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Industrial Cluster Development and Innovation in Singapore

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This paper examines the dynamics of formation of two innovation-driven industrial clusters in Singapore: the biomedical sciences (BMS) cluster; and the offshore marine engineering cluster. The first represents an emerging technology cluster in the early stage of formation; the second represents a more mature cluster that has evolved from an earlier shipbuilding and repair industry-base. By comparing and contrasting these two clusters, we highlight key challenges and relevant policy implications for promoting industrial clusters at different stages of formation. The case studies show that it is possible to accelerate the development of knowledge-based industrial clusters through public policy. Since key processes for cluster development are common to both new and existing clusters, there are common elements in the strategies used in their development. However, there are also distinct differences in the specific roles and timing of state involvement depending on the maturity and nature of the industrial clusters involved.

1. Brief Overview of Singapore Economy

Among developing economies, Singapore has achieved one of the most impressive economic growth records in the last four decades since her political independence in 1965, averaging 7 per cent GDP growth per annum over the 1960-2006 period. Despite an economic slow-down in 2001-03 (with a strong recovery in 2004), Singapore's per capita GDP of US$29,474 in 2006 still stands as the second-highest in Asia, at 67% of the US level (IMD, 2006).

The rapid economic growth of Singapore has been achieved through continuous industrial re-structuring and technological upgrading. In the first decade after independence, growth was led largely by labour-intensive manufacturing. In the two subsequent decades, it was propelled by the growth of increasingly technology-intensive manufacturing activities by foreign MNCs, with high-technology products contributing an increasing share of total value added. The development of Singapore into an increasingly important business, financial, transport, and communications services hub in the Asia-Pacific region has provided additional engines of growth since the 1980s. Nevertheless, manufacturing has remained important to the economy, with its share of GDP remaining above 25 per cent for most years in the last two decades. Thus in 2006 27.7% of Singapore's GDP was contributed by the manufacturing sector, and another 26.5% by ICT and financial/business services. Within the manufacturing sector, the key industries of electronics, chemicals, engineering and the biomedical sciences together accounted for $219 billion (93%) of total manufacturing output.

Along with its rapid economic growth, Singapore achieved significant technological capability development. R&D was minimal until the late 1980s, with a Gross Expenditure of R&D (GERD) to GDP ratio of only 0.86% in 1987, significantly below the norm of advanced countries. Since then, however, R&D investment intensity in Singapore has increased significantly, with GERD experiencing a thirteen-fold increase between 1987 and 2006, and the GERD/GDP ratio more than doubled to reach 2.4 per cent in 2006, at parity with the OECD average.

2. Conceptual Framework for analyzing the link between innovation and knowledge-based industrial cluster development

2.1 Knowledge-based industrial clusters

A knowledge-based industrial cluster is one that derives significant value creation from advanced knowledge creation and utilization. Both of these aspects are important, requiring both the creation of knowledge-intensive output as well as the use of knowledge-intensive processes in the generating this output.

Such a cluster will be characterized by knowledge-intensity in every component of the cluster. Firstly, there will be sources of knowledge creation that generate intellectual property (as embodied in patents, copyrights, trademarks, etc) and tacit know-how (such as skills, tacit knowledge and creativity). The creation of both tangible and intangible know-how takes place in every component of the cluster. For example, the development of technical skills takes place within formal education and training institutions but also within firms and R&D institutions through learning by using and learning by doing**.** Knowledge creation is not in itself sufficient however, since if the knowledge is not effectively utilized, the system will be left with much under-utilized (or mis-utilized) technological resources, resulting in low returns to the efforts expended in the creation process. Knowledge utilization processes therefore, are equally important in the cluster, embodied in firms' operating capabilities and innovation capabilities. Even this on its own is insufficient; there is also a need for knowledge transactions between firms to stimulate the creation and utilization of innovations, such as close interaction between suppliers and buyers or users, or strategic technology alliance between firms.

A knowledge-based cluster has a number of different components. Firstly, a knowledge infrastructure is required. This comprises public R&D institutes (PRIs) and universities as the lead generators of knowledge, particularly for fields in basic research, as well as for training manpower that will eventually work in other parts of the cluster. Secondly, linkages to lead users of knowledge are critical. Without such linkages, PRIs and universities run the risk of producing innovations and manpower that are irrelevant to industry. These linkages can include university/PRI-industry R&D collaboration, and high involvement of industry in the design of the training programs of training institutions. In early stages of cluster development, lead users may be found overseas rather than in the domestic market, necessitating the formation of linkages with firms and institutions in those countries. Thirdly, in order for the cluster to be sustainable, a critical mass of knowledge commercializing/innovating firms is required. Fourthly, the cluster requires supporting industries and services. Such support includes industries which provide industry-specific support to firms in the cluster (eg suppliers), as well as companies which provide services required by all knowledge-intensive clusters, such as lawyers and patent agents. Finally, the entire cluster must be supported by a regulatory framework and business environment in which to operate.

2.2 Key processes in developing knowledge-based clusters

In order to create a knowledge-based cluster, each of the components must be put in place:

- Establishment of public knowledge infrastructure, ie universities and PRIs. This may involve creating new institutions. It may also include re-structuring existing institutions, or creating new programs within them, to give priority to the fields of research and education needed for the cluster under development.

- Attracting private sector actors to the cluster. This includes both knowledge-intensive/commercializing firms which will form the core of the private sector of the cluster, as well as the supporting services which will surround them. The development of the private sector can take the form of both attracting foreign firms to set up operations in the country though DFI, or by nurturing local firms through incentives and development schemes which will attract firms into the industry and encourage those already in the industry to upgrade their knowledge-intensity.

- Establishing linkages with lead-user markets. These will commonly involve links to overseas markets, particularly for small or late-entrant economies. Business linkages are needed to expand the market for companies in the cluster, and innovation linkages are needed to give companies access to more advanced products and know-how. Such linkages could take the form of anchoring foreign lead-user firms in the country, and then encouraging intra-firm technology transfer between the parent headquarters and the overseas subsidiaries of a transnational corporation. New entrants will then be able to leverage on the expertise of the early entrants for learning and knowledge transfer, thus facilitating cluster growth A complementary strategy is to build international links through, for example, international R&D consortia, common technical standards coalition, cross-licensing of technologies, or long-term supplier-buyer relationship.

- Facilitating knowledge flows and network links among the key actors within the cluster. This will include inter-sector networks, such as between universities/PRIs and private firms (eg through technology transfer, joint R&D & training links), as well as creating platforms and mechanisms for inter-firm collaboration within the private sector. Examples of these are R&D alliances and industry consortia

- Establishing a regulatory framework/business environment

2.3 The role of the State in developing knowledge-based clusters

The State can play a significant role in facilitating the development of knowledge-based clusters through its policies and investment programs. This is especially true for economies where the overall business or innovation infrastructure is less well-developed – in these cases, the State will play a critical role in cluster development. Moreover, given the diverse strategies that can be adopted in the development of the cluster, the strategic choices eventually chosen by the State can have significant impact on the resulting dynamics of cluster development.

Some examples of the strategic choices availably to public policy makers include:

- Choice of actors to promote: The State can choose to focus on either local or foreign resources in developing the cluster. This includes private firms (attracting foreign firms vs nurturing local firms), manpower (recruiting foreign talent vs developing local talent), and even universities/PRIs (attracting foreign institutions vs establishing local institutions)

- Timing of entry into emerging technologies: The State chooses when to develop the cluster for emerging clusters and technologies. It can enter the global market while the technology is still new, requiring early-entrant strategies, or it can wait until the market and technology is more mature, necessitating using late-follower strategies

- Knowledge infrastructure development: The State chooses between the relative emphasis it gives in developing PRIs vs universities. The dynamics of cluster development will also be influenced by decisions such as the timing of investment in public R&D (eg, whether the State allows the cluster to first be developed by relying more heavily on private R&D, or whether it invests early and aggressively in public R&D), and also for training of R&D scientists and engineers (RSEs) (whether it will focus on training of RSEs directly through public institutions, or allow the private sector to play a greater role)

2.4 Knowledge-based industrial cluster development: upgrading existing cluster vs. developing new cluster

In developing knowledge-based clusters, the State also faces the choice of upgrading the knowledge-intensity of existing clusters or creating entirely new emerging technology clusters. Regardless, there will be common elements in the strategies used, as the key processes for cluster development are common to both new and existing clusters. However, as the case studies below will illustrate, there will also be distinct differences regarding the specific roles and timing of State involvement depending on the maturity and nature of the cluster to be developed.

3. Two case illustrations: Case studies of knowledge-based industrial cluster development in Singapore

This paper examines the dynamics of formation of two innovation-driven industrial clusters in Singapore: the biomedical sciences (BMS) cluster, and the offshore marine engineering cluster. The first represents an emerging technology cluster in the early stage of formation; Singapore had virtually no BMS infrastructure or industry to speak of when the government announced its intention to develop the country into a BMS hub. The second represents a more mature cluster that has evolved from an earlier shipbuilding and repair industry-base. From another perspective, the former represents a later-entrant approach by Singapore to “catch-up” with more developed clusters in other advanced countries. The latter cluster in Singapore had already become one of the leading hubs for offsore oil and gas platform production in the world, being the home-base for global leaders like Keppel Offshore & Marine; thus the transformation of Singapore's maritime services cluster into an International Maritime Centre involved upgrading the knowledge-intensity of existing industries. By comparing and contrasting these two clusters, we highlight the key challenges and relevant policy implications for promoting industrial clusters at different stages of formation.

3.1 Creating a new cluster: Biomedical sciences (BMS) cluster

3.1.1 Development of BMS Cluster in Singapore

For much of its history of rapid economic growth, Singapore had relied on a strategy of attracting DFI from global MNCs and leveraging them to exploit technologies and know-how developed elsewhere (Wong 2001, 2005). This global MNC-leveraging strategy has served Singapore well in the past, by making Singapore a leading information technology and electronics manufacturing and services hub in the world (Wong 2002). The same leveraging strategy was adopted in the pharmaceuticals sector, although on a smaller scale and starting later than for IT and electronics manufacturing, and appears to have been similarly effective in turning Singapore into a major pharmaceutical manufacturing hub. As can be seen from Table 1a, pharmaceutical manufacturing output in Singapore has grown rapidly since 1980 (18% p.a.), reaching S$20.9 billion in 2006. Similarly, its value added has grown at 18.8% p.a. over the same period, reaching $12.4 billion in 2006. This amounted to a contribution of 22.4% of total value added in the manufacturing sector, up from 2% in 1980. Reflecting the high capital intensity and scale of operations of such manufacturing activities, the average capital per worker for the industry amounted to S$0.95 million per worker in 2005, while the average output per firm was S$376.9 million, both significantly above the average of all manufacturing.

[Table 1a positioned about here]

The main drive to create a BMS cluster in Singapore as a whole however, began in 2000, when the Singapore government announced a strategic shift towards the promotion of biomedical science and technology in order to diversify from high dependence on IT/electronics manufacturing. The intention was for life sciences to become a key pillar of Singapore's economy, alongside electronics, engineering and chemicals. The government's vision is to turn Singapore into Asia's premier hub for biomedical sciences, with world-class capabilities across the entire value chain, from basic research to clinical trials, product/process development, full-scale manufacturing and healthcare delivery (Biomed-Singapore, 2003).

In order to jumpstart the development of the BMS cluster, a coordinated set of major new initiatives was launched (see Table 2 for a summary of major initiatives and developments in the Singapore BMS cluster). A US$1 billion fund was initially allocated to boost public investment in several new life science research institutes, to co-fund new R&D projects by global pharmaceutical firms, as well as to initiate the building of a new life science complex called Biopolis. Additional public funding was further announced to sustain the growth of the life science cluster beyond 2006 (Wong 2007).

[Table 2 positioned about here]

These initiatives, which will be discussed in detail below, have had visible impacts on the biomedical sector in Singapore. The sector has expanded significantly, with pharmaceutical manufacturing output more than quadrupling between 2000 and 2006. Furthermore, a medical technology manufacturing industry has emerged. The output of the medical technology sector has grown from only $31.4 million in 1980 to $2.1 billion in 2006, although it remains only one-tenth the size of pharmaceuticals (Tables 1a-c and 3). With these two sectors combined, the BMS cluster as a whole had an output of $23.0 billion in 2006, having grown at an average annual rate of 17.9% since 1980. Its fastest growth however, has been seen since 2000 (23.8% per annum from 2000-06 vs 15.2% from 1980-90 and 17.2% from 1990-2000). Similarly, value added in the cluster has grown at an average annual rate of 19.0% between 1980 to 2006 (23.5% from 2000-06) to reach $13.6 billion. Employment in the BMS cluster has almost doubled since 2000, to reach 10,571 in 2006, while labor productivity has also grown steadily, from $0.65 million per worker in 2000 to $1.3 million per worker in 2006.

[Table 1b positioned about here]

[Table 1c positioned about here]

[Table 3 positioned about here]

The initiatives have also had an impact on R&D. In 2006, BMS R&D in Singapore exceeded S$1 billion, up from $43.1 million in 1993 (Table 4). Although this shows R&D growth has been rapid over this time period (averaging 28.3% p.a.), it has been particularly so since 2000. From 2000 to 2006 Singapore's BMS R&D expenditure grew at an average annual rate of 38.2%. The share of total R&D expenditure in biomedical fields has also risen sharply, from less than 5% in the 1990s to over 20% by 2006 (see Table 5). However, symptomatic of the long gestation nature of much of biomedical research, the share of biomedical-related patenting in total output of patenting by Singapore-based inventors continued to lag behind its share of R&D spending. As can be seen from Table 6, while the cumulative number of biomedical US patents granted to Singapore-based inventors and Singapore-based organizations quadrupled in the eight years 2000-07 compared to before 2000, the share of biomedical patents in total patents granted remains at 2.6%.

[Table 4 positioned about here]

[Table 5 positioned about here]

[Table 6 positioned about here]

Consistent with the larger role of public sector (including universities) in life science research, two-thirds of biomedical R&D expenditure in Singapore in the 2000-06 period were conducted by public organizations, versus about one third for non-biomedical R&D (Tale 3). Taking into account the financial incentives given to some private sector pharmaceutical firms to conduct R&D in Singapore, the share of public funding in R&D spending in Singapore is likely to be larger than two-third. It is also interesting to note that, while biomedical R&D accounted for only 13% of total research scientist and engineers (RSE) in 2006, it accounted for 61% of all PhD RSEs. Again, the larger role of the public sector is not yet reflected in the distribution of patent ownership; ownership of life science patents is fairly equally divided between the public and private sector (about 44% each, with the remainder being assigned to other foreign institutions and indivduals, or unassigned) (Table 7).

[Insert Table 7 around here]

Notwithstanding this recent rapid growth in importance of life science R&D in Singapore, it is important to recognize that, compared with the advanced countries that are the world leaders in biomedical science and technology, the scale and intensity of Singapore's biomedical R&D remains modest. For example, Singapore's total annual biomedical R&D spending of about US$692 million is only a fraction of the US federal annual funding for biomedical R&D (estimated at US$38 billion in 2002). Even in terms of intensity, Singapore's biomedical share of around 22% of total national R&D is still lower than that of UK and US (over 25%).

3.1.2 Launch of the Integrated Bio-Medical Sciences (BMS) Hub initiative

The two arms of the government responsible for establishing the country as a biomedical science hub are the Agency for Science, Technology and Research (A*STAR), formerly known as the National Science and Technology Board, and the Economic Development Board (EDB). A*STAR – or, more specifically, the Biomedical Research Council (BMRC) within A*STAR - concentrates on putting in place the appropriate policies, resources, and research and education architecture that will build biomedical science competencies internally, including funding and supporting public research initiatives. EDB is responsible for bringing in investments and generating long-term economic value in the BMS sector, which it does primarily through the Biomedical Sciences Group (develops industrial, intellectual and human capital in Singapore in support of the biomedical sciences), and Bio*One Capital (functions as an investment arm). Together, the Biomedical Sciences Group and Bio*One Capital work to attract BMS companies to establish R&D operations in Singapore and develop the local BMS manufacturing sector (Finegold et al 2004). Figure 1 shows a flow-chart summarizing the strategies adopted by A*STAR and EDB to develop the BMS cluster in Singapore, while the initiatives themselves are discussed in Section 3.1.3.

Given the lack of an existing indigenous BMS cluster, Singapore has made extensive use of international talent in its BMS development. The Biomedical Sciences Executive Committee which leads Singapore's BMS Initiative is advised by the International Advisory Council (IAC), which comprises eminent scientists from around the world, including Sir Richard Sykes (Rector, Imperial College London, UK), Dr John Mendelsohn (President, M.D. Anderson Cancer Center, USA), Dr Alan Bernstein (President, Canadian Institutes of Health Research, Canada), Dr Suzanne Cory (Director, The Walter and Eliza Hall Institute of Medical Research, Australia), Prof Peter Gruss (President, Max Planck Society, Germany), Dr Philippe Kourilsky (Director, Institute Pasteur, France), Dr Harriet Wallberg-Henriksson, (President, Karolinska Institute, Sweden)

Another high-level advisory body is the Bioethics Advisory Committee (BAC), which was formed in 2000, at the time of the US stem cell controversy, to develop recommendations on the legal, ethical and social issue of human-biology research. The recommendations of the Committee, accepted by the government, have led to a regulatory environment in Singapore that is broadly supportive of BMS. The BAC recommended that human cloning not be permitted, but doing stem cell research and the use of cloning as a therapeutic tool is allowed.[1] This early and clear legal support for stem cell research combines with compliance with strict international guidelines which require seeking consent from couples and using only excess embryos from IVF treatment,[2] to give Singapore a relative advantage in stem cell research. Thus the US Institutes of Health allows the US federal government to fund research that uses Singapore-produced stem cells (Finegold et al 2004).

