JURONG ISLAND: CREATING A WORLD-CLASS ENERGY AND CHEMICALS HUB

Jurong Island: Creating a World-Class Energy and Chemicals Hub chronicles the genesis, planning and development of Jurong Island. Originally seven small islands located south of Singapore, Jurong Island today serves as the base of operations for over 100 leading chemical and energy companies. Convincing international companies to invest in Singapore was no easy feat and required the creation and provision of competitive advantages, such as its vertically integrated structure and plug-and-play concept. Jurong Island is also constantly examining ways to remain competitive and sustainable in an increasingly unpredictable world, whether through diversifying to include specialty chemicals, building research and innovation capabilities, implementing digitisation, or moving towards a circular economy. This study examines Singapore's approach to managing and growing such heavy industries while maintaining a high level of liveability and sustainability.

"Today, we are the third largest oil refining centre in the world, and [a] petrochemical centre, with all the major oil companies having significant investments here. It is a huge achievement considering that we have no energy supplies of our own, not much land area, nor any other natural advantages except that we had the idea, we could execute and implement, and we made it happen."

Prime Minister Lee Hsien Loong

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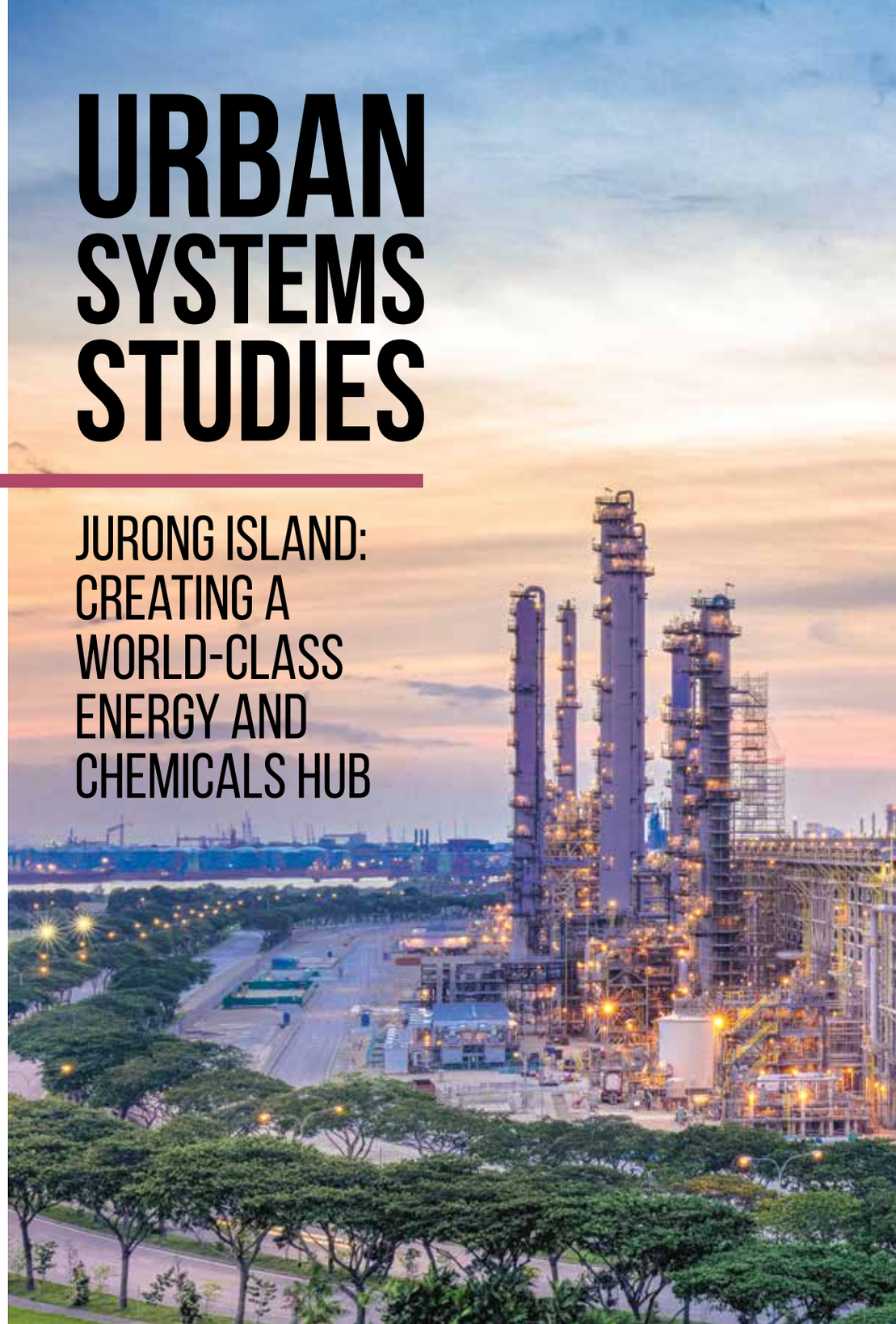

JURONG ISLAND:
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CENTRE for LiveableCities SINGAPORE

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Editorial Team

Writer:	James Tan Song En
Research Supervisors:	Ken Lee, Limin Hee
Editor:	Brooklyn-media Pte Ltd
Production Supervisor:	Gregory Lee
Design and Production:	Epigram

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Set up in 2008 by the Ministry of National Development and the then Ministry of the Environment and Water Resources, the Centre for Liveable Cities (CLC) has as its mission to distil, create and share knowledge on liveable and sustainable cities. CLC's work spans four main areas—Research, Capability Development, Knowledge Platforms, and Advisory. Through these activities, CLC hopes to provide urban leaders and practitioners with the knowledge and support needed to make our cities better. For more information, please visit www.clc.gov.sg.

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For queries, please contact:
CLC Publications
45 Maxwell Road #07-01
The URA Centre
Singapore 069118
T: +65 6645 9560
E: CLC-Publications@mnd.gov.sg

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Jurong Island, one of the world's leading energy and chemical hubs, formed through the amalgamation of seven offshore islands in 2009.
Photo courtesy of JTC Corporation.

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FOREWORD

Singapore's industrial strategy has continuously evolved for it to remain competitive, relevant and sustainable since its independence. Starting with labour-intensive, low-skilled industries in the 1960s, Singapore moved on to skill-intensive industries from the 1970s to the early 1980s. As a consequence of this focused effort, Singapore successfully developed a vibrant and competitive electronics and precision engineering sector.

From the late 1980s, Singapore started to explore and leverage future market trends to identify and capitalise on new drivers of economic growth. The stiff competition that the oil refining sector faced, along with the need to diversify the manufacturing base, led to the idea that the chemicals industry, if conceptualised as a cluster, could provide a critical mass of related-industrial activities. A cluster would allow for vertical integration, where the output of one company would become the input of another without the need to transport intermediates between chemical plants. Furthermore, common facilities could be provided to let companies "plug and play" into shared utilities and services, thus benefitting from economies of scale. Given the potential health and safety hazards posed, the chemicals cluster should ideally be located away from residential and business districts to minimise risks.

These principles eventually led to the massive reclamation works to merge seven islands into Jurong Island to host the cluster. Today, Jurong Island is a world-class energy and chemicals hub, home to over 100 leading petroleum, petrochemicals, speciality chemicals and supporting companies, cutting-edge industrial infrastructure, and a thriving environment for innovation and applied research. Further development of the island continues to be explored, guided by initiatives outlined in the recent Energy & Chemicals Industry Transformation Map and the Jurong Island Circular Economy Study.

Jurong Island: Creating a World-Class Energy and Chemicals Hub opens by drawing the context of Singapore's industrialisation strategy and the development of the oil-refining sector after internal self-governance. It traces the sequence of ideas and the processes behind the reclamation to create Jurong Island and concurrent efforts to market the space to chemical companies, frequently ahead of actual reclamation works!

This publication takes readers through the various urban systems such as transport, energy, water and waste needed to support the companies while ensuring that Singapore's environment and the quality of life for its people remains unaffected. It then delves into some of the contemporary efforts related to diversifying into speciality chemicals, research and innovation,

digitalisation and improving labour productivity that allow Jurong Island to remain competitive and sustainable.

Finally, it closes with a commentary on the position of Jurong Island in light of climate change debates and the initiatives that would take Jurong Island into the next lap and beyond.

I hope this Urban Systems Study will provide you with deeper insight into the dynamic interactions behind Jurong Island's development and growth, as well as the visionary leadership, long-term planning, strong private-public partnerships and constant innovation to stay ahead.

Philip Yeo
Chairman, Economic Development Board (1986–2000)
Chairman, SembCorp (1994–99)
Co-Chairman, Economic Development Board (2001–06)
Chairman, Agency for Science, Technology and Research (2001–07)
Chairman, Standards, Productivity and Innovation for Growth (2007–18)

PREFACE

The Centre for Liveable Cities' research in urban systems unpacks the systemic components that make up the city of Singapore, capturing knowledge not only within each of these systems, but also the threads that link these systems and how they make sense as a whole. The studies are scoped to venture deep into the key domain areas the Centre has identified under the Singapore Liveability Framework, attempting to answer two key questions: how Singapore has transformed itself into a highly liveable city over the last five decades, and how Singapore can build on our urban development experience to create knowledge and urban solutions for current and future challenges relevant to Singapore and other cities through applied research. *Jurong Island: Creating a World-Class Energy and Chemicals Hub* is the latest publication from the Urban Systems Studies (USS) series.

The research process involves rigorous engagement with our stakeholder agencies, as well as numerous oral history interviews with Singapore's urban pioneers and leaders to gain insights into development processes. The tacit knowledge drawn out through this process allows us to glean useful insights into Singapore's governance and development planning and implementation efforts. As a body of knowledge, the Urban Systems Studies, which cover aspects such as water, transport, housing, industrial infrastructure and sustainable environment, reveal not only the visible outcomes of Singapore's development, but the complex support structures behind our urban achievements.

The Centre would like to thank the Economic Development Board, Energy Market Authority, JTC Corporation, Ministry of National Development, National Climate Change Secretariat, National Environment Agency, PUB, Singapore's National Water Agency, Urban Redevelopment Authority and all those who have contributed their knowledge, expertise and time to make this publication possible. I wish you an enjoyable read.

