of medical R&D funding currently available in Singapore. Members of the Fund are permitted to issue tax-deductible receipts for outright cash donations received in support of medical research. A new Ministry of Health funding stream (established 2009) is the Health Services Research Competitive Grant Scheme, which aims to promote health services research and the translation of findings into policy and practice.



The public sector has invested substantially to create in Singapore a global centre of excellence in biomedical research as well as an infrastructure that is attractive to industry. A number of foreign pharmaceutical and biotechnology companies have come to Singapore and are investing in health-related research (e.g. Novartis, Eli Lilly, Siemens, Abbott and others). In addition to life science companies, Siemens (in partnership with the National University of Singapore, NUS) has invested USD 2.5 million to create a clinical imaging research centre and provide grant support for translational medical research projects. Singapore's government has offered a number of incentives to foreign investors including low corporation tax, tax exemption for 10 years for projects of strategic importance and easy entry for foreign employees by means of open immigration policies. In addition, it has embarked on a programme to encourage working relationships between state agencies and universities (Green, 2007). At least 25 multinational life science companies have established R&D units in Singapore since 2000 (Sandström, 2009).

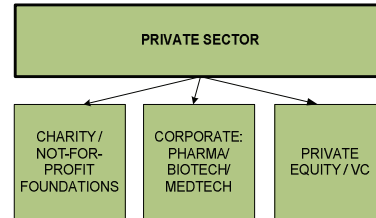


Biomedical and health research is financed by various national charities and philanthropic foundations. Generally, charities and not-for-profit foundations in Singapore tend to fund disease-specific research that is similar in priority areas to the funding provided through government sources. Some examples include: the Singapore Cancer Society; the Singapore Anti-Tuberculosis Association; the SingHealth Foundation; the Singapore Heart Foundation; and the National Kidney Foundation. The Singapore Cancer Society supports individual grants for cancer research. The Singapore Anti-Tuberculosis Association provides funding for research projects related to tuberculosis and lung health and disburses up to SGD 300,000 per financial year. The SingHealth Foundation funds research efforts to catalyse the bench-to-bedside progression of basic science discoveries, with a particular emphasis on cancer, diabetes, heart disease, neurological diseases and childhood disorders. In the 2007 financial year, the Foundation channelled SGD 10.05 million (30% of total SingHealth 2007 expenditure) into research. The Singapore Heart Foundation has funded research projects aimed at reducing disability and death from heart disease through understanding its nature and causes. Apart from assisting clinical research projects, this Foundation has supported community-based studies, and since 1999, it has funded 30 research projects. The National Kidney Foundation provides research grants in the area of kidney disease, with individual grants capped at SGD 300,000 for up to three years.

Private sector funding of biomedical R&D in Singapore

Private equity/venture capital

- Singapore Venture Capital & Private Equity Association
- Economic Development Board Investments Pte Ltd
 - Start-up Enterprise Development Scheme
 - EDBV Management Pte Ltd.
 - Bio*One Capital



Private equity and venture capital investors have a presence on the ground and fund companies in Singapore. In total, more than 150 venture capital companies have invested in Singapore's SMEs, many in the biomedical sciences (Sandström, 2009). The Singapore Venture Capital and Private Equity Association was formed in 1992 under the patronage of the EDB to promote and foster growth in the venture capital and private equity industry. Investments Pte Ltd is a wholly-owned investment arm of the EDB, which was established in 1991 for the purpose of equity investments. Through the cluster development fund, Investments Pte Ltd makes strategic direct investments into projects that expand Singapore's clusters of key industries in partnership with local and multinational companies. Investments Pte Ltd's portfolio of companies encompasses various industries, including biomedical sciences. In addition, there are three other investment groups within Investments Pte Ltd: the Start-up Enterprise Development Scheme, EDBV Management Pte Ltd (EDBVM) and Bio*One Capital. The Start-up Enterprise Development Scheme was set up to foster entrepreneurship and innovation activities in Singapore through matching financing. EDB matches the investments raised by start-up companies, taking an equity interest. EDBVM manages 10 venture capital and private equity investment funds exceeding USD 400 million, and has made more than 100 investments to date in Singapore and overseas. Bio*One Capital was established in 1990 as the private investment arm of the EDB and is dedicated to the biomedical sciences. It has nearly SGD 1.2 billion under management and key investments are in therapeutics, medical technology and healthcare services (Sandström, 2009).

International organisations

- American Association for Cancer Research (USA)
- Duke University (USA)
- Liggins Institute for Epigenetics (New Zealand)
- Ludwig Institute for Cancer Research (International)
- MERLION Programme (France and Singapore)



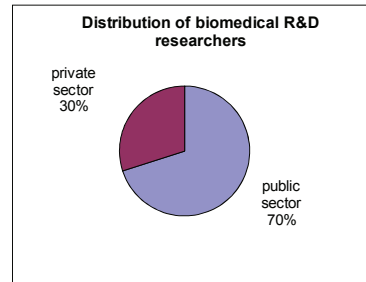
Singapore's researchers collaborate with those from overseas and have attracted funding from international research organisations which have established their presence in Singapore. Such organisations include: the American Association for Cancer Research; Duke University; the Liggins Institute for Epigenetics; and the Ludwig Institute for Cancer Research (Singapore Economic Development Board, 2009b).

Local companies and public sector researchers are working with international research institutes to develop new treatments for unmet healthcare needs. The MERLION Programme (SEA-EU-NET, 2009), an initiative of the French Embassy in Singapore, provides funding for collaborative research between Singaporean and French institutions across science and technology areas including biomedical R&D, and encourages the formation of Franco-Singaporean research laboratories. Funding is awarded for research efforts whose focus meets the scientific priorities of Singapore and France.