3.1.3 BMS hub development: Key elements of development strategy

a) Attracting foreign pharmaceutical MNCs into manufacturing, R&D, clinical trials and other knowledge-intensive services

EDB has successfully attracted MNC investments to Singapore; so much so that the BMS cluster is largely dominated by foreign companies. All of the largest pharmaceutical manufacturing firms in operation in Singapore in 2005 are foreign

[1] Interview with Kong Hwai Loong of the Biomedical Research Council
[2] The Straits Times. Chang Ai Lien. "Maintaining S'pore's lead in stem-cell race." Sept 5, 2001.

majority owned (see Table 8). Firms like GlaxoSmithKline (GSK), Schering-Plough, and Merck first came to Singapore to take advantage of the country's well-established competency in manufacturing. The majority of these firms are headquartered in the United States, and they manufacture pharmaceutical bulk active or intermediate products. Companies such as Genencor, AstraZeneca, and BristolMyersSquibb also established regional headquarters here because Singapore is a major business hub in Asia (Table 9).

[Insert Table 8 around here]
[Insert Table 9 around here]

In order to move these MNC investments into higher value-added portions of the biomedical industry value chain, EDB encourages foreign companies to set up R&D or clinical research operations in Singapore. Some prominent early examples of these partnerships with MNCs include S*Bio, Merlion, and Lilly Systems Biology. S*Bio was established as a joint venture between Chiron and the EDB using Chiron's technology platform to develop products for cancer and infectious diseases, especially those in Asia. Merlion originated as a joint venture between Glaxo and the EDB to perform more traditional drug-discovery and screening natural samples from across Asia for possible drug targets. After the merger that formed GSK, this unit was spun off and was privatized as a stand-alone business, with Merlion obtaining all of GSK's vast library of natural compounds along with its Asian samples. Today, Merlion owns one of the world's best private collections of natural samples with close to half a million extracts that they are screening for potential drugs, and has grown through collaborations with international drug companies, including Merck, British Biotech and NovImmume. Lilly Systems Biology (LSB) is a wholly owned subsidiary of Lilly that was launched in Singapore in 2002 with generous, multi-year financial incentives from EDB. LSB's mission is to integrate various biological data and approach the problem of studying complex diseases from a more encompassing perspective of a cell and its system. Through intensive use of computational biology, LSB hopes to discover new drug-targets and biomarkers, and better understand mechanisms of action within the cell (Finegold et al 2004).

More recently, as BMS development in Singapore moves beyond establishing basic life sciences infrastructure and industry to developing translational and clinical research, EDB has moved to encourage investments in these areas. Examples are The West Clinic's Excellence Cancer Center (established in Singapore in 2006) and Eisai's Regional Clinical Research Centre (2007) (see Table 9).

b) Developing an integrated physical infrastructure to house the BMS research cluster ("Biopolis")

Singapore already possesses an excellent general infrastructure (efficient transportation, high speed internet network, safe and clean city); however it went one step further in building Biopolis, a S$500 million physical hub for life sciences. Dedicated to biomedical R&D activities and designed to foster a collaborative culture among the institutions present and with the nearby National University of Singapore (NUS), the National University Hospital (NUH) and Singapore's Science Parks, the Biopolis also provides integrated housing and recreation facilities for the many foreign scientists to be attracted to work in the research facilities.

Singapore's seven biomedical public research institutes (PRIs) all have a presence in Biopolis, and are intended to attract biomedical MNCs, start-ups, and support services such as lawyers and patent agents to locate there (Finegold et al 2004). The government hopes that creating such a cluster will create informal networks for knowledge sharing and accelerate the growth of a critical mass of biomedical expertise in Singapore, facilitating its development as a BMS R&D hub for the Asian region. Current private-sector tenants in Biopolis include GSK, Novartis and Isis Pharmaceuticals.

c) Establishment of seven public R&D institutes (PRI) in BMS

Singapore has seven BMS PRIs, overseen and funded by the BMRC (Table 10). Basic research right up to clinical trials are supported using four types of grants: project grants provide seed funding for new investigators, program grants support more extensive research programs of established investigators, co-operative grants sponsor inter-disciplinary work, and lastly, core competence grants are meant for PRIs to develop or strengthen capabilities in areas of strategic importance.

[Insert Table 10 around here]

The oldest of the PRIs is the Institute of Molecular and Cellular Biology (IMCB), first established in 1987 at NUS. Four new PRIs in bioinformatics, genomics, bioprocessing and nanobiotechnology were established over the period 2000-02, while the existing IMCB was expanded. More recently, the Singapore Institute for Clinical Sciences (SICS) was established to expand Singapore's clinical R&D capabilities, while the Centre for Molecular Medicine was repositioned as the Institute of Medical Biology (IMB) to facilitate translational research.

d) Attracting foreign top talents ("whales") and grooming young local talents ("guppies")

Because of the ambitious scale and speed of development of the BMS cluster in Singapore, the attraction of foreign talent has become an integral part of the government's life science strategy. Not only would it have taken much too long for the local university to train and develop the large number of scientists needed to staff these major new research institutes, there was also a dearth of local star researchers with sufficient international reputation and stature who can serve as the initial magnet to attract other younger researchers (Zucker and Darby, 1996). Consequently, the strategy is to attract a number of internationally-renowned scientists ("whales") to head up research leadership positions in the BMS PRIs, who will in turn recruit more junior scientists from their network contacts as well as attract other young scientists from around the world to work under them. Examples of top scientists attracted to Singapore include:

- Sidney Brenner, a Nobel laureate (Chairman of BMRC and Co-chairman of the IAC)
- Alan Colman, the leading transgenic animal cloning scientist from Scotland's Roslin Institute (now Executive Director of Singapore Stem Cell Research Consortium and Principal Investigator at IMB)

- Edison Liu, the former head of the US National Cancer Institute (now Executive Director of Genome Institute of Singapore)
- Sir David Lane, the former director of Cancer Research UK's Cell Transformation Research Group (now Chairman of BMRC, Executive Director of IMCB and CEO, Experimental Therapeutics Centre)
- Yoshiaki Ito, a leading Japanese cancer researcher (now Principal Investigator of IMCB)
- Jackie Ying, a young but rising star researcher from MIT (now Executive Director of the Institute of Bioengineering and Nanotechnology)
- Axel Ullrich, a well-known molecular biologist from Max Planck Institute for Biochemistry (now Director, Singapore Onco-Genome Laboratory)
- Dr. Birgit Lane, Cox Chair of Anatomy & Cell Biology, University of Dundee (now Executive Director of IMB)
- Dr. Neal Copeland, head of the Molecular Genetics of Oncogenesis Section and Director of the Mouse Cancer Genetics Program of the National Cancer Institute-Frederick (now Principal Investigator, IMCB)
- Nancy Jemkins, head of the Molecular Genetics of Development Section of the National Cancer Institute-Frederick (now Principal Investigator, IMCB)
- Dr. Judith Swain, Dean for Translational Medicine and the Founding Director of the College of Integrated Life Sciences at University of California at San Diego (now Executive Director, Singapore Institute of Clinical Sciences)
- Markus Wenk, a noted biophysicist and lipid researcher from Yale (now Associate Professor at NUS)

In addition to these star scientists, the government is sending the top students from Singapore's education system ("guppies") to leading research universities for graduate science and business education. The government pays for their education provided that they return to Singapore when they complete their studies. The scholarships, which are provided by A*STAR, target different segments of young talent, ranging from those seeking undergraduate and post-graduate studies to medical doctors seeking training to become clinician scientists. As of 2007, more than 100 students have been trained, with a target of 1000 trained PhDs by 2015.

In the long-term, the government hopes that Singapore's own universities and research institutes, bolstered by alliances they have established with universities such as Johns Hopkins and MIT, can grow their own bioscience manpower (Finegold et al 2004).

e) Nurturing venture capital & promoting dedicated biotechnology firms (DBFs) & bio-medical device start-ups

As with other aspects of the BMS cluster in Singapore, the government has played a significant role in developing a specialized BMS venture capital industry. The biomedical science industry is very capital intensive and risky, with most new ventures failing to generate a return on their investment. With no history of home grown, high-tech companies, Singapore has not developed a community of venture capitalists or other private investors who are knowledgeable about and interested in investing in biomedical start-ups. Those investors interested in this sector have tended to put their resources in U.S. firms with more proven track records and lower perceived risk. Consequently, the government took a lead role in directly running a number of life-science related funds, which were subsequently centralized under one fund management umbrella called Bio*One Capital.

Bio*One Capital manages about S$1.2 billion in funds, and invests in drug discovery/development, biologics & cellular therapy, and medical technology companies and startups. It currently has over 60 companies in its investment portfolio, many of them were originally founded outside Singapore. Through a strategy of investing in companies that will bring key new technologies and generate higher value-added research jobs in Singapore, the fund had been instrumental in causing some companies to move some of their operations to Singapore. One example is S*Bio. EDB offered a multi-million dollar deal to transfer Chiron's technology platform to a new drug discovery start-up in Singapore, in which Chiron was then given a significant ownership stake. Another example is Bay Area-headquartered Fluidigm, which chose Singapore to locate her first Asian manufacturing operation (Wong 2007).

In addition to bringing overseas BMS investments to Singapore, the efforts of Bio*One and other support mechanisms have resulted in a fledgling dedicated biotech firms (DBFs) sector emerging in Singapore (Table 11). This includes a number of spin-offs from local universities (see Table 12 for DBF spin-offs from NUS). The main focus areas for Singapore's DBFs are drug discovery and development (eg S*Bio, established in 2000, Merlion Pharmaceuticals (2002), ProTherapuetics (2004)), medical devices (eg BioSensors (1990, listed in 2005), Merlin Medical (2002)), stem cells (ES Cell International (2000), Cordlife(2002)), and bioinformatics (KOOPrime (2000), HeliXense (2000), ReceptorScience (2000)).

[Insert Table 11 about here]
[Insert Table 12 about here]

Although the number of DBFs in Singapore is still relatively small when compared to the leading biotech clusters in the world, the record is actually creditable, given that there were virtually no such DBFs before 2000. Indeed, until recently, only two drug-discovery companies, Lynk Biotechnology and AP Genomics, had products. Some still only have drug candidates in their pipeline or remain in the extremely early stages of research. All the bioinformatics firms have some products in the market because product development in software is significantly shorter than it is for drugs. Nevertheless, a major commercial success has yet to emerge amongst Singapore's DBFs.

f) Expanding clinical research capabilities in the healthcare services sector

The first phase of Singapore's BMS development (2000 - 2005) focused on establishing a foundation of basic biomedical research in Singapore. From 2006, Singapore's BMS Initiative moved into its second phase, which focuses on the development of capabilities in clinical and translational research, while continuing to strengthen basic sciences (A*STAR 2007).

Singapore has several advantages in clinical research, including a good healthcare system. There are seven public hospitals, six national specialty centres on cancer, cardiac, eye, skin, neuroscience and dental care, and 16 private hospitals. It also has a primary healthcare network of 18 public polyclinics and over 2000 private medical practitioners. The country's healthcare system has a strong regional reputation for advanced services, attracting over 370,000 foreign patients in 2005 and having a target of 1 million by 2012. Other advantages include its compact size and a population with a mix of Asian ethnic groups, which makes it conducive for developing new treatments and technologies, as well as drug trials customized to Asian populations.

Earlier in its BMS cluster development, Singapore began to market itself as a regional clinical trials center. They have had some early success attracting companies like Pharmacia, Novo Nordisk and some of the large contract research organizations (CROs) to establish clinical trial centers in Singapore. Johns Hopkins University and NUH set up an International Medical Center to provide patient care and to conduct clinical trials in oncology. This center also offers clinical education programs and degrees in conjunction with NUS. Despite these early successes, there are still relatively few clinical trials taking place in Singapore. This may be due to the strong and growing competition for the Asian clinical research market from Taiwan, Australia and Japan, which have the advantage of larger domestic markets and the fact that pharmaceutical companies may be reluctant to use these clinical trial centers due to an unproven track record (Finegold et al 2004).

More recently, further development of clinical research capabilities has gained prominence. To this end, clinical research was explicitly included in the mandate of the Ministry of Health (MOH) as of 2006, and the National Medical Research Council (NMRC) under MOH has significantly increased funding for clinical research by the healthcare sector. The establishment of the SICS was a further step in this direction, with the institute focusing on the development of disease-oriented clinical and translational research programs in the areas of genetic medicine, hepatic diseases and metabolic diseases. The development of clinical research necessarily involves developing translational research; thus the SICS and the other newest PRI, IMB, both have explicit aims of building bridges between basic science conducted by the other PRIs and clinical research programs in Singapore's public hospitals, disease centres and the universities.

As with other sectors within the BMS cluster, clinical research suffers from a lack of manpower; as such, the development of clinician-scientist manpower has also come into focus. One scheme in the National Science Scholarship, offered by A*STAR specially target medical doctors who want to become clinician scientists. Two other talent attraction and development schemes recently launched by A*STAR are the Singapore Translational Research Investigatorship, which aims to recruit world-class clinician scientists and clinician investigators to undertake clinical and translational research in Singapore, and the Clinician Scientist Award, which targets top local clinicians with proven leadership potential towards research (A*STAR 2007).

g) Promoting translational research & other linkages between R&D institutes, universities and healthcare services sector

In the development of clinical and translational research capabilities, there has been a deliberate strategy of forming and promoting collaborations between clinicians and scientists in multiple agencies. Recent examples of this are the consortia initiated by BMRC to promote translational research links between the BMS PRIs/Universities and the healthcare sector. These consortia are to coordinate and drive translational research at the national level by consolidating existing research activities and scientific expertise, optimizing the use of critical research resources, filling in gaps in research capabilities, and building sufficient critical mass to make Singapore's efforts in translational research internationally competitive.

The consortia that have been set up are intended to date include:

- Singapore Cancer Syndicate
- Singapore Bio-imaging Consortium
- Singapore Stem-Cell Consortium
- Singapore Consortium of Cohort Studies
- Singapore Immunology Network

These consortia engage in a variety of activities including funding of joint projects, engaging in joint training, and establishment of research infrastructure and links between local and overseas institutes.

Singapore has also become a member of the International Biomarker Consortium headed by Dr Leland Hartwell, President and Director of the Fred Hutchinson Cancer Research Center in Seattle. It aims to launch a large-scale, coordinated effort to discover biomarkers for the early detection of cancer by providing opportunities for collaboration and platforms for data and technology and sharing among consortium members. Singapore's project focuses on biomarkers for gastric cancer, and involves a collaborative research effort NUH, NUS, the Genome Institute of Singapore (GIS), IMCB, and the Bioinformatics Institute (BII). There are also plans to establish a Biomarkers Consortium within Singapore, which would bring together basic and clinical research groups working on biomarker discovery in cancer and other diseases (A*STAR website).

Although it is too early to evaluate the effectiveness of the consortia, their formation is to be welcomed. One weakness of the Singapore innovation as a whole is a lack of linkages between sectors; the expansion and promotion of collaboration through consortia is thus a step in the right direction.

3.1.4 Growing R&D and educational role of local universities

a) Education

The development of the BMS cluster in Singapore has necessitated a growing role played by local universities in both R&D and education. In terms of education, the universities have put in place programs to help develop the manpower necessary for the BMS cluster. Among the initiatives undertaken by NUS, the most ambitious has been the building of a second medical school. Unlike the existing medical school, which is in the British tradition of taking students directly from high schools, the new school was modeled after the US post-graduate, professional medical school, with students drawn from graduates from various disciplines and faculty recruited to emphasize research excellence. The school was established in collaboration with a leading US medical school (Duke University), and is located on the same campus as to the largest public hospital (Singapore General Hospital (SGH)) to facilitate close interactions, particularly in research (Wong 2007).

NUS also set up an Office of Life Sciences (OLS) in 2001 to integrate and facilitate life sciences research and education throughout the university and its affiliated institutions. Among the educational initiatives introduced by OLS is an integrated life science undergraduate major program that involves the participation of five core faculties (computing, dentistry, engineering, medicine and science). OLS also established a bioinformatics program with faculty members from the computing and medical schools, as well the engineering and science faculties.

A new bio-engineering division was also set up in the Engineering faculty in 2001. The division has been structured so as to cross traditional departmental boundaries within the faculty and the university. Thus policy decisions are made by a Board comprising academic staff from the engineering, science and medicine faculties. Similarly, academic staff in the division hold joint appointments with other departments in the Engineering faculty and other faculties and research institutes. This gives students to access expertise and resources across the faculties involved; for examples, exposure to clinical practices in the medical school and NUH (Wong 2007).

Singapore's second-largest university, Nanyang Technological University (NTU), has also entered BMS education and research. Its School of Biological Sciences was established in 2001, within the College of Sciences, while a School of Chemical and Biomedical Engineering has been established within the College of Engineering.

b) Research

As mentioned above, BMS research programs in NUS are consolidated by the Office of Life Sciences. OLS brought together researchers from the five core faculties involved in life sciences to identify and agree on ten areas of research, grouped under two broad headings of diseases (cancer, neurobiology/ageing, vascular biology/angiogenesis, hepatology, infectious diseases) and platform technologies (bioinformatics /registries/molecular epidemiology, structural biology/proteomics/genomics, immunology, bioengineering, experimental therapeutics /medicinal chemistry/toxicology /clinical trials). The forging of this consensus provides greater focus for BMS research within NUS, and for new collaborations established with other research institutes in Singapore and overseas (Wong 2007).

The National University Medical Institutes (NUMI), formed in 1994, translates some of these target research areas into specific research programs. It has research programs in oncology, low temperature preservation, neurobiology, diabetes and ROS biology & apoptosis. NUMI also supports research in the medical school, providing centralized research facilities and services such as confocal microscopy, DNA sequencing and flow cytometry.

The Proteins and Proteomics Centre similarly supports BMS research within the NUS Faculty of Science. The Centre provides equipment and services for researchers, as well as training for both undergraduate and postgraduate students in support of research projects in proteomics, protein science and technology, chemical biology, drug design, immunology, and structural biology.