Hugh Lim
Executive Director
Centre for Liveable Cities

ACKNOWLEDGEMENTS

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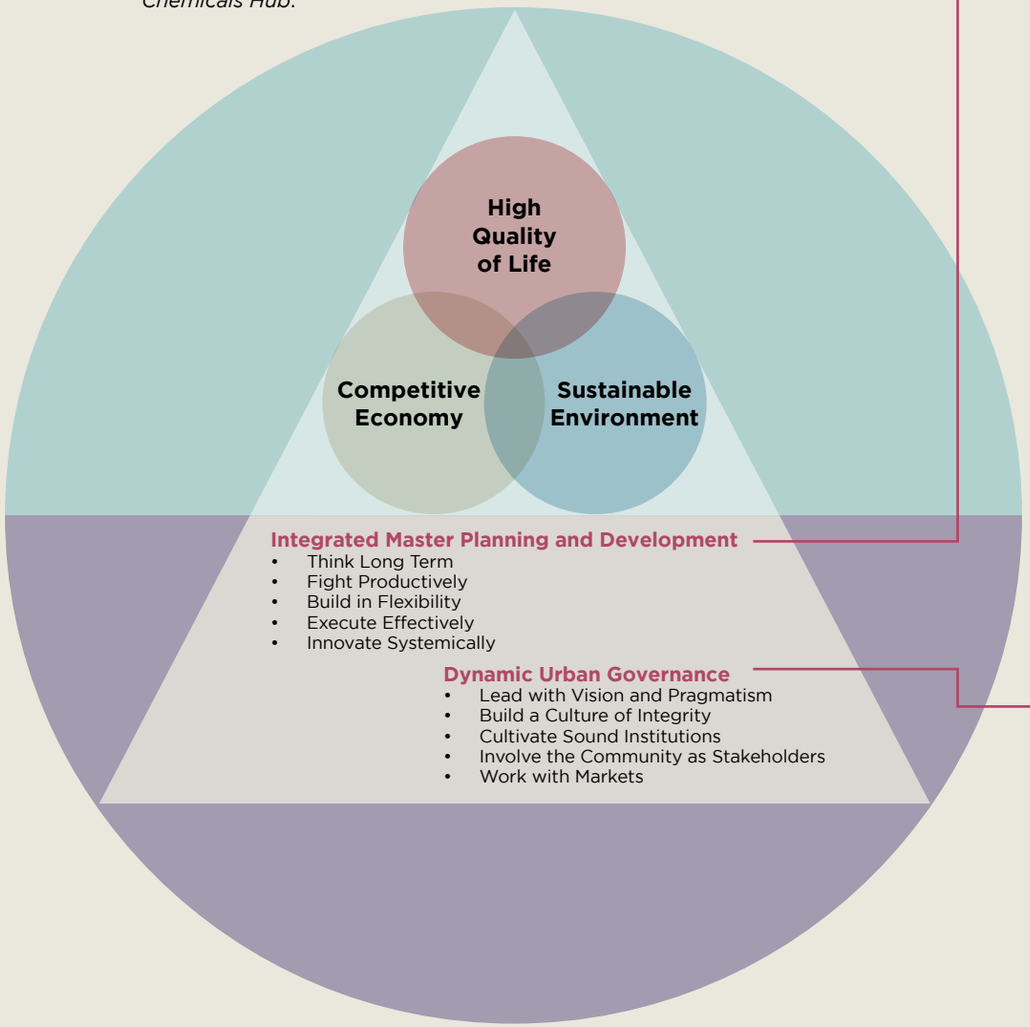
The researcher, James Tan Song En, would like to thank Hugh Lim, Khoo Teng Chye, Michael Koh, Limin Hee, Ken Lee, Cherub Ho and Wong Kai Yeng for their time, guidance and support. He appreciates the research assistance from Jeremy Chan and Ng Zu Xiang. He also acknowledges the meticulous editorial and production assistance from Gregory Lee.

The Centre would also like to thank Philip Yeo and Tan Boon Khai for contributing the foreword and post-script, respectively.

THE SINGAPORE LIVEABILITY FRAMEWORK

The Singapore Liveability Framework is derived from Singapore's urban development experience and is a useful guide for developing sustainable and liveable cities. The general principles under Integrated Master Planning and Development, and Dynamic Urban Governance are reflected in the themes found in *Jurong Island: Creating a World-Class Energy and Chemicals Hub*.



Integrated Master Planning and Development

Think Long Term

When Singapore gained full internal self-governance in 1959 and embarked on economic development, it did not adopt a "develop first, clean later" mentality. As part of the land use plans, heavy industries were grouped in the western part of Singapore and the Southern Islands to allow for greater environmental management and higher quality of life. Companies were required to ensure that the refineries were equipped with anti-pollution equipment. Even though this added to their cost and threatened potential investments, Singapore remained firm in not compromising on the environment. While Jurong Island has been achieving great heights and hosting leading global chemical companies, Singapore has continued to improve Jurong Island's sustainability and competitiveness to remain at the forefront of the industry. See Chapters 1 (pages 6 and 15), 4 (page 52) and 5 (page 69).

Innovate Systemically

A land-scarce nation, Singapore joined up the seven southern islands and performed large-scale reclamation in a brownfield area to support the growth of the energy and chemicals industry. Despite having neither a drop of oil on the island nor an anchor investor to attract and create a petrochemical cluster, Singapore's value proposition was in gathering companies that could be vertically and horizontally integrated to form an efficient co-located ecosystem and to put in place the appropriate infrastructure to allow the flows of feedstock and utilities "over the fence". As global competition further intensified and issues such as climate change became more prominent, Singapore continued to display its ability to stay ahead of the curve by building up capabilities and developing urban solutions. See Chapters 2 (page 25), 3 (page 32) and 4 (pages 55 and 57).

Dynamic Urban Governance

Lead with Vision and Pragmatism

In considering pathways to growth, Singapore had numerous sectors that it could have centred its economy around. Ultimately, the island-nation chose to focus on the chemical sector as it would suit the local context better over other industries, such as the automotive sector. Great conviction was needed to inspire companies to invest in Singapore even before the land for the cluster was reclaimed, whereas previously the common practice had been to set aside and prepare industrial land before selling it to investors. Furthermore, having a clear vision has guided the development of Jurong

Island from an assemblage of companies towards a functional circular economy in its next stage of development. See Chapters 2 (pages 18, 20 and 27), 3 (page 32) and 5 (page 69).

Work with Markets

Creating an ecosystem of companies involved in research, manufacturing, and the provision of utilities necessitated a good understanding of the individual companies' requirements, to ensure that ongoing developments would not impact them negatively. As Jurong Island coalesced and evolved to become the host site for a resource-intensive industry, energy-related infrastructure, water and waste management capabilities had to be put in place to support companies in their day-to-day operations. These requirements drove the public and private sector to cooperate in developing more efficient and sustainable urban solutions, in turn contributing to the resource security on the mainland. At every turn, the private sector has been a valuable partner, from developing manpower capabilities to improving the landscape of Jurong Island. See Chapters 2 (page 27), 3 (pages 34 and 41) and 4 (page 64).

OVERVIEW

Drawing on archival research and interviews with urban practitioners and policymakers, this Urban Systems Study traces Singapore's journey in becoming the world-class energy and chemicals hub that it is today. Jurong Island spans an area of 32 km^2 and serves as the base of operations for over 100 leading chemical and energy companies.[1] The island is a major pillar in Singapore's economy and is estimated to contribute about a third of the nation's total manufacturing output.[2] What is perhaps surprising about this achievement is that Singapore lacked land, a domestic market and natural resources for feedstock. However, sound policies, long-term planning and systemic innovations have enabled the success that Jurong Island enjoys today.

While Singapore's history with oil can be traced back to the 1890s as a regional distribution centre for kerosene,[3] it was not until self-governance in 1959 that the chemicals industry started taking shape. Singapore faced issues such as high unemployment and low quality of life. The nation's priority was hence to attract investments that could generate jobs for an increasingly restless population. Against this backdrop, oil refineries were set up offshore—south of Singapore—due to the lack of land and to create a safety buffer from the population. As a result of its pro-business policies, by the mid-1970s, Singapore had established itself as one of the top three global oil refining centres.[4]

Emerging from an economic downturn in the 1980s, Singapore knew it had to continue innovating in order to maintain a competitive advantage over regional competition. The nation's strategy evolved to encompass a twin-engine approach of manufacturing and services.[5] The oil refining sector was generating low value-add and there was a need to diversify the value chain. The lack of industrial land led to the bold idea of reclaiming land and amalgamating seven smaller islands, eventually forming Jurong Island, officially completed and opened in 2009.[6] Simultaneously, Singapore worked hard to attract the right companies along the value chain to form a petrochemical cluster to create economies of scale.[7] Time after time, Jurong Island has continued to capture key trends to remain relevant by diversifying towards speciality chemicals, building research and innovation capabilities, harnessing digitalisation, and moving towards a circular economy. In housing a resource-intensive sector, Jurong Island has continued to innovate in order to become more self-sufficient and competitive. Overall, Singapore's approach in managing and growing such heavy industries has been holistic and integrated, enabling it to overcome challenges and ensure the global city continues to be liveable and sustainable.

Disclaimer: All maps in this publication are for illustrative purposes only, to highlight the islands that make up Jurong Island and its land use zoning. Not to be used for other purposes.

CHAPTER 1

THE OIL REFINING INDUSTRY: AN UNLIKELY ALLY IN SINGAPORE'S ECONOMY

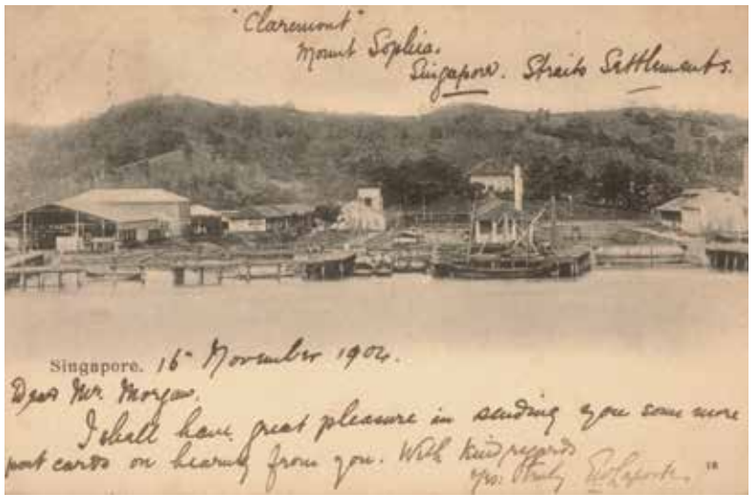
"We have to find the right economic strategy which will generate a fast enough rate of economic growth. But economic policies by themselves are sterile unless they are backed by an energetic implementation, and both policies and their implementation need a climate of confidence in order to yield results.[8]"

DR GOH KENG SWEE
Singapore's first Minister for Finance

Colonial Legacy

Singapore's early exposure to oil can be traced back to the first half of the 19th century during its development as a regional entrepôt. On 4 August 1845, the steamship Lady Mary Wood from the Peninsular and Oriental (P&O) Steam Navigation Company arrived in the harbour, heralding an era of greater connectivity between Singapore, the metropole in Britain, and other ports of call throughout Asia.[9] By 1851, P&O had secured a British government contract to provide shipping services to India, China and Australia.[10] The increased shipping volume in the Singapore Strait necessitated new port facilities, leading to the construction of the Horsburgh Lighthouse in 1851 and the New Harbour (Keppel Harbour today) in 1852—the latter which was opened by P&O. These facilities included a coal bunkering pier to refuel passing steamships, contributing to the port expansion in Singapore.[11]

1891 saw the establishment of Singapore's first oil storage facilities when M. Samuel & Co. of London decided to set up a base for the storage and distribution of imported Russian kerosene in Singapore.[12] The initial request to store kerosene in the town was rejected by the colonial government, eventually leading to M. Samuel & Co. establishing its facilities on present-day Pulau Bukom. This offshore island was close enough to the mainland and featured a deep, sheltered harbour.[13] M. Samuel & Co. eventually formed a separate entity, Shell Transport and Trading, to focus on its oil business. In 1907, it merged with the Royal Dutch Petroleum Company to form Royal Dutch Shell.[14]



1. Postcard featuring Pulau Bukom Wharf in 1904.

In the following decades, Pulau Bukom expanded such that prior to the Second World War, the island had a capacity of 60 storage tanks and five wharves. During the Japanese invasion of Malaya, the British engaged in scorched-earth tactics and torched the tanks to prevent the Japanese from acquiring these assets. After the war ended, these were rebuilt by Shell engineers.[15]

Setting the Scene: The Path to Industrial Development

By 1959, Singapore had grown significantly and was faced with issues of high unemployment, poverty, overcrowding, and a lack of basic amenities such as housing. Singapore's population growth rate averaged at 4.5% between 1947 and 1957, with an estimated unemployment rate of 10% at 1959.[16] The People's Action Party government, winning a majority in the legislative assembly action in May that year, were immediately responsible for Singapore's full internal self-governance as granted by the British Crown.[17] Dr Goh Keng Swee, Singapore's first Minister for Finance, recounted that it was a pessimistic time:

> When my [People's Action Party] government first assumed office on 3 June 1959...businessmen and industrialists, far from hailing this event as a happy augury for the future, felt for the most part that the end of the world was around the corner. The stock market collapsed and there was a flight of capital out of Singapore. Several people fled the country.[18]

If Singapore was to survive and prosper, it needed to address the urgent problem and challenge of creating an economic foundation. However, the country lacked natural resources and it could not devote an extensive amount of land to agriculture. Nor could Singapore continue to rely on its legacy of maritime trade to support job-creation needs, along with the issue of increasing competition from neighbouring countries relative to the increase in international trade.[19] Dr Goh hence decided that industrialisation would be Singapore's main economic effort.[20] Job creation from labour-intensive industries would complement Singapore's existing role as a trading hub, enabling the country to prosper economically and create the social attitudes necessary for a modern country.[21] Industrialisation meant that the country had to make large investments into modern infrastructure while planning and managing land use carefully to alleviate problems of pollution.