Biomedical R&D actors in Singapore

- Public research institutes
- Universities
- Hospitals/hospital groups
- Consortia
- Industry
 - pharmaceutical
 - biotechnology companies
 - contract research organisations
- Collaborations
 - public—private
 - international
- Regulatory bodies

Approximately 4,000
biomedical scientists in total



Source: Agency for Science, Technology and Research, Singapore (2007)

Organisations conducting biomedical and health research in Singapore span the public and private sectors. Most of the biomedical and health research takes place at public research institutes and specialist disease centres, universities and hospitals, but also increasingly in private settings. Singapore's government places strong emphasis on the importance of collaboration between clinicians and academics in translational research, between disciplines and between the public and private sectors. This is grounded in a broader vision of building a biomedical R&D sector that will strengthen Singapore's economic competitiveness and attractiveness as the regional destination of choice for modern, patient-centred healthcare services. Of approximately 4,000 research scientists and engineers employed in biomedical R&D in 2007, 70% worked for the public sector and 30% for the private sector (Agency for Science, Technology and Research Singapore, 2007). Approximately 46% of public sector scientists were educated to PhD or higher level and 27% were in the private sector.

Biomedical R&D actors in Singapore: Public

- Public research institutes
 - Bioinformatics Institute
 - Bioprocessing Technology Institute
 - Genome Institute of Singapore
 - Institute of Bioengineering and Nanotechnology
 - Institute for Medical Biology
 - Institute of Molecular and Cell Biology
 - Singapore Institute for Clinical Sciences
- Universities
 - National University of Singapore
 - Nanyang University
- Hospitals/hospital groups
- Consortia

Seven public research institutes are supported by the BMRC: Bioinformatics Institute; Bioprocessing Technology Institute; Genome Institute of Singapore; Institute of Bioengineering and Nanotechnology; Institute for Medical Biology; Institute of Molecular and Cell Biology; and Singapore Institute for Clinical Sciences. In addition, the BMRC has established five research consortia: Singapore Cancer Syndicate; Singapore Bioimaging Consortium; Singapore Stem Cell Consortium (SSCC); Singapore Immunology Network; and Singapore Consortium for Cohort Studies.

These biomedical research institutes are housed in the Biopolis and develop the knowledge and technologies needed to translate basic scientific discoveries from bench-to-bedside. (The Singapore Institute for Clinical Sciences will be training clinician scientists and act as a bridge linking basic research at A*STAR institutes with clinical programmes at hospitals and disease centres; Agency for Science, Technology and Research Singapore, 2009b.)

The largest of Singapore's two public universities – the NUS – hosts the Cancer Science Institute, which is supported and funded by the Ministry of Education and NRF. The university's Life Sciences Institute also tackles some of the major diseases relevant to the Singapore population (cancer, cardiovascular biology, infectious diseases, neurobiology and ageing) and collaborates with the faculties and schools of computing, engineering, medicine and science. A bioengineering division was established at NUS in 2001 (Sandström, 2009), which promotes interdisciplinary research. The second public university – Nanyang University – conducts biomedical R&D within its School of Biological Sciences, which encompasses a basic research centre (Biosciences Research Centre) and a translational and clinical research centre (Drug Discovery Centre). Major

biomedical research themes at Nanyang University include ageing, cancer, pathogenesis and drug discovery.

BMRC has established various consortia to coordinate and drive translational research in strategic thematic areas (Agency for Science, Technology and Research Singapore, 2009c). The consortia include the following: Singapore Cancer Syndicate; Singapore Bioimaging Consortium; SSCC; Singapore Immunology Network; Singapore Consortium for Cohort Studies; A*STAR–Duke University–NUS Graduate Medical School Neuroscience Research Partnership; and Experimental Therapeutics Centre (ETC; a member of the International Cancer Biomarker Consortium).

Research in Singapore's hospitals is primarily disease-specific. The largest healthcare group in the country is Singapore Health Services, which was established in 2000 as part of the restructuring of public healthcare clusters. Singapore Health Services consists of three hospitals, five national specialist centres and nine polyclinics. The strongest research areas within this group are oncology, ophthalmology, neurosciences and cardiology. The group is establishing new research initiatives in experimental medicine and molecular therapeutics, regenerative and advanced cell therapy, advanced bio-imaging, clinical trials and personalised medicine, in order to cut across the signature disease-specific programmes. Singapore Health Services is investing in improved translational research and clinical trials infrastructure (including through the Investigative Medicine Unit, SingHealth Tissue Repository and SingHealth Clinical Trials initiative). The group also has a centre for health services research. The centre handles three research streams: outcomes research, healthcare system design and health technology assessment studies.

The National Healthcare Group (NHG) is the second largest public healthcare group in the country. It was formed in 2000 and has three public hospitals, five specialist centres and eight polyclinics. The Group focuses on research which can enhance medical quality, that is aligned with national biomedical research priorities and is patient-centric. Funding opportunities for research in the Group are available internally and from external organisations (National Healthcare Group, 2009).