Within the Engineering faculty, the Division of Bioengineering has set up a Bioengineering and Nanobioengineering Corridor to facilitate research in nanotechnology and bioengineering. The Corridor consists of numerous multidisciplinary laboratories in a single location, with the aim of encouraging cross-fertilization of ideas and multi-disciplinary teaching and research. The laboratories include those on biomaterials, biomechanics, biophysics, bionanotechnology, biosignal processing & instrumentation, chemotherapeutic engineering, computational bioengineering, nanobioengineering, nano biomechanics, tissue engineering, and biofluids,

In addition to research within the various faculties of universities, BMS research is conducted in university-affiliated research institutes. One example is the Temasek Life Sciences Laboratory (TLL), which is affiliated with both NUS and NTU. Located within the NUS campus, TLL and conducts research in molecular biology and genetics.

c) Translational research

The NUS-Duke Graduate Medical School (GMS) was established in 2005, having a research-intensive curriculum based on the Duke University model of medical education. This focuses on developing clinician-scientists who will engage in translational research. As mentioned above, this is facilitated by the school's location on the same campus as the Singapore General Hospital and the national specialty centres. Researchers have access to specialized research support facilities, and the physical proximity facilitates collaboration for translational research. Recently, GMS announced a partnership with A*STAR to develop an integrated multidisciplinary neuroscience research program with a strong focus on translational research. The Neuroscience Research Partnership will widen the collaborative scope of researchers in GMS further still, to include the resources and expertise within the BMS public research institutes under A*STAR.

Another high-profile avenue of translational research is the Singapore Gastric Cancer Consortium, which is a collaboration of researchers from NUS, NUH and the National Cancer Centre Singapore (NCCS), as well as from the PRIs and overseas cancer centers. This research is the first project to be supported by the NMRC's Translational Clinical Research Flagship Programme, receiving S$25 million over the next five years. The NUS module is built around ongoing clinical studies and relevant research laboratories in the university. The NCCS module will focus on the genetic analysis of gastric cancer, while NUH module will focus on clinical trials. The consortium has partnered with several international groups as well as with other hospitals, PRIs and universities within Singapore (A*STAR 2007a)

The infrastructure for translational research in the university medical schools, and the hospitals with which they are co-located, is being further developed through a $140 million project announced in 2007. The plans include the development of new research buildings for laboratory research, investigational medicine units, and animal research facilities. Not only will research facilities be expanded, but the research infrastructure of the institutions involved will be integrated, resulting in two campuses for translational research: one comprising NUS and NUH; the other comprising GMS, SGH and the national disease specialty centers (A*STAR 2007).

d) International multidisciplinary research

A initiative for promoting international multidisciplinary research among Sinagpore universities was put in place by the National Research Foundation’s Campus for Research Excellence and Technological Enterprise (CREATE). CREATE aims to foster joint multidisciplinary research and linkages between top research universities and Singapore-based knowledge organizations.

The first research centre within CREATE is one that builds on an existing relationship between MIT, NUS and NTU known as the Singapore-MIT Alliance (SMA), in which the three universities collaborate in graduate education and research. The universities have extended their partnership to form the Singapore-MIT Alliance for Research and Technology (SMART) Centre, a research centre where faculty, researchers and graduate students from MIT collaborate with those from universities, polytechnics, research institutes and industry in Singapore and Asia. SMART will establish five inter-disciplinary research groups, two of which are currently operational. The first is the Centre is on Infectious Diseases, with eight senior MIT faculty members and 17 Singapore collaborators from NUS, NTU, TLL and other PRIs in the fields of biology, engineering, medicine and computing. The second research group is a Centre for Environmental Sensing and Modelling, involving collaborators from MIT, NUS, NTU, the Tropical Marine Science Institute and the Public Utilities Board in the fields of engineering, earth and atmospheric sciences, architecture and computing (NRF 2007).

3.2 Offshore marine engineering cluster

The development of Singapore’s offshore marine cluster needs to be examined in the context of the holistic strategies to develop Singapore’s Maritime Cluster (SMC). Singapore’s maritime cluster has been well established for many years as the island’s strategic location has propelled it to its current position as one of the world’s most important port and shipping locations. The current policy impetus is to enhance the SMC in order to position Singapore as a leading International Maritime Centre in the Asian region.

3.2.1 Overview of the development of Singapore's Maritime Cluster (SMC)

Singapore's maritime cluster is defined to broadly comprise two groups: Core Maritime Sectors which include the traditional water transportation sectors and Non-Core Maritime sectors which include services that support marine transportation. Core Maritime sectors are those that derive their revenues entirely from maritime related activities. Non-Core sectors are those for which maritime activities form only a part of their total operations. **Table 13** shows the sectors within these two broad groupings.

[Table 13 here]

The SMC has experienced impressive growth over the last few years, as seen in **Table 14**. In 2005, the SMC generated value added of $14.3 billion, accounting for 7.4% of Singapore's total GDP. This compares to 5.1% share of GDP in 2000. In the intervening five years, the SMC grew in excess of 12% annually, while generating employment growth of close to 7% annually. Labour productivity has correspondingly improved over the years. Value Added per worker increased from S$117 in 2000 to S$149 in 2005. The SMC's labour productivity figures compare favourably against those achieved economy-wide, which stood at S$74 in 2000 and S$84 in 2005.

[Table 14 here]

Table 15 contrasts the economic contribution of the SMC with the maritime clusters of other selected countries. This illustrates the significance of maritime-related activities to Singapore's economy. Among the different countries included in this benchmarking exercise, Singapore was the only one where maritime activities account for over 5% of Gross Domestic Product (GDP). The contribution in the other countries was below 3%, even in traditional maritime nations such as Hong Kong and Norway. Additionally, the SMC demonstrates strong linkages to the rest of Singapore's economy (**Table 16**). In 2005, the SMC generated S$31.4 billion worth of output in non-maritime related sectors. The SMC also generated $3.45 billion of indirect Value Added in the rest of the economy, bringing the total (direct + indirect) Value Added contribution of the SMC to SGD 17.76 billion or around 9.2% of GDP.

[Table15 and Table 16 here]

Table 17 shows the composition of Value Added and Employment in the SMC for 2005. Two sectors, shipping lines and brokering & chartering, account for almost half the Value Added generated by the SMC, with the ports sector contribution another 14.5%. However, of these three dominant sectors, only brokering & chartering has recorded significant growth over the last five years. Outside of these traditional shipping and port activities, the Offshore and Marine Engineering sectors are significant components of Singapore's maritime cluster. These sectors account for almost one fifth of value added in the SMC and generate one quarter of maritime employment. The offshore construction sector contributed 6.8% of maritime value added and 9.2% of maritime employment. The shipbuilding/repair sector contributes one tenth of total maritime VA and is the single largest employer of maritime labour, accounting for 38.2% of employment in the SMC. Additionally, the Offshore and Marine Engineering sectors boast of high growth rates in the last five years. For both value added and employment generation, Offshore and Marine Engineering sectors recorded double-digit growth rates per annum between 2000 and 2005. Growth rates in value added generated are especially impressive, outstripping many other sectors in the SMC, which recorded average growth of 6.8% per annum in the same period.

[Table 17 here]

3.2.2 Competitiveness and Development of the Singapore Maritime Cluster

3.2.2.1 Upgrading of Knowledge Intensity of Existing Industries in the Maritime Cluster

The continued growth of Singapore's maritime cluster has been achieved in the face of increasing regional and global competition. This may be attributed to improved labour productivity and increasing levels of knowledge intensity in key maritime sectors.

Examples of such improvements are evident in the port sector, which is the traditional "anchor" of Singapore's cluster of maritime-related sectors. In recent years, the Port of Singapore has experienced intense competition from new rival ports in the region, in particular Port Tanjung Pelapas in Malaysia as well as emerging ports in China. These ports enjoy the advantages of operating with substantially lower land and labor costs. Despite this, the Port of Singapore was able to defend its market through a significant increase in productivity achieved via aggressive investment in ICT and automation. As a result of these measures, the Port of Singapore continued to attract significant vessel traffic and retained its position as the top container port in the world and the 2nd largest port in terms of total cargo throughput.

Another segment of the maritime cluster that has upgraded technological capabilities and increased knowledge intensity is the marine engineering industry, comprising the offshore sector and the shipbuilding/repair sector. Until quite recently, the ship building and repair industry was involved in traditional shipyard activities, providing newbuilds and repair services to vessels calling at the Port of Singapore. The industry was able to transform itself by successfully diversifying into major players in the offshore oil & gas construction and marine engineering services sectors. As a result of this, a number of indigenous firms with roots in traditional shipbuilding activities have becoming global leaders in the offshore construction business. More detailed analysis of the offshore sector is provided later in this paper.

Other sectors that achieved high growth through increased productivity and knowledge intensity include bunkering & logistic services. The knowledge-intensive Maritime finance, insurance, legal and classification services also registered strong growth, albeit from a small base.

3.2.2.2 Role of the State in Promoting the Development of International Martime Centre in Singapore

The Ministry of Transport's sea transport policy spells out a vision of Singapore as the leading maritime hub in Asia, with a vibrant International Maritime Centre (IMC) cluster that not only complements and reinforces Singapore's hub port status, but serves as an additional engine of growth. In 2003, the Maritime & Port Authority (MPA) was appointed as the "champion agency" for the comprehensive development of Singapore from a primarily sea-transport hub towards becoming the *leading comprehensive integrated IMC* in Asia.

MPA plays a leading role in IMC development in the context of a multi-agency co-ordination approach. As seen in **Figure 2**, the institutional framework for IMC development in Singapore involves a number of Ministries and government agencies as well as industry representation through associations and the Singapore Maritime Foundation. The presence of multiple agencies and stakeholders ensures an integrated development approach.

[Figure 2 here]

Several initiatives are underway to steer the development of Singapore as an IMC. **Figure 3** details the components of Singapore's IMC Development strategy. MPA is overseeing the expansion Singapore's maritime activities from core port and shipping services into bunkering, ship brokering/chartering, logistic support and classification/surveying services. Another important and related strategic initiative under the IMC thrust is the development of maritime ancillary services such as marine insurance, maritime finance and maritime legal services. MPA has emphasized the attraction of key global players in these fields to Singapore, in addition to promoting local participation. To achieve these goals, the continued vibrancy of the port and shipping services sectors is vital and investments in port upgrading and technological improvement have to continue apace.

MPA has also worked with the Singapore Economic Development Board and International Enterprises Singapore to expand the traditional shipbuilding and repair industry into offshore oil & gas platform construction and marine engineering services. Diversification in these new areas has created opportunities for R&D and IT projects and provides additional incentives for attracting and growing the maritime ancillary services sectors such as maritime insurance, finance and legal services.

[Figure 3 here]

3.2.2.3 Government Programmes for R&D and Innovation in the Singapore Maritime Cluster

The Ministry of Transport has identified the development of Singapore as a maritime R&D centre to be one of the measures for creating a vibrant IMC hub. MPA has instituted a number of initiatives in line with this strategic thrust, among these a Memorandum of Understanding between MPA and the Research Council of Norway (RCN). Signed in 2002, the MOU provides a framework for MPA, RCN and research institutes, academic institutions and industry representatives from Singapore and Norway to collaborate on a number of maritime R&D, Education and Training (RDET) projects that are business and user oriented. Areas covered by the MOU include marine environment protection, shipping operations and maritime technology. The scope of the MPA-RCN MOU includes a broad range of activities such as exchange programs and industrial attachments, education and training courses and cooperation in commercialization results of maritime RDET projects.

In addition to the MPA-RCN MOU, MPA has launched and administers the Maritime Innovation and Technology (MINT) Fund. This is a S$100 million Fund established to support development programs under the Maritime Technology Cluster Development Roadmap. $50 million from the Fund has been earmarked for enhancing maritime R&D capabilities.

Programs and schemes funded by the MINT fund include:

- *TRIDENT Platform* (joint program with EDB): This is a platform for development and test-bedding of maritime innovations called Test-bedding, Research and Innovation Development for New-Maritime Technologies (TRIDENT). The program supports companies and TRIs (tertiary & research institutions) in undertaking maritime-related R&D, innovation development, using Singapore's port and maritime facilities as test-beds for innovations.

- *Maritime Seed Fund:* This fund targets young or growing maritime companies seeking to bring technologies or innovation from concept to commercialization, and established maritime technology companies seeking to embark on further R&D, set up facilities in Singapore or venture overseas. The Fund invests in companies registered in Singapore in exchange for equity based on the 3 funding levels: Up to $50,000 for early-stage start-ups; Up to $300,000 for start-ups; on case-by-case basis for post-start-ups
- *Joint TRI and MPA R&D Programme:* The programme co-funds joint maritime-related R&D projects by tertiary research institutes (TRIs) and MPA. MPA will participate in the projects as a R&D partner. Projects are to be relevant to the maritime industry and should produce technologies or innovations with the potential to be developed into commercial products, systems or services. TRIs are encouraged to have industry partners in their R&D projects.
- *Maritime Technology Professorships:* MPA has set up Maritime Technology Professorships in local universities involved in technological R&D (NUS and NTU). Universities are encouraged to source for industry's contributions through a dollar-for-dollar matching governmental funding for the industry's contribution. The aim of the Professorships is to encourage R&D relevant to the maritime industry.
- *Maritime Industry Attachment Programme:* This programme aims to immerse engineering, IT and science students from TRIs in the maritime industry. From the attachment, maritime R&D concepts and projects can be generated by the students. At the end of their attachment, students can submit their suggestions for maritime R&D projects. Accepted suggestions will be awarded prizes, and final-year or post-graduate R&D projects will be funded by the MINT Fund

3.2.3 Offshore & Marine Engineering Cluster in Singapore

The strategy of diversifying traditional shipbuilding and repair into offshore construction and marine engineering services (Figure 3) has borne enviable results. Singapore has emerged as a leading Offshore & Marine Engineering cluster in the world, boasting of 70% global market share for the conversion of Floating Production

Storage Offloading (FPSO) vessels and 70% of world market share in jack-up rig construction. Two indigenous firms, Keppel FELS and SembCorp Marine have emerged as the largest offshore oil rig platform manufacturers in the world.

In addition, Singapore has 20% of world market share for ship repairs and is among the top 3 global centres for oil & gas (O&G) equipment manufacturing and servicing. In recent years, Singapore ranks first in Asia by production volumes for six of the top 10 players in the oil and gas equipment.

Table 18 reports the sales revenue of Singapore's Marine and Offshore Engineering (M&OE) industry in the last 10 years. Adopting the Singapore Standard Industrial Classification (SSIC) categories, the M&OE industry is composed of the Offshore sectors, Shipbuilding sector, Ship Repair sector and Other Marine Engineering sectors. The two Offshore sectors are oil rigs and the other oilfield/gasfield machinery & equipment.

In 2006, offshore and marine engineering activities generated over SGD 12 billion worth of products and services. Over 40% of this amount, or SGD 5.4 billion, is contributed by the Offshore segment of the industry, with another one third of output, or SGD 4.5 billion being generated by the ship repair sector. Revenue in the shipbuilding sector is more modest, at SGD 1.3 billion, representing around 11% of the industry. In the ten years since 1996, the composition of the M&OE industry has changed

The M&OE industry as a whole has grown at 20.2% per annum between 2001 and 2006, a turnaround from negative growth of 1.8% per annum in the preceding 5 years. Of the M&OE sectors, the oil rigs sector achieved the highest growth rates, averaging remarkable growth of 49% per annum since 2000, in contrast to annual contraction of 15.8% in 1996-2000. From sales of around SGD 600 million in the mid 1990s, the oil rig sector has multiplied to over SGD 3 billion in revenues in 2006. The shipbuilding sector also grew at a healthy pace, in the last six years, at 24.3% per annum, outpacing the ship repair sector's growth of 14.4% per annum.

[Table 18 here]

Tracing revenues in the shipbuilding and repair industry over the last thirty five years, as shown in **Figure 4**, the most rapid growth has been seen in the recent few years since 2000. Prior to that, growth in all three segments – shipbuilding, ship repair and rig construction – was much more gradual although the ship repair sector experienced a spike in growth in the mid 1980s.

[Figure 4 here]

3.2.3.1 Productivity of Offshore Sector and Shipbuilding/Repair Sector

The growth of the M&OE industry in the last few years is associated with increased productivity, as seen in **Table 19**. Labour productivity as measured by VA per worker has increased from SGD 42,000 in 1996 to SGD 55,000 in 2006. The improvement in labour productivity is most pronounced in the oil rig sector, where VA per worker more than tripled from SGD 22,600 in 1996 to SGD 76,900 in 2000 and maintaining at SGD 72,600 in 2006. The other sector with marked improvement in labour productivity is the Shipbuilding sector. Fixed asset utilisation in all the M&OE segments has declined, suggesting that there have been real improvement in efficiency and or gains in Total Factor Productivity to explain the observed growth in labour productivity.

Corresponding to improvement in labour productivity, remuneration per worker has improved slightly over the years for the M&OE industry. Average salaries have increased significantly in the offshore and shipbuilding sectors, but declined marginally in the ship repair sectors.

On the other hand, value added as a share of revenue has decreased slightly for the M&OE industry as a whole. This was due to declining VA/revenue ratios in the Ship repair sector and the Oilfield machinery and equipment sector. For the oil rig sector, sectors, the share of VA in revenues generated has increased in the last 10 years, while the ratio has remained relatively unchanged in the shipbuilding sector.

[Table 19 here]

3.2.3.2 Development of Innovation Capability in Offshore & Marine Engineering Cluster in Singapore

Table 20 presents a profile of the leading offshore and marine engineering companies in Singapore. There are three major players in the offshore engineering construction sector, namely Keppel FELS, SembCorp Marine and Labroy Marine. All three companies have been in existence for many years, being involved in more traditional shipyard activities in their earlier years. Today, Keppel FELS and SembCorp Marine have consolidated their leading status as the world’s two largest oil-rig builders.