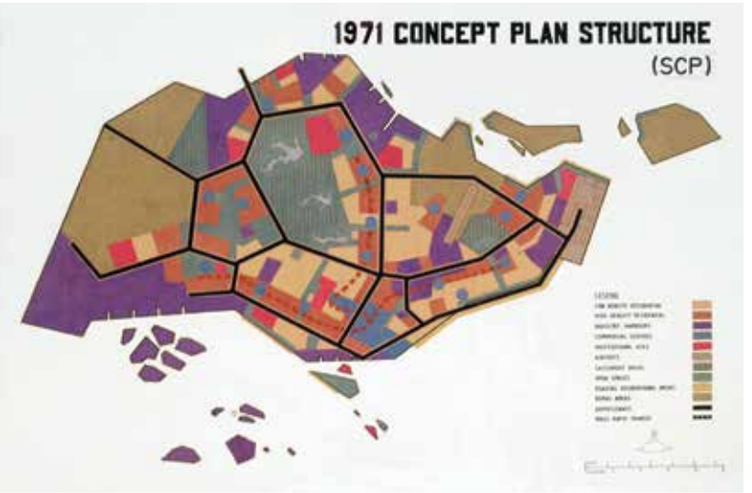
Planning for Industries: The Winsemius Report and the 1971 Concept Plan

Upon the request of the Singapore government, a visiting team from the United Nations Development Program (UNDP), led by Dr Albert Winsemius, arrived to do a survey of the country in 1960. The resulting Winsemius Report highlighted two main recommendations: to create a government organisation to spearhead industrialisation efforts, and the physical construction of industrial estates necessary to accommodate these developing industries.[22]

The Economic Development Board (EDB) was created in 1961 as a result of the first recommendation to oversee the process of industrialisation. The EDB would work to attract international capital and businesses to Singapore, bringing jobs and employment to Singaporeans.[23] In 1968, the Jurong Town Corporation, known today as JTC Corporation, was formed to take over the industrial estate management function of the EDB, while the Development Bank of Singapore would handle industrial financing.[24]

The second recommendation led to the creation of the Jurong Industrial Estate, as part of Singapore's land-use plan. According to the first Concept Plan in 1971—which was a continuation of work from the earlier 1963 Ring Plan proposed by UN experts Otto Koenigsberger, Charles Adams and Susumu Kobe—Jurong and its offshore islands would be a dedicated industrial estate for heavy industrial activities.[25] The area was suitable for this endeavour. Jurong was largely rural in nature, so there was less of a need for land acquisition exercises. In addition, the water around the coast was generally deep and its location near sizable offshore islands further south offered the possibility of eventually developing an industrial town alongside future port facilities.[26]

Such planning was significant from an environmental standpoint. Loh Ah Tuan, former Deputy CEO of the National Environment Agency (NEA), reflected on how agencies did *not* adopt a "develop first, clean later" approach in Singapore's land use planning. Instead, industries were grouped to build a strong foundation that minimised the negative effects of potential pollution and decreased quality of life.[27] Through the zoning work conducted by the Anti-Pollution Unit,[28] only light, non-polluting industries were allowed near residential estates to enable job-creation, while heavy industries were located away from the residential area.[29] Many of these were located in the Jurong Industrial Estate, where environmental protection services, such as the safe disposal of waste, could be consolidated and provided in a cost-effective manner.[30]



2. 1971 Concept Plan showing the Southern Islands zoned for heavy industries.

However, despite the Southern Islands being zoned for heavy industries, planners were uncertain as to how to best utilise and integrate them into Singapore's development strategy. Pulau Blakang Mati, present-day Sentosa, was a military camp for the British navy due to be vacated in September 1967.[31] Pulau Bukom housed refinery facilities by Royal Dutch Shell, which expanded from early storage operations into production after news of competition from the Japanese oil trading company, Maruzen Toyo.[32] Many of the other southern islands housed traditional fishing communities still engaged in subsistence lifestyles.[33]

Differing objectives among government officials further exacerbated the uncertainty about what to do with the islands. The EDB proposed utilising Pulau Blakang Mati for industrial purposes, going so far as to evaluate the site in conjunction with foreign experts. A six-man team of Canadian experts from McNamara Engineering Ltd., headed by K.K. Philpott, was brought in to study the possibility of Pulau Blakang Mati as a "second phase" for the expansion of Jurong Industrial Estate in 1966.[34] The Minister for Law and National Development, E.W. Barker, disclosed a competing plan to locate casinos on Pulau Blakang Mati to generate tourism, while highlighting that the Port of Singapore Authority (PSA) favoured use of the island for expanded shipping facilities due to its deep waters.[35] JTC assigned its most junior officers to oversee the Southern Islands, echoing the uncertainty over their use and the general notion that they were industrial backwater meant for "long-term" development.[36] To the public, the possibility that these islands could be used for industrial purposes seemed a far-fetched goal.[37]

SOUTHERN ISLANDERS

Commonly known as the *Orang Laut* or "People of the Sea", inhabitants of the Southern Islands of Singapore share sociocultural ties with both Singapore and the Indonesian Riau islands.

Archaeological evidence reveals that the *Orang Laut*'s presence on the Southern Islands dates back to the 14th century, with some more recent islanders having moved there during the colonial era to avoid British rule.[38] In modern times, this identity has also been shared by residents of Pulau Bukom, some of whom have moved from mainland Singapore to manage the Shell oil refinery on the island.[39]

3. Scenic view of the Southern Islands in 1963.

Islanders, especially on larger communities like at Pulau Seking, were largely self-sufficient, carrying out activities like fishing, agriculture and even providing limited medical services like midwifery during the 1960s. The day-to-day administration was conducted by the *penghulu*—the village head—who received official recognition from both British and Singapore governments. Islanders remember living in wooden houses facing the sea and having the freedom to fish from surrounding waters, enjoying an idyllic life growing up away from the mainland.[40]

As the community size decreased over time, the *penghulu* would work with the Coast Guard to deliver basic services for residents, especially for medical needs. Fresh water was also an issue, as wells on the island had been drying up since 1945 and had become salty by 1959. As a temporary measure, the islanders collected rainwater but also relied on the generosity of the nearby Shell oil refinery at Pulau Bukom for a steady supply of fresh water, free of charge.[41]

Ties were maintained between islands, with common experiences such as schooling and the organisation of the "Pesta 5S" inter-island games between Sekijang (Lazarus Island), Sudong, Semakau, Seking and Seraya islands. The last of these games took place in 1975, opened by Minister for Culture and Social Affairs Othman Wok.[42] Officially, by 1992, the last islanders were relocated to mainland Singapore, though a small number stayed on after that in secret.[43]

Early Industrial Investments in the Island State

As a result of Singapore's early industrialisation efforts and the EDB expanding manpower training for workers, the country was well-positioned to accept new production facilities. Ngiam Tong Dow, former Permanent Secretary of the Ministry of Finance, recalled that "We [Singapore] did not talk about high-tech, low-tech or whatever. Anybody who was prepared to put in some money and create jobs for Singaporeans was welcomed".[44] During this time, Western semiconductor companies sought to produce their goods overseas, leading the EDB to establish a local industrial base in electronics and precision engineering—which primed Singapore for the manufacture of more complex electronic goods in later years.[45]

Beyond the manufacturing of electronic goods, Singapore also saw significant industrial investments from the development of oil refineries. Previously, Singapore had a reputation for being a major global and regional centre for the blending, packaging and transshipment of oil, owing to the growth of Royal Dutch Shell in the interwar years and the associated expansion of its facilities on Pulau Bukom.[46] In 1959, Shell announced plans for a new refinery in Malaya to produce a million tonnes of crude oil per year, at an estimated capital investment cost of S$60 million.[47] A new refinery was eventually built on Pulau Bukom at the cost of S$30 million and was officially opened on 26 July 1961 by Dr Goh.

Less than a year later, Japanese oil trading company Maruzen Toyo established a refinery at Tanjong Berlayer, site of present-day Labrador Park.[48] In 1964, this refinery was purchased by oil giant British Petroleum, which took over operations at the site as part of their expansion into the Far East.[49]

Originally, it was Maruzen Toyo that made the first decision to establish a refinery in Singapore. Although it was a small company, unable to compete with international oil trading giants, its move to set up facilities in Singapore spurred Shell into action. Ngiam recalled how the Managing Director of Shell Eastern rushed into his office to announce his decision for a new refinery on Pulau Bukom after hearing the news of Maruzen Toyo's expansion.[50] Shell was eventually awarded Pioneer Certificate No. 1, under the government's Pioneer Certificates programme to attract investors through providing tax relief.[51]

4. View of the S$25-million refinery at Maruzen Toyo Oil Company (Singapore) Limited located in Tanjong Berlayer. It was one of the first major industrial investments in the island state.