Biomedical R&D actors in Singapore: private

- Industry:
 - pharmaceutical companies include AstraZeneca, Aventis, Eli Lilly, GlaxoSmithKline, Merck & Co, Novartis, Novo Nordisk, Sanofi-Synthelabo and Schering-Plough;
 - more than 50 biotechnology companies carry out R&D activities in Singapore;
 - contract research organisations include Covance, Quintiles and ICON.
- Singapore is the secretariat for the Asia-Pacific Economic Cooperation Coordinating Centre for Good Clinical Practice
- Singapore is one of the world's leading manufacturing sites for research tools and diagnostics instruments

Singapore is the secretariat for the Asia-Pacific Economic Cooperation Coordinating Centre for Good Clinical Practice, which plays an important role in developing good clinical practice in Asia and creating an efficient operational, administrative and regulatory environment for multi-centre clinical trials in the region. This has attracted industry – and in particular global pharmaceutical companies – to establish regional clinical trial centres in Singapore in order to expand their outreach into Asian markets (e.g. AstraZeneca, Aventis, Eli Lilly, GlaxoSmithKline, Merck & Co, Novartis, Novo Nordisk, Sanofi-Synthelabo and Schering-Plough; Singapore Medicine, 2007). For example, the Novartis Institute for Tropical Diseases was established at the Biopolis; Eli Lilly has built a drug discovery research centre; Abbott has opened a new pharmaceutical R&D laboratory; and a number of biotechnology firms from abroad have set up shop in Singapore (e.g. the UK-owned Paradigm Therapeutics and various stem cell firms), in part due to liberal bioethical regulations. More than 50 biomedical sciences companies are carrying out R&D activities that include drug discovery, TCR and medical technology innovation. In medical technology, Singapore is one of the world's leading manufacturing sites for research tools and diagnostics instruments, supplying more than half of the world's micro-arrays and 50% of the global demand for polymerase chain reaction instruments (Singapore Economic Development Board, 2009b).

Several contract research organisations have established operations in Singapore to support the pharmaceutical firms' growing outsourcing needs. These include the global contract research organisations Covance, Quintiles and ICON. Singapore's pro-business environment allows operations to begin within a short lead-time. It takes 15 minutes to register a business online, three weeks to receive approval for clinical trials and 24 to 36 months for a manufacturing facility to be operational (Singapore Economic Development

Board, 2009b). Three of the best known Singaporean start-ups include: S*Bio (a joint venture between Chiron and Bio*One Capital), which is developing products for cancer and infectious diseases; MERLION, a drug discovery company; and ES Cell, a key player in the field of regenerative medicine.

According to the World Bank 2007 rankings, Singapore was rated as the best place in the world to do business (AsiaOne, 2007).

Biomedical R&D actors in Singapore: collaborations

- Collaborations between public and private R&D organisations are increasing
- Collaborations are encouraged by Singapore's government
- Public-private collaborations:
 - Lilly Singapore Centre for Drug Discovery, Singapore's National Neuroscience Institute, and the Singapore Institute for Clinical Sciences have collaborated on drug discovery using stem cells
- International collaborations:
 - Cancer Therapeutics Research Group – a multinational collaboration involving the National University Hospital, Singapore; Sydney Cancer Centre; Johns Hopkins Singapore; Chinese University of Hong Kong; National Cancer Centre, Singapore; Yonsei Cancer Centre, South Korea; and Sir Charles Gardner Hospital, Perth.

In the past few years, collaboration between public and private R&D organisations has been increasing and is encouraged by government. Within the Biopolis and Singapore's Biomedical Science Initiative, scientists in public research institutes and corporate laboratories have access to shared facilities. Recently, the Lilly Singapore Centre for Drug Discovery, Singapore's National Neuroscience Institute and the Singapore Institute for Clinical Sciences teamed up to advance drug discovery using stem cells. Moreover, international collaboration between Singapore's research institutes, university groups and foreign research organisations is on the rise, with some research organisations from abroad attracted to the region. One example of a multinational collaboration is the Cancer Therapeutics Research Group, which is a multi-institutional research partnership involving the following: National University Hospital–NUS; Sydney Cancer Centre–University of Sydney; Johns Hopkins Singapore–International Medical Centre, Chinese University of Hong Kong and National Cancer Centre, Singapore. Another example is Duke University–NUS Medical School.

Biomedical R&D actors in Singapore: regulatory bodies

Key regulatory bodies include:

- Singapore Bioethics Advisory Committee
- Genetic Modification Advisory Committee
- Health Sciences Authority
- Health Promotion Board

Key regulatory bodies in Singapore include the following:

- **Singapore Bioethics Advisory Committee** – this addresses the ethical, legal and social issues arising from biomedical sciences research in Singapore.
- **Genetic Modification Advisory Committee** – this oversees and provides advice on R&D, and the use and handling of genetically modified organisms in Singapore.
- **Health Sciences Authority** – this is a statutory board of the Ministry of Health with a remit to protect and advance national health and safety. The Authority serves as the national regulator for health products, ensuring that they meet safety, quality and efficacy standards.
- **Health Promotion Board** – this is the main driver for national health promotion and disease prevention programmes. Programmes implemented by the Board are designed to reach out to the population, tackling initiatives such as AIDS education, breast screening, smoking control and nutrition.

Singapore's national R&D agenda

Five strategic goals are:

- to intensify national R&D spending to achieve 3% of GDP by 2010
- to identify and invest in strategic areas of R&D
- to fund basic and applied research within strategic areas
- to provide resources and support to encourage private sector R&D
- to strengthen linkages between public and private sector R&D

Biomedical Sciences Initiative (BSI):

- launched in 2000
- aims to develop a biomedical R&D and manufacturing cluster
- three key agencies work closely to develop the BSI cluster:
 - Biomedical Research Council (BMRC)
 - Biomedical Sciences Group (BMSG)
 - Bio*One Capital

Between the 1960s and 2000, Singapore experienced rapid development with a twelfold surge in per-capita wealth. Economic growth was based primarily on manufacturing, electronics, chemicals, financial services and port activities. However, more recent competition from cheaper manufacturing regions (e.g. China) has forced Singapore to focus on building knowledge-based industries (Colman, 2008). Singapore established its first national R&D programme in 1979, and through time developed institutions such as A*STAR (in 1992) to support such activities. During the 1990s, Singapore identified biomedicine as an important focus for the future. The government's approach is to develop Singapore's life science R&D base for the study of diseases perceived as more prevalent throughout Asia, including related activities such as clinical trials and drug development, and services ranging from basic research to manufacturing. Policies that support innovation include: strong public investment in R&D; subsidies to encourage private investment; a strong commitment to training and education at all levels (including subsidised training schemes for employees and those seeking work); and support for the formation of clusters.

