COMMENTARY

Advancing innovation through R&D the A*STAR way

Lim Chuan Poh
Agency for Science, Technology and Research, 1 Fusionopolis Way, #20-10 Connexis North Tower, Singapore 138632

[DOI: 10.1116/1.3519874]

I. NEED FOR RELENTLESS INNOVATION THROUGH R&D

The need to innovate in this rapidly changing economy to create new and higher value is given. At the Agency for Science, Technology and Research (A*STAR), innovation is our raison d'etre to help create the future of Singapore.

Data Storage Institute (DSI) is one of A*STAR's research institutes (RIs). It was established to support the growth of the data storage industry in Singapore. In the early days of DSI in the 1990s, one in two disk-drives worldwide was made in Singapore. Over time, the production of such disk-drives began to move to lower cost countries. DSI continued to develop new capabilities and innovate and supported the shift of the data storage industries toward higher value-added activities.

Today, eight out of ten higher value-added high-end enterprise drives and nearly five out of ten hard disk media are manufactured in Singapore. These growth and success of the data storage industry in Singapore have also persuaded key industry players, such as Seagate, Fujitsu, EMC, Seiko, and Nitto Denko, to establish corporate R&D laboratories in Singapore. Seiko and Nitto Denko, in particular, are now colocated with DSI in Fusionopolis—the science and engineering hub in Singapore. We are mindful that these companies will remain in Singapore for as long as we continue to offer a competitive value proposition.

This is why DSI has to continue to look ahead to build capabilities to support the key industry players on developing next-generation products such as cost-competitive nonvolatile memory devices and high density magnetic storage at 10 Tbytes/in.^{2}.

The challenge therefore is how to do this right by leveraging on what little natural or man-made advantages that Singapore has to sustain Singapore's competitive advantage. This is the only way for us to achieve our mission to foster world-class research and talent for Singapore in this knowledge-based and innovation-driven world, and it is how we can contribute toward establishing Singapore as Asia's innovation capital.

II. CAPITALIZING ON THE NATURAL ADVANTAGES OF OUR ENVIRONMENT

There are inherent strengths in Singapore that we can capitalize on to innovate so as to achieve our mission. The Massachusetts Biotechnology Council's April 2009 report on "Strategic Outlook for 2015 and Strategic Plan," noted that Singapore, an emerging biotech cluster, was "aiming to move up the value chain and position itself as a world-class center for R&D through significant government investment." It noted that Singapore's key strengths lie in the following:

(1) supportive government committed to R&D,
(2) integrated and well-connected public sector,
(3) educated and skilled workforce, and
(4) supportive business and regulatory environment.

These strengths enable A*STAR to adopt certain differentiating strategies at various stages of our development to achieve our mission. Some of these strategies include the following:

(1) creating the biomedical sciences hub in Biopolis to jump-start the development of biomedical sciences (BMS) R&D efforts,
(2) establishing the science and engineering hub in Fusionopolis in close proximity to Biopolis to spearhead multidisciplinary and cross council research in A*STAR,
(3) collaborating with industry in R&D through responsive innovation platforms,
(4) partnering clinicians in hospitals for bench to bedside translational work and biomedical engineering innovation, and
(5) enthusing and providing young people with many opportunities to pursue the study of science and a career in R&D.

III. CREATING THE BMS HUB IN BIOPOLIS AND JUMP-STARTING BMS R&D

A. The BMS initiative

Since its inception in 2002, A*STAR has been the engine that powers the BMS R&D. BMS was then identified as a new growth area in Singapore. Once a strategic decision was taken to proceed, A*STAR quickly set out to create the BMS cluster and build Biopolis from scratch to be a BMS hub of the world.

In the first phase of the BMS initiative (2000–2005), key building blocks were put in place to establish core scientific BMS research capabilities through the development of hu-

man capital, intellectual capital, and industrial capital. In the second phase of the initiative (2006–2010), the focus was on strengthening basic research while building new capabilities in translational and clinical research. This allows scientific discoveries from the bench to be translated to the bedside to improve human health and healthcare delivery, and ultimately contribute to the economy and bring benefits to society.