Both of these early refineries were particularly significant in terms of Singapore's development. Shell represented the first major multinational corporation making a significant investment into Singapore's industrialisation,[52] while Maruzen Toyo represented the first of many industrial partnerships between Singapore and Japan.[53]

The Move towards Island Refineries

Oil and gas investments took place in the Jurong Industrial Estate as well. The Standard-Vacuum Oil Company, which had been selling bottled cooking gas and lubricants in Singapore, underwent a corporate separation in 1962.[54] Assets in Singapore and Malaysia were transferred to Standard Oil of New Jersey, which later became Esso, while former local partners of Standard-Vacuum Oil established Mobil Oil. Mobil expanded into oil refining, establishing its first refinery in Jurong along Pioneer Road in 1966 with a capacity of 18,000 barrels per day.[55]

The situation with Esso was more complex. Originally, Esso was granted permission by the Singapore Cabinet to build and expand a refinery on Pulau Blakang Mati, present-day Sentosa. The need for the plant and other dedicated facilities that cater to possible future expansion would mean that a specialised plot of land would be required, away from the ready-built factories in much of Jurong.[56] Opposition to these plans came from Dr Winsemius in June 1967, who believed that Singapore would quickly reach full employment in 10 to 20 years and would have a greater need for recreational spaces near the city centre. Pulau Blakang Mati was well positioned to serve as such a location, if it was not developed immediately into an oil refinery.[57] As Dr Winsemius recalled:

> So, it was a matter of having that refinery today, but having it till eternity in the centre of a city, which is [Pulau] Blakang Mati, or reserving it for tourist and other recreational purposes[58]

Together with Dr Alan Choe of the Urban Renewal Department and a team of Canadian experts, a plan was drafted to find a different island. Dr Winsemius headed to New York, with a letter from then-Prime Minister (PM) Lee Kuan Yew, to discuss the situation with Esso. Esso was enthusiastic about the proposition and agreed to the changes, allowing Pulau Blakang Mati to be redeveloped into modern-day Sentosa.[59]

The alternate site chosen for the project, Pulau Ayer Chawan, was off the coast of the Jurong Industrial Estate. There were multiple immediate challenges to be overcome before production could even begin. Infrastructure such as electric cables and telephones lines had to be laid, as well as piping for fresh water to be brought into the island via undersea utilities.[60] Sea channels had to be dredged by the PSA,[61] so that they would be wide and deep enough to accommodate the large hulls of oil tankers. Land on the site itself had to be prepared for construction to take place,[62] and a new public jetty was constructed in Jurong for staff to travel to and from the islands on sampans.[63]

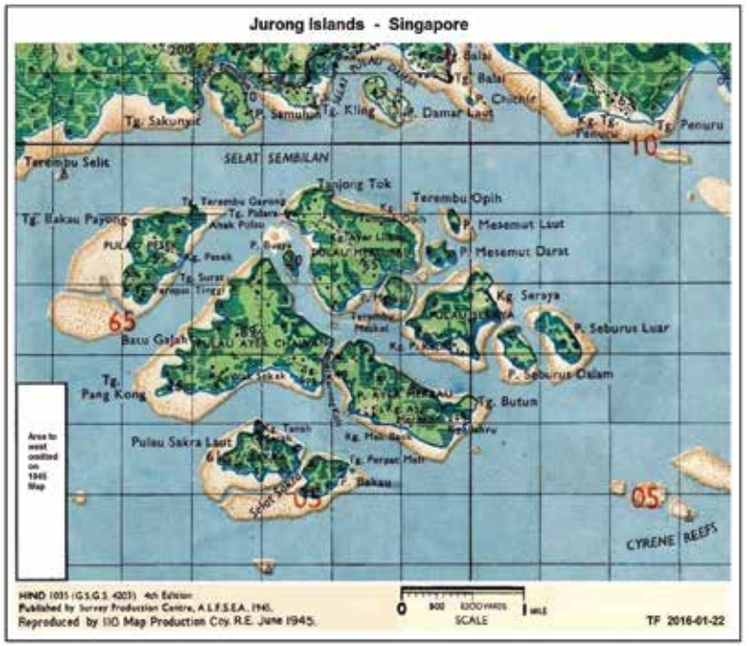
Esso's facilities marked a significant expansion of Singapore's oil refining capabilities. The 0.22 km^2 site would refine 80,000 barrels per day[64] of petroleum products for sale and distribution to the international market like Shell's Pulau Bukom refinery, with expectations to export to the growing Japanese market as well.[65] Esso's choice of investing in Singapore, over an alternative plan to expand oil production and refining in the Philippines, included Singapore's geographical location and infrastructural development, especially in terms of port facilities and communications.[66] J.M. Shievers, the head of the Esso team negotiating with the Singapore government, remarked that incentives for private sector investment put forth by the government had a significant impact on bringing in major industrial projects to Singapore.[67]

5. Esso Refinery at Pulau Ayer Chawan, off Jurong, 1971.

The Esso refinery marked another major multinational investment into the industrialisation of Singapore, giving the EDB the ability to market the country to more hesitant investors.[68] Both refineries on Pioneer Road and Pulau Ayer Chawan would eventually be linked up after the 1999 merger of Esso and Mobil into Exxon-Mobil Corporation, forming the Singapore Integrated Manufacturing Complex.[69]

Growth and Expansion of the Island Refineries

The pace of development only accelerated further in the 1970s. Three new refineries were built throughout the course of the decade—one by the Singapore Petroleum Company on Pulau Merlimau in 1971,[70] another on Pulau Ayer Merbau by a joint venture between the Singapore Government and Sumitomo Chemical Corporation of Japan in 1974,[71] and the last by Mobil on Pulau Pesak in 1977.[72] Simultaneously, production capacity on the mainland increased. For instance, a further S$150-million investment was made into Mobil's Pioneer Road refinery in 1973 to expand production capacity to 175,000 barrels per day.[73]



6. Map of the small islands that now make up Jurong Island, published in 1945.

To accommodate the pace of development, JTC began intensive land reclamation works around these islands with the approval of Parliament.[74] Reclamation works previously done on Pulau Ayer Chawan for the Esso refinery increased land space from 0.73 km² to 1.54 km², but still more space was required for petrochemical usage.[75] In 1973, JTC undertook a project to amalgamate three islands—Pulau Seraya, Pulau Seburus Luar and Pulau Seburus Dalam—creating 1.56 km² of usable industrial land space at the cost of S$26 million.[76] When completed in 1979, the space was earmarked for downstream petrochemical industries as well as a coal-fired power plant on the island, managed by the Public Utilities Board (PUB).[77] JTC also undertook various public works projects, including the construction of a 0.254 m submarine water pipeline from Pulau Ayer Merbau to Pulau Ayer Chawan, sea water intakes for cooling, and docks for oil, cargo and workers,[78] to support the Singapore Petroleum Company refinery on Pulau Merlimau.

Balancing between Growth and Liveability

Not all was smooth sailing for Singapore. Developmental pressures to provide employment opportunities meant that Singapore's leaders had to make difficult decisions in balancing growth and liveability, especially in its more vulnerable early years. The Ministry of Environment (ENV) and PSA had a close working relationship with the refineries to ensure that anti-pollution equipment measures were adopted in order to minimise air and sea pollution.[79] Former Cabinet Minister S. Dhanabalan recounted an incident where Singapore refused to sacrifice liveability for unchecked growth:

> When Sumitomo built its petrochemical plant [in the mid-1970s], the ENV said that there were certain environmental requirements they must meet in terms of the kind of investments they make to ensure that the effluent from the stacks were of acceptable quality and so on. And Sumitomo said, "No, if you insist on this, the costs will go up so much that it becomes not viable anymore." Of course, the EDB and Ministry of Trade & Industry felt strongly that we should concede to Sumitomo so that they [could] build the petrochemical plant. But the ENV said, "No, we should not concede. It will pollute Singapore." This went to Cabinet, and Cabinet agreed with the ENV. They said, "No, we insist." Then, Sumitomo proceeded and put in the investments necessary.[80]

Industrial development on the islands also resulted in the displacement of island residents, as well as the loss of their traditional lifestyles and homes. While most villagers were subsequently rehoused in Housing & Development Board (HDB) flats, many expressed a sense of dislocation and loss of community as this happened.[81] One group of islanders were resettled multiple times, first from Pulau Samulun to Pulau Merlimau following the development of the Jurong Port,[82] then to Tanjong Keling and finally, to HDB flats in Jurong. Efforts were made to improve service provision and amenities during resettlement,[83] to minimise instances of resettlement, and to allow the communities to remain in place for as long as possible.[84] Jobs were also provided for those whose livelihoods were affected, which highlighted a degree of compassion in the resettlement process.[85]

Finally, international pressures sought to threaten petrochemical investments in Singapore. In the wake of the 1973 Yom Kippur War and oil-price shocks, then-PM Lee Kuan Yew reassured oil companies that the

government would not assume control over their oil stocks. He personally met with CEOs and managing directors of the oil companies to further assure them that the government would support measures taken by the oil companies in light of the international circumstances.[86] Such moves led to the growth of international confidence in the Singapore Government, which would be vital down the road in securing further investments.

By the mid-1970s, Singapore was ranked among the top three international oil refining and trading centres alongside Houston and Rotterdam.[87] Good geographical location, coupled with Singapore's reputation for political stability and efficient urban governance, attracted international oil and gas investors to set up and expand their facilities in Singapore.

CHAPTER 2
BIRTH OF JURONG ISLAND

"I visited the petrochemical clusters in Rotterdam and Houston, and...people live there. Chemical projects are never permanently safe. All it needs is an accident. When you have housing around, it is quite dangerous. So when I was thinking of a petrochemical cluster, I wanted it on the island and I did not want anybody to live on that island. The island should just be for production because I do not want to risk the lives of people by having homes there.[88]"

PHILIP YEO
Former Executive Chairman,
Economic Development Board

Twin Engines of Growth

The 1980s brought a new set of problems, with an oil crisis in 1979 following the Iranian Revolution. Oil production capacity from Iran decreased by 4.8 million barrels a day, which accounted for 7% of global oil production at that time.[89] While precautionary demand drove short-term price increases, there was a long-term decrease in petroleum prices due to a lack of demand, which translated into poor performances from oil refining. Supporting industries such as shipbuilding and repair also suffered from the excess capacity and associated slowing of the economy. Singapore started to feel the pinch as its higher labour costs relative to the neighbouring developing countries served as a deterrent to investments, which further slowed down the economy. This was further aggravated by other internal factors, such as a high rate of domestic savings as well as a slump in the domestic construction industry.[90] After two decades of continuous growth, where even in a bad year gross domestic product growth was 5%, Singapore slipped into its first post-independence recession in 1985.[91]

The recession was significant in exposing structural weaknesses in the economy, which led to a fundamental review of the policies in place at that time. At the direction of Tony Tan, then-Minister for Trade and Industry, an economic committee was formed that year to assess the reasons behind the recession and for possible future directions for the country.[92] The resulting Economic Committee Report recommended that Singapore should switch to a "Twin Engine" approach of economic growth, with manufacturing and services being the two pillars of the economy.

Conceptualisation of the Chemicals Cluster

While Singapore had previously benefitted from the semiconductor industry, it was labour-intensive and Singapore could not rely on it in the long term.[93] Philip Yeo, then-Executive Chairman of the Economic Development Board (EDB), was concerned about the direction Singapore's economy should take. He visited various cities and companies to better understand the demands of the market and to identify potential drivers of growth. One of his key takeaways was the importance of building a petrochemical cluster:

> At the upstream, you have Mobil, Exxon and Shell. And downstream, you have the chemical companies. They want to be together, in an area where everybody is. That creates a critical mass. You realise even in the retail sector; they go by clusters. If you have only one little shop, nobody will come. But when all the same types of shops are in one place, it will create a critical mass.[94]

Singapore already had the oil refining capabilities in place, but there was a need to diversify the industry, especially with regional competition from India, Thailand and China.[95] The EDB team was aware of the potential that the chemicals industry could unlock in driving economic development, as demonstrated by the German and Japanese economies prior to the Second World War.[96] Singapore had the right elements to further develop this sector given its political stability, its excellent geographical position as a trading hub, and its existing refineries within its boundaries.[97] Philip Yeo's strategy was hence to develop a petrochemical cluster, alongside the electronics, precision engineering and biomedical sciences cluster in the 1980s.[98] The cluster development strategy would mark a shift from previous operations, where there was little connectivity between industrial activities. This approach emphasised a symbiotic relationship between companies, where the output of one plant would become the input for another plant, while concurrently sharing core capabilities and infrastructural facilities, thus resulting in economies of scale.