In 2006, the NRF identified three strategic areas of research in which to build up core capabilities: (i) the Biomedical Sciences Initiative (phase 2); (ii) environmental and water technologies, including clean energy; and (iii) interactive and digital media. All three areas were selected based on existing research strengths and anticipation of the potential for further R&D to contribute to building Singapore's knowledge-based economy and international competitiveness in science and innovation. The sectors aim to provide 86,000 jobs with value added of SGD 30 billion by 2015. A high-level steering committee and an executive committee, with representatives from public sector agencies, industry and

academia, has been formed for each of the strategic research programmes and is responsible for overseeing and coordinating activities (Government of Singapore, 2007b).

Singapore's national R&D agenda and key strategic objectives are to: intensify national R&D spending to achieve 3% of GDP by 2010; identify and invest in strategic areas of R&D; fund a balance of basic and applied research within strategic areas; provide resources and support to encourage private sector R&D; and strengthen linkages between public and private sector R&D (Government of Singapore, 2007c).

The Biomedical Sciences Initiative (BSI) was launched in 2000 to develop a biomedical R&D and manufacturing cluster. Three key agencies work in close coordination and in an integrated fashion to develop the BSI cluster: BMRC funds and supports public research initiatives; EDB Biomedical Sciences Group promotes private sector manufacturing and R&D activities; and Bio*One Capital functions as an investment arm.

The first phase of Singapore's biomedical sciences initiative (2000–2005) focused on establishing a foundation of basic biomedical research in Singapore. The second phase (2006–2010) intends to build on Singapore's existing basic research and drug discovery capabilities, the industry cluster and healthcare services' capacities to develop Singapore into "the best location in Asia for scientific proof of concept in man" (Government of Singapore, 2007b). It brings together academia, hospitals, research funding agencies, business development agencies and regulatory authorities.

National biomedical and health R&D priorities

Disease research:

- cancer
- cardiovascular disease
- neurobiology
- ageing
- eye diseases
- infectious diseases

Cross-cutting themes:

- medical technologies
- clinical trials
- immunology
- stem cell research
- regenerative medicine
- health services research

Priorities based on public health and economic considerations

Health research priorities in Singapore reflect efforts to balance public health needs with opportunities for commercial and economic competitiveness. There is a strong recognition of the potential for both medical and economic benefits from biomedical science R&D in the country. Health research priorities include chronic diseases which place a high burden on the Singaporean population, as well as infectious diseases common in the region. As illustrated in previous sections, funding has been channelled into research in cancer, cardiovascular disease, neurobiology and ageing, eye diseases and infectious diseases, but also into cross-cutting themes such as medical technologies, clinical trials, immunology, stem cell research, regenerative medicine, health service research and others.

Singapore has a reputation for possessing a well-established, modern and well-staffed healthcare infrastructure. Singapore was ranked first in Asia and sixth in the world for quality of healthcare by the World Health Organization (WHO, 2000), yet it spends fewer than 4% of GDP on healthcare.³ The public healthcare institutions in Singapore are wholly owned by the government but run as private companies (with management autonomy in decision-making). They receive government subsidies for service provision to patients and are subject to broad policy guidance through the Ministry of Health. Approximately 80% of secondary and tertiary care is provided through the public sector (Ministry of Health Holdings, 2009).

Although Singapore is considered to be a nation in good health by international standards, it remains exposed to a significant burden from many chronic diseases (e.g. cancer, coronary heart disease, stroke, pneumonia, diabetes, hypertension), many of which are linked to risk factors such as smoking, obesity, physical inactivity and alcohol

³ Singapore was ranked 6th out of 191 countries and top in Asia (WHO, 2000).

consumption. In 2006, cancer, cardiovascular diseases and stroke together accounted for approximately 60% of all deaths (Ministry of Health, 2007c). In addition, infectious diseases such as Dengue fever, influenza, respiratory syncytial virus, influenza, tuberculosis and malaria are a significant burden on the region (Thomson, 2007).

In 2006, the Ministry of Health updated its portfolio and formally incorporated clinical research as part of its mandate. Within this mandate, NMRC became committed to fund and promote “excellence in translational and clinical research, nurture a vibrant research community of clinicians and scientists in Singapore and enhance knowledge exchange to improve human health” (Ministry of Health, 2007d). The Ministry aims to increase the TCR capabilities of public hospitals, research institutions and medical researchers. Singapore has committed SGD 1.55 billion to drive TCR: as discussed in previous sections, the government’s TCR Flagship Programme has set up five strategic programmes in cancer, eye disease, neuroscience, infectious diseases and metabolism.

Stem cell research is a distinct area where Singapore hopes to establish a sustainable competitive advantage. The country comes from a good starting point – claiming recognition for the first human embryonic stem cells derived from five-day-old human blastocysts and successfully maintained in culture (Bongso et al., 1994). Singapore’s first stem cell company (ES Cell International) was established in 2000, and today more than 40 research groups in public settings are engaged in stem cell research at hospitals, universities and research institutes. Substantial government core funding, project and programme grants are available for stem cell research (Arnold, 2006). In addition, the SSCC (an initiative of A*STAR BMRC) was created in 2005, with the aim of establishing a coordinated and focused translational research and development programme in stem cells. The Consortium supports intramural research within the Institute of Medical Biology. Singapore has a fairly relaxed political and legislative stance towards stem cell research (it abides by the 2002 guidelines drafted by the Bioethics Advisory Committee and is modelled on the UK legislation). In Singapore, stem cells can be taken from discarded embryos or aborted foetuses and the embryos can be cloned and kept for two weeks to produce stem cells. Another of Singapore’s ambitions is to manufacture cell-based therapies for heart failure, eye diseases, diabetes and others, and to act as a hub providing patients with stem cell-based therapies. However, significant challenges remain before stem cells can become viable clinical products (Arnold, 2006).

