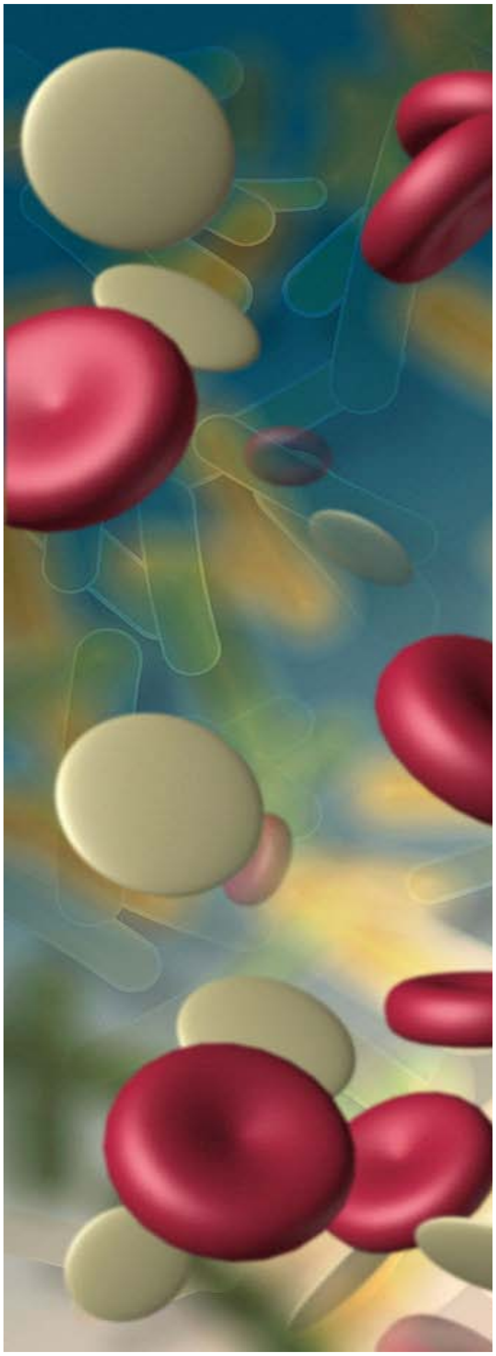

Science & Technology Value Creation (STVC) 2015 Panel Report

Healthcare, Wellness & Aging

A*STAR
Science and Engineering Research Council

Healthcare, Wellness and Aging

Contents

Executive Summary

The vision of the Healthcare Wellness and Aging Panel is to establish coordinated interdisciplinary research programmes in medical technology and systems to enable healthcare professionals and caregivers to deliver higher quality of care for patients; to enable a high quality of life for the elderly population, and to provide technology for diagnosis and cure of disease. The research programmes are applications-oriented and are enabled by scientific capabilities and technology in wireless communications, materials development, data storage and data mining, imaging, and chemical synthesis.

The Science & Technology Value Creation (STVC) 2015 Healthcare Wellness and Aging Panel included experts from A*STAR and external government agencies such as Economic Development Board, SPRING Singapore and the Ministry of Health. Through a series of extensive discussions using the Siemens Picture of the Future framework, panel members have proposed research programmes under this theme which will create economic impact and meet national needs.

The panel first identified the scope of the research area, and selected aging, assisted living, remote health monitoring, hospital equipment, drug discovery and delivery. The 6 programmes which are proposed are:

1) **Right Siting of Care**
2) **Point of Care Diagnostics**
3) **Neurotechnology**
4) **Intelligent Personal Protective Equipment**
5) **Medical Management and Monitoring**
6) **Portable Medical Devices and Digital Pathology**

The proposed programme in **Right Siting of Care** covers development in assisted living, care for the aging in homes and remote health monitoring. **Point of Care Diagnostic** seeks to improve testing and diagnostic devices, such as advanced disposable test kits, for the accurate and early detection of diseases. Due to increasing awareness of psychiatric disorders and neurological conditions, the proposed programme in **Neurotechnology** will bring about greater development in psychiatric diagnosis and neuorological treatments such as deep brain simulation. **Intelligent personal protective equipment** is novel or improved protective equipment with the corporation of sensors or detectors primarily for enhanced personal protection, to ensure the safety of healthcare workers and caregivers. **Medical Management and Monitoring** refers to tracking patient medication taking, and the sharing of patient information between consumers, clinicians, inpatient and emergency services, pharmacists and organisations that provide health insurance and pharmacy benefits, in order to support relevant aspects of the medication management cycle with better interoperability and efficiency. **Portable Medical Devices and Digital Pathology** involves the development of tools which meet the demand for more rapid pathology; to be facilitated by automated data analysis, by high throughput techniques

With an aging population, shrinking household size, and a shift of emphasis towards preventative healthcare, the panel considered that the 6 programmes could have significant economic potential and meet national priorities in healthcare in Singapore. By exploiting the strengths of the research institutes, and linking with clinicians and scientists in the healthcare services, A*STAR can create cutting edge technologies that will put Singapore on the world map in these multi-disciplinary areas of Healthcare, Wellness and Aging research.

Chapter 1 Introduction

1.1 Introduction

Singapore is an affluent urbanised society with an aging population. Primary healthcare which addresses the fundamental needs of the population is readily accessible. In recent years, growing affluence has become a driver for hospital-based specialised care, and high quality medical technology. Globalisation and regional competition have also opened up new growth areas in health services and medical tourism. This is pushing national health systems towards borderless market-based services.

Owing to the city state's well established infrastructure and efficiency, it is in a unique position as a test bed for technologies for health, wellness and aging. A number of test bed platforms in the healthcare space already exist today. For example, Infocomm Development Authority of Singapore (IDA) has a joint call in collaboration with the Ministry of Health with the objective of encouraging the use of infocomm technologies to enable the healthcare sector. The Ministry of Community Development, Youth and Sports, which is promoting active aging and aging-in-place has also launched the Silver Community test bed programme for companies to test bed their technologies in HDB homes. These programmes focus more on deployment than on the invention of new tools and equipment.

A*STAR's STVC 2015 research programmes under the theme of Healthcare Wellness and Aging are proposed with potential economic impact and the fulfilment of Singapore's future needs in mind. They will complement existing programmes in Healthcare launched by other government agencies to achieve significant economic and social outcomes

The Healthcare, Wellness and Aging panel, comprising expert members from the A*STAR, worked closely with the Economic Development Board, Ministry of Health and SPRING Singapore to propose the technology programmes by leveraging on the existing and planned capabilities of the A*STAR Science and Engineering Research Council Research Institutes (SERC RIs).