In order for the cluster approach to succeed, there was a need to increase officers' competencies and expertise in each of the industries. Dr Tan Chin Nam, then-Managing Director of the EDB, explained some of the capability development undertaken to equip officers:

> One of the first things that I did was to talk to Michael Porter [Professor at the Institute of Strategy and Competitiveness at Harvard] to convince him to come over to conduct a two-day programme on competitive advantage, competitive strategy, [and] competitive analysis, which would pave the foundation for EDB officers to adopt the cluster approach of developing our industry.[99]

Other measures taken to promote industry partnerships included launching a Cluster Development Fund alongside a Co-Investment Programme, which would see the government intervene to make strategic investment, fill industry gaps, and support local enterprises.[100] Now, what was needed was finding the appropriate site and sufficient land to fit the chemical cluster, considering potential safety and environmental hazards, along with increasingly scarce industrial land.

THE AUTOMOTIVE INDUSTRY IN SINGAPORE

Under the cluster development strategy, Singapore was to develop according to the four focus areas of petrochemicals, electronics, precision engineering and biomedical sciences. However, at one point of time, Singapore considered further developing the automotive industry as part of its industrialisation strategy. In 1963, Singapore merged with the Federation of Malaya, North Borneo, and Sarawak to form Malaysia. Within the same year, the Central Government and the Singapore Government announced plans for a car industry programme. Dr Lim Swee Aun, Malaysia's then-Minister of Commerce and Industry, was of the view that "assembling and [the] progressive manufacturing of cars was the next logical trend in our [Malaysia's] industrial programme".[101] Under the joint policy, both governments provided licenses to both local and foreign companies to set up operations for automobile assembly plants in any state, which included Singapore. The government envisioned that a focus on the automobile industry would create more jobs directly as well as indirectly, through the manufacturing of components such as tyres.[102] Furthermore, the presence of foreign car manufacturing companies would mean a potential transfer of knowledge and upgrading of the technical skills of local workers, which would prove beneficial for home-grown automobile brands.[103]

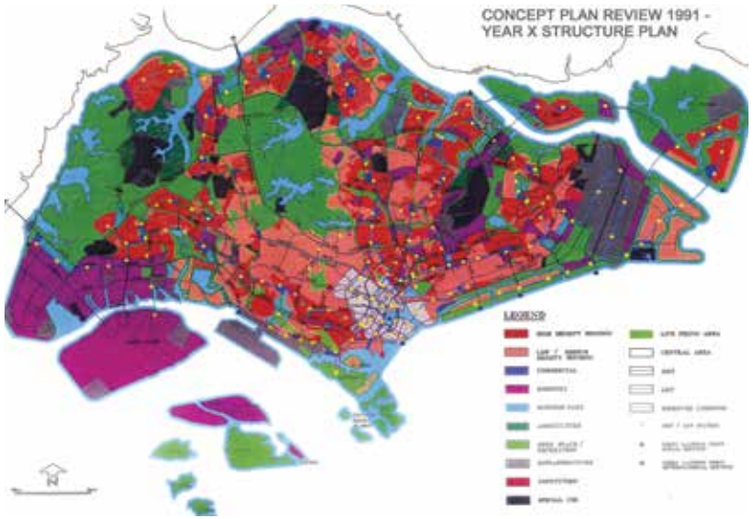
7. Japanese Prime Minister Eisaku Satō (centre) visiting Bridgestone Corporation's tyre factory at the Jurong Industrial Estate. Inaugurated on 3 April 1965, it was the first tyre factory in Singapore, jointly financed by Japanese and Malaysian businessmen.

When Singapore split from Malaysia in 1965, it resulted in the disintegration of the common market and the subsequent competition for foreign investments. The Malaysian Motor Vehicle Assemblers' Association advocated for Singapore and Malaysia to combine their automotive programme, given that the combined market was of only 33,000 vehicles a year, in comparison to Australia, which supplied 400,000 new vehicles a year.[104] However, negotiations ultimately fell through and both nations continued to compete for investors.[105] While Singapore continued assembling cars in the following years, eventually it was announced in January 1980 that Singapore would aim to halt any local production of cars in the subsequent three years. The domestic market was too small, and it was not economically feasible to manufacture all the components for conventional internal combustion automobiles locally.[106]

Lim Chin Chong, former Director of Specialised Parks Development Group, JTC Corporation, elaborated more on the rationale of why Singapore did not pursue the automotive industry further. Besides the lack of a domestic market and hinterland, the value chain for the automotive industry was very long and required a lot of logistics in parts and components supplies, and there was simply a lack of support for it.[107] At the end of the day, Singapore decided to play more to its strengths at that point of time and focus on petrochemicals. Investing in this industry made logical sense for Singapore due to the nation's existing port facilities in handling such cargo and facilitating the trading of products internationally.

Planning for Jurong Island and the 1991 Concept Plan

In the 1971 Concept Plan, the islands that would eventually form Jurong Island had already been zoned for heavy industrial activities. The 1991 Concept Plan then highlighted the idea that the seven low-lying, southern islands off the coast of Jurong could be amalgamated into a single landmass for the petrochemicals industry. The choice for the location of the industry was borne partly out of careful planning and an existing industrial base, but also due to the lack of alternatives.



8. Concept Plan 1991. To support the development of a petrochemical industry, the Plan also proposed for seven low-lying, southern islands to be amalgamated into one large island–known today as Jurong Island.

When the idea for the petrochemical industry was proposed, there were initial concerns among the agencies on the environmental implications. However, the EDB believed that the petrochemical industry was critical for the growth of Singapore.[108] The various agencies, such as JTC, the Urban Redevelopment Authority (URA) and the Ministry of Environment, supported the EDB in planning for the industry. The idea to join up the islands in order to form the larger, single entity of Jurong Island started to gain traction.

Ong Geok Soo, Head of Civil and Structural, JTC, recounted that in the 1980s, there was a pressing need to reclaim more land to support industrial development.[109] Waterfront sites were in high demand due to the boom in shipbuilding, ship repair and oil rig fabrication.[110] While the government had previously enlarged some of the southern islands through reclamation works—Pulau Seraya for a power station between 1982 and 1983, Pulau Ayer Merbau for the Petrochemical Corporation of Singapore's first chemical complex in 1984, and Pulau Sakra, formed through the merging of Pulau Sakra and Pulau Bakau, in 1985 for future industrial activity—it was the advent of the "Tuas Hockey Stick" that emboldened JTC to reclaim more land, leading ultimately to Jurong Island.[111]

The Tuas Hockey Stick, nicknamed after its shape, was formed through the reclamation of 6 km^2 of land from the sea off Tuas in 1988. The project was significant in comparison to earlier efforts as it demonstrated the possibility of larger-scale reclamation works that were also economically viable. Francis Mak, JTC's General Manager at the time, commented:

> When [the] Tuas Hockey Stick was reclaimed for less than S$1 million per hectare, we found it to be economically viable. You are talking about only S$10 per square foot. We said, "Hey we need more land. How about reclaiming more?".[112]

Ong subsequently conceptualised the joining of the southern islands off Jurong to form one massive landmass and showed the ambitious plan to create a large tract of industrial land to several JTC engineers, including Lim Chin Chong and Chuah Seng Gee.[113] Extensive studies were carried out subsequently on the feasibility of the reclamation, including confirmation of the island's profile through a hydraulic study done by the Nanyang Technological University before the concept plan for the island was completed and sent to the other agencies.[114] This was to ensure Jurong Island was ready to host the chemicals cluster, meeting technical requirements such as having a sufficient coastline to support the types of ships that would transport goods to and off the island.[115]

In the early 1990s, Philip Yeo was on a helicopter flight back to Singapore after scouring Indonesia's Karimun Islands for a shipyard site.[116] During the ride, Yeo's guests pointed out that the channels between the islands were shallow, which could pose an issue for bunkering. Yeo requested that the helicopter fly closer to the waters and was inspired by what he saw. He recounted, "It sounded like a crazy idea, but what if we filled up the channels to link up the seven islands and create a big one? An offshore island, where petrochemical complexes could be built, sounded like a good idea. We touched down in Singapore and I called up my guys when I reached back to the office."[117]

For the petrochemical cluster, Yeo explained that he wanted it to be an island purely for manufacturing without any residential land use as the quality of life for residents would be lower, and that it would also safeguard against any accidents.[118] Furthermore, he had previously observed that chemical companies were decentralised, hence planning a cluster where companies were in close proximity to one another was prudent given the shortage of industrial land and would create a critical mass of related industrial activities.[119] Yeo had originally wanted to establish the cluster on Sentosa, as it was isolated from the mainland, but the government had rejected the proposal. On hindsight, Sentosa was too small, covering an area of just 3.4 km^2, whereas 30 km^2 of industrial land was needed for such a cluster.[120]

Lim Neo Chian, former Chairman, JTC, reflected that Jurong Island was the merger of "two powerful ideas".[121] The first was the amalgamation of the seven islands into one singular landmass, while the second was utilising the islands specifically for the petrochemical cluster rather than other industries. However, it must be said that the decision to locate the industry there was not strictly due to planning, but also evolutionary in nature. Lim Chin Chong added that while industrial development on the island had the benefit of risk containment, which made it easier to do integration, monitoring and environmental control, the petrochemical cluster was located on Jurong Island due to the lack of viable alternatives. The refineries had already been located on the southern islands since the 1960s, and it was difficult to alter this legacy and shift the plants elsewhere.[122]

The development of Jurong Island continued to be influenced by strategic land-use planning and requirements on the mainland. Dr John Keung, then-Physical Planning Director, URA, recalled that while preparing the 1991 Concept Plan, the URA was of the view that Singapore's future mega-port should be sited in Tuas instead of Pasir Panjang due to long-term considerations.[123] The waterfront land at Pasir Panjang could potentially be used for residential and commercial activities. The PSA, however, disagreed with this suggestion. Lim Kim San, then-PSA Chairman, advised that the waters off Tuas were too shallow for container ships to berth.[124] Furthermore, there would be cost savings derived from locating the new port at Pasir Panjang where there would be synergies with the existing city terminals at Keppel and Tanjong Pagar.[125] Eventually a decision was made for the port to be developed at Pasir Panjang, with the view of relocating the port to Tuas only in the future. Dr Keung reflected that:

> Had Pasir Panjang been designated, re-planned as the residential area, then it may not be so suitable to expand Jurong Island so much.... It does not make sense if you expand the residential area and then expand the petrochemical island almost at the same location... because you are basically getting two rather incompatible uses closer and closer to each other.[126]

Though seemingly isolated, Jurong Island, as with all power stations and refineries in Singapore, is required to have a nuisance buffer that places restrictions on the types of land use within the buffer. For example, residential areas cannot be located within the nuisance buffer. In addition, health and safety buffers have to be established based on a quantitative risk assessment carried out by a registered consultant for premises such as refineries that transport, handle or store hazardous materials.[127]

Despite such restrictions, the Pasir Panjang Terminal area never over-extended into any existing health and safety buffers from Jurong Island. This is especially important given that the long-term plan for the Greater Southern Waterfront—of which Pasir Panjang is a part—is to have mixed-use developments including residential projects after the port terminals move to Tuas.[128] The long-term and holistic approach to planning for the mainland and Jurong Island, as well as the adoption of stringent environmental standards, helps to safeguard the quality of life for future residents in the area.