B. Attracting and developing human capital

A*STAR's undergirding strategy in R&D is talent. We recognize early that knowledge creation and value-generating R&D activities go where there are world-class research talent and technological expertise. With a limited population base of only 5×10^6 in Singapore, there is a pressing need to devise a holistic talent strategy to attract and develop world-class scientists, both local and international, at all levels and areas in its R&D landscape.

Internationally renowned scientists were attracted to come to A*STAR to pursue their passion in science, and help Singapore develop new capabilities and create new knowledge. They include top scientists such as Edward Holmes and Judith Swain from University of California, San Diego, Edison Liu, Neal Copeland and Nancy Jenkins from National Cancer Institute, David and Birgit Lane from the University of Dundeee, UK, as well as Jackie Ying from MIT. They helped to jumpstart Singapore's BMS efforts, provide leadership to the RIs under A*STAR and mentor young scientists in the RIs.

To ensure that we have a strong pipeline of young talent to support the growing BMS research and manufacturing activities, A*STAR also provides a slew of scholarships for the most capable and committed young Singaporeans to pursue undergraduate and graduate scientific training in top universities locally and around the world. Many of our scholars and fellows can be found in top U.S. and UK universities. According to Stanford University president, Professor John Hennessy, Singapore has the highest per capita Ph.D. students in Stanford with almost all of them on A*STAR's scholarships. In addition, A*STAR also offers many opportunities for top international students to pursue all or part of their research training in Singapore.

C. Building intellectual and industrial capital

Today, A*STAR's biomedical medical research council (BMRC) has seven RIs and five research consortia under its umbrella. We have also built up considerable strengths in six key research areas spanning the whole spectrum of BMS research from basic to translational and clinical research. The research areas include biomedical engineering and bioprocessing; cancer genetics; infectious disease and immunology; metabolic diseases; molecular, cell, and development biology; and stem cells and regenerative medicine. These are well supported by platform technologies such as bioimaging; bioinformatics and genomic sequencing capabilities. Taken together, they are aligned with four main industry sectors—biotechnology and biologics, healthcare services and delivery, medical engineering and technology, and pharmaceuticals.

The BMRC research institutes and research consortia are housed in Biopolis, the BMS hub. Biopolis has grown into an integrated R&D complex with more than 2×10^6 ft^2 of space. It also houses corporate laboratories of international and local pharmaceutical and biotechnology companies. This colocation of private and public sector research is a unique feature of Biopolis. It enables scientists from A*STAR and industry to exchange ideas and explore collaborations, thus facilitating the commercialization of our research outputs. It also enables private sector laboratories to make use of shared infrastructure, such as research equipment, core scientific services, and conference facilities that also support the public sector institutes. Together with the many residential, recreational, and entertainment options in the immediate vicinity, Biopolis is an excellent plug-and-play location for industry R&D with access to world-class scientific collaborators within the A*STAR RIs.

D. Success of BMS R&D and Biopolis

Singapore's BMS R&D efforts have elicited positive attention internationally. In May 2007, Massachusetts governor, Deval Patrick, was quoted by Boston Globe as saying that Singapore was one of the top "competitor states and foreign nations" to Massachusetts' life sciences initiative when he announced his $1 billion life sciences initiative at BIO International Convention 2007. The same report noted that the administration felt that one of the top "challenges" for Massachusetts' initiative was that "the United Kingdom, Ireland, China, and Singapore had developed coordinated strategies to attract researchers and companies." Across the Atlantic in the United Kingdom, Lord Martin Rees, the President of the Royal Society, and the Master of Trinity College in Cambridge, was quoted in an article by the Press Association in December 2008 as comparing Biopolis favorably with the UK Center for Medical Research and Innovation (UK CMRI). He said that just as Biopolis in Singapore had sent a signal, the creation of the UK CMRI would send a signal from London to raise the standing of science.