[Table 20 here]

Although a cluster of Singaporean firms have become major players in offshore oil rig platform production and associated marine engineering services in the world, with production and services contracts around the world, the industry did not engage in significant R&D and patenting activities until recent years.

In the Offshore Rig-Building sector, capability development was achieved primarily through a continuous process of learning by doing. Firms such as Keppel FELS and Sembcorp Marine initially licensed designs from firms in advanced countries, and with enhanced capabilities, shifted from sub-contractor to main contractor roles. Later, these firms acquired rights to design, and subsequently acquired design companies and developed their own in-house design capabilities.

The development of the core rig building firms has stimulated the growth of various marine services firms, as shown in **Table 21**. Such firms are involved in activities such as chartering of offshore supply vessels, logistics and procurement support services, equipment distribution & maintenance support. Several of these firms subsequently expanded into oil rig repair, equipment development, IT services and related marine engineering services.

[Table 21 here]

3.2.3.3 Development of Public R&D Institutions and Innovation Collaboration with Offshore Industry

It is in recent years that the government started to promote R&D activities in the Marine Engineering field, to support the upgrading of innovation capability among the private sector firms.

As part of these efforts, collaborations with institutes of higher education were encouraged. In 2003, the Centre for Offshore Research & Engineering (CORE) was established at National University of Singapore. CORE was officially launched in 2004 by the Economic Development Board (EDB) and NUS to help strengthen Singapore's performance as an oil and gas hub in the wake of high growth forecasts for the industry globally. CORE aims to develop advanced technologies and enlarge the talent pool in offshore engineering research through working with other local research & development (R&D) institutes, international experts and partners in the oil and gas industry. CORE enjoys strong support from the Agency for Science, Technology and Research (A*STAR) and collaborates with a number of leading research organizations, including Imperial College of the University of London and Det Norske Veritas. Several R&D projects have been conducted, including collaborations with local companies as well as overseas organizations such as Norway's Norsk Hydro in Norway and Delft University of Technology in the Netherlands. The centre has recently, in March 2007, been provided with S$ 10 million in funding by A*STAR and MPA for a new Offshore Technology Research Programme.

At the Nanyang Technological University (NTU), a graduate education program in Marine Engineering was established in 2004. Jointly developed by NTU and the marine and offshore industry, the program aims to produce talent to meet the technological and operational demands of the fast growing offshore industry. At the program's inception, six leading offshore and marine engineering companies, including five members of the Association of Singapore Marine Industries (ASMI), pledged over half a million dollars in scholarship to fund students undertaking the course over the next three years.

Another significant move was the establishment of a Marine & Offshore Technology Centre of Innovation (COI (MOT)) at SPRING Singapore, the government agency responsible for enterprise development. The COI (MOT) provides consulting, R&D and technology transfer services to assist SMEs in the Marine engineering & equipment industry to upgrade their technological capability. The centre works on a collaborative model and form partnerships with industry players and in some cases, with research institutes or centres. Among the services provided by the Centre is assistance through the Technology Innovation Programme (TIP). Through the TIP, the Centre shares the salary costs of expert manpower and defrays costs of technology innovation projects; up to 50% of allowable costs for technology projects and up to 70% for industry wide projects.

Reflecting the recent policy emphasis on technological development in Marine Engineering, R&D expenditures in the sector has recorded significant increase in the late 1990s, as shown in **Table 22**. From annual expenditure of $2.21 million in 1993, R&D spending on marine engineering technologies increased to over $20 million in 2000. In the 6 years since, the annual amount has fluctuated somewhat but averages at above $20 million annually. Correspondingly, the number of Research Scientists and Engineers (RSEs) involved in marine engineering R&D has increased from 23 to 1993 to 134 in 2006.

[Table 22 here]

Similarly, research output in the form of offshore-related patents has increased substantially since the mid 1990s. Since 1978, there have been 23 offshore-related patents granted by the US Patents and Trademarks Office (USPTO) that are either invented by Singaporean residents or assigned to Singaporean-based interests. Of these 23 patents, 11 have been granted post 2000, as shown in **Table 23**. Four of the recently granted patents are technologies developed two companies, Offshore Technologies and Deepwater Technologies, which are subsidiaries of Keppel FELS.

[Table 23 here]

A survey conducted in 2004 covering 13 ship-building & offshore marine engineering services firms found 4 to have close collaboration with public research institutes & universities, and another 6 reporting sporadic contacts (Wong, Ho and Ng, 2005). **Table 24** provides some examples of collaborative projects between private sector firms and public research institutes and universities.

[Table 24 here]

3.2.4 Case Study of Leading Offshore Construction Company – Keppel FELS

Table 25 presents a summary profile of Keppel FELS and its major milestones. A profile of SembCorp Marine Limited is also provided as a point of comparison, showing how these two companies have evolved to their status as world leaders in offshore construction. **Table 26** reports the turnover and profits achieved by these two firms in the last 13 years, showing the improved financial figures in the late 1990s resulting from the surge in their contract books in this period.

SembCorp Marine operates as a large corporation providing a full suite of services, including offshore construction, and is not organized in such a way that any single corporate entity serves as its offshore division. On the other hand, Keppel FELS is organized as an entity that focuses primarily on offshore activities and as such, is the basis for this paper's case study.

[Table 25 and Table 26 here]

Keppel FELS is today the leading designer and builder of sophisticated drilling rigs, having constructed most of the world's jackups in the last decade. As the wholly-owned offshore arm of Keppel Offshore & Marine (Keppel O&M), Keppel FELS's strategy is also boosted by Keppel O&M's strategic network of 16 yards worldwide.

Keppel FELS has a long corporate history, tracing its beginnings to the incorporation, in 1967, of Far East Shipbuilding Industries Limited (FESL). FESL was primarily involved in rig construction, undertaking a handful of construction projects in its first decade of operations. In 1970, FESL was renamed as Far East Levingston Shipbuilding Limited (FELS), after signing a 3 year management agreement with Levingston Shipbuilding Company of Texas, USA.

In a separate development, Keppel Shipyard was formed in 1968 to take over the dockyard department of the Port of Singapore. Keppel Shipyard was engaged in the traditional shipyard activities of ship repair and later developed capabilities for shipbuilding. Three years after its formation, Keppel Shipyard acquired a 40% stake in FELS and in subsequent years, acquired other shipyards in Singapore and Philippines as part of its expansion plans. In 1980, Keppel Shipyard was listed on the Singapore Stock Exchange and took over complete management of FELS, although the renaming of FELS to Keppel FELS only took place many years later in 1997. Keppel Corporation was incorporated in 1986, with Keppel Shipyard as the major operating division.

Since the incorporation of Keppel Corporation, the Keppel group has grown substantially through acquisition of interests in overseas operations as well as incorporation of local and overseas subsidiaries, such as FELS Baltech in Bulgaria. In 2002, Keppel FELS and Keppel Shipyard were integrated to form Keppel Offshore & Marine Limited (KOM), a wholly owned division of Keppel Corporation. With the formation of KOM, Keppel FELS is identified as the offshore engineering arm of KOM while Keppel Shipyard is the shipbuilding and repair division. In addition to Keppel FELS and Keppel Shipyard, a number of other subsidiaries also come under the KOM umbrella. This includes two offshore technology firms – Offshore Technology Development (OTD) and Deepwater Technology Group (DTG) – as well as FELS Offshore Pte Ltd, a holding company for managing the overseas subsidiaries involved in offshore related activities.

It is instructive to analyse the evolution of KFELS' activities and strategies over the years to understand how it has achieved its current market leader status in the construction of offshore drilling rigs. From its inception in 1967 throughout the 1970s, FELS managed a small number of projects, delivering 4 drillships and rigs.

In the 1980s, after coming under the management of Keppel Shipyard and having access to the Keppel's substantial yard facilities, FELS embarked on a number of joint ventures to broaden its markets and scope of services. These include ventures with Finland's KONE corporations and Nanhai Oil Equipment Repairs and Maintenance Company Shenzhen. During the 1980's FELS secured its first contract from an oil company, CONOLCO and successful delivery of the Tension Leg Wellhead Platform to CONOLCO positoned FELS as a world class rig builder. There was a flurry of activities with more than 10 contracts secured, including the first contract for a deepwater drilling rig. The 1980s saw the FELS venturing into technological development. In 1981, CAD/CAM technology was introduced to FELS, marking a technological upgrade in its design operations. A subsidiary firm, Offshore CIM Engineering Projects (OECP) was later formed in 1990 to further develop computer-integrated manufacturing technology. In 1985, FELS launched into its first rig R&D initiative in an agreement with Foramer SA, Friede & Goldman to build and own the *Columbus Explorer*, a MOD V jackup. However, under this arrangement, the technology and rig design resided with Friede & Goldman.

In the 1990s, Keppel FELS aggressively entered into consortia, alliances and co-ownership arrangements as part of its expansion strategies. Significant acquisitions included stakes in AMFELS in the US and Offshore & Marine A.S. in Norway. In the early 1990s, FELS clinches its first few contracts to fabricate FPSO vessels and in the late 1990s, began working on offshore conversion projects. Several key technological developments took place in this period, allowing for FELS to deepen their capabilities and embark on FPSO construction and conversion projects. The Keppel Group embarked on a series of scholarship and study schemes, sending Keppel staff to be trained in technologically advanced countries; UK, USA, Germany, France, Norway and Japan. Through these programs, Keppel brought technology into Singapore and laid the foundations for Singapore to develop its own infrastructure for offshore and marine technology. In 1993, Offshore Technology Development Pte Ltd (OTD), a wholly owned subsidiary of KOM, was set up with the support of the Singapore National Science and Technology Board (NSTB) to develop proprietary technologies in offshore construction. OTD made great strides in a relatively short time and delivered its first proprietary design in 2000. At the same time, Keppel FELS continued to acquire technology from external sources. In 1997, it acquired the rights to the Friede & Goldman MOD V and MOD VI rig designs. These developments indicated the dual mode being adopted for technological development at Keppel FELS; acquisition and enhancement of external technology while developing in-house capabilities.

In the late 1990s and into the 2000s, Keppel FELS has experienced the most productive period in its history. Contracts are being secured at a rapid rate and construction activities have grown apace to keep up with market demands. As a result, Keppel FELS has consolidated its position as the world's leading designer and builder of jackups, FPSO and FSO conversions. At the same time, it has extended its offerings to provide integrated total solutions, not only in newbuildings but also upgrades and conversions, offshore repairs as well as design and engineering solutions. A KOM subsidiary, Keppel Singmarine has also developed capabilities to become a niche player in conversions and construction of specialized offshore vessels, such as Anchor Handling Tug Supply vessels and cable ships.

A significant development at Keppel FELS and KOM, more generally, is the increase in emphasis and resources devoted to R&D. In 2004, the Keppel Technology Advisory Panel was set up, comprising eminent scientists, industrialists and practitioners in the offshore field. In line with management's R&D thrust, the KOM Technology Centre (KOMTECH) was inaugurated in 2007 to step up the growth of in-house competencies for R&D and technological development. Continued investment in R&D has borne fruit as seen by KOM's success in creating IP assets in rig designs and systems. The two technology firms under the KOM umbrella – OTD and DTG - had 2 patents each granted by the US Patent Office between 2000 and 2007. At present, OTD has another 6 published applications with the USPTO. OTD's patented rig designs and equipment feature extensively on rigs constructed by Keppel FELS while DTG's patents on semisubmersible vessels are suitable for operations worldwide. As at December 2007, it was estimated that KOM's proprietary technologies have generated SGD 15 billion worth of contracts, including projects currently under construction [3].

KOM sees itself as a main driver in developing Singapore as a centre of excellence for offshore and marine technology. When KOM was inaugurated in 2002, the Executive Chairman of Keppel Corporation kick-started Keppel's Centre of Excellence. The Centre aimed to conduct extensive R&D activities and to build a repository of expertise, experience and knowledge. One of the key initiatives was the establishment of the Keppel Professorship in Ocean, Offshore and Marine Technology at the National University of Singapore (NUS). KOM sponsors the Keppel Professorship with an initial funding of SGD 1.5 million to initiate research projects and product and technology development. In addition to the Keppel Professorship, KON has worked with NUS to launch a series of Keppel Offshore & Marine Lectures, attracting audiences from industry, as well as the student and research communities. KOM also sponsors visiting professors in related fields and supports international conferences such as the International Conference on Technology and Operation of Offshore Support Vessel (OSV Singapore 2005) in September 2005.

KOM is also the First Founding Member of the Centre for Offshore Research & Engineering (CORE) at the National University of Singapore [4]. CORE was unveiled in 2004 by the Economic Development Board and EDB in an official launch, during which the founding members signed a "Pledge of Commitment" to reinforce their support for the R&D initiatives of CORE. KOM has since gone on to work with CORE on a number of collaborative R&D projects. A KOM-CORE collaboration on jack-up platforms and spudcan foundation has resulted in the filing of a patent.

Aside from its collaborations with NUS, KOM has also forged links with the Nanyang Technological University (NTU). In 2005, KOM endowed $50,000 into two student schemes at NTU's School of Mechanical & Aerospace Engineering. The two

[3] Estimate mentioned in speech by Mr George Yeo, Minister for Foreign Affairs, at Keppel Offshore & Marine's 5th Anniversary Celebrations. Available as a media release from Government of Singapore: http://app.sprinter.gov.sg/data/pr/20071203983.htm (accessed, January 28, 2008)

[4] Information on the establishment of CORE is drawn from Cheah et al. (2006)

endowment schemes, a medal and book prize, will benefit final year students excelling in selected subjects. The endowment is viewed by KOM's COO, Mr Tong Chong Heong, as an investment in the new generation of talents needed in the maritime industry. KOM is also one of the seven sponsors of the Marine & Offshore Engineering specialization and scholarship program introduced at NTU in 2004.

4. Conclusion

4.1 Common elements in cluster development strategies

Several common elements were observed between strategies for developing the biomedical sciences cluster and those for the offshore marine engineering cluster. In both cases, there was significant involvement from the state. The government of Singapore adopted a top-down, coordinated multi-agency approach to developing the two clusters, comprising measures for investment promotion, promoting R&D through developing public R&D institutes and providing incentives for private sector R&D, and infrastructure and manpower development.

Another key cluster development strategy is the attraction of a critical mass of anchor firms or institutions to jump-start the cluster. For the BMS cluster, foreign pharmaceutical MNCs were incentivized to establish operations for knowledge-intensive services such as R&D. In the offshore engineering cluster, firms in the traditional shipbuilding and repair sector were diversified into offshore construction activities. Attracting anchor firms has involved investment promotion policies that are pro-active, targeted and concentrated. Another strategy for building critical mass is geographic agglomeration of cluster players, such as that achieved by the Biopolis facility. With the presence of anchor firms in a newly formed cluster, new entrants are able to leverage on the expertise of the early entrants for learning and knowledge transfer, thus facilitating cluster growth.

In Singapore, government involvement in cluster development is clearly seen in the investments made in cluster-wide ecosystem development. For both biomedical and offshore clusters, relevant government agencies have made pro-active investments to develop core infrastructures (for eg., setting up R&D institutions) and skills (for eg.

working with educational institutions to introduce courses and programs). Additionally, the government has successfully leveraged on anchor firms or institutions to stimulate development of more specialized resources, supporting industries and services. For instance, the well-developed healthcare sector provided a basis for developing medical technology services and R&D activities and stimulated the formation of start-up firms in drug discovery and medical devices. In the offshore sector, the activities of Keppel FELS and Sembcorp Marine created opportunities for the offshore support service sector.

4.2 Differentiating elements in cluster development strategies

The timing of cluster development policies has differed in the two clusters in question. The State was involved in the conception of the BMS cluster, playing a leading role in its creation and growth, beginning with the BMS Hub initiative launched in June 2000 and followed by a series of broad-based policy initiatives. In the Marine engineering services cluster, the role of the state is more supportive and state involvement took place when the original shipbuilding and repair cluster (from which the offshore engineering cluster was developed) was at a mature stage. The private sector companies took the lead in growing the offshore cluster and have been doing so since the 1990s.

There was a notable difference in the role played by indigenous firms versus the role of foreign MNCs in the two clusters. While policies to attract foreign global MNCs were critical in the development of pharmaceutical manufacturing, policies to nurture indigenous firms were more important in the case of marine engineering services.

For both clusters, R&D and innovation were important elements of their development paths. However, R&D and innovation played different roles at different stages of cluster development. For BMS, the establishment of R&D capabilities, generation of IP and their subsequent commercialization were critical right from the start in the cluster development process. On the other hand, for Marine Engineering, cluster development started with manufacturing, learning by doing, and gradual accumulation of tacit process knowledge and innovation capabilities. The role of public R&D

institutions came much later, and the creation of IP was not important until much later in the cluster development process.

The contrasting nature of BMS and offshore engineering meant that there would be different emphasis on the local or regional production base. Although Singapore was able to attract a sizable manufacturing base of Global pharmaceutical MNCs, this was not sufficient to jump-start entry into the biotech/life science industries. Because early stage start-ups are the key drivers for BMS, venture capital was essential. Rather than foreign investments, the attraction of global *talent* was more critical to build the critical mass of expertise needed. The situation is different in the offshore engineering cluster where leveraging on the local production base was more effective in stimulating cluster growth. The prior establishment of indigenous manufacturing in shipbuilding/repair play a significant role in facilitating the learning of know-how and development of innovation capabilities in marine engineering.