Process of Land Reclamation

Compared to previous reclamation projects, the reclamation of Jurong Island was much greater in scale and complexity. David Tan, current Assistant CEO of JTC recounted:

> This was not a greenfield site either. There were already a few refineries and petrochemical companies operating on some of the islands and their facilities included jetties, pipe bridges, and submarine pipelines and cables. On top of that, the companies used the seawater to cool their process plants. The reclamation might affect these facilities.[129]

Jurong Island presented a challenge as a brownfield site with existing refineries, petrochemical companies, a power station, storage tanks and jetties, which meant that reclamation works could lead to potential disruptions to these companies' operations. JTC had to ensure that development works were carried out around the existing infrastructure whenever possible so that they would not be affected.[130]

9. View of land reclamation works in progress at Jurong Island, taken during the launch ceremony of Jurong Island's amenity centre Oasis@Sakra and internet portal JurongIsland.com.

Numerous preliminary studies were conducted to identify technical issues and establish planning parameters before the actual engineering and reclamation could be executed.[131] Lim Chin Chong shared that JTC had the Reclamation Unit study the viability of reclaiming the land along the coastline for the purpose of industrialisation.[132] This included hydraulic studies to ensure that reclamation works would have limited bearing on maritime activities, which included providing sufficient anchorage areas for ships and safe passage through the sea. With limited technology at the time, the team had to depend a lot on physical modelling rather than using computer simulations, which are more easily available today. Furthermore, David Tan added that such studies were also conducted to safeguard and protect the environment and marine life:

> We must make sure that our development works are sustainable. We carried out a lot of studies to make sure that the current flow, water temperature and water quality around the island are acceptable. We also made sure that after we have reclaimed the land, we do not cause siltation, and we do not create erosion of the land, so making sure that the environment is protected and sustainable over the long-term.[133]

Such a large project meant that there was need for coordination between the government agencies and companies. In order to facilitate cooperation between the public and private sectors, the Jurong Island Coordination Committee and the Jurong Island Industry Group were formed in the 1990s, where the former comprised government agencies while the latter included both government agencies and companies.[134] The groups were responsible for overseeing the development of Jurong Island from the technical, environmental and economic perspectives, such as planning the industry ecosystem where the individual companies would be situated. A testament to the good cooperation between the public and private sectors in Jurong Island's development was the minimisation of disruptions to companies, as shared by Ong Geok Soo:

> Now one of the big things that we did was that there was a compensation committee. So that if some of their works are affected, we will sit down together and deal with the claims. But when the thing worked out, actually the claim amount was very small. Some of the jetties and warehouses were affected, but those were minor. We [had] planned carefully so that we would avoid all this need to relocate or demolish the existing structure. Everything was quite well done and the amount claimed was very small.[135]

While the reclamation of Jurong Island was a tremendous task on its own right, the EDB was also facing the uphill task of attracting investors when most of the land was still submerged under the sea.

Selling Land under the Sea

Beginning in 1992, the EDB started actively marketing Jurong Island to top players in the international chemicals industry in a bid to attract these foreign investments to Singapore. Previously, industrial land was readily available, such as in the Jurong Industrial Estate, which convinced companies to undertake high-risk venture of investing in Singapore in the 1960s. In contrast, marketing Jurong Island would prove a challenge, and the take-up rate was slow in the initial years as it was akin to "selling stretches of seawater, with only the promise of land sometime in the future".[136] Companies were unconvinced of the benefits of integration, and reclamation only started in 1995.[137]

The EDB kept in close contact with investors through frequent meetings to convince them of the overall strategy for the development of Jurong Island, provide updates on the progress of the island, and understand their barriers to investing in order to resolve them.[138] Philip Yeo recalled the determination of the officers in meeting the needs of the companies through finding the right partners for them in the cluster:

> You got to call all the companies one by one. There is also a cumulative effect. Once I break one or two key guys, I could run to the others and say, "Hey, I got your feedstock." You've got to run to and fro. You cannot sit down and wait for the manna from heaven. We had to chase every project. There is nothing more humiliating than when you have to sell. You must have supreme confidence in what you are trying to do, otherwise, why should they believe in you?[139]

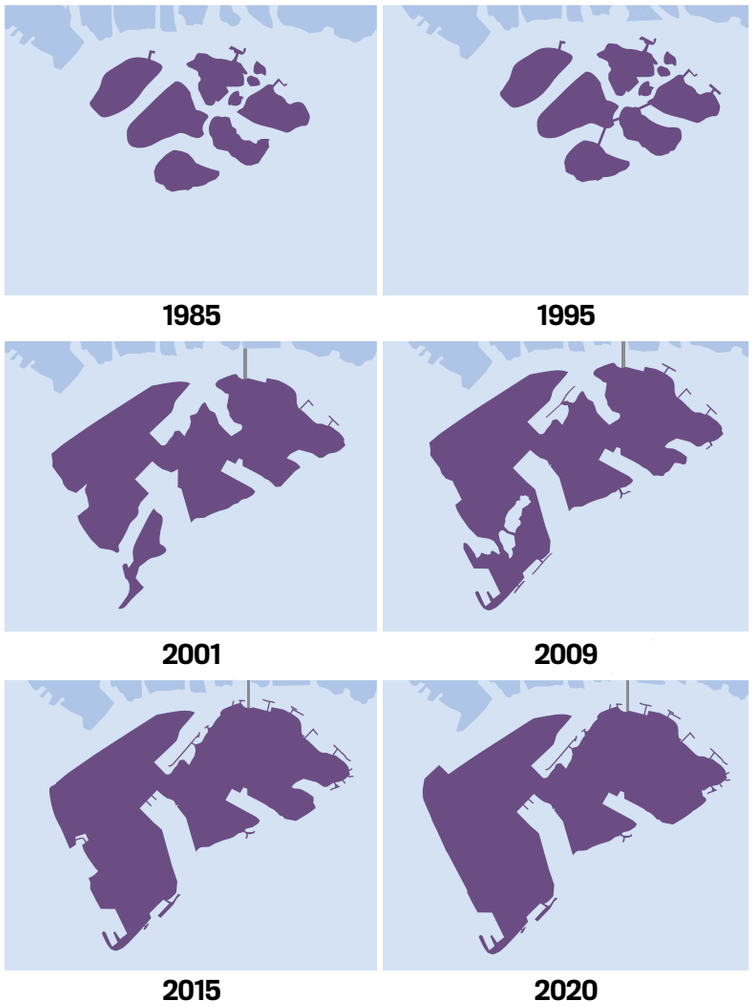
It was the EDB and JTC's track record, the good relations with companies built up over the years, and unwavering persistence that eventually won over investors. Goh Chok Tong, then-Prime Minister, commented, "[The] EDB succeeded [in convincing companies to invest in Jurong Island] because international investors have confidence in Singapore, and in our ability to deliver what we promise. This reputation has been earned over the years. It is a competitive asset, which we must not only retain but also improve upon."[140] In 1995, the breakthrough finally came when Celanese Chemicals invested in a US$100-million plant to produce up to 190,000 tonnes of vinyl acetate monomer annually.[141]

Celanese Chemicals was initially reluctant to invest due to the amount of infrastructure required. However, the EDB found suitable partners in SUT Sakra, to deliver utilities through a network of service corridors, and Vopak, which could provide additional bulk liquid storage. This convinced Celanese Chemicals to invest in Singapore,[142] creating a chain reaction as other big players, such as Chevron, Sumitomo Chemical and Mitsui Chemical, also became interested. The number of companies on the island more than tripled from 19 in 1995 to 60 in 2000.[143]

Another example of the agencies' commitment and ability to deliver just-in-time was when the Chairman and CEO of Teijin Polycarbonates, Hiroshi Itagaki, visited his site in December 1996 with about two-thirds of it still underwater.[144] Itagaki was skeptical of the project, as reclamation in Japan tended to be a slow and tedious process.[145] Nevertheless, when he returned in six months, the entire site was completely reclaimed.[146]

Phases and Opening

EXHIBIT 1
TIME-LAPSE OF THE JURONG ISLAND RECLAMATION:
(TOP ROW) 1985 (PRE-RECLAMATION) AND 1995, (MIDDLE ROW) 2001 AND 2009, (BOTTOM ROW) 2015 AND 2020.



Source: Google Earth.

In October 1993, a S$7-billion budget was set aside to build Jurong Island.[147] In comparison, Jurong Industrial Estate was developed at a cost of S$100 million. Yeo had to persuade then-Deputy Prime Minister Lee Hsien Loong that this strategic investment was necessary.[148] The reclamation of Jurong Island started in 1995 and proceeded in phases—2.03 km^2 in Phase 4.78 km^2 in Phases 2 and 3A, 9.77 km^2 in Phase 3B[149], and 5.50 km^2 in Phase 4.[150] Due to the sheer size of the project, the original timeline was for it to be completed by 2030, but this was brought forward by about 20 years to 2009.[151] Jurong Island has subsequently undergone additional reclamation works although at a smaller scale, such that its land size measured 32 km^2 by 2015.[152]

10. View of the oil refineries at Jurong Island when it was officially opened in 2009 by then-Prime Minister Goh Chok Tong.

CHAPTER 3

PIECES OF THE PUZZLE: ASSEMBLING THE JURONG ISLAND PICTURE

> “If you create the cluster, you must make sure that they (the companies) service as well as support one another. We created a cluster because that was the only way for us to compete. We had no land, no domestic market, no oil. Our labour costs were higher compared to our neighbours and so were our land costs. These were all our handicaps. We had nothing. So the only way for us to be competitive was to bring in raw materials, treat the companies as a cluster, given maximum value add and then go down the chain.[153]”

PHILIP YEO
Former Executive Chairman,
Economic Development Board

Hospitality for International Companies

Singapore's decision to diversify its manufacturing base and aggressively promote the petrochemical industry was borne out of necessity. The country did not have any raw materials or a domestic market, whilst its labour costs were higher compared to other countries in the region. Providing industrial land through the massive reclamation of Jurong Island was just the beginning. There was a need to provide greater competitive advantages and reasons for companies to invest in and create a cluster of related industries on the island.[154]

To elaborate further on the cluster approach adopted for the petrochemical industry, the Economic Development Board's (EDB) then-Director of European operations, Ong Wee Hock, shared that the inspiration for the chemical hub came from Germany's Ludwigshafen.[155] Established in 1865, it is the world's largest chemical complex.[156] At Ludwigshafen, Badische Anlin und Soda Fabrik (BASF), one of the world's largest chemical producers,[157] serves as an anchor investor and attracted a host of upstream and downstream companies to situate around the company.[158] BASF's strategy, also known as the Verbund concept, involves integrating production plants and technologies in order to create efficient value chains that encompass basic chemicals all the way to high value products.[159] Damian Chan, current Executive Vice President and former Executive Director, Energy and Chemicals Cluster, EDB, highlighted that while Singapore learned from the concept, Jurong Island deviated from having a single company dominate the cluster, and focused on bringing in a diversity of players to form the petrochemical ecosystem.[160] This was partly due to the fact that Singapore did not have its own chemical giant to serve as an anchor.[161]