In terms of private sector BMS R&D, Singapore has fared well. Today, more than 100 global biomedical sciences companies are carrying out strategic business operations ranging from regional headquarters to cutting-edge research and manufacturing in Singapore. These include companies such as Abbott, Roche, GlaxoSmithKline, Merck, Novartis, Pfizer, Schering-Plough, Wyeth, Siemens, and Becton-Dickson. In terms of economic outcomes, the manufacturing output for BMS of S$21 billion in 2009 was more than a threefold increase from the S$6.3 billion in 2000. BMS's share of Singapore's total manufacturing output had also increased from 3.9% in 2000 to 10% in 2009. The compound annual growth rate (CAGR) from year 2000 to 2009 was 14%—a good indication of Singapore's strong and steady progress in

building up its BMS R&D capabilities. There were also slightly more than double the jobs in this sector by 2008, up from less than 6000 jobs in 2000.

Biologics manufacturing is a prime example of how Singapore's efforts to build up BMS R&D capabilities have successfully attracted large-scale industry investments. The efforts by A*STAR's Bioprocessing Technology Institute (BTI) to develop its bioprocessing capabilities as well as skilled talent in the field attracted leading biologics manufacturing multinational corporations (MNCs), such as GlaxoSmithKline, Baxtor, Roche, and Lonza, to set up commercial-scale biologics manufacturing plants in Singapore, which will potentially employ 1300 staff and bring in more than S$2.5 billion in investments. Building upon this success, A*STAR's Singapore Stem Cell Consortium and BTI engaged Lonza in further discussions which culminated in the recent establishment of a the Cell Therapy Manufacturing Facility in Singapore, the first one set up by Lonza outside the U.S. and Europe. This facility will support and catalyze the growth of stem cell therapies in the Asia-Pacific region.

Some significant breakthroughs have also been made in the laboratories with significant impact on society. In 2007, a team of researchers from the Institute of Bioengineering and Nanotechnology developed the microfluidic device and chemical kit that is capable of detecting the Influenza A (H5N1) virus using a simple swab sample from the throat. During the outbreak of the Influenza A (H1N1) virus, the device was adapted to detect the Influenza A (H1N1) virus within 2 h when it used to take days. With its unique ability to perform automated and speedy gene extraction and gene detection on a wide variety of biological samples including tissues and body fluids, this technology is now further developed for the fast and accurate detection of cancer and other infectious diseases. It is now licensed by SG Molecular Diagnostics, a local company. Besides this microfluidic device, A*STAR has also commercialized other technologies, resulting in spin-off companies such as VeriStem, Curiox Biosystems, and MerLion Pharmaceuticals.

IV. ESTABLISHING FUSIONOPOLIS AND VENTURING INTO CROSS COUNCIL RESEARCH

BMRC's counterpart, Science and Engineering Research Council (SERC), has a longer history in R&D with some institutes such as Data Storage Institute and Institute of Microelectronics having their roots in the 1990s. Currently, it has seven research institutes and one center. The SERC RIs have built up strengths in eight key areas, namely, biotechnology, chemistry, computational and device technologies, information, communications and media, materials, manufacturing technology, mechatronics and automation, and metrology. Their research areas are also aligned with four main industry sectors, namely, electronics, infocomm, chemicals, and engineering.

Combined, BMRC and SERC have a spectrum of deep capabilities between them that make it possible for them to vastly open up the space for research and innovation through multidisciplinary and cross council collaborations. Such an approach to research is particularly critical in an age where problems are so complex that they need solutions that lie not in a single discipline, but in interfaces between disciplines and from multiple sources. This concept is well accepted and actively pursued by top research universities and centers with varying degrees of success.