Similarly, the role of local/regional markets was different for the two clusters. The initial creation of the BMS cluster was driven primarily by perceived global market growth opportunities rather than local/regional market opportunities; nevertheless, in the future, a greater focus on leveraging local/regional health-care markets by engaging local/regional hospitals in translational research will be important in sustaining cluster development. In contrast, the presence of offshore oil & gas production in Southeast Asia (particularly Indonesia) provided an early opportunity for Singaporean firms to learn & develop capabilities in marine engineering services. Subsequent development of the cluster was driven by globalization of these local firms, while growth opportunities from the regional markets continue to be pursued.

For the BMS cluster, establishing a strong IP protection regime, and providing a strong public policy framework regarding bioethics and standards for clinical trials were critical to attracting foreign interest to participate in the cluster. In contrast, for the marine engineering services cluster, tacit process knowledge is more important, although the role of the state in providing transparent rule of law and reputation for trust & security also contributed.

Apart from IP policies, supporting policies also played vastly different roles in the two clusters. The role of the state in developing a centralized physical infrastructure (Biopolis) was critical to the development of the BMS hub. In the case of Marine Engineering, the role of the state was in making available lands for ship-building/repair and developing and maintaining a world-class maritime port infrastructure that facilitated maritime activities in general.

In terms of policies related to finance, the active promotion of Singapore as a financial hub for maritime industries, in particular the listing of stocks of maritime companies on the Singapore Stock Exchange, facilitated the development of indigenous firms in the marine engineering services industry in terms of fund-raising. In contrast, the Singapore stock market has played little role in attracting biotech firms, although the role of the state in providing venture capital (BioOne) has been critical in attracting some biotech firms.

4.3 Implications for Other Economies

The case studies of the BMS and offshore clusters in Singapore show that it is possible to accelerate the development of Knowledge-Based Industrial Clusters through public policy. Singapore's experience suggests that this is likely to require a coordinated, strategic approach involving multiple government agencies and sustained investment over a long period.

That being said, there is no "one-size-fits-all" approach for the role of the state in cluster development. While all the key component elements of a knowledge cluster need to be developed, the specific roles and timing of state involvement depend on the nature of the industrial clusters to be developed. As Singapore's experience in the BMS and offshore clusters has shown, there are multiple factors to consider, such the nature of technologies or processes involved and the market environment.

Another lesson to be learnt from the Singapore experience is the potential trade-off between sourcing for external capabilities versus internal expertise. Because of Singapore's small population, the strategy to leverage on global MNCs and foreign talents has long been in practice. This can be effective in accelerating the development of a cluster, as seen in the BMS industry. However, this may also the risk of slowing indigenous capability development.

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Figure 1 Flow-Chart of Singapore's BMS Cluster Development Strategy

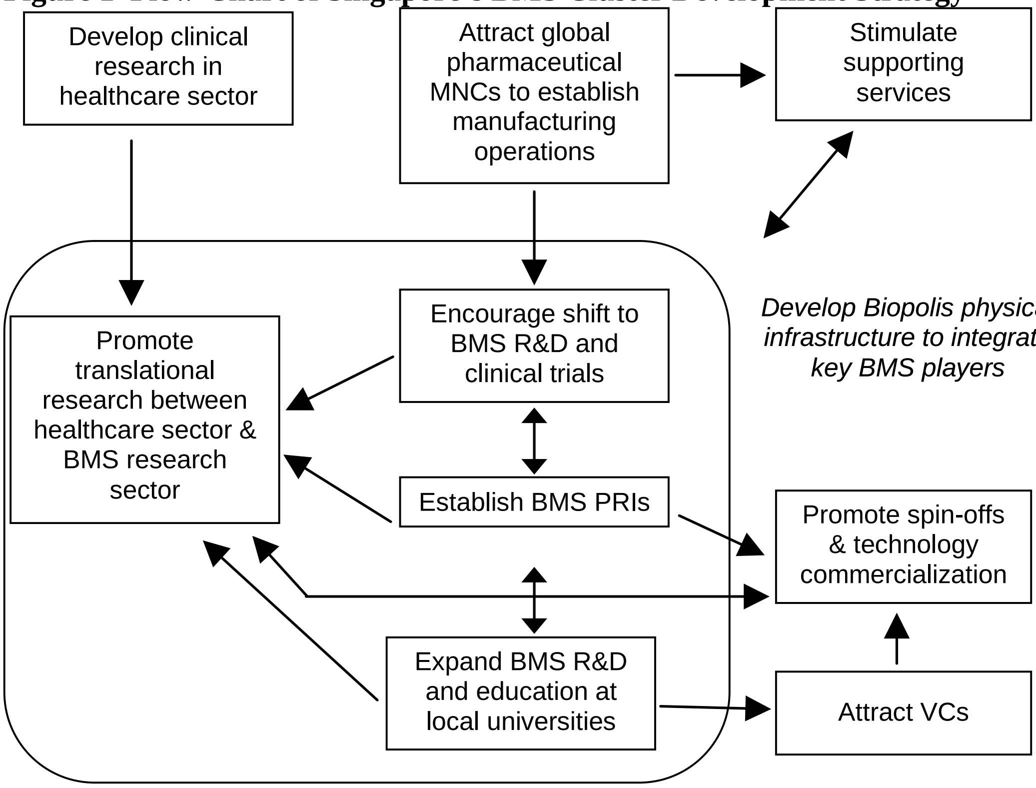
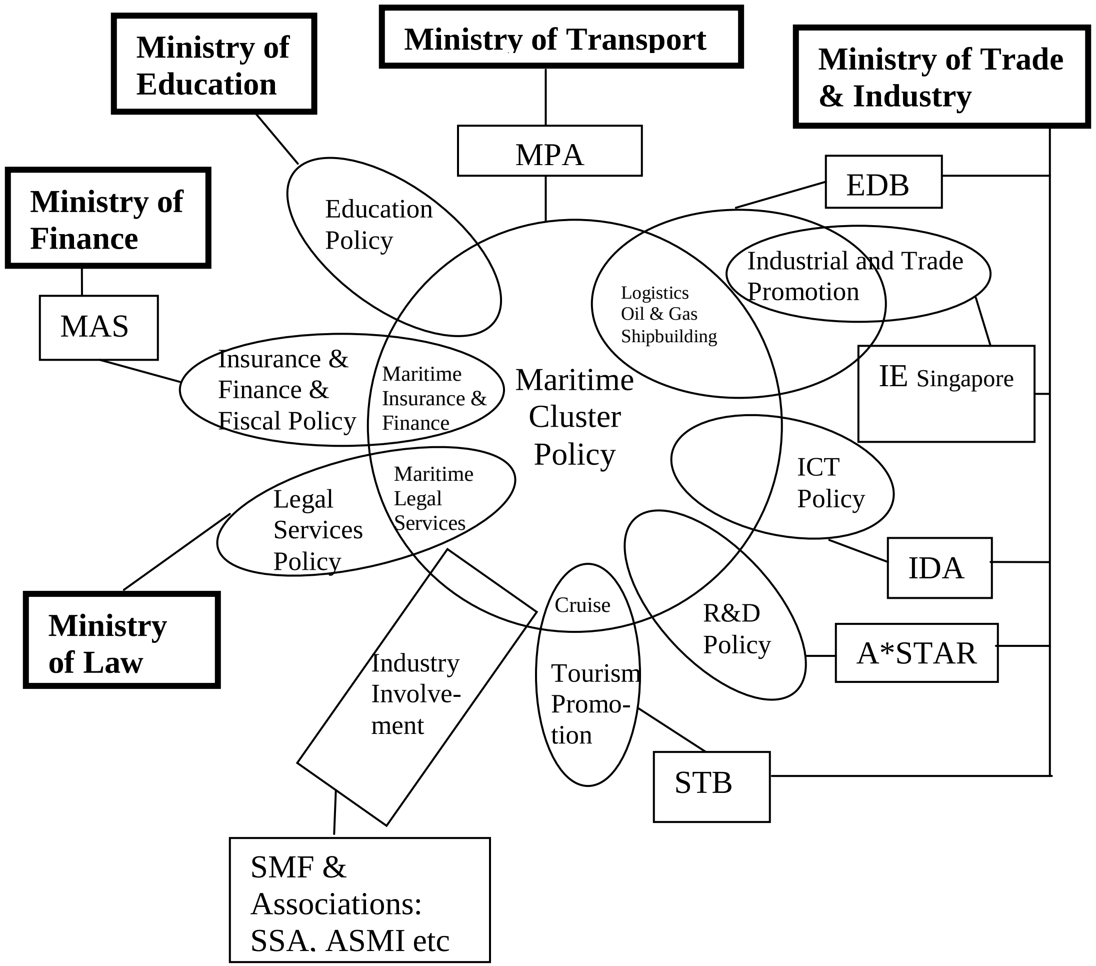


Figure 2: Overall Institutional Framework in Singapore for IMC Development



Source: Wong, Ho and Ng (2005)

Figure 3: Flow-Chart of Singapore's IMC Development Strategy

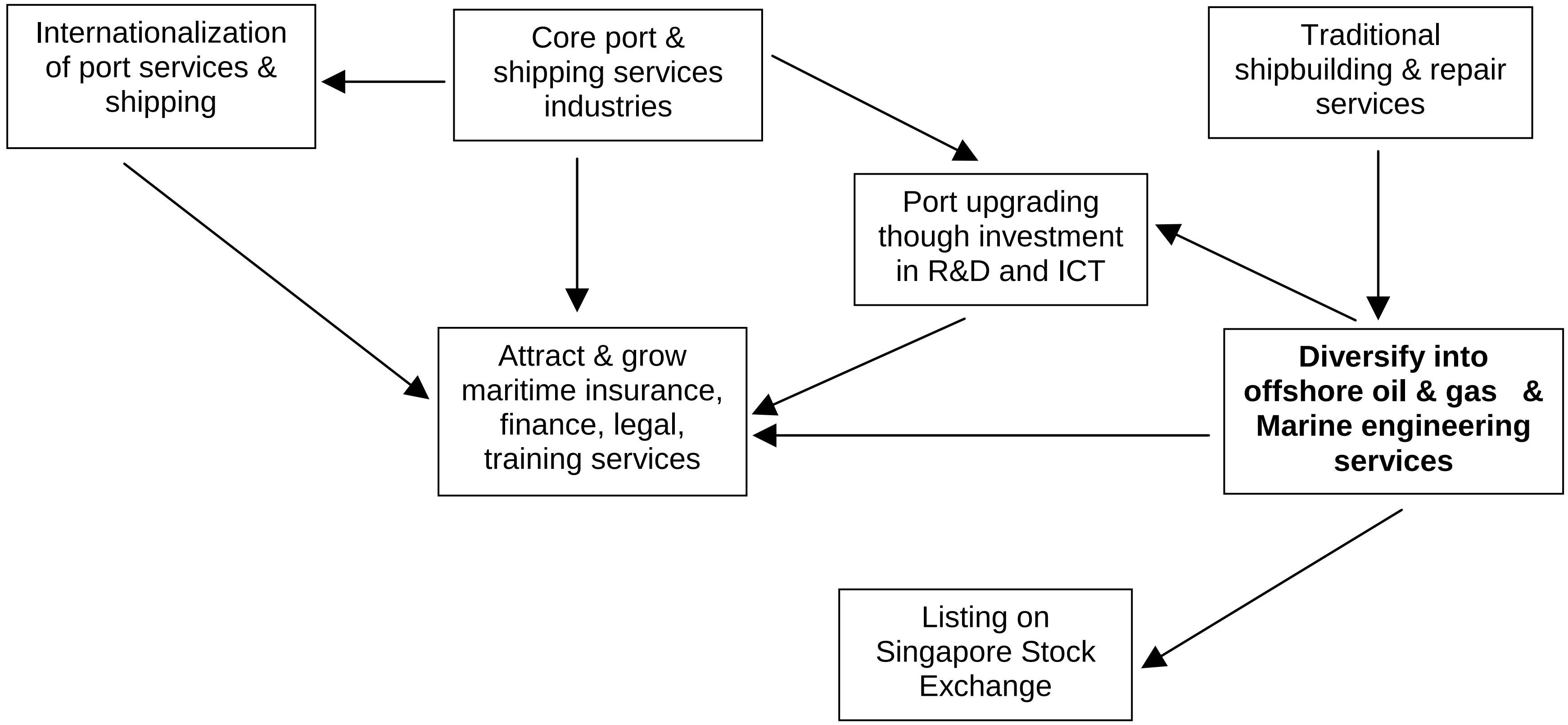
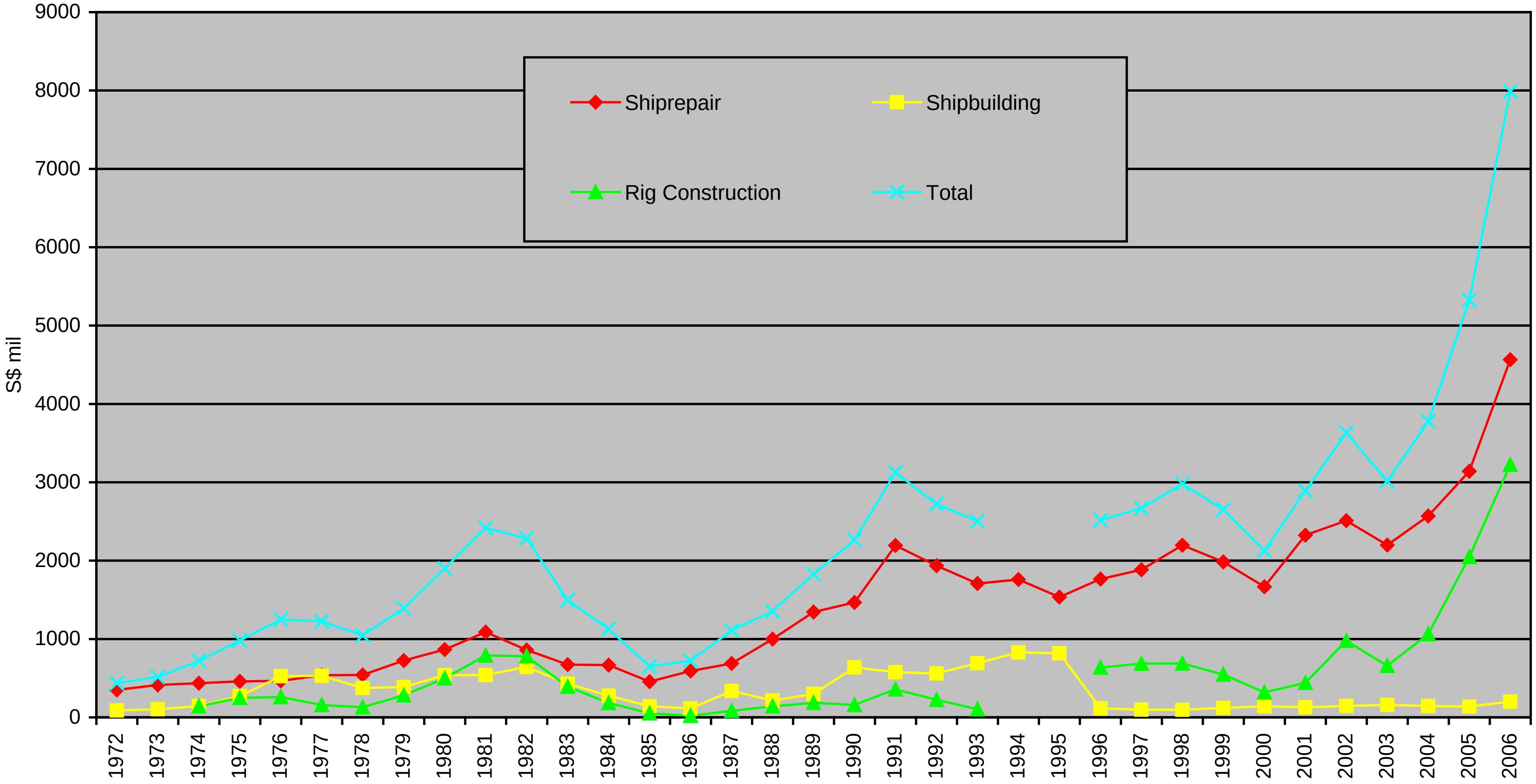


Figure 4: Shipbuilding and Repair Revenues, 1972-2006



Note: Figures for Rig Construction sector not available for 1994 and 1995
Source: 1972-1995: Various issues of Singapore Marine and Ocean Engineering Directory/ Singapore Marine Industries Directory , Directory of Singapore Shipbuilding & Offshore Industries 1997; 1996-2005: Economic Development Board

Table 1a Profile of the Singapore Pharmaceuticals Sector, 1980-2006

Year	Number of Firms	Number Employed	Output S$million	Net Value Added S$million	Net Fixed Assets S$million	Val.Add/ Labour $'000	Fixed Asset/ Labour $'000	Output/Firm $million	Val.Add/ Output %
1980	17	1,270	285.1	138.8	54.5	109.3	42.9	16.8	48.7
1985	16	1,463	507.9	333.2	176.5	227.7	120.6	31.7	65.6
1990	18	1,645	1,013.1	745.2	193.4	453.0	117.5	56.3	73.6
1995	18	1,855	1,342.5	1,063.5	583.7	573.3	314.7	74.6	79.2
2000	25	1,928	4,839.1	2,999.0	858.6	1555.5	445.3	193.6	62.0
2001	28	2,375	5,134.2	2,797.1	2085.3	1177.7	878.0	183.4	54.5
2002	38	3,203	8,170.7	4,893.7	2607.1	1527.8	813.9	215.0	59.9
2003	40	3,584	10,216.9	5,746.5	3200.7	1603.4	893.0	255.4	56.2
2004	43	3,857	15,605.8	8,927.9	3705.6	2314.7	960.7	362.9	57.2
2005	43	3,903	16,208.8	8,110.3	3697.6	2078.0	947.4	376.9	50.0
2006	na	4,020	20,934	12,355	na	3073	na	na	59.0
Average per Annum Growth Rate (%)									
1980-90	0.6	2.6	13.5	18.3	13.5	15.3	10.6	12.9	
1990-2000	3.3	1.6	16.9	14.9	16.1	13.1	14.3	13.1	
2000-06	11.5	13.0	27.6	26.6	33.9	12.0	16.3	14.3	
1980-2006	3.8	4.5	18.0	18.8	18.4	13.7	13.2	13.2	