In more recent years, the Singapore government has placed greater emphasis on improving its health services research capacity. Through some recent initiatives, it is trying to promote the role of health services research in health policy planning and implementation, and to encourage the use of health services research in the translation of scientific knowledge into clinical practice. As discussed previously, in 2009 the Ministry of Health launched the Health Services Research Competitive Grant Scheme (Ministry of Health, 2007e), which provides a new source of funding for principal investigators and other researchers wishing to engage in health services research. Smaller projects can receive up to SGD 200,000, while larger intervention effectiveness-focused projects can bid for up to SGD 1 million. Health services research is conducted in both academic and hospital settings: for example, the Singapore Health Services group of care providers hosts the Centre for Health Services Research.

Processes and performance of the Singapore health research system

Research capacity building: types of funding packages

- Non-competitive:
 - institutional block grants
 - enabling block grants
- Competitive:
 - programme grants
 - project grants
 - individual training scholarships, fellowships
 - investigator awards
 - clinician scientist awards
- Loans and equity investments for R&D in small and medium-sized enterprises

Attracting and retaining foreign expertise and nurturing and retaining home-grown talent is central to Singapore's strategies to build a biomedical and health R&D hub. Funding packages available through various sources include support for research, infrastructure and training. The overall purpose is to create a local environment with optimal conditions for biomedical R&D and investment in human capital development and empowerment. This is pursued through a combination of non-competitive development funding grants, competitive programme and project grants, investigator awards in recognition of research excellence, scholarships and fellowships as well as investment in R&D in the private sector.

NMRC provides funding in three main ways: institutional block grants, competitive research grants and fellowship awards. According to 2006 data, SGD 63.5 million has been committed to biomedical and health R&D. Non-competitive block grants aim to help develop a critical mass of researchers, research capabilities, physical infrastructure and pump-prime research activity, so as to enable institutions to build critical mass to bid for competitive grants. In 2006, block grants supported 23 institutions. There are two types of block grants: institutional and enabling. Institutional block grants are awarded to restructured hospitals and public research institutions in order to enable core expertise and research capabilities to be built. Enabling block grants are given to institutions to build up

research capabilities and nurture a research culture for clinical trials support and pilot studies. The NMRC also runs a competitive exploratory and developmental grant programme to encourage researchers to conduct exploratory research and to develop subsequently larger research grant proposals and bid for individual research grants. Competitive individual research grants are provided to researchers for studies on a specifically defined clinical and translational research topic, within a limited time period (three years) at a local public institution. The grants are awarded based on the scientific merits of the projects. Furthermore, there are a range of talent development awards, fellowships and scholarships funded via NMRC (e.g. the STaR Investigator Award). In addition, a clinician scientist award was introduced in 2007 to fund 35 new clinician scientists in the period 2007–2010. The objective of the award is to provide salary and funding support for selected clinician scientists, to enable them to carry out internationally competitive TCR. NMRC research training fellowships are awarded to clinicians for overseas research training or to pursue a PhD at local institutions to become clinician scientists. More than 70 fellowships have been awarded to date. Joint NRF–Ministry of Health research scholarships are administered via the NMRC in order to train medical specialist trainees to pursue clinician scientist careers.

BMRC provides funding through various research grants, investigatorships and research programmes. BMRC research grants focus on activities which can contribute to Singapore becoming an international hub of excellence in biomedical R&D, and often are awarded in collaboration with NMRC and NRF. A*STAR investigatorships promote the early career development of the next generation of scientific research leaders. They provide funding for an independent position at one of A*STAR's biomedical research institutes and cover remuneration, support for set-up costs, research funding, research staff and enable access to scientific equipment and facilities, including the Biopolis shared facilities and Biological Resource Centre. Through the BMRC, there is symposia sponsorship support available for organising scientific seminars and conferences, and for raising social awareness of biomedical sciences in Singapore.

As discussed previously, NRF provides funding via the TCR Flagship Programme to help build up critical mass of excellent researchers in selected areas, and establish Singapore as a leader in five disease-orientated areas. Another NRF scheme is the Competitive Research Programme Funding Scheme. This complements other strategic research programmes by funding a broad base of ideas to help identify new potential strategic areas in which Singapore can invest to develop core capabilities for new industries of the future. Each award is for a maximum of SGD 10 million per programme over three to five years. The programme is open to both public and private sector organisations and aims to encourage collaboration and partnerships between academia and industry. The scheme involves two types of calls for proposals: general and scenario-based. The general call allows the principal investigators to pursue new areas of research with potential economic and societal benefits for Singapore. In scenario-based calls, NRF articulates a future scenario that presents either a major challenge or opportunity for Singapore, and the research community is invited to submit proposals for research programmes that address the scientific and technological challenges presented by a given scenario. The NRF also offers research fellowships to attract, recruit and grow young scientists and researchers to conduct independent research in Singapore. The fellowship programme is a key initiative in the

government's effort to develop and nurture R&D talent and build R&D capacity in Singapore.

The SPRING Singapore Agency brokers access to loans, grants and equity investments for SMEs, including those conducting biomedical R&D. For example, via the business angels and enterprise investments schemes, young start-ups can access matched funding from SPRING for every dollar invested by external funders (within a capped amount). Its young entrepreneurs' scheme provides up to SGD 50,000 to individuals under the age of 26 to start up innovative business (although this is not earmarked exclusively for biomedical R&D). In addition, various loan programmes offering between SGD 100,000 and SGD 5 million are available for enterprise. 'Over-the-counter' capital of up to SGD 5 million is offered for enterprises in return for shares in the alternative investment market.