Opening of Fusionopolis

A*STAR has a slight edge in this area of engendering multidisciplinary research by turning a natural constraint of lack of geographical size into an advantage of collocating research institutions. In 2008, A*STAR opened Fusionopolis[1] as the science and engineering hub with the intention of bringing together the diverse capabilities of the SERC RIs in a compact location. Fusionopolis, which will also be home to public sector agencies and the private sector companies, is an emblem of community, collaboration, and cooperation. It is designed to facilitate the coming together of talent from different scientific disciplines and sectors, and create opportunities for them to contribute their capabilities as a vibrant and collaborative community.

This physical proximity of Fusionopolis to Biopolis, only 600 m apart, is the natural advantage for A*STAR to drive cross council research both in an organic manner and at the organizational level. Opportunities are therefore available for researchers from either council to meet serendipitously. These encounters may help to engender conversations which may spawn new ideas and lead to research collaborations further down the road. To further facilitate dialog between researchers from BMRC and SERC, and foster multidisciplinary and cross council research, A*STAR set up the A*STAR Joint Council in 2009. The joint council organizes meetings and scientific conferences to bring researchers from the two councils together to share their various research projects with one another, as well as provided platforms and funding for supporting cross council research. This is intended to be catalytic to foster a collaborative environment within the research community.

Although cross council research at A*STAR is in its nascent stage, it is heartening that we are taking small, but meaningful steps toward such collaborative research. We are beginning to see some successes in the work-in-progress, e.g., the research on a home-based medical diagnosis system or the intelligent toilet bowl. This project brings together researchers from disparate scientific disciplines, such as infocomm and materials science from SERC, and molecular and cell biology from BMRC, to research on how to detect and make a quick and accurate diagnosis of certain illness and diseases from the qualitative analysis of certain biomarkers in a urine sample. This collaborative effort aims to make healthcare delivery more accessible to people in the future. Another example is the development of the fastest and least

[1)] Fusionopolis currently houses two of SERC's RIs. By 2014, all of SERC's RIs, with the exception of the Institute of Chemical and Engineering Sciences will be colocated together in Fusionopolis.

expensive DNA sequencing device based on pyrosequencing chemistry and high resolution image sensing. This project brings together the vastly different expertise of DNA sequencing from BMRC, and image sensor development and microfluidics from SERC.

One area of research that will benefit greatly from cross council research is biointerphase science research since it requires the knowledge and expertise of researchers from a diverse range of disciplines such as biology, physics, chemistry, and materials science. With the space and platforms readily available for researchers to explore cross council research, it only follows that new knowledge will be created, innovative scientific advances made and ingenious technologies developed to deal with the many challenges prevalent today and in the future.

A*STAR's ability to affect cross council research is what many research hubs have hoped to do but have not yet achieved. The ability to integrate diverse research capabilities from the two councils and achieve the maximum impact is A*STAR's one significant value proposition to industry.

V. COLLABORATING WITH INDUSTRY IN R&D THROUGH INNOVATION PLATFORMS

The concept of collaboration in research extends beyond the A*STAR RIs to include industry players as well. In line with the recommendations of the Economic Strategies Committee's subcommittee on "Growing Knowledge Capital"[2] to establish Singapore as Asia's innovation capital—a vibrant hub for knowledge creation, innovation, and enterprise, A*STAR is taking the lead to engage and partner industry in R&D so as to grow innovation capital. Innovation capital refers to our ability to translate ideas to the marketplace and create value from our R&D investments. To achieve this, we are aligning some of our knowledge creation efforts with the marketplace and put in place innovation platforms that offer flexible and customized approaches to cater to the needs of different types of enterprises and foster research collaborations among the different R&D players. These enterprises include MNCs, globally competitive companies (GCCs), small and medium enterprises (SMEs), and high tech startups. Our approach will also capitalize on the advantages of our environment, in particular that of a "whole of Singapore" approach, to enable us to integrate our efforts and build greater collaboration and alignment between the public and private sector.