1.2 Definition and scope

The scope of the Healthcare Wellness and Aging theme encompasses the areas described in the following table:

Drug discovery and delivery	The discovery of new drugs and technologies for dispensing and delivery into the patient. This covers compound screening, drug discovery tools, drug discovery methods and medicinal chemistry
Hospital equipment	New, improved hospital equipment. This covers non-invasive surgery, robotic surgery, training models for surgeons ("virtual" body), image-guided surgery and surgical instruments.
Long term population studies	Data collection devices and data handling technologies.
Rehabilitation	Devices that aid rehabilitation. This covers therapeutic gaming (for rehabilitation) and physiotherapy tools.
Personal health care	Systems and devices to promote and sustain personal health care
Central nervous system	Technologies relating to the brain and the central nervous system. This covers neurotechnology, neuro-prosthesis, neuro-rehabilitation, brain imaging devices systems, and neuro-informatics.
Diagnosis	New diagnostic technologies. This covers biomedical imaging and image processing, computer- aided diagnosis, allergy detection devices, stress biomarkers, monitoring vitality, immunity measurement devices and other new diagnostics tools.
Assisted Living	Technologies to aid the elderly and physically and mentally impaired and to improve performance of individuals. This covers enhancement devices for aging, assistive technologies, especially for disabled and aging, and robotics for home care, social robotics, ambient intelligence for elderly care and robots for elderly care.
Remote health monitoring	Devices which enable medical practitioners to monitor the health of patients remotely. This covers infocommunications technology for participatory healthcare, tele-health and virtual consultation.
Epidemic tracking and modelling	Technologies that track and study the spread and location of epidemics world wide. This covers integrative systems for epidemiology, technology to study trend in the spread of disease throughout populations.
Aging	Technologies to benefit the elderly, including smart homes. This covers enhanced treatments for aging and disability, better treatment for diseases associated with aging and social tools enabled by technology.
Wellness	Technologies to promote wellness. These include health screening, bio toxin detection especially in food and water, wellness monitoring, nutraceuticals, food supplements, behaviour modification tools for health education preventative treatments for disease and health problems, preventive healthcare and personalised nutrition "nutrigenomics". This theme also covers mental health, eye care,

	oncology, cosmetic treatments at home and metabolic diseases.

Research areas that were covered extensively by other panels like manufacturing technologies for health related products are excluded.

1.3 Key drivers and trends

Globally, cardiovascular diseases, cancer and diabetes continue to be major issues for many countries, and there is increased awareness of tropical diseases and the threat of epidemics. Life expectancy is increasing, the world population continues to grow, and more of the world is becoming urbanized. There is a trend towards more people living alone. There is a shift of emphasis from curing diseases to prevention. People generally are becoming better educated about health issues and as a result, they pay more attention to their lifestyles and diet. Counter to this is the growing affluence of China and other parts of Asia, and the increase in those regions in health problems associated with increased affluence.

On the technological front, the universal use and dependency on the internet and virtual reality give rise to the increasing exchange of health information through telecommunication systems. Greater computing power makes the rapid processing of vast amounts of information more readily available. With the advances in genomics, it is becoming possible to understand the likelihood of any individual suffering from a particular illness based on their genetic profile, leading to the possibility of specially tailored medicine and personalised cures. With new manufacturing technologies, the miniaturization of medical devices and diagnostics has become a reality.

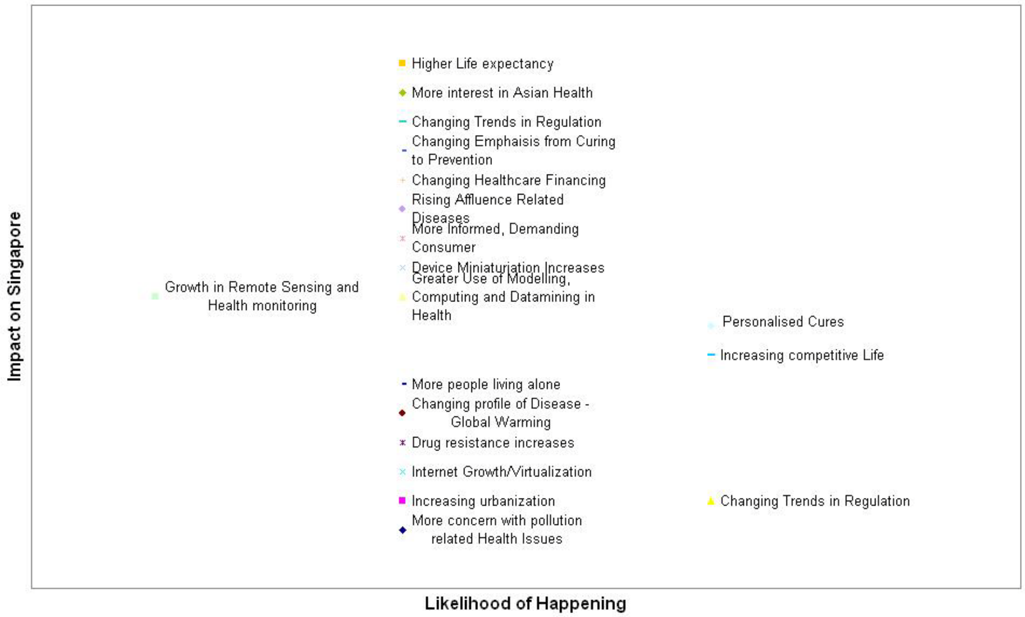

Figure 1: The likelihood of global/local trends and their potential impact on Singapore

These trends (Figure 1) are the drivers for change that provide new opportunities to invent new technologies within the scope of the Healthcare, Wellness and Aging field. The programmes proposed to respond to these trends are described in Chapter 3.

Chapter 2 Vision

2.1 Key global / local needs and challenges

Singapore is one of the world's fastest aging nations. The proportion of those aged 65 and above will reach 20 % by 2030. It is also projected that the population may eventually grow to 6.5 million. It is therefore a national priority to have in place a well organised system of care for the elderly. It is also important to keep healthcare costs low to ensure good access for all in society. Singapore is therefore potentially ideally placed to invent and to develop products for "The Silver industry" and The Economic Development Board has identified Health and Wellness as a business growth theme (Figure 2).