Hospital groups in Singapore provide some internal funding. For example, the NHG provides intramural grants ranging from studentship grants for early research training through to funded time for mid-career senior investigators to conduct research and internal research grants. Extramural support is available through the previously described public funding sources.

Charities and other not-for-profit research foundations offer research grants through competitive bidding processes.

In addition, funding in Singapore is awarded through peer-review processes. Peer review is conducted by expert panels which often consist of both local and international experts. NMRC revamped its peer-review system in 2007 to ensure greater consistency, transparency, fairness and rigour in scoring applications. Across government and private funding bodies, peer-review processes are often two-staged. In some cases, a local peer-review panel reviews submissions for funding (although this panel usually includes locally-based but internationally recruited experts), then locally reviewed and shortlisted submissions are sent to international peer-review panels (e.g. as is the case for NRF competitive research programme scenario grant calls). In other cases, the process occurs in reverse order (e.g. NMRC individual research grants). In some circumstances, only a local review panel is used (e.g. a local 30 to 35-member scientific panel assesses exploratory and developmental grant bids for NMRC).

Science commercialisation

- Intellectual property policy harmonised with international standards
- Singapore ranked second globally in intellectual property protection
- Exploit Technologies is the main science commercialisation body
- National Framework for Innovation and Enterprise:
 - supports technology transfer and R&D commercialisation;
 - allocates SGD 350 million over five years (2008–2012) to fund initiatives that enable technology transfer and the exploitation of intellectual property;
 - establishes support for entrepreneurship in universities;
 - creates enterprise support structures;
 - enhances technology transfer;
 - supports innovation policy studies.

Consistent with Singapore's strategic investments in biomedical R&D has been an effort to create intellectual property policies and a technology transfer infrastructure to enable the economic benefits of R&D to be harnessed.

In order to strike a balance between the protection of rights for owners of intellectual property and increased public access to it, Singapore has harmonised its intellectual property and copyright laws with global laws (e.g. WHO Trade-Related Intellectual Property Agreement (TRIPS) and the Berne Convention 1886 and Paris Convention 1883). This is meant to alleviate the concerns of any international investors who are participating or considering engaging in local R&D activities, investment and collaboration. Singapore was ranked second in the world in terms of intellectual property protection by the World Economic Forum and the International Institute for Management Development in 2009 (Singapore Economic Development Board, 2009c).

Exploit Technologies is the main technology transfer and science commercialisation body in the country. It is the intellectual property management division of A*STAR and manages all intellectual property generated by A*STAR institutes. Its key functions include evaluating technology disclosures, preparing and administering patent applications and maintaining granted patents, all with the common objective of obtaining a patent portfolio which can be licensed. Currently Exploit Technologies manages more than 2,000 active applications and patents, licensing deals and spin-offs. Because A*STAR institutes are publicly funded, usually the licence of intellectual property to industry is tied to fee and royalty payments. A*STAR owns the intellectual property created by employees of A*STAR (Exploit Technologies, 2007).

NMRC has a somewhat different intellectual property policy. In the first instance, all intellectual property rights resulting from any research project funded by NMRC are owned by the host institution. If the intellectual property is commercially exploited, NMRC has rights to 50% of the net profits derived from commercial exploitation.

Universities and hospital groups tend to have their own technology transfer activity (sometimes through divisions called research development and industry liaison offices), and on an externally-sponsored research basis, respect and adhere to the principles of their funders. For example, the National University of Singapore Industry Liaison Office (ILO) is a key element of the university's effort to engage with industry (National University of Singapore, 2005). The office promotes industry collaboration, technology transfer and commercialisation of the university's intellectual assets and expertise. Nanyang University also has its own technology transfer office. In general, rights to intellectual property created by the staff and students of universities in Singapore are owned by the university. The Singapore Health Services group of healthcare providers exploits intellectual property via the Office of Research, where the SingHealth Intellectual Property Unit oversees the protection and commercialisation of SingHealth-affiliated institutions' intellectual property assets.

In an effort to coordinate the technology transfer and science commercialisation activities of various organisations, the Technology Transfer Network – a collaborative alliance of technology transfer organisations in the country – was formed in 2008 to increase effectiveness in transfer to the industry. The core activities of the national network include: intellectual property cluster mapping; training and certification of technology transfer professionals; marketing; commercialisation advisory services; brokering of networks and collaborations with industry; and engagement in sharing good science commercialisation practices.

National Framework for Innovation and Enterprise Initiatives

- Establishment of University Enterprise Boards
- Innovation funds to promote commercialisation of university technologies
- Proof-of-concept grants for researchers
- Co-funding for companies accepted into technology incubators
- NRF will match funds raised by venture capital firms
- Technology incubation scheme
- Translational R&D grants for polytechnics
- Promoting national intellectual property principles for publicly-funded R&D
- Innovation vouchers scheme for small and medium-sized enterprises to procure R&D
- Industry proof-of-concept and technology incubation scheme
- A national innovation policy centre

In March 2008, NRF introduced the National Framework for Innovation and Enterprise. The framework puts a structure in place to support technology transfer and R&D commercialisation. A sum of SGD 350 million over five years (2008–2012) is allocated to fund the initiatives under the framework, which include various national schemes to enable technology transfer and the exploitation of intellectual property. For example, via a proof-of-concept grant scheme, SGD 75 million has been allocated to researchers to enable them to demonstrate the commercial feasibility of their ideas. A parallel SPRING Singapore scheme has supported 17 projects in private companies. In addition, NRF has facilitated the establishment of the Early Stage Venture Fund scheme, which provides seed capital. Moreover, a SGD 10 million Disruptive Innovation Incubator Fund has been established to select promising companies with disruptive innovation characteristics and provide them with funding and mentoring support. A sum of SGD 50 million has been allocated to support a university innovation fund to fund entrepreneurship education, technology incubators, entrepreneurs-in-residence and to promote commercialisation of university technologies. In addition, a National Framework for Intellectual Property Policies has been developed to facilitate a speedier technology transfer process from academic to private sector institutions, and to help promote indigenous innovation (Government of Singapore, 2007d).