One of the innovation platforms we have developed is the research consortium to foster research collaborations among different R&D players. An example is the A*STAR Aerospace Consortium, set up in 2007, which brings together 18 companies from the aerospace industry. The companies include aerospace industry giants such as Boeing, EADS, Pratt & Whitley, and Rolls Royce; other MNCs such as BASF, Sonatest, and IDI Laser Services; local GCCs such as SIA Engineering Company; and SMEs such as IDI Laser, Sunny Instruments, and TruMarine. These companies come together to collaborate with our various SERC RIs in precompetitive R&D that are valued by the industry. Such a platform will create new knowledge for use globally as well as enable the Singapore aerospace industry to grow and move up the industry value chain—from the current service-oriented activities in maintenance, repair, and overhaul to higher value-added R&D such as design and manufacturing. By teaming up SMEs with MNCs through the Aerospace Consortium, we are also nurturing a local supply chain and open up business opportunities for the local enterprises.

The three-dimensional through-silicon via (3D-TSV) consortium is another example of research consortia innovation platform that A*STAR established last year. This consortium brings MNCs and local research institutes together to research on 3D-TSV, touted to be a key alternative enabling technology to boost next-generation wafer manufacturing capability. This will make electronic devices smaller than ever and give our semiconductor industry a leg-up to get it ready for the next wave of product miniaturization. Other more recent examples include Micro-Electro-Mechanical-Systems (MEMS) Consortium and the Industrial Consortium on Nanoimprint (ICON).

VI. PARTNERING CLINICIANS IN HOSPITALS FOR BIOMEDICAL ENGINEERING RESEARCH

By 2008, the BMS landscape in Singapore has evolved greatly. Besides the biologics and pharmaceutical industries, the healthcare services and medical technology industries are also growing. By then, the medical technology industry already had an output of S$3 billion and employed more than 8000 people in Singapore in 2008. It has also seen early successes in attracting leading MedTech companies, such as Hill-Rom and Siemens Medical, to invest in R&D in Singapore. A total of 30 MedTech companies with manufacturing activities hiring more than 400 researchers, scientists, and engineers have been set up in Singapore then. The prospect of the medical technology in Singapore looked bright, given the growing Asian market and the need for companies to customize their products and services to this market. This is why A*STAR decided to give this sector a decisive push.

A*STAR has the natural advantage of venturing into medical research technology. Research in this area is characterized by cross-disciplinary research collaborations among clinicians, biomedical scientists, and engineers, and it is defined by a constant flow of innovation to develop meaningful solutions to address complex medical problems. A*STAR, with the spectrum of capabilities in basic BMS research and translational and clinical research, and our traditional strengths in physical sciences and engineering research, plus the capacity to advance cross council research collaborations, was in a unique position to give the medical technology industry an added push to develop it further.

We, therefore, launched the Biomedical Engineering Program in 2009 and created opportunities for A*STAR researchers to collaborate with clinicians in hospitals. Under

[2]Economic Strategies Committee. August 11, 2010. http://www.esc.gov.sg/attactments/Subcommittee%20on%20Growing%20Knowledge%20Capital.pdf

this program, grants are awarded to research projects helmed collaboratively by research engineers at A*STAR and clinicians in local hospitals, and involving researchers from the universities and hospitals. These projects aim to develop and provide cost-effective, innovative, and clinically impactful solutions for healthcare systems. With the active participation of clinicians who understand the needs of their patients, these projects will be highly relevant to patients and be able to meet their needs. The intention is for these innovations to eventually be developed for the local, regional, and international markets.

Two examples of on-going projects are the advanced rehabilitation therapy for stroke based on brain-computer interface jointly led by Dr. Guan Cuntai from the Institute for Infocomm Research and Dr. Karen Chua from Tan Tock Seng Hospital, in collaboration with Dr. Ang Beng Ti from National Neuroscience Institute. This project makes use of the novel and award-winning technology of the brain computer interface also developed by Dr. Guan, and improves on it to achieve a holistic and comprehensive system for advanced rehabilitation therapy for stroke patients. Another project is automatic glaucoma diagnosis and its genetic association study through medical image informatics (AGLAIA) led by Dr. Jimmy Liu from I^2R and Professor Wong Tien Yin from Singapore Eye Research Institute. When it is developed, AGLAIA will be the first of its kind software system that will be able to detect and diagnose glaucoma in the general populace in a cost-effective and efficient manner.