There is greater awareness of the potential for infectious diseases, particularly viral diseases, to spread rapidly across the world. Singapore has good experience and a good reputation globally in controlling epidemics, as demonstrated during the SARS crisis. Rapid diagnosis and early detection of disease are important elements of any response to a potential epidemic and Singapore is well placed to invent and to implement diagnostic devices not only for local use but for the global market.

Singapore is a relatively affluent society, and is therefore well placed to introduce new healthcare technology. Although any technology for general use throughout the population must be low cost to enable widespread uptake, the first in the market will tend to be more expensive than when well established, and the initial uptake is therefore more likely in a society that is reasonably affluent.

A trend observed in western society, but perhaps not so clear in Asia, is towards a greater number of households being a single individual that is more people are living alone. This emphasises the need for dispersed health monitoring, the availability of support for healthcare in the community and the systems and infrastructure to provide assisted living for those in need.

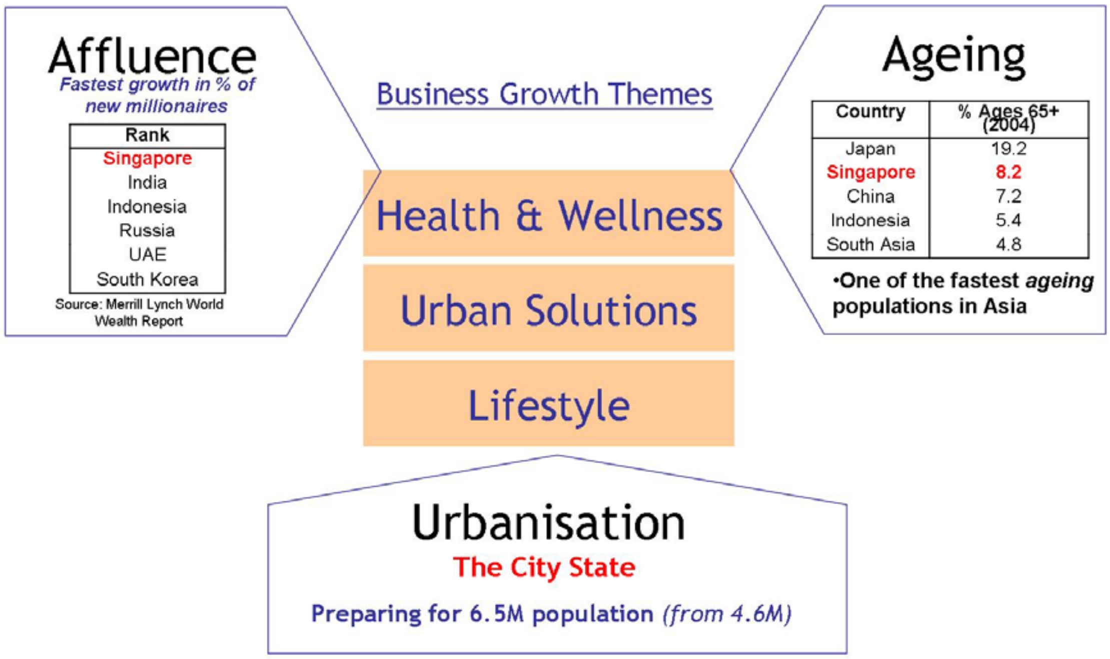

Figure 2: Business Growth Themes in Health and Wellness, Urban Solutions, and Lifestyle. [Source: Economic Development Board]

2.2 Vision and overall goals

A*STAR's vision is to establish coordinated interdisciplinary research programmes in medical technology and systems to enable healthcare professionals and caregivers to deliver higher quality of care for patients and to enable a high quality of life for the elderly population. Concurrently, it seeks to provide technologies for diagnosis and cure of disease.

There are 6 proposed programmes under the Healthcare Wellness and Aging theme:

1) **Right Siting of Care**
2) **Point of Care Diagnostics**
3) **Neurotechnology**
4) **Intelligent Personal Protective Equipment**
5) **Portable Medical Devices and Digital Pathology**

These programmes are described in Chapter 3.

2.3 Economic potential value capture and value added

According to the Economic Development Board [1], Singapore's medical technology sector contributed US$1.8 billion to manufacturing output and over 7,300 jobs in 2007. Singapore has established a position as a trusted and competitive site for leading medical technology companies to develop and manufacture innovative products for the global market, with immediate access to the growing market in Asia. 17 of the world's leading medical devices companies have invested in more than 20 manufacturing plants here. Applied Biosystems, Affymetrix, Baxter International, Becton Dickinson, Bio-Rad, Ciba Vision, Thermo Fisher Scientific, Fluidigm, Edwards Lifesciences, Hoya Healthcare, Hill-Rom, Qiagen, Japan Medical Supply, and Siemens Medical Instruments are all Global leaders that have set up manufacturing, R&D and headquarters functions in Singapore.

To illustrate the potential, the total global revenue of medical device companies in 2007 was $173.5bn (US). Even a 10% share would still represent an order of magnitude growth in an already flourishing industry in Singapore. However in order to capture a sizeable share of this market, it will be necessary to form strategic collaborations with the global leaders in key field of science and technology.

2.4 Key enabling technologies and technology platforms

The scientific programmes are proposed are user-oriented and focus on specified application areas. It will be necessary to strengthen our existing capabilities in the platform technologies (Figure 3) which cut across these programmes, and are essential to the successful delivery of solutions based on systems, materials and devices.

Information and wireless technology also enables the elderly and chronically ill people to continue receive top-notch, quality care in their own homes with improved health monitoring and telemedicine. This means that there will be smooth exchange of data between clinics, hospitals and pharmacies. The plethora of data and information generated by modern imaging processes can be managed more efficiently through knowledge databases and computer processes.

Material development and chemicals synthesis are crucial to the development of diagnostic and medical devices. For example, bioelectronics and the characterisation of biological interfaces and surfaces will be essential to the invention of sensors. Novel manufacturing technology will be essential to make the low cost mass production of relatively high tech devices accessible to the general public.