Performance of biomedical and health R&D in Singapore

- National University of Singapore ranked 17th in world by THES-QS university rankings for life sciences and biomedicine (2008)
- A*STAR biomedical research units produced 392 publications
- 3,164 full-time equivalent researchers were employed in the biomedical R&D sector in 2007
- 42 patents applied for by the private sector in 2007
- SGD 420,000 from life science-related patents in 2007
- SGD 210,000 from biomedical manufacturing patents

To our knowledge, there is no integrated publicly available source of evidence on how Singapore's biomedical and health R&D funding agencies monitor and review the performance of their programmes, or of the projects that they fund. Most government and national agencies report on annual spending and sometimes provide highlights and case-vignettes of successful projects.

According to THES-QS 2008 global university rankings for the life sciences and biomedicine, the National University of Singapore ranked 17th in the world (THES-QS, 2008). The ranking is a composite indicator drawing on peer review, employer review, international staff, international students, staff/student ratio and citations per faculty. Across sectors, Singapore Gross Domestic Expenditure on R&D (GERD) was 2.61% of GDP in 2007. The country had 104 researchers per 10,000 labour force, with 1,739 patent applications and 941 patents awarded in the same year. A*STAR biomedical research units produced 392 publications (Singapore Economic Development Board, 2009c).

Research highlights in Singapore, 2008

- Development of a monoclonal antibody that targets undifferentiated human embryonic stem cells
- New pharmacological approach to killing colon cancer cells
- Established a link between the disruption of RUNX3 gene and colon cancer
- A Singapore publication named by Sciencewatch.com as one of the top three papers in the past decade

As reported by the EDB, some of the biomedical R&D highlights for 2008 (Singapore Economic Development Board, 2009a) include the following.

- Bioprocessing Technology Institute researchers developed a monoclonal antibody that targets undifferentiated human embryonic stem cells and causes them to undergo induced cell death.
- Genome Institute of Singapore researchers, along with the University of California–San Francisco, collaborated in developing a novel pharmacological approach to killing colon cancer cells. The results of the research were published in the journal *Cancer Cell* (Jiang et al., 2008). The Institute team is working with other local institutes to develop drug candidates based on the technology.
- The Institute of Cell and Molecular Biology and Yong Loo Lin School of Medicine at the National University of Singapore, led by the Institute, established the link between the disruption of RUNX3 gene and colon cancer. These findings are important for further research to inform the early detection and therapy of colon cancer. The results of the research were published in the journal *Cancer Cell* (Ito et al., 2008).
- Sciencewatch.com, a comprehensive web resource for tracking trends and research performance, has named a publication on mesoporous materials by Singapore researchers as one of the top-three papers in the past 10 years. The paper (Ying et al., 1999) has received 971 citations.

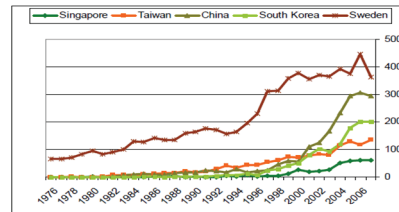
According to the National Survey of R&D in Singapore (Agency for Science, Technology and Research Singapore, 2007), 3,164 full-time equivalent researchers were employed in the biomedical R&D sector (this covers basic medicine, biological sciences, clinical

medicine, health sciences, pharmaceutical services and manufacturing and other related biomedical sciences). Of these, 1039.8 full-time equivalents were working in the private sector (local SMEs, large enterprises and foreign companies) and the rest in the government sector, higher education sector and public research institutes. Within the private sector, in 2007 42 patents were applied for, 13 were awarded and 90 were owned by local SMEs, local large enterprises and foreign companies with a presence in Singapore. In addition, 64 biomedical manufacturing-related patents were applied for, nine were awarded and 26 were owned. Licensing revenue amounted to SGD 210,000 from biomedical manufacturing patents in 2007 and SGD 0.42 million from life science-related patents and associated new technologies.

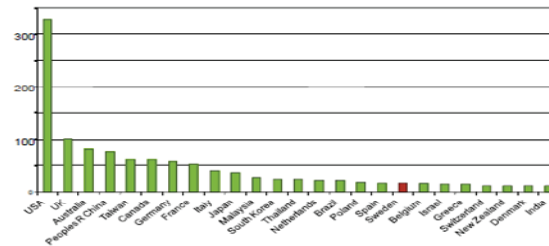
Scientific output

- More than 350 articles in top medical journals in 2006
- Doubled scientific annual output compared to before the 1990s
- Active in international co-publishing

Development of the number of articles by researchers in Singapore, Taiwan, China, South Korea and Sweden in non review top medical journals



Country collaboration with Singapore non-review medical journals with impact factor > 6 for 1991-2006



Source: Sandström (2009)

According to a recent report by Sandström (2009), Singapore's output of medical journals is above most of its regional competitors, and considering its size, Singapore also performs well in an international context. Scientific output of articles in top medical journals has increased substantially since before the 1990s. In 2007, there were more than 600 clinical research publications from Singapore, with A*STAR biomedical research units contributing 370 journal publications. Singapore's scientists are active in international co-publishing, with the USA topping the collaborator list. Alongside the seven public sector biomedical sciences research institutes and world-class hospitals, 50 companies from the USA, Europe, Japan, Korea and other parts of Asia are carrying out R&D that straddles drug discovery, translational research and medical technology innovation. Today there are more than 2,000 international researchers in Singapore.