[1] Calculated using 2005 data where 2006 data is not available

Source: Census of Manufacturing Activities, data from EDB; BMRC. (2007). "Exceptional Growth For Singapore's Biomedical Sciences Industry", downloaded from: http://www.biomed-singapore.com/bms/sg/en_uk/index/newsroom/pressrelease/year_2007/6_feb_-_exceptional.html

Table 1b Profile of the Singapore Medical Technology Sector, 1980-2006

Year	No. of Firms	No. Employed	Output S$million	Net Value Added S$million	Net Fixed Assets S$million	Val.Add/ Labour $'000	Fixed Asset/ Labour $'000	Output/ Firm $million	Val.Add/ Output %
1980	7	878	31.4	10.0	na	11.4	na	4.5	31.9
1985	6	1192	103.2	75.0	na	62.9	na	17.2	72.7
1990[1]	14	2,793	293.8	151.9	189.7	54.4	67.9	21.0	51.7
1995	16	3404	641.8	305.1	215.9	89.6	63.4	40.1	47.5
2000	21	3952	1543.0	820.9	338.6	207.7	85.7	73.5	53.2
2001	24	4510	1655.4	904.9	303.5	200.6	67.3	69.0	54.7
2002	55	4520	1853.2	992.3	329.5	219.5	72.9	33.7	53.5
2003	55	5058	1967.1	1061.7	324.0	209.9	64.0	35.8	54.0
2004	58	5536	1977.0	884.2	342.4	159.7	61.9	34.1	44.7
2005	62	6268	2103	1115.6	509.7	178.0	81.3	36.5	49.2
2006	na	6551	2069	1210	na	184.7	na	na	58.5
-				Average per Annum Growth Rate (%)					
1980-90	7.2	12.3	25.1	31.3	na	16.9	na	16.7	
1990-2000	4.1	3.5	18.0	18.4	6.0	14.3	2.4	13.3	
2000-06[2]	24.2	8.8	5.0	6.7	8.5	-1.9	-1.0	-13.1	
1980-2006[2]	9.1	8.0	17.5	20.3	6.8[3]	11.3	1.2[3]	8.7	

1Data is for 1991

2Calculated using 2005 data where 2006 data is not available

31991-2005

Source: Census of Manufacturing Activities, data from EDB

BMRC. (2007). "Exceptional Growth For Singapore's Biomedical Sciences Industry", downloaded from: http://www.biomed-singapore.com/bms/sg/en_uk/index/newsroom/pressrelease/year_2007/6_feb_-_exceptional.html

Table 1c Profile of the Singapore Biomedical Sciences (BMS) Sector, 1980-2006

Year	No. of Firms	No. Employed	Output S$million	Net Value Added S$million	Net Fixed Assets S$million	Val.Add/ Labour $'000	Fixed Asset/ Labour $'000	Output/ Firm $million	Val.Add/ Output %
1980	24	2148	316.5	148.8	na	69.3	na	13.2	47.0
1985	22	2655	611.1	408.2	na	153.7	na	27.8	66.8
1990[1]	32	4438	1306.9	897.1	383.1	202.1	86.3	40.8	68.6
1995	34	5259	1984.3	1368.6	799.6	260.2	152.0	58.4	69.0
2000	46	5880	6382.1	3819.9	1197.2	649.6	203.6	138.7	59.9
2001	52	6885	6789.6	3702	2388.8	537.7	347.0	130.6	54.5
2002	93	7723	10023.9	5886	2936.6	762.1	380.2	107.8	58.7
2003	95	8642	12184	6808.2	3524.7	787.8	407.8	128.3	55.9
2004	101	9393	17582.8	9812.1	4048	1044.6	431.0	174.1	55.8
2005	105	10171	18311.8	9225.9	4207.3	907.1	413.7	174.4	50.4
2006	na	10571	23003	13565	na	1283.2	na	na	59.0
Average per Annum Growth Rate (%)									
1980-90	2.9	7.5	15.2	19.7	na	11.3	na	11.9	
1990-2000	3.7	2.9	17.2	15.6	12.1	12.4	9.0	13.0	
2000-06[2]	17.9	10.3	23.8	23.5	28.6	12.0	15.2	4.7	
1980-2006[2]	6.1	6.3	17.9	19.0	17.3[3]	11.9	11.0[3]	10.9	

[1]calculated using 1991 data for medical technology
[2]Calculated using 2005 data where 2006 data is not available
[3]1990-2005
Source: Census of Manufacturing Activities, data from EDB; BMRC. (2007). "Exceptional Growth For Singapore's Biomedical Sciences Industry", downloaded from: http://www.biomed-singapore.com/bms/sg/en_uk/index/newsroom/pressrelease/year_2007/6_feb_-_exceptional.html

Table 2 Milestones in the Singapore Biomedical Sector

1987	- Setup of Institute of Molecular and Cell Biology (IMCB)
1995	- Setup of Bioprocessing Technology Institute (BTI)
1998	- Setup of Centre for Drug Evaluation (CDE) - World-renowned Johns Hopkins University setup Johns Hopkins Singapore
1999	- Setup of Genetics Modification Advisory Committee (GMAC)
2000	- Singapore became first Asian country to accede to the Pharmaceutical Inspection Co-operation Scheme, Geneva - Setup of Genomics Institute of Singapore (GIS) - Setup of Life Sciences Ministerial Committee - Agency for Science, Technology and Research (A*STAR) established Biomedical Research Council (BMRC) - Setup of Bioethics Advisory Committee (BAC) - Setup of Biomedical Sciences International Advisory Council (IAC) - Tuas Biomedical Park
2001	- Formation of Biomedical Sciences Manpower Advisory Committee (BMAC) - Lilly setup Biology R&D Centre focused on systems biology - Setup of Bioinformatics Institute (BII) - Groundbreaking of Biopolis - Setup Norvatis Institute for Tropical Diseases (NITD) in Singapore - BioMedical Sciences Innovate 'N Create Scheme
2002	- Setup of Singapore Tissue Network (STN) - Merger of Laboratories for Information Technology and Institute for Communications Research to form Institute for Infocomm Research (IIR) - Setup of Institute of Bioengineering and Nanotechnology (IBN) - Setup of Cancer Syndicate
2003	- Centre for Natural Product Research privatized to become MerLion Pharmaceuticals - Launch of SingaporeMedicine - Launch of Proof of Concept (POC) Scheme - Opening of Biopolis - Establishment of Singapore Dengue Consortium
2004	- Setup of The Regional Emerging Diseases Intervention (REDI) Centre - Setup of The Centre for Molecular Medicine (CMM) - Setup of Chemical Process Technology Centre (CPTC) - Opening of Swiss House - Launch of Singapore Researchers Database - Passage of the Human Cloning And Other Prohibited Practices Bill - Setup of GSK Corporate R&D Centre - Launch of BioSingapore - The National Advisory Committee for Laboratory Animal Research (NACLAR) announced amendments to the Animals and Birds Act to prevent inhumane treatment of lab animals - BAC announced the publication of "Research involving Human Subjects: Guidelines for IRBs"
2005	- Launch of Medtech Concept -Launch of Medtech Local Supplier Group - Chemical Synthesis Laboratory @ Biopolis opened - Goverment accepts Bioethics Advisory's paper 'Genetic Testing and Genetic Research' - Establishment of Singapore Stem Cell Consortium
2006	- New Bioimaging and Stem Cell Laboratories opened @ Biopolis - GMAC releases the Singapore Biosafety Guidelines for Research on GMOs

	- Singapore Government approves S$550 million for Biomedical Sciences Phase 2 - New Executive Committee to lead Phase 2 of Biomedical Sciences initiative -- Sector to get an injection of S$1.44 billion - STaR (Singapore Translation Research) Investigatorship Awards & Translational and Clinical Research Flagship Programme launched - Biopolis Phase 2 officially opened
2007	- Opening of Singapore Institute for Clinical Sciences (SICS) - 11 institutions sign MOU for Singapore Dengue Consortium - Launch of Singapore chapter of the Association for Clinical Research Professionals (ACRP) - Establishment of a Clinical Imaging Research Centre by A*STAR and NUS, with Siemens as industry partner - Launch of Facility Sharing Programme under the Growing Enterprises with Technology Upgrade" (GET-UP) programme, allowing SMEs to have direct access to facilities at 7 A*STAR research institutes - Initiatives endorsed by the Biomedical Sciences IAC: - A*STAR - Duke-NUS GMS Neuroscience Research Partnership - Development of new research infrastructures NUS Kent Ridge Campus and Outram Campus - Proposal to set up a national Academic Clinical Research Organization (ACRO) to provide core services and infrastructure as well as intellectual leadership for later phases of clinical research in Singapore - A*STAR - Duke-NUS GMS Neuroscience Research Partnership announced - MOU signed Ludwig Institute for Cancer Research to establish a branch for translational and clinical cancer research in Singapore - Opening of Institute of Medical Biology (IMB)

Source: A*STAR, Bio-med Singapore

Table 3 Pharmaceutical and Medical Technology Share of Singapore Biomedical Sector, 1980-2006

	Output							
	S$ million				Percentage (%)			
	1980	1990*	2000	2006	1980	1990*	2000	2006
Pharmaceuticals	285.1	1,013.1	4,839.1	20,934	90.1	77.5	75.8	91.0
Medical		293.8						
Technology	31.4		1543	2069	9.9	22.5	24.2	9.0
BMS Total	316.5	1306.9	6382.1	23003	100	100	100	100
	Value-added							
	S$ million				Percentage (%)			
	1980	1990*	2000	2006	1980	1990*	2000	2006
Pharmaceuticals	138.8	745.2	2,999.0	12,355	93.3	83.1	78.5	91.1
Medical	10	151.9						
Technology			820.9	1210	6.7	16.9	21.5	8.9
BMS Total	148.8	897.1	3819.8	13565	100	100	100	100
	Employment							
	S$ million				Percentage (%)			
	1980	1990*	2000	2006	1980	1990*	2000	2006
Pharmaceuticals	1,270	1,645	1,928	4,020	59.1	37.1	32.8	38.0
Medical								
Technology	878	2,793	3,952	6,551	40.9	62.9	67.2	62.0
BMS Total	2,148	4,438	5,880	10,571	100	100	100	100

*Medical technology data is for 1991

Source: Census of Manufacturing Activities, data from EDB

BMRC. (2007). “Exceptional Growth For Singapore's Biomedical Sciences Industry”, downloaded from: http://www.biomed-singapore.com/bms/sg/en_uk/index/newsroom/pressrelease/year_2007/6_feb_-_exceptional.html

Table 4 R&D Expenditure & Manpower in the Biomedical Sector[1], 1993-2006

Year	Private sector	Higher education sector	Government sector	PRIC sector	Total	Total RSEs[2]
			S$million			
1993	3.6	32.1	7.4	0.0	43.1	447
1994	5.0	39.5	14.8	0.0	59.4	386
1995	29.1	37.0	15.3	0.0	81.8	570
1996	7.8	42.4	18.2	0.1	68.5	507
1997	15.0	47.5	25.2	3.5	91.2	556
1998	24.8	52.1	35.6	5.9	118.3	625
1999	37.1	53.1	29.1	3.6	122.9	654
2000	47.0	62.5	32.5	15.6	157.6	1333
2001	88.4	87.3	57.9	77.1	310.7	2055
2002	147.4	106.8	87.5	121.5	463.1	2150
2003	149.3	87.6	91.8	46.7	375.4	2504
2004	238.1	124.9	116.7	280.7	760.4	2238
2005	312.5	150.2	101.4	324.8	888.9	2700
2006	530.7	178.0	114.2	276.6	1099.5	3049

[1] Includes biomedical sciences and biomedical engineering. From 2002 biomedical & related sciences and biomedical engineering.
[2] RSE: No. of full-time equivalent Research Scientists and Engineers
Source: National Survey of R&D in Singapore (various years), A*STAR (previously National Science & Technology Board).

Table 5 Biomedical[1] share of Singapore R&D expenditure & RSEs, 1993-2006

Year	Biomedical R&D expenditure S$ m	Total Sg R&D expenditure S$ m	Biomedical share of total Sg R&D expenditure %	Biomedical RSEs	Total RSEs in Sg	Biomedical share of total Sg RSEs %
1993	43.1	998.2	4.3	447	6,629	6.7
1994	59.4	1175.0	5.1	386	7,086	5.4
1995	81.8	1366.6	6.0	570	8,340	6.8
1996	68.5	1792.1	3.8	507	10,153	5.0
1997	91.2	2104.6	4.3	556	11,302	4.9
1998	118.3	2492.3	4.7	625	12,655	4.9
1999	122.9	2656.3	4.6	654	13,817	4.7
2000	157.6	3009.5	5.2	1333	14,483	9.2
2001	310.7	3232.7	9.6	2055	15,366	13.4
2002	463.1	3404.7	13.6	2150	15,654	13.7
2003	375.4	3424.5	11.0	2504	17,074	14.7
2004	760.4	4061.9	18.7	2238	18,935	11.8
2005	888.9	4582.2	19.4	2700	21,338	12.7
2006	1099.5	5009.7	21.9	3049	22,675	13.4

[1] Includes biomedical sciences and biomedical engineering. From 2002 biomedical & related sciences and biomedical engineering.
Source: National Survey of R&D in Singapore (various years), A*STAR (previously National Science & Technology Board).

Table 6 Share of life science patents in Singapore, 1977-2007

Year	Life science patents	Total Sg patents	Life science patents/ Total patent (%)
1977-99	31	1156	2.7
2000-07	125	4795	2.6
Total	156	5951	2.6

Note: Singapore assigned patents and patents with at least one Singapore inventor.
Following the NBER technological categories, life science patents are taken to be those in drugs, surgery and medical instruments, biotechnology and miscellaneous-drugs and medical
Source: Calculated from USPTO database

Table 7 Breakdown of Singapore life science patents by assignee, 1977-2007

	No. of patents	%
Private	68.5	43.9
NUS	32.5	20.8
Government and PRIC	37.5	24.0
Individual/unassigned	13	8.3
Other foreign institution	4.5	2.9
Total	156	100.0

Note: Singapore assigned patents and patents with at least one Singapore inventor.
Following the NBER technological categories, life science patents are taken to be those in drugs, surgery and medical instruments, biotechnology and miscellaneous-drugs and medical
Source: Calculated from USPTO database

Table 8 Top Pharmaceutical Companies in Singapore, 2005

	Company	Nationality	2005 sales (S$ million)
1	Glaxo Wellcome Manufacturing Pte Ltd	UK	30419.6
2	Merck Sharp and Dohme Asia Pacific Services Pte Ltd	US	2079.4
3	Beecham Pharmaceuticals (PTE) Ltd	UK	562.4
4	DSM Nutritional Products Asia Pacific Pte. Ltd	Netherlands	585.1
5	JMS Singapore Pte Ltd	Japan	120.2
6	Becton Dickinson Medical (S) Pte Ltd	US	114.4
	Total		*3,3881.1*

Source: Singapore 1000

Table 9 Major Foreign Pharmaceutical Companies operating in Singapore

	Company	Business Focus	Date of Establishment[5]	Size of Operation
Manufacturing	GlaxoSmithKline (GSK)	Bulk active biomanufacturing & regional headquarter	1989	>S$1 billion invested. As of 2004, GSK announced an additional $100 million to expand existing manufacturing facility and $50 to develop a Process Technology Centre (to be completed in 2005) 2006 - Vaccine manufacturing plant (>S$300 million). To be completed in 2010
	Schering-Plough	Bulk active biomanufacturing (Clarityne)	1994 1997—began production	3 of 6 manufacturing plants built in Singapore with a total investment of US$730 million in Singapore, 29,000 employees worldwide
	Genset Singapore	Oligonucleotide manufacturing	1997	536 employees worldwide (2000) with manufacturing sites in US, Japan, Singapore
	Wyeth-Ayerst	Biomanufacturing (Infant nutritional, Premelle)	1999 2002—began operation	Will employ up to 600 employees at full capacity
	Aventis	Bulk active biomanufacturing (Enoxaparin)	2000	65,000 employees worldwide
	Pfizer	Active ingredient biomanufacturing	2000 (fully operational in 2004)	241 employees in Singapore as of mid-2003, 98,000 worldwide. 2006 – trigeneration facility
	Merck Sharp & Dohme	Bulk active biomanufacturing (Vioxx, Singulair)	1993[6] (operational in 2001)	>200 employees in Singapore, 62,000 employees worldwide 2007 – expansion of production facilities, S$100 million
	Proligo	Oligonucleotide manufacturing	2002 2004 - oligonucleotide manufacturing operations	13 staff
	Novartis	Pharmaceutical production	2005—ground-breaking of facility. (Completion in 2008)	S$310 million. Will employ 200 people
	Ciba Vision	Contact lens manufacturing	2004—construction of facility began	Will employ > 500 employees
	Lonza	Biopharmaceuticals production	2006	US$250 million
	Fluidigm Corporation	R&D and manufacturing of integrated fluidic circuits	2006	US$250 million
	Edwards Lifesciences Corp	Heart valve manufacturing	2006	8,000 sq ft facility, will employ up to 500 people (expected)
	MDS Sciex	Manufacturing of cellular analysis product, component production for mass spectrometer product lines and the Turbo V ion source	2006 (fully operational by end 2008)	> 30,000 sq. ft. facility, will employ >100 people (expected)
	Waters Corp	Manufacturing of high performance liquid chromatography system	2006 (1994 – Asian HQ)	

[5] Date established in Singapore
[6] Establishment date of Sales and Marketing arm