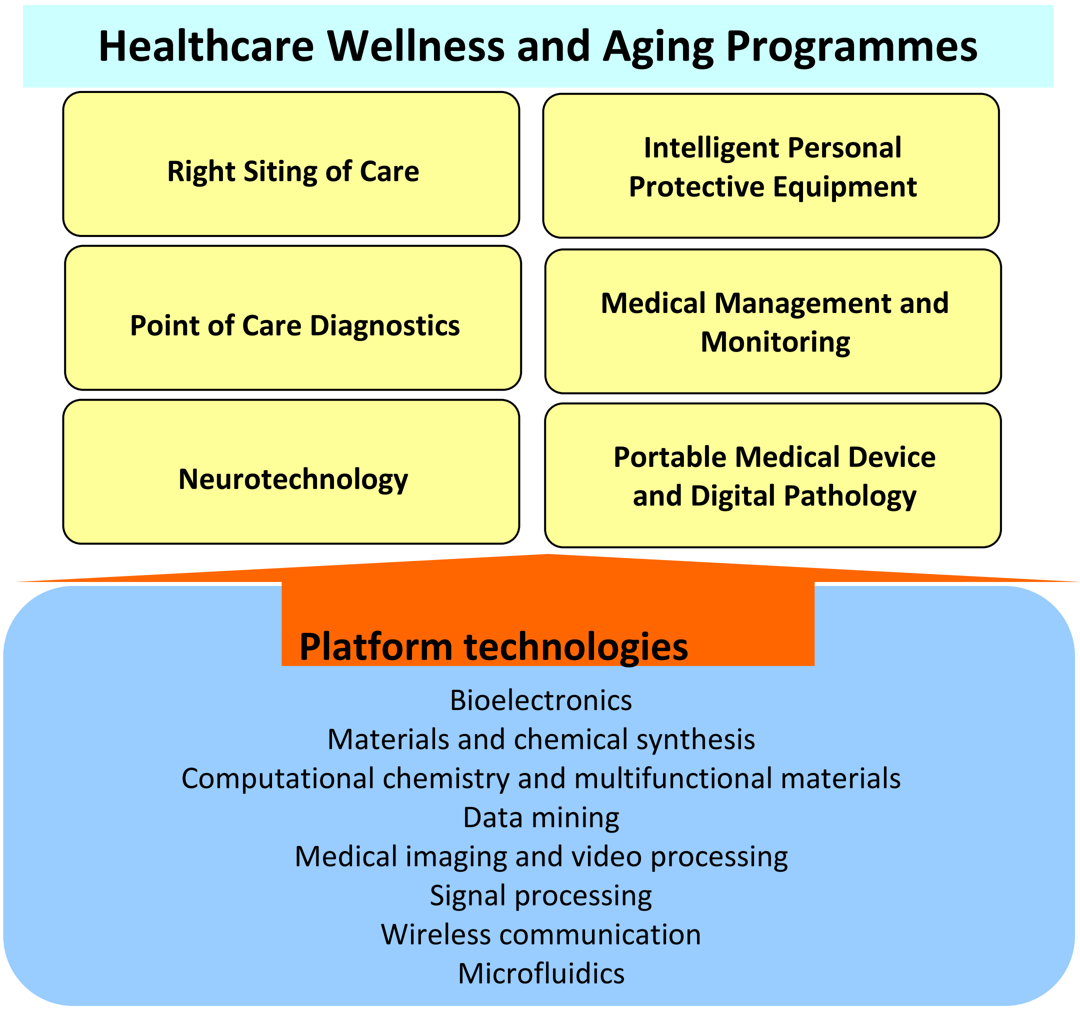

Figure 3: Platform technologies

Chapter 3 Proposed Programmes

3.1 Right Siting of Care

3.1.1 Description of the Programme

Right siting of care refers to the move of caregiving for the elderly, people with special needs, patients recovering from major treatment, patients receiving relatively minor treatment and patients with chronic diseases, away from major hospitals and centres into the community. It represents a move from Primary Care to Community Care.

There are initiatives in many countries towards this. For example in Singapore, the Chronic Disease Management Programme under the Health Promotion Board and the upgrading of more HDB flats with elderly-friendly features, in the USA the HomMed Health Monitoring System set up by Meridian Health Care (NYT February 12 2009). The following quotations are extracted from the UK Department of Health July 2008 review *NHS Next Stage Review: Our Vision for Primary and Community Care*: "...The NHS needs to reach out and make services available in other settings, such as schools, workplaces and people's own homes", and "...The potential to use community settings for some services traditionally provided in hospitals – and in a way that really shifts the emphasis to supporting health and wellbeing rather than simply curing disease – is set to grow faster in the coming years as a result of demographic, economic and technological changes."

In the STVC 2015 review, three areas were identified as high priorities that come under this broad programme:

- Assisted Living
- Aging in the Home
- Remote Patient Monitoring

The trends that make this programme particularly relevant and high priority are:

1. There is a global change in demographics; life expectancy is increasing and the average age of populations around the world is increasing. In Singapore the current life expectancy at birth is 80.6 years. It is projected that the fraction of the Singapore population over 65 will rise from 8% to 19% by 2030. This is a common trend in the developed world, for example

the USA population over 65 is projected to rise from13% to 19% by 2030. (Sources: Singapore Statistics and USA Census Bureau)

2. An increasing proportion of the population in the developed world will live alone. For example in the UK 30% of households are one person (UK National Statistics), in Norway it is 55%. (Statistics Norway), and the trend is increasing.

3. Shift of emphasis from cure to prevention, as exemplified by the UK review referenced above

4. Continued growth of internet and population with access to high speed communications in the developed world.

The programme has elements which are very long term and some elements which are immediate. It has potential to achieve a balance between delivering short term results and longer term impact.

3.1.2 Economic and Technological Opportunities; Potential Impact

Singapore is not large enough for these potential businesses to have a major impact on economic development based on the local market alone, but it is believed that, in line with the EDB initiative in medical devices, there will be opportunities for Singapore-based invention, development and manufacture of such devices and systems for the global market, and particularly with a focus on Asia. There is potential to enhance the biomedical cluster by adding systems and devices as a further element.

Singapore has a particular advantage because of its potential close integration between healthcare, housing, biomedical device development and demonstration in controlled conditions in a well ordered and well managed society. To develop such systems and products and to demonstrate them in a live situation in the community requires a well integrated healthcare system, good cooperation between many arms of government, well organised housing and immediate access and interaction between the medical practitioners, community services and researchers. This addresses a national need and gives Singapore the potential to be a “living lab” to demonstrate technology.

Moving forward, this will require continuous dialogue and integration between A*STAR and other government agencies to transfer the technology to the community.