Singapore focused on creating a vertically integrated structure where companies would trade "over the fence".[162] Companies were linked via a common pipeline service corridor where the output of one plant would serve as the input of another plant, creating a synergistic relationship. The service corridor facilitated the flow of feedstock, products and utilities such as steam and cooling water, to meet the needs of the companies on the island. For example, Solvay receives ethylene oxide as a raw material via a dedicated pipeline from Shell to produce specialty alkoxylate surfactants to create agrochemicals and coatings.[163] As a result of the proximity, companies would be able to "save on their initial capital outlay, reduce operating costs, enjoy economies of scale and concentrate on their core business".[164]

11. Chemical and utility pipelines as seen on Jurong Island today.

Lim Chin Chong, former Director of Specialised Parks Development Group, JTC Corporation, shared that while the value chain was not a new concept, but the lack of a giant anchor investor for Jurong Island meant that there were difficulties in assembling the value chain.[165] Many of the chemical companies were also competitors, making a value proposition necessary to convince them to co-locate on the same island. This came in the form of the plug-and-play concept. This concept meant that chemical companies only had to focus on key investments, such as facilities for their core production units. By tapping on third-party logistics and utility providers, they could significantly reduce their initial capital outlays on infrastructure such as power stations, jetties or storage facilities.[166]

On Jurong Island, most of the utilities and services are supplied by the Sembcorp Utilities group of companies, alongside power suppliers such as PowerSeraya and infrastructure builders like PowerGas.[167] Subsidiary companies such as SUT Sakra and SUT Seraya, established in 1995 and 1999 respectively, were sometimes set up to provide common utilities to the chemical companies.[168] Pipenet, a subsidiary of Keppel Infrastructure, was formed in 2006 to provide a pipeline corridor and centralised utilities services on Jurong Island.[169] Today, it owns and operates an extensive pipeline corridor network linking the various parts of the islands, connecting Merbau to the Banyan and Tembusu regions, through to the Sakra region.[170] Philip Yeo remarked that Singapore's approach was akin to a hotel business, in terms of providing hospitality and services, as companies only had to

build their plants and plug into the network to commence their production activities.[171]

Beyond integration and the plug-and-play concept, Singapore served as an attractive investment destination due to its stability. Chan elaborated on how the energy and chemicals industries were highly capital intensive, with projects ranging from millions to even billions of dollars.[172] Singapore's rule of law and predictability of government policy gave investors the assurance that Singapore would be a stable location to base their operations.

Mobility between Jurong Island and the Mainland

The common pipeline service corridor mainly facilitated the flows of feedstock and utilities around the island, but additional transport infrastructure was required to enable the flow of labour between the mainland and Jurong Island in support of day-to-day operations.

When refinery operations first started on the individual islands in the 1960s, workers had to travel in 12-man *sampans* (small boats) from a makeshift pier where the Jurong Shipyard is located today.[173] In 1995, in response to the increased activities at the Southern and Jurong offshore industrial lands, the Pasir Panjang and West Coast domestic ferry terminals were constructed to transport workers to the islands.[174] Philip Yeo viewed that the ferry services were inefficient and wanted to build a bridge linking Jurong Island to the mainland.[175] This would also facilitate the flow of equipment and goods between the island and the port facilities on the mainland.[176] However, the idea was initially met with resistance as the agencies were concerned that the flow of goods and people would be too light to justify the investment.[177]

Eventually in 1997, then-Parliamentary Secretary for National Development Koo Tsai Kee announced the construction of the Jurong Island Road Link. He explained how "connecting the island to Jurong Pier will certainly make Jurong Island a more attractive place for investors. It will help reduce operating costs for industrial companies setting up on the island. This road link will thus contribute to the commercial attractiveness of Jurong Port, as well as for shipyards and industries in the area".[178] This causeway featured the ability to open for vessels to pass through by using a large concrete pontoon, which could be floated away. Furthermore, when the causeway was opened, public utility services were unaffected, as the pipes were laid underwater.

In 2000, the road link was fully completed and officially opened to all vehicular traffic by then-Deputy Prime Minister (DPM) Lee Hsien Loong.[179]

In his speech, then-DPM Lee expressed his regret that the project was completed at least three years too late. He shared that though the Ministry of Trade & Industry and JTC discussed the possibility of building the road link early on, the concerns on usage led the agencies to settle on ferry services and postpone the road link to a later phase of the project. However, the EDB and JTC surpassed expectations in attracting investors and ultimately it was apparent that the road link was urgently needed. If built earlier, the project would have saved more "commuting time, transportation and construction costs, and inconvenience".[180]

12. Jurong Island Highway, 2010.

The presence of roads leading into the island meant that carparks were required for workers. However, if carparks were situated at every company's worksite, a significant portion of land would need to be allocated, which would affect the masterplan of the island.[181] As a result, a multistorey carpark was placed in a centralised location known as Oasis@Sakra. Conceptualised as a neighbourhood centre where workers could park and ride shuttle services to their workplace, Oasis@Sakra also featured a waterfront, a garden and other amenities. George Yeo, then-Minister for Trade and Industry, expressed his hope that with the improved accessibility, Jurong Island could serve other recreational and educational purposes while rebranding the industrial estates from their negative stereotypes:

> Jurong Island should be a thriving community with a conducive environment, attractive landscaping and good social amenities. We do not want it to be a bleak expanse of equipment, pipes and tubing, but a fascinating place with high technology and remarkable human organisation, which students and tourists would want to visit. This

> amenity centre we are opening today is a start towards that end. Called Oasis@Sakra, it houses a food court, an al-fresco restaurant, a 24-hour medical centre and convenience stores, all firsts on the island.[182]

Initially, the public were allowed access into Jurong Island. However, after the 2001 September 11 attacks in the United States (US) and regional terrorist threats from Jemaah Islamiah, the island was later declared a Protected Area.[183] Access to the island was restricted, and security measures were implemented to control the flows of people and goods coming in and out of the island.

Even after the construction of the Jurong Island Highway, modifications to transport infrastructure were implemented for various reasons. In 2005, ExxonMobil signalled its interests to construct a multibillion-dollar liquids cracker and associated downstream petrochemical complex.[184] The plant needed to be built parallel to its existing refinery, an 800 ktpa (kilo-tonnes per annum) cracker called the Singapore Chemical Plant (SCP), in order to create synergies. However, there was a lack of industrial land available. JTC eventually identified a plot of land south of the cracker, but the Jurong Island Highway cut through the middle of the site, which meant that it had to be diverted if the plot was to be used for industrial activity.

The highway diversion was a multi-agency effort involving many parties, including JTC, the Land Transport Authority (LTA), PUB, Singapore's National Water Agency, Energy Market Authority (EMA), Singapore Civil Defence Force (SCDF) and EDB.[185] Beyond engineering works, there was a need to ensure that vehicular traffic could continue without any disruptions. Furthermore, the highway diversion works would cause inconvenience for more than 25 existing companies on Pulau Sakra, as there were almost 20 key product and utilities pipelines running alongside the highway. JTC was thus involved in seeking the cooperation and agreement of affected companies for the project, which lasted almost three years and cost S$70 million.

The presence of one entry point into the island translated into congestion during rush hour. To cope with this, JTC implemented a reversible system in 2008.[186] Under this system, instead of four lanes in either direction on the linkway between 6:30 a.m. and 8:30 a.m., the number of entry lanes would be increased to six while the number of departing lanes would be reduced to two. The first iteration was a manual version, requiring 15 workers and 30 minutes to deploy the system, at an annual cost of S$400,000 to operate. In 2017, an automated system was launched to replace the manual version, requiring only two traffic coordinators and 10 minutes to deploy the system. At a cost of S$2 million, the system broke even in five years.

The economic activities of Jurong Island and the transportation of chemicals also affected transport planning on the mainland. Loh Ah Tuan, former Deputy CEO of the National Environment Agency (NEA), shared that heavy vehicles carrying hazardous chemicals are not permitted to travel on roads in population centres, water catchment areas and road tunnels.[187] In addition, the drivers are required to attend a training course on how to react and deal in an emergency involving vehicles carrying hazardous substances. Annual emergency response exercises were conducted to respond to chemical spillage on the Causeway and on the Tuas Link.

Connecting Jurong Island to the World

Beyond road infrastructure to transport people and goods between Jurong Island and the mainland, port facilities were required to provide accessibility to the wider region for the import of raw materials and export of products. The closest port to Jurong Island was Jurong Port, which commenced operations in 1965 to support the economic activities at the Jurong Industrial Estate.[188] The natural deep waters off the coast made the location an ideal spot for establishing the port. While the port was initially run by the EDB with assistance from the Port of Singapore Authority (PSA), the port function and management were shifted to JTC in 1968. In 2001, Jurong Port was corporatised in order to remain competitive.[189]

The port's proximity to Jurong Island translated into improved cost and time efficiencies in transferring products. Ng Cheng Cheong, former CEO of Singapore Petroleum Company, commented on the importance of Singapore's port to the success of Jurong Island:

> Jurong Island will succeed because we are in close proximity to the best port infrastructure in the region, if not of the world. We can create the most efficient logistics hub so close to the manufacturing base. Neighbouring hubs may be endowed with natural resources, but their manufactured products and components require long overland journeys before reaching a seaport. Even though their start-up and running costs may be lower, their logistics costs are sizeable, making it less optimum to compete in a global market. I found no other hub like Singapore so compact, so close to a mega port that it takes minimum time to transit from factory to marketplace. Singapore offers the most optimum point to distribute the manufactured products worldwide—just-in-time.[190]

In 2019, the Jurong Port Tank Terminals (JPTT) was opened, further increasing the competitiveness of Jurong Island. Pipelines between Jurong Island and Jurong Port meant that vessels were not required to transfer products between the two places, resulting in savings of up to 30% in terms of transportation and handling cost.[191] In addition, the JPTT offered 252,000 cm^3 of clean petroleum product storage capacity. The presence of large capacity pumps and jetty arms increased the ship loading and unloading process by up to 50%, which translated into reduced port stay times for ships and greater cost savings for companies.[192]

Furthermore, while Singapore did not have a domestic market, its network of free trade agreements (FTAs) with other countries would provide Singapore-based businesses a gateway to preferential markets, complementing its world-class port infrastructure. Such benefits would include free or reduced import tariffs, along with enhanced intellectual property regulations.[193] Singapore signed two types of FTAs, namely bilateral agreements such as the China-Singapore FTA (CSFTA) and India-Singapore Comprehensive Economic Cooperation Agreement (CECA), and regional agreements such as the ASEAN Free Trade Area (AFTA).[194] The market for commodities produced by the energy and chemicals industry tends to be more regional, and Singapore's FTAs proved highly attractive for businesses to tap on these markets.[195]

While Jurong Island contributed significantly to Singapore's economic development, its industries are resource-intensive, utilising a large amount of industrial land, energy and water, as well as contributing significantly to Singapore's carbon footprint.[196] Hence, while infrastructure was put in place to support the industries, appropriate measures were required to manage the resource-intensiveness and pollutive aspects of the industries on the island.