	Abbott	Nutritional powder manufacturing	2008	US$280 million
Clinical research and trials	Novo Nordisk	Administration, clinical trial coordination	1989—regional HQ 1999—clinical trial center	50 employees in Singapore, 18,221 employees worldwide
	Quintiles	Clinical research organization	1995	60 employees in Singapore, 800 employees in Asia-Pacific, 18,000 employees worldwide Investment of $10 million for clinical trial supplies facility
	Covance	Clinical research organization	1996—Clinical development 2000—Lab site 2006 – expanded lab	118 employees in Singapore, 7,900 employees worldwide Investment of >US$1 million
	Pharmacia & Upjohn	Clinical research & medical services	2000	See note [7]
Research & Development Center	Genelabs Diagnostic	Diagnostic biotechnology	1985	42 employees in Singapore in 2001, 70-90 employees worldwide
	Becton Dickinson	Instrumentation, medical products	1986—Medical product 1991—Regional HQ	1000 employees in Singapore, 2,500 employees in Asia Pacific
	Oculex Asia	Ophthalmic drug delivery systems	1995	13 employees in Singapore, 59 employees worldwide (mid 2000)
	PerkinElmer	Thermal cycler	1998	Opened S$10 million manufacturing and R&D facility
	Sangui Singapore	Blood supplements and therapeutics	1999	5-15 employees in Singapore, 30 employees worldwide (mid 2002)
	Cell Transplants International	Cardiac myoblast therapeutics	2000	15 employees in Singapore
	Schering-Plough	Pilot plant, development laboratories, supplying materials for late-stage clinical trials	2000	Constructing US$25 million Chemical R&D center
	Surromed	Biomarker discovery tools	2001	25 employees in Singapore (2002), closed down in 2004
	Affymetrix	Microarray	2001	R&D center is US$25 million investment, 877 employee worldwide (2002)
	Lilly Systems Biology	Systems biology R&D	2001	29employees in Singapore, 41,000 worldwide
	ViaCell	Stem cell therapeutics	2002	US$4 million invested over a 5-yr period. 138 employees worldwide (2001)
	PharmaLogicals Research	Cancers and other diseases in Asians	2002	S$142 million over the next three years into research on drugs
	Novartis	Institute for Tropical Diseases	2002	Will house 70 scientists in Singapore, 77,200 employees worldwide
	GlaxoSmithKline	Treatment for neurodegenerative diseases and schizophrenia	2004	Investing S$62 million in preclinical research facility. Will employ 30-35 scientists
	Isis Pharmaceuticals	Micro-RNA and antisense drugs to treat Severe Acute Respiratory Syndrome (SARS), cancer and blood diseases	2004	12 scientists by end 2005
	Essilor	New coating and materials technologies	2004	Current staff strength of 8 people, will grow to 25 staff by 2007

[7] On April 16, 2003 Pharmacia was acquired by Pfizer.

	Olympus Corporation[8]	Higher order brain functions	2004	
	Albany Molecular Research	Chemistry technologies	2005	
	Biosensors International	Development and production of drug eluting stents	2005	
	SpineVision	Develop next-generation implants and instruments for non-fusion spinal surgery	2005	
	CombinatoRx	Development of drug candidates for infectious diseases	2006	US$20 million, 20 full-time researchers (expected)
	Welch Allyn	Development of next generation technology for patient vital signs monitoring		
	Oxygenix	Development of therapeutic drugs, including small molecules and biologics	2006	Approx 15 full-time researchers
	Codexis	Biocatalyst R&D for product development	2007	50 researchers
HQ and Distribution	Ferrosan	Supplements and lifestyle products	2003 (2004 – conferred International Headquarters Award)	
	Miltenyi Biotec	Magnetic cell separation (HQ Operations)	2004	
	Philips Medical	Medical imaging equipment (regional distribution centre)	2004 (2007 – Learning Centre for medical diagnostics equipment training)	
	Schering AG	Pharmaceuticals	2005	
Other	West Clinic Excellence Cancer Center	Cancer treatment and management to patients in Southeast Asia	2006	
	Joint Commission International	Evaluation and improvement of quality and safety of patient care (Asia Pacific office)	2006	
	Invitrogen Corp	Provision of scientific supplies to researchers (S$1 million)	2006	
	Eisai	Regional clinical management office (approx 10 staff)	2007	
	SGS	Lab for quality control testing of pharmaceuticals, biopharmaceuticals and medical devices		
	PT Kalbe Farma	Research co-ordination and licensing	2006	

Source: updated from Finegold, D., Wong, P.K. and Cheah, T.C. (2004) based on information from Bio-med Singapore website, http://www.bio-singapore.com and company websites.

[8] Olympus partnered Waseda University to establish the Waseda-Olympus Bioscience Research Institute

Table 10 Establishment of Life Science Public Research Institutes under A*STAR

PRIC	Established	Description
Institute of Molecular and Cell Biology	1987	Established to help develop and support biomedical R&D capabilities in Singapore. Has core strengths in cell cycling, cell signaling, cell death, cell motility and protein trafficking.
Institute of Bioengineering and Nanotechnology	2002	Founded to conduct research at the cutting-edge of Bioengineering and nanotechnology. Has six research areas: nanobiotechnology, delivery of drugs, proteins and genes, tissue engineering, artificial organs and implants, medical devices, and biological and biomedical imaging.
Genome Institute of Singapore	2000	Initially established as the Singapore Genomics Program. GIS pursues the integration of technology, genetics, and biology towards the goal of individualised medicine. Its focus is to investigate post-sequence genomics; to understand the genetic architecture of pan-Asian populations with emphasis on cancer biology, pharmacogenomics, stem cell biology and infectious diseases.
Bioprocessing Technology Institute	1990 (as Bioprocessing Technology Unit); re-designation in 2001	Established to develop manpower capabilities and establish technologies relevant to the bioprocess community. Its core expertise in expression engineering, animal cell technology, stem cells, microbial fermentation, product characterisation, downstream processing, purification and stability, with supporting proteomics and microarray platform technologies.
Bioinformatics Institute	2001	Established to train manpower and build capabilities in bioinformatics. BII's research focus centres around knowledge discovery from biological data, exploiting high-end computing in biomedicine, advancing molecular imaging of biological processes, modelling of drug design and delivery, computational proteomics and systems biology
Singapore Institute for Clinical Sciences	2007	SICS' mission is the development of disease-oriented clinical and translational research programs in focused disease areas.
Institute of Medical Biology	2004 (as Centre for Molecular Medicine); 2007	IMB's mission to study mechanisms of human disease in order to discover new and effective therapeutic strategies for improved quality of life. It focuses on issues at the interface between basic science and medicine. The aim is to facilitate the development of translational research by building bridges between clinical and basic science.

Source: Websites of individual research institutes/centres

Table 11 Dedicated Biotechnology Firms (DBFs) founded in Singapore

	Company	***Business Focus***	**Products/services**	**Date of Establishment**
Drug Discovery	S*Bio	Drug discovery	N/A	2000
	Lynk Biotechnology	Drug discovery and development	Biolyn™ Hair Serum Several leads	2000
	APGenomics	Genomics-based products, services, and technology	Dengue SmartPCR™ diagnostic kit	2000
	Qugen	Gene therapy	3 products nearing clinical	2001
	Agenica	Breast cancer treatment	N/A	2001
	Merlion Pharmaceuticals	Drug discovery	N/A	2002
	ProTherapeutics	Sublingually delivered peptide therapeutics	Analgesic peptide	2004
	SingVax	Prophylactic vaccines for infectious diseases prevalent in the Asia Pacific region	Japanese Encephalitis (JE) vaccine for the prevention of JE virus infection and an Enterovirus 71 (EV71) vaccine for the prevention of Hand, Foot and Mouth Disease (in development)	2005
Medical Devices	Biosensors International	Minimally invasive surgical devices	Catheters, transducers, stents	1990
	SiMEMS Pte Ltd	Manufacture and marketing of MEMS based sensor products that support clinical diagnostics.	Chip based system that accelerates and miniaturizes the process of extracting and detecting DNA	1999
	Forefront Medical Technology[9]	Medical devices used in anaesthesia	Contract manufacturing	2000
	Attogenix Biosystems	Integrated molecular analysis chip with microfluidic technology	High throughput reaction array biochip (AttoChip) and real time sequence detection system (AttoCycler) (to be launched in 2005)	2002
	Merlin Medical	Minimally-invasive medical devices	Coronary stent	2002
	Veredus Laboratories	Diagnostic assays for infectious diseases prevalent to the Asia region	VereFlu (TM) Lab-on-Chip to diagnose all flu types (including avian flu)	2003
	Amaranth Medical	Bio-absorbable stents for peripheral and coronary vascular applications	Bio-absorbable urinary stent and vascular stents	2005

[9] Forefront Medical Technology is a 50-50 joint venture between Singapore company Vicplas International and UK-based Laryngeal Mask Company

	HealthSTATS International	Continuous, non-invasive bio-monitoring devices for hypertension control	BPro®, a medical device allowing hypertension to be analyzed at both the macroscopic and microscopic levels	2005
	Curiox Biosystems	Commercialize and develop the DropArray technology	DropArray - miniaturized aqueous bioassays for drug discovery and other life sciences applications.	2007
Stem Cell	Promatrix Biosciences	Hematopoietic stem cell (HSC) therapy	Has developed a method of constructing multi-cellular tissue to resemble normal tissue	2002/3
	ES Cell International	Stem cell research and production	Human embryonic cell lines	2000
	CordLife	Stem cell banking & therapeutics	Sample collection and counseling services	2001
Bioinformatics	ReceptorScience	Bioinformatics software	ReceptoMiner ™ database and tools	2000
	KOOPrime	IT solutions for life sciences	Platforms, engines, databases	2000
	HeliXense	Bioinformatics platform	Genomics Research Network Architecture	2000
Others	Mycosphere	Fungal diversity, bioprospecting	Contract research	1997
	AP Metrix	Healthcare and patient monitoring	RemoteC@re™ (patient-provider management platform)	2000
	BioSurfactants	Surfactants manufacturing & development	N/A	2001
	Maccine	Preclinical service provider supporting drug development and safety assessment	GLP laboratory facility will be ready by Q1 2006	2003
	A-Bio Pharma	Biologics contract manufacturer	Partnership with GlaxoSmithKline to develop and manufacture vaccines	2003
	NeuroVision	Non-surgical treatment for low-grade myopia and amblyopia	Neural Vision Correction technology	2004-treatment centre
	Davos Life Science	Active ingredients based on natural tocotrienols	Tocotrienol isomers, health supplements Co3E and Co3E + CoQ10,	2004

Source: updated from Finegold, D., Wong, P.K. and Cheah, T.C. (2004). “Adapting a Foreign-Direct Investment Strategy to the Knowledge Economy: The Case of Singapore’s Emerging Biotechnology Cluster”, based on information from Bio-med Singapore website http://www.bio-singapore.com and company websites

Table 12 Profile of NUS Biomedical-Related Spin-off Companies

Incorporated Date	Name	Nature of Business	Founders from NUS	Department
1995	Allegro Science Pte Ltd	Produce and market sequencing and DNA labeling kits	Dr Victor Wong Wong Thi	Biology
1999	BioMedical Research and Support Services	Biological evaluation of medical devices and equipment	Assoc Prof Eugene Khor	Chemistry
2001	BioNutra International Pte Ltd	Nutraceuticals and biopharmaceuticals	Mr Victor Ong Yek Cheng, Assoc Prof Paul Heng, Assoc Prof Yong Eu Leong	Pharmacy
2002	Chiral Sciences & Technologies Pte Ltd	Pharmaceutical and biopharmaceutical intermediates and fine chemicals	Prof Ching Chi Ban, Assoc Prof Ng Siu Choon	Chemistry
2000	ES Cell Pte Ltd	Embryonic stem cell technology	Scientific Advisor, Dr Ariff Bongso	Medicine - Obstetrics and Gynaecology
2000	KOO Prime Pte Ltd	IT solutions provider for the life sciences, bio-mining software	Mr Lim Teck Sin	Center for Natural Product Research
2000	LYNK Biotech Pte Ltd	Drug development technology	Assoc Prof Lee Chee Wee	Medicine - Physiology
1997	Oribiotech Pte Ltd	Develop tumor markers.	Dr Ng Wee Chit	Medicine
2003	OsteoPore Pte Ltd	Biodegradable Bone Scaffold	Prof Teo Swee Hin Dr. Dietmar Hutmacher	Bio-engineering
2003	Quantagen Pte Ltd	Label-free detection technology for gene analysis	Prof Casey Chan	Orthopaedic
2003	BioNano International Singapore Pte Ltd	Biosensors using multi-walled carbon nanotubes	Assoc Prof Sheu Fwu-Shan, Dr Ye Jian-Shan, Assoc Prof Lim Tit Meng	Biological Sciences
2004	ProTherapeutics	Sublingual delivery of peptide therapeutics	Prof Manjunatha Kini, Assoc Prof Ge Ruowen, Assoc Prof Peter Wong	Biological Sciences, Pharmacology
2005	BioMers	Polymer composite products for numerous biomedical applications (orthodontics, dentistry, orthopedics)	Ms Renuga Gopal, Ms Karen Teo, Dr Mervyn Fathianathan	Mechanical Engineering, Restorative Dentistry

Source: National University of Singapore

Table 13: Key Component Industries within Singapore Maritime Cluster

Traditional 'Core' Maritime Sectors	Non Core Maritime Sectors
• Offshore • Shipbuilding & Repair • Shipping Lines • Ship Brokering and Chartering • Port Sector • Wholesale & retail marine equipment • Classification societies and marine surveying services • Shipping Agencies • Ship Management Services • Ship Chandlers • Ship Bunkering • Cruise • Inland Water Transport	• Logistics and supporting services, incl: *Freight forwarding* *Cargo survey services* *Container services* • Engineering and other technical services • Ancillary services, incl: *Maritime legal services* *Maritime finance* *Maritime insurance* *Maritime education & training* *Maritime R&D & technology*

Source: Wong, Ho and Ng (2004)

Table 14: Growth Trends in Singapore Maritime Cluster

	2000	**2005**	**CAGR %(2000-05)**
Direct VA (S$ million)	8,104	14,311	12.10%
Direct VA as Share of GDP (%)	5.1	7.4	na
# of employed	69,257	96,136	6.90%
VA/worker (S$'000)	117	149	4.10%
VA/worker – Economy-wide (S$'000)	74	84	2.10%

Source: Wong, Ho and Singh (2007)

Table 15: Maritime Clusters Value Added, International Benchmarks 2001

	Value Added in USD (2001)		**VA as share of GDP (%)**	
	Maritime VA excluding Non Transportation Services (eg. Legal, Finance)	Total Maritime VA including Services	Maritime VA excluding Non Transportation Services (eg. Legal, Finance)	Total Maritime VA including Services
Denmark	1.9	Na	1.1	Na
Germany	9.7	Na	0.5	Na
Netherlands	4	Na	1	Na
Norway	4.8	Na	2.9	Na
UK	8.6	10.3	0.6	0.7
Hong Kong	3.96	4.04	2.41	2.44
Singapore	4.3	4.4	5.2	5.3

Note:

a. For all European nations except UK, maritime VA excludes non-transportation services such as finance, legal services, insurance
b. Estimates for European countries apart from UK are average over 1999-2001
c. For UK, HK and Singapore, VA is for 2001
d. Singapore's Maritime VA includes Offshore sector

Source: Wong, Ho and Ng (2004)

Table 16: Linkages of Maritime Cluster to Economy

	Output	**Value Added**
Estimated Multiplier, 2005 (based on 2001 I-O tables)	1.39	0.23
Direct Contribution of Maritime Cluster	S$ 79.71 billion	S$14.31 billion
Indirect Contribution of Maritime Cluster	S$ 31.41 billion	S$ 3.45 billion
Total	S$ 111.11 billion	S$ 17.76 billion

Source: Computed from sectoral multipliers provided by Department of Statistics

Table 17: Principal Statistics of Singapore Maritime Sector, 2005

	Value Added			Employment		
	2005	2005	2000-05	2005	2005	2000-05
	($mn)	% share	CAGR (%)	No.	% share	CAGR (%)
Core Maritime Sectors	**12,865.00**	**89.89**	**6.335**	**77,036**	**80.13**	**12.017**
Offshore	978.0	6.83	12.8	8,838	9.19	13.3
Shipbuilding and Repair	1479.9	10.34	10.1	36,688	38.16	11.9
Wholesale/Retail of Marine Equipment/ Accessories	318.1	2.22	4.5	4,063	4.23	6.5
Ship Chandlers	117.6	0.82	8.6	1,950	2.03	12.5
Ship Bunkering	266.0	1.86	14.0	1,238	1.29	42.3
Shipping Lines	3479.1	24.31	-1.0	2,573	2.68	12.7
Cruise	2.0	0.01	14.0	79	0.08	-1.0
Inland Water Transport	284.7	1.99	-2.3	1,916	1.99	2.1
Ship Brokering Services and Ship Chartering	3219.8	22.50	21.7	2,359	2.45	32.0
Classification Societies and Marine Surveying Services	152.7	1.07	6.8	901	0.94	14.1
Shipping Agencies	312.0	2.18	-6.0	3,542	3.68	-1.3
Port	2074.1	14.49	0.8	10,400	10.82	0.6
Ship Management Services	181.0	1.26	-1.7	2,489	2.59	-0.5
Non-Core Maritime Sectors	**1446.9**	**10.11**	**8.7**	**19,100**	**19.87**	**12.3**
Logistics and Supporting Services	1017.9	7.11	6.6	15,642	16.27	7.1
Engineering & Other Activities	120.1	0.84	4.5	859	0.89	32.3
Legal Services (Maritime)	28.4	0.20	3.5	240	0.25	6.5
Insurance, Reinsurance And P&I (Maritime)	86.3	0.60	2.3	398	0.41	19.0
Maritime Related Finance	63.2	0.44	14.5	282	0.29	27.1
Training/Education (Maritime)	37.6	0.26	16.0	570	0.59	12.6
Maritime Related R&D and Information Technology	93.3	0.65	2.8	1,109	1.15	4.4
Singapore Maritime Sector	**14311.9**	**100**	**6.8**	**96,136**	**100**	**12.0**