3.1.3 Assessment and Stock-take of R&D capabilities needed

The specific capabilities needed will depend upon the exact technology selected, following a more detailed analysis of potential projects within the proposed programme, However it is clear that it will be necessary to manufacture devices that are based on advanced science and technology, but can only be taken out into the community if they are low cost. This has significant implications for future manufacturing, which could be developed in SIMTech.

Many aspects of the programme rely on infocommunications technology. It is likely that a large part of the programme will require the capabilities available in I2R.

Materials, chemical sciences and chemical engineering will be required in many aspects of the programme; which can be provided from IMRE and ICES.

Many of the inventions will be based on convenient, easy-to-use, small scale devices founded on micro-scale technology. IME has expertise in several relevant areas.

The capabilities required but currently missing in SERC are in ergonomics, human-machine interface, product design, and the special skills needed in dealing with elderly and disadvantaged people.

Strong links with community care and clinicians will also be required.

3.1.4 Programme and Milestones

Examples of the proposed technologies to be developed include:

- Assistive PDA for people with intellectual disabilities, for tracking, providing directions and general assistance to live independently
- Portable stair climber for physically disadvantaged and infirm
- “Intelligent” walking aid
- Sports apparel for enhanced performance
- Strength augmentation, partial robotics for the infirm
- Similarly for aids to enable people with disabilities to feed themselves
- General assistive robots for infirm people in an otherwise “normal” home
- Intelligent home with in-built assistive devices and monitoring
- Intelligent home with the ability to summon assistance in the event of emergency
- An environment that gives reassurance of safety and security; fall detection, connectedness to family and support

- Non slip floor surfaces; surfaces and furnishings protect against fractures and serious injury in the event of fall
- Remote monitoring of patients with specific diseases, for example non-invasive blood sugar measurement; monitoring of tumour progression
- Continuous monitoring of vital signs for patients with chronic conditions; but who are otherwise mobile
- Interactive tele-monitoring and access to healthcare
- Monitoring of progress of treatment and ensuring compliance, managing medication, reminder systems for regular medication.

This is a very wide and diverse list of potential projects and further detailed analysis will be required to refine the specific programme. However it is clear that some solutions are becoming available or close to available whilst some are very long term. This will enable SERC to build a programme that has both short term benefits and longer term success.

3.2 Point of Care Diagnostics

3.2.1 Description of Programme

The development of point of care (POC) diagnostics for use at the immediate point of care is a key factor in the accurate and early detection of diseases. It allows the appropriate treatment to be provided to the patient in a timely fashion, and enables prompt measures to be taken to curb the spread of infectious diseases.

This programme targets the invention of POC diagnostic devices for screening, monitoring and detection of disease to be used at home, in public places, in clinics and hospitals by doctors, nurses, security personnel, as well as patients and the general population. It requires A*STAR's multidisciplinary capabilities in design, manufacturing, materials, microelectronics, chemistry and biotechnology to deliver systems and devices that can be tested within the well managed and controlled environment of Singapore health care.

3.2.2 Economic and Technological Opportunities and Impact

The global POC diagnostic market was estimated to be US$11.3 billion in 2007. With the trend in emphasis away from curing disease more towards prevention, there are increasing demands for low cost, miniaturised intelligent devices for point of care diagnostics. In developing countries, the lack of extensive laboratory infrastructure needed to perform immune or serological diagnostic examinations leaves many infectious disease patients undiagnosed in remote regions. In developed countries, the demand on hospitals to increase the turnover of patients and to reduce costs of testing means that rapid diagnostics are a key target for hospital administrators. The threat of an epidemic of infectious disease such as influenza, and the potential for the spread of tropical diseases such as dengue fever also demands technology readiness for accurately and immediate diagnostics. According to The Global Market for Point of Care Diagnostics by Espicon Business Intelligence, the POC market will grow at 11% per annum in the near future. This means that any breakthrough in technologies has great potential for commercial successes.

In Singapore, the continual threat of common tropical diseases and the multi-racial population provide an ideal test bed for POC diagnostics. In the Science and Technology Plan 2010, the medical technology sector was identified as an important development area. Diagnostics has been identified as one of the five key segments in the Singapore medical technology industry by EDB. A number of multi-national medical technology companies have already established production here. Further developments of POC applications in Singapore will potentially generate opportunities for the biomedical industry, and will help the local suppliers and precision engineering industry to develop in this area.

3.2.3 Assessment and stock take of R&D capabilities needed

The development of POC diagnostics technology and products requires capabilities in materials, design, manufacturing processes, microelectronics, sensing, detection and analysis technologies.

SIMTech's manufacturing technology for polymers, glass, ceramic and metals provides a solid base for prototyping and scalable production of POC diagnostic devices, in particular disposable test kits. Its competence in product development and measurement technology will support device design and sensing and detection techniques.

IME's R&D capabilities in POC diagnostics are in wireless integrated Microsystems. They are based on silicon fabrication technology and include biological sample preparation, detection and microfluidic components. This encompasses an integrated capability of design, process, microsystems, surface chemistry and bioanalysis.

IMRE's strengths lie in low cost organic electronics, colloidal biomarkers, the characterisation of biological interfaces and surfaces and sensor development.

IHPC's capabilities in computational chemistry and multifunctional materials facilitate the search for new functional materials for diagnostic devices; computational electromagnetics, nano-electronics and photonics permit the modelling of electronic integrated circuits and the exploration of electromagnetic and optical devices for POC disease detection; computational fluid dynamics and mechanics provide effective tools to solve complex mechanical processes involved in the development of POC diagnostic devices.

I2R can contribute data mining for data with complex interconnections; medical image and video processing technologies; signal processing; and low power wireless communication.

ICES can contribute polymer synthesis for the new substrate materials needed.

3.2.4 Recommended programme roadmap and milestones

The proposed programme will generate new scientific knowledge, as well as technologies with commercialisation potential. Specifically, the programme will develop technologies for the following applications or products:

- Home-based specimen tests
- Non Intrusive and continuous diagnosis kits
- Inexpensive, rapid test kits to detect specific virus
- Devices for blood analysis
- Genetic testing kit for Alzheimer's disease, Schizophrenia
- Fast and accurate infection or bacteria detection
- Technology to simplify process of surveying public exposed to disease
- Device/systems to screen foreigners at point of entry and track records
- Integrated self help health screening facilities
- Health monitoring in public spaces

3.3 Neurotechnology

3.3.1 Description of Programme

Mental disorders are common worldwide. According to the United States National Institute of Mental Health (NIMH) [2], an estimated 6 percent of Americans ages 18 and older, about one in seventeen adults or 13.3 million people, suffer from a serious diagnosable mental disorder. Major mental disorders include Anxiety Disorders, Attention Deficit Hyperactivity Disorder (ADHD), Autism Spectrum Disorders, Depression, Panic Disorder and Schizophrenia. In addition to psychotherapy and medication, neurotechnology provides an alternative treatment to certain groups of patients.