To augment the medical technology research, A*STAR also designed the A*STAR-Center for Integration of Medicine and Innovative Technology (CIMIT) program in 2009, which is an adaptation of the model by the Boston-based research consortium, CIMIT. Under this program, opportunities will be created for engineers, clinicians, and BMS scientists in Singapore to work with clinicians in Boston to come up with engineering solutions that have clinical and market relevance. This will allow us to leverage on CIMIT's existing technologies and best practices which will significantly shorten our own innovation cycles. The collaboration will result in the codevelopment of intellectual property between A*STAR, the universities, hospitals, and CIMIT in time to come. This will accelerate the commercialization of innovative medical technologies and also give rise to high tech start-ups.

In addition, A*STAR also established the Singapore-Stanford Biodesign (SSB) program this year to train teams of young professionals from diverse backgrounds, from the medical, engineering, and business disciplines, to develop innovative medical devices to address Asia's growing healthcare needs. The SSB will also start innovation classes in NUS and NTU to equip graduate students with the skills to participate in the I&E value chain. They will be able to participate as innovators, technology transfer professionals, patent agents, and start-up mentors to lead and carry out R&D and R&D commercialization activities to achieve economic impact.

VII. CONTRIBUTING TO THE SINGAPORE ACADEMIC SYSTEM

We recognize the need to develop a pipeline of local scientific talent who will form the core group of researchers in A*STAR and Singapore. To that end, A*STAR has been providing plenty of opportunities to young Singaporeans to pursue their passion in science and realize their potential through our various scholarship and investigatorship programs.

The scholarships include the national science scholarship for top young Singaporeans to pursue undergraduate studies all the way to Ph.D. levels at top overseas universities, and the A*STAR graduate scholarship which gives top local graduates from NUS and NTU a chance to do their Ph.D. training at nine prestigious universities locally and abroad[3] through a sandwich Ph.D. program. In addition, A*STAR also offers Ph.D. graduates from NUS and NTU who are keen on a life of research the A*STAR international fellowship. This gives them the chance of undertaking a two year fully funded postdoctoral training at top overseas universities and private sector laboratories of their choice. Such training will expand their research experience, deepen their domain knowledge as well as enable them to establish networks and linkages with international researchers.

To date, we have exceeded our target of awarding 1000 scholarships to local talent to be trained at the Ph.D. levels and beyond. Of this number, about 240 of the scholars and fellows have completed their Ph.D. training and are working in the various A*STAR research institutes. However, we are not resting on our laurels and will continue attracting promising young talent to pursue a career in research.

Attracting and developing promising international talent

In addition to local scientific talent, we are also adding diversity to the research environment by attracting top foreign Ph.D. students and postdoctorals from all corners of the world. They not only add color to the environment in A*STAR and the local universities, but they also partner us in contributing toward Singapore's development as a knowledge-based and innovative-driven economy. For many of them, they will also become the future bridges that link A*STAR to the research communities in their host countries. Some of the programs we have put in place to bring in top talent at different levels include the A*STAR Investigatorship Program, the Singapore International Graduate Award and the A*STAR research attachment program.

[3] the universities include the following: Carnegie Mellon University, Imperial College London, Karolinska Institutet, Nanyang Technological University, National University of Singapore, University of Cambridge, University of Dundee, University of Illinois at Urbana-Champaign, and University of Oxford.

VIII. CONCLUSION

The various plans have been put in place to advance R&D in BMS. These include multidisciplinary and cross council research, partnering industry for growth through customized innovation platforms, collaborating with the clinical community to advance biomedical engineering research, and attracting and developing local scientific talents. The plans are carefully designed and implemented, and are made possible because of the inherent strengths in the Singapore system to be able to plan and act long term. They are a record of the efforts made by A*STAR to innovate relentlessly with the times to help Singapore sustain its competitive advantage.