Source: EDB, DOS and computations from NUS Entrepreneurship Centre Survey of Maritime Ancillary Services

Table 18: Sales Revenue of Marine and Offshore Engineering Industry

Sales Revenue ('000 SGD)	**Offshore**		**Shipbuilding**	**Ship Repair**	**Other Marine Engineering**		**Marine and Offshore Engineering Industry**
	Mfg & repair of oil rigs	Mfg & repair of other oilfield /gasfield machinery & equipment	Building of ships, tankers & other ocean vessels	Repair of ships, tankers and other ocean vessels	Building and repair of pleasure crafts, lighters and boats	Mfg & repair of marine engine and ship parts	
1996	635,110	570,292	623,492	1,765,819	114,345	344,613	4,053,671
1997	685,180	693,900	458,803	1,883,759	99,124	371,108	4,191,874
1998	687,907	832,836	465,856	2,196,496	95,887	322,145	4,601,127
1999	546,618	658,201	402,035	1,984,042	120,111	324,915	4,035,922
2000	318,922	916,749	364,504	1,665,994	141,059	365,825	3,773,053
2001	440,369	1,136,767	449,416	2,325,768	128,887	449,762	4,930,969
2002	977,281	1,045,209	443,048	2,510,931	144,077	527,371	5,647,917
2003	658,538	1,209,661	492,978	2,199,417	158,542	458,328	5,177,464
2004	1,061,525	1,320,759	785,208	2,569,369	143,863	559,524	6,440,248
2005	2,047,241	1,696,337	1,058,242	3,140,156	136,889	706,509	8,785,374
2006	3224299	2214282	1330904	4564192	200204	830109	12,363,990
Growth rate per annum (%)							
1996-2000	-15.82	12.60	-12.56	-1.44	5.39	1.50	-1.78
2001-2006	48.91	14.26	24.25	14.44	9.21	13.04	20.18
Share in Marine & Offshore Engineering Industry (%)							
1996	15.67	14.07	15.38	43.56	2.82	8.50	100.00
2000	8.45	24.30	9.66	44.16	3.74	9.70	100.00
2006	26.08	17.91	10.76	36.92	1.62	6.71	100.00

Source: Economic Development Board

Table 19: Principal Statistics of Marine and Offshore Engineering Industry

	Offshore		Shipbuilding	Ship Repair	Other Marine Engineering		**Marine and Offshore Engineering Industry**
	Mfg & repair of oil rigs	Mfg & repair of other oilfield /gasfield machinery & equipment	Building of ships, tankers & other ocean vessels	Repair of ships, tankers and other ocean vessels	Building and repair of pleasure crafts, lighters and boats	Mfg & repair of marine engine and ship parts	
VA / EMPLOYMENT ('000 dollars per headcount)							
1996	22.6	101.5	70.7	32.0	37.9	50.2	41.9
2000	76.9	138.6	81.3	30.4	47.8	44	49.7
2006	72.6	127.0	129.4	38.5	61.3	35.9	55.0
VA / REVENUE							
1996	0.087	0.42	0.246	0.318	0.265	0.549	0.291
2000	0.438	0.408	0.288	0.322	0.297	0.514	0.367
2006	0.142	0.288	0.240	0.240	0.300	0.433	0.237
FIXED ASSETS / EMPLOYMENT (‘000 dollars per headcount)							
1996	57.6	70.7	79.4	51.2	41.4	41.6	10.8
2000	54.7	67.7	73.8	37.2	34.0	25.5	10.8
2006	23.5	69.4	60.4	22.7	20.8	11.2	9.3
REMUNERATION / EMPLOYMENT ('000 dollars per headcount)							
1996	22.8	52.1	31.4	23.8	28.9	37	28.1
2000	21.1	57.8	32	21.8	26.9	33.3	27.4
2006	37.0	60.3	50.9	22.0	29.9	25.6	29.6
OPERATING SURPLUS / REVENUE							
1996	-0.019	0.155	0.108	0.030	0.025	0.061	0.052
2000	0.255	0.211	0.142	0.059	0.096	0.079	0.129
2006	0.077	0.143	0.148	0.095	0.151	0.092	0.105

Source: Computed from data from Economic Development Board

Table 20: Leading Offshore Engineering Companies

Company	Sales, S$ million (2005)	Profit S$ million (2005)	Founding year and activity	Listed	Principal Activities today
Keppel Fels Ltd	1,458.70	127.9	1967 as Far East Shipbuilding Industries Ltd (FESL), involved in rig building	1969 (FESL) 1980 (Keppel)	Designs, builds, converts, upgrades and repairs mobile offshore drilling units, floating production systems, production topsides and pecialized vehicles
Sembcorp Marine Ltd	2,119.30	125.6	1963, as Jurong Shipyard, focus on ship repair	1987 (Jurong Shipyard)	Specialising in a full spectrum of integrated solutions in ship repair, shipbuilding, ship conversion, rig building, topsides fabrication and offshore engineering.
Labroy Marine Ltd	515.8	55.9	1978, involved in shipping and shipbuilding	1996	Shipbuilding, repair, offshore rig construction and shipping. Entered into the premium rig building market in 2006

Source: Compiled from company annual reports and S1000.

Table 21: Leading Offshore Support Services Companies

Company	Sales, S$ million (2005)	Profit S$ million (2005)	Founding year and activity	Listed	Principal Activities today
CH Offshore	47.6 (USD million)	23.0 (USD million)	1976 as Mico Line Pte Ltd as a offshore service provider	2003	Owns and operates a fleet of Anchor-handling Tug/Supply (AHTS) vessels that provide services to the offshore oil and gas industry
Jaya Holdings (inc Jaya Shipbuilding & Engineeringand Jaya Offshore)	168.9	86.9	1981 as Java Marine Lines, a ship owning company	1994	Fleet Owning and Chartering Operations and Shipyard operations in the building of new vessels. In the 2002, made strategic decision to focus on Offshore Shipping Division and reduce Conventional Shipping Division.
Swissco International Ltd *	13.9	12.4	1970 as Well Industrial and Ship Supply Company, a ship chandler	2004	Marine logistics support services and ship repair and maintenance services to the shipping and offshore oil and gas industries. One of the leading operators of workboats servicing offshore supply vessel services and “Out -Port-Limit” (OPL) marine logistics.
Swiber	25.2 (USD million)	5.7 (USD million)	1996, chartering support vessels	2006	An integrated offshore Engineering, Procurement, Construction, Installation and Commission ("EPCIC") contractor with supporting in-house offshore marine capabilities.
KS Energy Services Ltd	269.1	37.1	1974, company dealing in hardware	1999	Distribution of oil & gas products, procurement, engineering and offshore chartering services

Company	Sales, S$ million (2005)	Profit S$ million (2005)	Founding year and activity	Listed	Principal Activities today
Aqua-Terra Supply Co Ltd**	112.8	6.1	1972, initial focus on product distribution	2004 (Sesdaq) 2006 (Main board)	Service provider and procurement specialist. Material procurement of oil & gas consumables, product distribution for the oil & gas, marine and mining industries
Ezra Holdings Ltd	72.5	36.1	1992 as Emas Offshore, managing and operating offshore support vessels	2003	Offshore support services - chartering of offshore support vessels, ship management services. Marine Services – ship and rig repair, logistics and product sourcing
Singapore Technologies Marine Ltd	659.8	70.3	1968, design, upgrade and build commercial vessels, including offshore supply vessels	1990	Turnkey shipbuilding, ship conversion and maintenance & shiprepair services, design services

Note:
*Swissco's associated company, Swiber Holdings Pte Ltd (now operating as Swiber Holdings Ltd), was publicly-listed on the Stock Exchange of Singapore Ltd in 2006. Before that Swissco had equity accounted for the results of its associated company Swiber Holdings Pte Ltd (Swiber).
**Subsidiary of KS Energy

Source: Compiled from company annual reports and Singapore 1000.

Table 22: Key R&D Indicators for the Singapore Marine Engineering Sector 1993-2006

	R&D expenditure ($m)	RSEs (FTE)
1993	2.21	23
1994	3.39	32
1995	4.85	41
1996	13.15	69
1997	19.09	122
1998	11.64	87
1999	17.99	194
2000	20.95	61
2001	20.53	82
2002	124.8	145.9
2003	16.27	77.9
2004	23.4	90.4
2005	19.01	127.6
2006	20.66	133.9

Source: A*STAR National Survey of R&D in Singapore (various years)

Table 23: Offshore Patents invented in Singapore or assigned to Singapore interests

	Total	**1978-1989**	**1990-1999**	**2000-2007**
FOREIGN ASSIGNEES	**7**	**1**	**4**	**2**
ABB Vetco Gray (Texas, USA)	2	0	2	0
FMC Corporation (Illinois, USA)	1	0	1	0
GlobalSantaFe Corporation (Texas, USA)	1	0	0	1
Schlumberger Technology Corporation (Texas, USA)	1	0	1	0
Dril Quip Inc (Texas, USA)	1	0	0	1
A.R.M. Design Development (SG)	1	1	0	0
SINGAPORE ASSIGNEES	**16**	**2**	**5**	**9**
Keppel Offshore and Marine subsidiaries:	4	0	0	4
Deepwater Technology Group Pte Ltd (SG)	*2*	*0*	*0*	*2*
Offshore Technology Development Pte Ltd (SG)	*2*	*0*	*0*	*2*
Notrans Group (SG)	6	0	4	2
Nortrans Offshore Pte Ltd	*2*	*0*	*0*	*2*
Nortrans Shipping and Trading Pte Ltd	*3*	*0*	*3*	*0*
Nortrans Engineering Pte Ltd	*1*	*0*	*1*	*0*
Prosafe Production Pte Ltd (SG)	3	0	0	3
Individual Assignee (Foster T Manning) (SG)	1	0	1	0
Petroleum Structure Inc (SG)	1	1	0	0
Robin Shipyard Pte Ltd (SG)	1	1	0	0
TOTAL SINGAPORE INVENTED / OWNED OFFSHORE PATENTS	**23**	**3**	**9**	**11**

Note: To identify offshore patents, searched IPC classes E21B, B63B and E02B. The resulting patents were manually vetted for applicability to offshore sector by reading through the full descriptions. Patents applicable to non-offshore vessels are excluded

Source: US Patent and Trademark Office

Table 24: Examples of Private – Public/IHE Collaborations in Offshore Sector

Private Sector Company	**Collaborating Institution**	**Nature of Collaboration**
Sembawang Marine and Offshore Engineering Pte Ltd	National University of Singapore	1. R&D project: "Design Automation for Marine/Offshore Lift Installation of Structures" funded by NSTB. (1996) 2. R&D Project: "Lift Dynamics and Decision Support System for Lift Installation of Structures" funded by NSTB (1998-2001)
Det Norske Veritas	National University of Singapore	Joint Industry Project "FPSO Fatigue capacity" (2001-2003)
Keppel Offshore & Marine	National University of Singapore	Establishing Keppel Professorship on Ocean, Offshore and Marine Technology in Dept of Civil Engineering (2002). Annual Keppel O&M Lecture.
Keyser Technologies Pte Ltd	Nanyang Polytechnic (Marine & Offshore Technology Centre of Innovation)	NP-MOTCI was engaged by the client, Keyser, to create a hydro-forming machine for automating expansion joints manufacturing process (2007)
Keppel FELS Ltd	Nanyang Technological University	Joint R&D for Wave run-up between NTU's Maritime Research Centre and KFELS

Source: Compiled from information from IHEs' websites and annual reports

Table 25: Profile of Keppel FELS and Sembcorp Marine

	Keppel FELS	**Sembcorp Marine**
Summary	The wholly-owned offshore arm of Keppel Offshore & Marine (Keppel O&M), Keppel FELS has a track record of successful conversions of floating production units and jackup rigs. It also designs, builds, converts, upgrades and repairs the complete range of mobile offshore drilling units, floating production systems, production topsides and specialized vessels.	Sembcorp Marine is a leading global marine engineering group, specialising in a full spectrum of integrated solutions in ship repair, shipbuilding, ship conversion, rig building, topsides fabrication and offshore engineering. The company offers a complete suite of turnkey services to serve the offshore oil and gas industry.
Milestones	1967: Incorporation of Far East Shipbuilding Industries Limited - FESL 1969: Listed on Singapore and Malaysia stock exchanges 1970: Renamed as Far East Levingston Shipbuilding Limited – FELS 1978: Formation of Keppel Shipyard 1971: Keppel Shipyard acquired 40% stake in FELS 1980: Keppel Shipyard listed on SEX. Keppel Shipyard took over management of FELS. 1997: Renamed FELS as Keppel FELS 2002: Keppel FELS integrates with Keppel Hitachi Zosen to form Keppel Offshore & Marine Ltd	1963: Incorporation of Jurong Shipyard 1968: Incorporation of Sembawang Shipyard 1987: Jurong Shipyard Ltd is public listed 1988: Jurong Shipyard Ltd acquires Sembawang Shipyard 2000: Name changed to SembCorp Marine Ltd

	Keppel FELS	**Sembcorp Marine**
Key Acquisitions	1990: 60% equity interest in AMFELS, Texas, USA (1992, AMFELS becomes fully owned subsidiary of FELS) 1994: FELS Baltech (Bulgaria) is incorporated 1995: 40% stake in Offshore & Marine A.S., Norway 1999: 77.3% interest in Singapore Petroleum Company (SPC) 2002: Acquires Velrome Botleck, Netherlands, and renames it Keppel Velrome	2001: Acquisition of 50% of PPL Shipyard (Singapore), 35% of Maua Jurong (Brazil) 2002: Acquisition of 20% of Cosco (Dalian) Shipyard (China); complete acquisition of PT Karimun Sembawang Shipyard (Indonesia) 2003: Acquisition of additional 35% of PPL Shipyard (Singapore) 2004: Acquisition of 30% of Cosco Shipyard Group (China), the enlarged group comprising five shipyards in the key coastal cities of Dalian, Nantong, Shanghai, Zhoushan and Guangzhou 2005: Acquisition of Sabine Industries Inc. (Texas, USA) 2006: Acquisition of SMOE Pte Ltd, Sembawang Bethlehem Pte Ltd
Evolution	1960's, 1970s : 3 projects to fabricate jackup rigs and drillships 1980's : First contract from an oil company (CONOLCO) positions Keppel FELS as a world class rig builder. In this period, more than 10 contracts are secured, including first contract for deepwater drilling rig. 1990's:	1960's to mid 1970s : Focus on shipbuilding and ship-repair 1975 to mid 1990s: Deepened capabilities in Shipbuilding and Ship-repair Introduction of ship conversion and offshore activities : jumboisation, reefer ship conversion 1995-2000: Niche shipbuilding and design and construction of large

	Keppel FELS	**Sembcorp Marine**
	Keppel FELS enters into consortia, alliances and co-ownership arrangements as part of its expansion strategies. In this period, Keppel FELS clinches its first few contracts to fabricate FPSO vessels. In the late 1990's, FELS begins offshore conversion projects. In 1993, Offshore Technology Development (OTD), a wholly owned subsidiary, is set up to develop proprietary technologies in offshore construction 2000's: Offers integrated total solutions, including newbuildings of jackup rigs and mobile rigs, upgrades and conversions of jackups and semisubmersibles, offshore repairs and design and engineering. In the last decade, Keppel FELS has consolidated position as world's leading designer and builder of jackup rigs, and FPSO and FSO conversions. Niche player in specialized conversions and constructions – including small to medium sized customized vessels such as Anchor Handling Tug Supply vessels, multipurpose support vessels and cable ships.	container vessels Introduce capabilities for offshore conversions: conversion of tankers to FPSO and FSO Commencement of offshore engineering activities: repair and upgrades of jack-ups and semi-submersibles 2000's: Proprietary designs of container vessels and design and construction of even larger container vessels Offers full range of offshore conversions: FPSO, FSO, FPU and specialized FPSO conversions, EPIC FPSO conversion Introduces Rig-Building service: construction of semi-submersibles and jackups Offshrore Production: Fixed Production Platforms, and floating production facilities: FPSO, FPU, TLPs, SPARS

Source: Company Annual Reports, corporate websites

Table 26: Turnover and Net Profit for Keppel O&M Ltd and Sembcorp Marine Ltd, 1993-2005

	Sales/Turnover (S$ million)		Net Profit (S$ million)	
FY	**Keppel Offshore & Marine Ltd (Keppel FELS figures in brackets)**	**Sembcorp Marine Ltd**	**Keppel Offshore & Marine Ltd (Keppel FELS figures in brackets)**	**Sembcorp Marine Ltd**
1993	-252.8	379.8	-27.3	68.8
1994	-500.9	334.1	-47.1	52
1995	-654.2	325.4	-50.4	39
1996	-855	357.2	-54.6	35.5
1997	-1094.7	665.1	-21	47.6
1998	-969.5	933.7	-20.2	72.9
1999	-386.7	921	-54.7	76.8
2000	-220.5	763	-85.3	75.3
2001	-350.3	854.5	-111.4	80.9
2002	1889.4 (702.1)	1011.5	202.9 (101.7)	93.2
2003	1441.9 (409.8)	1068	109.6 (100.0)	78.2
2004	2393.6 (863.3)	1362.8	191.9 (99.8)	98
2005	4068.0 (1458.7)	2119.3	228.4 (128.0)	125.6
2006	5743.4	3545.1	458.8	228.2

Note: Keppel Offshore and Marine Ltd incorporated in 2002, no financial figures prior to 2002
Source: Singapore 1000 (various years); Company annual reports