Strokes and Parkinson's disease are also major causes of mental disability. According to the World Health Organization[3], strokes are the leading cause of long-term disability worldwide. Each year, 15 million people suffer a stroke, of which, 5 million are permanently disabled. Long-term rehabilitation is required but the current occupational and physiotherapy are neither very effective nor economic. Parkinson's is a common neurological disorder that is thought to affect more than 4 million people. According to National Institute of Neurological Disorders and Stroke[4], there is no cure for Parkinson's disease, and a variety of medications and deep brain stimulation (DBS) can provide relief from the symptoms. These diseases pose a strong demand for innovative technology based therapies to provide better or more cost-effective treatment.

According to Neurotechnology Industry Organization[5], in 2007, the worldwide market for Neuro Devices, Neuro Diagnostics and Neuropharmaceuticals amount to $4.5 billion, $15 billion, and $101 billion respectively. There is a huge market for treatment products for neural and mental disorders. Advances in very large scale integration technologies for highly complex circuits, infocomm technologies, neuroscience, computer science and engineering, provide potential for neuro technology to advance into new areas such as neural interface, implant, neural prosthesis and neuromorphic design. Neuro-engineering is an extremely challenging area of science but has great potential. The fundamental activity is to reverse engineer the human brain, which is one of the 14 grand challenges to engineering in the 21st century identified by the USA National Academy of Engineering. It can be foreseen that effective technologies to provide new treatments for neural and mental disorders will be emerging in 3 to 7 years.

3.3.2 Economic and technological opportunities and impact

In Singapore, each year, there are over 10,000 new stroke cases[6], over 2,000 new ADHD cases. 3 out of every thousand individuals, aged 50 years and above will suffer from Parkinson's disease[7] . Depression in Singapore matches the worldwide incidences[8]. Although the market in Singapore for neurotechnology is not very big, these patients provide a big enough pool for significant clinical trials.

Although a neurotechnology industry would be new to Singapore, with a focused R&D effort from A*STAR and strong support from local healthcare service providers, such as National Institute of Neuroscience, Institute of Mental Health, Tan Tock Seng Hospital for Rehabilitation, Alexandra Hospital for Geriatric Care, Duke-NUS Graduate Medical School for Neuroscience, we have the potential to build new neurotechnology industries.

3.3.3 Assessment and stocktake of R&D capabilities needed

The neurotechnology industry is rather fragmented. There are no dominant companies in this field. Many companies are small or medium sized. This means that it is potentially a relatively open field for new companies to emerge.

There are several capabilities that we will have to develop to make a major impact. We lack the expertise in interfacing technologies with neuroscience or psychology. Within A*STAR we lack experience in clinical trial management although Singapore is a centre for clinical trials for many major pharmaceutical companies, and it is believed that we can learn from them.

Capabilities in areas relevant to neurotechnology have begun to be developed in SERC. These include the following:

- I^2R has developed a non-invasive brain-computer interface (BCI), and applied it to medical applications for the treatment of neurological disorders. They have developed a BCI-robotic system for stroke rehabilitation and are conducting a clinical trial at TTSH and NNI. They have developed a novel treatment for ADHD children, which is also under going trials.

- IME has capabilities in circuit design for multi-channel stimulation and recording neuronal signals, low power wireless communication IC and wireless sensor interfacing, energy harvesting sensors and circuit design for neuronal signal processing, biocompatible packaging, 3-D silicon probe design fabrication and assembly, and integrated biomedical nano-sensor and healthcare subsystems.

- SIMTech is strong in system design, packaging, robotics, bio-sensors, and microfluidics. SIMTech is developing a microfluidics platform for mental stress detection by saliva analysis.

3.3.4 Recommended programme roadmap and milestones

The following projects were proposed from the panel discussions:

1. Deep brain simulation devices such as electrical-neuro-modulation to treat epilepsy and depression.
2. Vagus nerve stimulation therapy for patients with chronic or recurrent treatment-resistant depression.
3. Identification of specific muscle functions and how to control them to minimize tremor in Parkinson patients.
4. Personalised treatment to help paralysed patients to recover motor movement by neuro-plasticity; technologies to monitor, measure and guide the patients in rehabilitation
5. Non invasive treatment and stimulation for depression and schizophrenia.

3.4 Intelligent Personal Protective Equipment

3.4.1 Description of Programme

This programme uses medical glove technology as an example of 'intelligent personal protective equipment'. Intelligent Personal Protective Equipment is novel or improved protective equipment which incorporates sensors or detectors primarily for enhanced personal protection but which may be for a variety of purposes.

The programme originated from the proposal to invent intelligent protective medical gloves, but has broader implications for "intelligent materials" in a wide range of medical applications. Further research will be required to define the broader scope of the programme, requiring further in-depth discussions with practitioners and users in clinics and hospitals. The programme described here is based on medical gloves, and is an example of how intelligent materials in medical applications could be developed.

The user group surveyed was instrumental in identifying the need to develop medical gloves which supersede currently available products by fulfilling three critical criteria:

1. They must be lightweight, highly flexible and thin enough to allow dexterous movement of the hands and fingers and also provide that 'second skin' feel required by medical professionals.
2. They must provide excellent protection against cuts and needlestick injuries.
3. They must provide protection against bodily fluids for long periods, e.g. longer than 10-15 minutes.

Further development of the technology is to incorporate sensors into the materials to alert the user to a potentially hazardous situation. Examples are the detection of the material expiring or being compromised followed by an immediate visual or audio alert, and rapid detection of bacteria e.g. Methicillin-resistant *Staphylococcus aureus* (MRSA) and viruses such as HIV and HCV again followed by a perceptible alert.