Outlook

As with all countries, there are some issues which are particularly important for Singapore to address regarding its health research system. These are highlighted in various documents, including press releases from government websites and other grey literature (there is no source of integrated information on key stories and issues akin to the Wellcome Trust *Science Policy and Information News* in the UK, or systematic reviews on the topic, that we could identify).

Some of the key issues discussed in the grey literature are overviewed below. These insights were validated through key expert interviews.

Attracting, retaining and rooting foreign talent. Singapore's government has been investing heavily in an R&D environment and a lifestyle infrastructure, to attract global and regional talent in order to help build its biomedical R&D sector. Open immigration policies are meant to aid in this effort (almost one-third of Singapore's residents were born in other countries; *The Economist*, 2007). According to EDB statistics for 2009, more than 2,000 foreign researchers are based in Singapore (Singapore Economic Development Board, 2009c), and the country has attracted many leading global experts from the UK, USA, Sweden, Germany and Japan to its laboratories and institutes (Sandström, 2009). The challenge is retaining foreign star scientists (or at least their engagement) for the longer term. Although recruitment has been going well, the political complexity of biomedical research (i.e. level of direct senior-level political involvement in a small environment such as Singapore) can be a deterrent or concern for some foreign experts who are considering coming to and/or staying in Singapore for the long term.

Growing and retaining local talent. Since 2001, government agencies have embarked on an aggressive programme to increase the number of Singaporeans pursuing PhD studies in the biomedical and health sciences through greater provision of scholarships and fellowships, a revamp of the education curriculum to promote life sciences and glitzy advertising campaigns (*The Economist*, 2004). A*STAR provides overseas training scholarships for Singaporean undergraduate and postgraduate students, as well as medical doctors wanting to become clinician scientists, on the condition of repatriation upon completion of studies (Sandström, 2009). Training a critical mass of clinician scientists is a particularly important and challenging task, because the concept of the physician scientist is new in Singapore, and because a culture of translational research is not very well entrenched in the medical community yet. Establishing a translational research paradigm in Singapore's hospitals will be important if the country is to build its translational research capacity successfully, and there is scope for more effort in this regard.

Strengthening health policy research capacity. RAND Health and the National University of Singapore have been working together to accelerate the implementation of health services research and to address needs for health outcomes research to inform public health policy. The second phase of this collaboration involves developing a national health scorecard, a model to forecast healthcare workforce needs and a national mental health study. The collaboration is also working towards a clinical scholar programme to produce a cadre of future health services researchers in Singapore.

Making better use of existing healthcare infrastructure, including e-health, in the translational and clinical research agenda. Although the quality of healthcare is very high in Singapore, the healthcare system is not effectively utilised in a research context as yet. For example, while a modern e-health and electronic patient record system is in place,⁴ there is little evidence of its application to help address important research questions. The ability of the modern health service and the patient populations that it serves to assist in translational and applied research is under-explored at present.

Sustaining competitiveness – a threat from China? Singapore's vision of an internationally leading biomedical sciences cluster integrates both manufacturing and R&D excellence. To some extent, Singapore has embraced knowledge-based industries as a response to competition from cheaper labour and manufacturing locations – including China. China is also a large market for biomedical products and technologies, and the Chinese government has invested in the development of the biomedical industry based on its own market needs.

Today, China has a growing scientific knowledge base, significant biotechnology R&D capabilities and is attracting increasing inward investment. Singapore currently holds a competitive edge in terms of a more credible and efficient biomedical regulatory environment, including more reliable intellectual property protection and faster and more reliable ethical clearances – but this is not to say that China is not on the road to catching up fast. China has plans to establish 'Biopolis equivalents', has more than 300 publicly-funded laboratories and more than 20,000 life science researchers. In addition, there are nearly 1,700 joint pharmaceutical ventures, approximately 200 bioengineering companies and numerous business incubator facilities. Therefore, the Chinese biomedical sector is much larger than Singapore's.

The challenge for Singapore is how to maintain competitiveness and provide added value (Italian Chamber of Commerce, 2003). One strategy may be for Singapore to become more interactive with other South-East Asian countries in its efforts to build health research excellence, and to focus on being a key node in a web of links. This would enable Singapore to engage better in later phase clinical trial activities, and gain access to adequate population sizes. Another approach might be to focus on research excellence in a specific area, rather than to try and build international competitiveness across all possible health research areas (i.e. to pursue a specialisation rather than a diversification-based competition strategy).

⁴ By 2030, 19% of Singapore's population is expected to be over 65. In this context, e-health is being considered increasingly as a way to meet the needs of an ageing population, and investing in e-health infrastructure is included in the e-government plan. The Ministry of Health and two public healthcare clusters, SingHealth and the NHG, launched the Electronic Medical Record Exchange in 2004, and share electronic medical records across all public hospitals and polyclinics in Singapore. The following information is shared under the Exchange: discharge summary which summarises recent hospitalisation records; laboratory, X-ray and other radiological test results; operation reports; and medicines prescribed. In 2007, the government announced plans to integrate further patient medical records into a single national information technology infrastructure, which would include both public and private sectors. This is a challenging process and the best approaches for dealing with regulation and audit, data protection and common standards are being considered.

Stem cell research and product development. Singapore's ambition is to become a global leader in both stem cell R&D and the industry for stem cell-based therapies. However, significant challenges remain before stem cells can be taken into the clinic, including scientific and technological (e.g. immunorejection, tumorigenesis, cell numbers, efficient differentiation) (Bongso et al., 2008), as well as legal, regulatory and ethical.

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