3.4.2 Economic and technological opportunities and impact

There is existing glove manufacture industry in Singapore e.g. Wee Yeng Glove Manufacturer and Trading Materials and in surrounding countries e.g. latex production by 'Synthomer' in Malaysia. Development of medical glove technology in Singapore would allow the glove manufacturing industry to flourish here and potentially attract investment from others in the region. However, medical gloves are currently very low cost and development of this business sector is not a major priority for EDB. In order to have significant economic impact, therefore, the research programme would have to extend from a base in gloves to the broader area of intelligent medical materials. This would enable materials manufacture to be linked with the current strength in medical devices and medical technology. A major challenge is to be able to build in intelligence without a major increase in cost. This is why further study is required to define exactly which areas of intelligent materials would provide the best commercial proposition.

Singapore has 9 general hospitals, 6 community hospitals and 12 specialist hospitals. Therefore, there is potential to work closely with hundreds if not thousands of nurses, surgeons and care givers. Any of these user groups are capable of demonstrating the technology and thus, would be invaluable in its development and validation.

Singapore's small size, dense population and industrial strength make it ideally placed for an intimate and synergistic interplay between R&D, manufacture and end user validation. This should give Singapore a critical competitive advantage over most countries in terms of speed of development and commercialization of the technology.

3.4.3 Assessment and stocktake of R&D capabilities needed

IMRE and ICES can invent new materials. IMRE and IME can invent miniature detection devices. SIMTech can provide manufacturing technology for polymers, potential for prototyping and scalable production of gloves and other IPPE. NUS and NTU can develop polymeric materials

'Know-how' on existing methods for glove manufacture from raw material processing to final product (e.g. latex-technology and the rubber industry, manufacture of Kevlar lined police gloves etc) need to be developed. In addition, feasibility analysis in terms of economic feasibility of the new technology, industry interest and potential consumer demand must be conducted. This will require liaisons (officers and / or scientists) with industrial collaborators.

The main competition in this area would come from the hundreds of major glove manufacturers (MNC's and SME's) rather than from academic research groups. Every major glove manufacturer is looking to develop new gloves for puncture and cut protection.

3.4.4 Recommended programme map and milestones

The programme roadmap involves the development of new materials, miniature detection devices. These will have to be integrated into the development of gloves or other IPPE prototype. The final milestone of the programme will involve the demonstration of the proof of concept and feasibility validation. In addition, there must be refinement of technology and continual product development.

3.5 Medical Management and Monitoring

3.5.1 Description of Programme

The proposed medication management & monitoring programme aims to develop technologies that help reduce medication errors and adverse drug events (ADEs). It has two aspects, medication management and medication monitoring.

It involves storing and protecting information on patient medication and allergies and sharing that information between consumers, clinicians in multiple sites and settings of care, inpatient care, emergency services, pharmacists and organisations that provide health insurance and pharmacy benefits. The chain of information goes from computerised physician order entry (CPOE), drug dispensing, packaging and labelling, tracking, to delivery to the patient. The loop is closed with verification, matching and administration. The programme will provide better interoperability and efficiency[9]. In Singapore, the healthcare providers are addressing this problem through a programme overseen by Ministry of Health Holdings (MOHH).

Additional problems to be addressed arise from the initiatives in care in the community, particularly with the elderly and mentally disabled:

- Monitoring that patients really do take medication as prescribed, detection that it has been taken
- Non-invasive technique to monitor drug levels in the body.

It is recommended to start this programme within 2 years to coincide with MOHH's ongoing efforts. The period for the work on medication management may take 2-3 years while the work on medication monitoring may take 3-5 years.

3.5.2 Economic and technological opportunities and impact:

According to the report "Preventing Medical Errors" by the US Institute of Medicine in 2006, there are at least 1.5 million preventable ADEs that occur in the US each year. The true number may be much higher[10]. These medication errors are costly to patients, their families, their employers, and to hospitals, health-care providers, and insurance companies. In 2006, one study found that each preventable ADE that took place in a hospital added about US$8,750 to the cost of the hospital stay. Assuming 400,000 of these events each yea, which is a conservative estimate, the total annual cost would be US$3.5 billion in this one group, in the USA alone.

The growing aging population increases the problem. Older adults are the largest consumers of prescription and over-the-counter medication, combined with the decline in physical and mental capacity with age, this makes this population especially vulnerable to medication errors and ADEs[11].

The U.S. medication management market is forecasted to grow at 18.2% CAGR between 2007 and 2012[12]. In Singapore, MOH and IMH clinicians are ready to validate or demonstrate the technologies developed from this programme. The development of medication management would potentially grow the existing electronics and infocomm industries in Singapore. A programme in non-invasive monitoring of drug levels in the body, and medication monitoring in general, would create new technologies to expand business for existing medical technology and precision engineering industries.

3.5.3 Assessment and stocktake of R&D capabilities needed

Most of the enabling capabilities for medication management are already in place in Singapore, for example, RFID/wireless electronics and infocomm technologies. The major players in this field are GE Healthcare and Siemens[11]. A programme in medication management would enhance Singapore's attractiveness as a test-bed for product development by these MNCs and provide collaboration opportunities to RIs and local industry.

An example which demonstrates the potential feasibility of medication monitoring, is a US start-up Proteus Biomedical, which has developed tiny, ingestible microchips which are composed of minerals found in common foods. These microchips, or so-called Ingestible Event Markers (IEMs), are added to a drug formulation which, when ingested, transmit a brief electronic message, conducted through the body tissue in a manner similar to an ECG signal. The IEMs are powered by a biogalvanic battery and are surrounded by a "skirt" made of pharmaceutical excipients that acts as a tiny antenna. The company claims to have 250+ patent filings. Accordingly, their products are currently in clinical testing in the US[13].

Non-invasive monitoring of drug levels in the body provides a major scientific challenge. Combining various RIs capabilities in materials & chemistry, e.g. surface chemistry, biocompatible materials, simulation, devices & systems e.g. biosensor, microfluidics, wireless wearable electronics and forging close partnership with clinicians could make it possible to make major achievements in this challenging field.

3.5.4 Recommended program roadmap and milestones

The panel recommended the following projects:

- Medication management (working together with MOHH);

- Transdermal patch for drug administration, in particular for patients who are unable to swallow medication or who do not take medication consistently;
- Monitoring/detection of patients really taking medication;
- Non-invasive drug monitoring technique to monitor drug levels in the body.

3.6 Proposed Programme 6: Portable Medical Devices and Digital Pathology

3.6.1 Description of Programme

The common scientific themes across this programme are imaging, automated image analysis and interpretation, data storage and rapid evaluation and diagnosis. These scientific themes are linked with miniaturisation and supported by technology to manufacture “high tech” imaging devices at low cost, to respond to the drive to move care into the community. This brings the requirement and demand for smaller more portable, “desk top” versions of major hospital equipment, particularly imaging equipment, which can be deployed cost effectively in community centres, used by the emergency services and even deployed in the home for special cases.

We have combined this with the need for more rapid pathology; to be facilitated by automated data analysis, by high throughput techniques. Stages in the process are acquisition of the specimen, analysis, often by imaging or spectroscopy of some form, and analysis of the results, often by observation of the image, identification of positive traits and comparison with reference samples. Automation requires equipment, projected to be based on current robotics and HTS (High throughput screening) equipment available, automated digitisation of the image, comparison by intelligent data handling systems with the ability to “self learn”, with minimal human intervention.

The trends that make this programme particularly relevant and high priority are: device miniaturisation, greater use of computer modelling and data mining in health care, shift of emphasis from cure to prevention, combined with the global trend to move care more into the community and away from the hospital setting.

Some elements of the programme will be relatively short term, using existing, modified equipment from other areas, combined with purpose developed software and image analysis. With the right applications and focus this aspect of the programme could deliver results very quickly.

In the longer term there are major challenges in attempting to make currently large and expensive imaging equipment into smaller and cheaper versions for more widespread use. Whilst portable X-ray devices are already available for forensic and veterinary use, and portable MRI systems are being developed. They are still some way away from widespread deployment in the community which requires new manufacturing methods, new technology for image handling and analysis and coordination and training of potential users.

3.6.2 Economic and Technological Opportunities; Potential Impact

The global economic potential is very large indeed. The 2007 total revenue of medical device companies was US$ 173.5 billion, according to *MX: Business Strategies for Medical Technology Executives* (May/June 2008 edition). However it is difficult to estimate just what the potential is for Singapore to take a share of this. The market in imaging technology is dominated by GE Healthcare, Siemens Medical Solutions and Phillips Medical Systems. The list of the top 25 medical device companies is dominated by the US, with Germany, the Netherlands, Switzerland, Canada and Japan contributing one or two each. To have major economic impact in Singapore, it will be important to be able to engage some of these companies in alliances and collaborations. The development of the medical device industry is an EDB initiative, and they will be important players in developing the economic potential.

Singapore has the potential to be a “living lab” to demonstrate technology, because of the potential for close integration between healthcare, housing, biomedical device development and demonstration in controlled conditions. To make this successful will require close cooperation across a number of government agencies; MOHH, MOH, EDB and A*STAR will have to work closely together to make it a success.

3.6.3 Assessment and Stock-take of R&D capabilities needed

Image analysis, data mining, intelligent data interpretation systems and the ability to store and analyse large amounts of data quickly are key to the success of these technologies. These are all well represented in SERC RI’s; for example ICES BTEM software and image analysis software, I2R systems for image analysis and data handling, IHPC strengths in high level computing, DSI expertise in storage and retrieval of large amounts of data are all potentially relevant.

Manufacturing technology will be the key to the success of this programme. In order to get these devices out into the community they must be relatively low cost, but safe and easy to use. SIMTech has expertise in this area.

Strong links with clinicians, emergency services and pathologists will be required to ensure that the devices developed are fit for purpose and address the most important needs. Product design, ergonomics will also be important but are not currently well represented within SERC.

Because of the existing strengths in medical imaging companies, it will be important to form, strategic alliances with them where possible.

3.6.4 Programme and Milestones

Examples of the proposed technologies to be developed are:

- Body imaging devices – portable and desktop
- Portable MRI imaging systems
- Brain scanning systems
- The general category of “more portable, desk top versions of major hospital equipment”
- Quantified computer aided diagnosis from images, for example from radiology
- Rapid detection for deep vein thrombosis
- High throughput digital pathology

However there are already devices being developed in some of these areas, and it will therefore be important to complete a thorough review of the detailed device requirements as compared to those currently known to be in development in order to establish a well-founded programme.

Chapter 4 Conclusions

The Health, Wellness and Aging Panel has effectively adopted the Siemens Picture of the Future process to provide recommendations for technology programmes. The process begins with the definition of the panel scope and the trends associated with the scope defined. The panel then identified the user segments, functions and living spaces and the trends that are applicable in each of these areas. Future innovations in each living space are then suggested and verified with identified users. Finally the suggested programmes are prioritised based on the following set of criteria:

1. Cross disciplinary
2. User oriented/validated
3. Potential to add to the growth of the economy
4. Addresses national needs
5. Novelty
6. Technical Challenge
7. Potential niche area of possibility of making an impact
8. In-line with key SERC strengths/capabilities

The programmes recommended by the Health, Wellness and Agng Panel are:

1. Right Siting of Care
   Right siting of care refers to the move of caregiving for the elderly, people with special needs, patients recovering from major treatment, patients receiving relatively minor treatment and patients with chronic diseases, away from major hospitals and centres into the community. It represents a move from Primary Care to Community Care.

2. Point of Care Diagnostics
   This programme focuses on the development of POC diagnostics devices for screening, monitoring and detection of diseases to be used at home, public places, clinics and hospitals by doctors, nurses, security personnel, as well as patients and normal people.

3. Neurotechnology
   This programme targets alternative treatments to certain groups of patients with major mental disorders which include Anxiety Disorders, Attention Deficit Hyperactivity Disorder (ADHD), Autism Spectrum Disorders, Depression, Panic Disorder and Schizophrenia, in addition to psychotherapy and medication.

4. Intelligent Personal Protective Equipment
This programme uses novel 'medical glove technology' as an exemplary case for the broader theme of 'intelligent personal protective equipment' ; novel or improved protective equipment which also incorporates sensors or detectors primarily for enhanced personal protection but which may be for a variety of purposes.

5. Medical Management and Monitoring
This programme aims to develop technologies that help reduce medication errors and adverse drug events. It has two aspects: medication management and medication monitoring.

6. Automation of Digital Pathology
This programme focuses on the miniaturisation of "high tech" imaging devices at low cost, to respond to the drive to move care into the community.

These programmes are described in the preceding chapters which highlight the economic and technological opportunities and impact within each programme. An assessment of the R&D capabilities needed and the roadmap for each recommended programme are also presented.

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