SECURING JURONG ISLAND

By the turn of the century, Jurong Island was shaping up to be a valuable economic asset. However, it was not until terrorist attacks in the US and within the region that its vulnerability became a glaring issue, as shared by Lim Neo Chian, former Chairman of JTC:

> It was not so evident at that time we were building it, but later it became obvious after September 11...Jurong Island [is] a more sensitive area that needed to be protected. So [these are] your trade-offs: you have got a wonderful economic cluster producing jobs, investments, but you need to get it protected.[197]

While the 2001 September 11 attacks in the US shook the world, the subsequent terrorist attacks in the Philippines and Indonesia, as well as the uncovering of planned attacks by Jemaah Islamiah on Singapore, underscored the threat of terrorism and brought it close to home.[198]

Jurong Island was immediately identified as a sensitive area that required protection. Lim Chin Chong recalled how on the day news broke of the September 11 attacks, he personally surveyed the island with Lim Neo Chian to identify vulnerable points to be protected.[199]

In 2001, Jurong Island was declared a Protected Area under the Protected Area and Protected Places Act and was subsequently covered by the Infrastructure Protection Act.[200] The island became formally recognised as a site that required special security measures. Such measures included the deployment of Singapore Armed Forces (SAF) soldiers to patrol the island in conjunction with the Police Coast Guard to patrol its surrounding waters, as well as the involvement of other Home Team agencies to ensure safety and security.[201] Over the years, as security technology advanced, improved measures have been installed, including checkpoints with X-ray inspection systems and remote anti-vehicle barriers.[202] More recently in 2018, unmanned watch towers (UWT) were installed to enhance coastal surveillance capabilities on Jurong Island. These towers provide 24/7 coastal surveillance using advanced sensor systems, video analytics to automatically detect targets, and long-range acoustic warning devices that are all controlled remotely from the central command centre.[203] It is estimated that UWTs can reduce the number of soldiers required for operations by 30%, optimising manpower resources.[204]

13. Smart "eyes" to enhance surveillance operations on Jurong Island, installed in 2018.

The SAF's Island Defence Task Force was established in 2010 to work with Home Team agencies to enhance national security and protect key installations including Jurong Island. Island Defence training is also centralised under the Island Defence Training Institute, equipping soldiers with the necessary operational competencies through a number of training centres and schools, to train approximately 18,000 soldiers.[205] In 2020, the Next Generation Island Defence concept was introduced to leverage digital technologies for intelligence gathering in a way that enhances interoperability between different government agencies to further bolster homeland security.[206]

Such an inter-agency approach has been key to the defence and security of Jurong Island, where the SAF works closely with Home Front agencies to overcome all security challenges from prevention to protection and consequence management.[207] Defending Jurong Island not only protects against potential threats but also secures the confidence of investors, showing Singapore's commitment to its petrochemical hub.[208]

Energising Jurong Island

Shortly after independence, Singapore moved from coal to fuel oil to meet its energy needs.[209] In 1988, Pulau Seraya became home to Singapore's first offshore power station and featured three 250 MW generating steam plants as part of Stage I.[210] The station included a 2.6-km undersea cable tunnel to transmit power to the mainland.[211] In addition, electrostatic precipitators were installed to remove particles in the flue gas from the boilers before discharge to the atmosphere, reducing air pollution.[212] The power station was meant to cater to the growing demand for electricity on the mainland even before the petrochemical hub was set up on Jurong Island.[213] In 1992, Pulau Seraya Power Station Stage II was completed, and the amount of electricity generated was projected to meet anticipated energy demands until 1997.[214]

Following deregulation in the 2000s, power companies switched to natural gas-fired power plants, as natural gas is cleaner and more efficient than fuel oil.[215] Under long-term contracts, natural gas was piped to Singapore from Malaysia and Indonesia through undersea pipelines. Initially, there were some political tensions between Singapore and Indonesia, which threatened the acquisition of natural gas. In 1998, B.J. Habibie became President of Indonesia and, upon learning that then-Senior Minister Lee Kuan Yew had remarked that the rupiah would fall, called Singapore a "red dot".[216]

It was against this political backdrop that Philip Yeo stepped in to help. An investor on Jurong Island needed natural gas as feedstock, and discovered that natural gas fields were being developed 480 km northeast of Singapore in West Natuna, Indonesia.[217] Being a close friend of President Habibie, Yeo approached him personally to discuss a 22-year natural gas supply deal for Jurong Island.[218] Being the Chairman of both the EDB and Sembcorp, Yeo created a company called Sembcorp Gas to sign the agreement with the Indonesian state-owned company, Pertamina.[219] Under the agreement, Singapore would import 9.2 million m^3 per day of natural gas via a 640-km undersea pipeline.[220] Upon the arrival of natural gas on Jurong Island, it was distributed to companies on the island as well as to the Singapore mainland to provide power.[221]

However, there were risks to Singapore's energy security with using piped natural gas for electricity generation. If there was any intentional or accidental damage to the undersea pipelines, it would disrupt the supply of natural gas to Singapore. Furthermore, Malaysia and Indonesia would naturally prioritise their own rapidly growing domestic demand for natural gas, and supply could not be guaranteed given the lack of major new gas field discoveries in recent years.[222] This would leave Singapore in a

vulnerable position if the contracts were not renewed after their expiry; as was the case in 2020, when Indonesia announced that it would terminate the gas supply to Singapore by 2023 in order to meet domestic demand.[223]

In a bid to diversity its sources of energy and to meet future demands, the Singapore government announced in August 2006 that Singapore would build a liquefied natural gas (LNG) terminal for import and storage.[224] LNG is a natural gas that has been liquefied by cooling, which significantly reduces its volume, and can be transported over long distances.

In 2010, construction began for Singapore's LNG terminal at Jurong Island. Then-Senior Minister of State for Trade and Industry, S. Iswaran, commented that the terminal "will not only help meet Singapore's growing energy needs, but also catalyse the development of a robust gas market to underpin our industrial growth".[225] The LNG terminal began operations in May 2013 and featured two storage tanks, a jetty, and a throughput capacity of 3.5 million tonnes per annum.[226] Today, the terminal has four tanks and two jetties, with a throughput capacity of around 11 million tonnes per annum—sufficient to support all of Singapore's natural gas need if required.[227] When the LNG reaches the terminal, it is transferred to the storage tanks, re-gasified, transmitted, and then distributed to power generation companies and chemical industries.[228]

14. Singapore LNG Terminal.

Damian Chan shared that Singapore's move to LNG was primarily for energy security and that, in the process, the energy and chemicals companies on Jurong Island benefitted as well; nor were the companies competing with the mainland for power from the grid:

> They [the energy and chemicals companies] do not offtake electricity from the grid— they actually have their own cogeneration facilities to make both electricity and steam or do so through third party utilities providers. And they use natural gas to do that. So actually, having the LNG terminal provided that additional benefit to them. And of course, then they would be able to have their own long-term contracts for LNG then, which would make it more competitive.[229]

The EMA issues term licenses to LNG importers to ensure their import and supply of LNG to end users are competitive and reliable.[230] Today, there are four appointed term LNG importers—ExxonMobil LNG Asia Pacific, Pavilion Energy Singapore, Sembcorp Fuels, and Shell Eastern Trading—thereby giving gas buyers more options to choose from.[231]

Jurong Island today is home to a number of power stations. These include Sembcorp's 815 MW cogeneration plant at Pulau Sakra, which opened in 2001;[232] the Sembcorp Cogen @ Banyan, which has a gross capacity of 400 megawatts of power and 200 tonnes per hour of process steam;[233] and Keppel Merlimau Cogen, which has a total generation capacity of 1,300 MW after completing its expansion in 2013.[234] The plants use natural gas, which supports the surrounding industry with power, while injecting electricity into Singapore's main power grid.[235]

In a bid to further diversify energy supply, Tuas Power began commercial operation at its Tembusu Multi-Utilities Complex (TMUC) on Jurong Island in 2013. As its name suggests, the TMUC adopts a multi-fuel strategy by using a combination of alternative fuels to ensure energy security, reduce risk of price volatility, and provide a reliable and cost-effective solution for utilities supply. The complex comprises a biomass-clean coal cogeneration plant, desalination plant, wastewater treatment facility and demineralised water treatment plant.[236] The entire complex was designed and commissioned to meet the NEA's strict emission standards by co-firing a high percentage (20%) of carbon-neutral biomass fuel to reduce its carbon footprint. Efficient bag filters are installed to capture particulates in the flue gas before it is discharged through the stack. Ash that is generated from the process is fully recycled and reused as useful construction materials.

To reassure the public that Singapore remains committed in its efforts to tackle climate change, Tan Quee Hong, former Director of Pollution Control Department, NEA, and Jenny Teo, former Director of Corporate Communications Department, EMA, shared:

> In approving the project, the Government has taken into consideration these measures by Tuas Power to ensure environmental sustainability. In particular, the NEA has assessed that the TMUC meets existing environmental standards in terms of the emissions of air pollutants. The TMUC project offers a good balance between the need to ensure Singapore's cost competitiveness and maintain our environmental sustainability.[237]

Despite Jurong Island being an energy-intensive industrial area, measures such as the LNG terminal and the power plants on the islands help the companies become more self-sufficient. Furthermore, Jurong Island also contributes to the energy security and electricity supply of Singapore, serving as a conduit for piped natural gas and LNG from around the world.

Every Drop of Water Counts

Jurong Island primarily draws NEWater, potable water and industrial non-potable water from the mainland for cooling and industrial processes, while some companies tap on the surrounding seawater.[238] In the 1980s, the Sewerage Department (then under the Ministry of Environment) oversaw supplying industrial water, while PUB's Water Department oversaw supplying potable water to the islands.[239] The process involved the construction of underwater pipes and an elevated surface reservoir on Jurong Island. Due to the high concentration of users in the area, the demand generated led to economies of scale and the provision of water to Jurong Island became a viable venture. However, Jurong Island utilises a large proportion of water, accounting for 46 million gallons of water a day or 10% of Singapore's water demand in 2016.[240] The strategy for Jurong Island has been evolving, from simply tapping on the mainland's water supply to becoming more self-sufficient, with the mainland instead serving as a backup in the event of water disruptions.[241]

In order to meet projected future demand for water and reduce water consumption, PUB has been supporting research and development in the domain of Industrial Water Solutions (IWS) from infancy to commercialisation.[242] Some strategies to reduce water consumption have included utilising seawater instead of NEWater for cooling purposes.

Over the years, there have been numerous IWS projects on Jurong Island. This includes projects implemented by Mitsui Phenols Singapore and Shell on improving cooling tower efficiency by recovering cooling tower blow down and improving cycles of concentration. Petrochemical Corporation of Singapore and Singapore Refinery Company (SRC) have implemented effluent water recycling plants. The final effluent is treated using membrane technologies to meet water quality similar to NEWater grade quality, thereby reducing the NEWater intake to their facility.

Harry Seah, current Deputy Chief Executive (Operations), PUB, explained that even though agencies knew the type of outcomes they wanted, a solid partnership with the private sector was needed to deliver on the projects. PUB would often work with companies, domestic as well as overseas, to source for urban solutions and to matchmake the appropriate companies with the industries on Jurong Island.[243] One example was SRC's water loss issues due to evaporation. PUB introduced an overseas company that had developed technology to create distilled water to be repurposed while harvesting waste heat generated rather than dissipating it into the atmosphere. By introducing the management of SRC to this solution, PUB was able to help SRC reduce their water demand.

Beyond reducing water consumption, Singapore has also explored ways to increase its water supply. In 2016, then-Minister for the Environment and Water Resources, Masagos Zulkifi, announced the development of a fifth desalination plant on Jurong Island, to enhance Singapore's water sustainability given the unpredictable weather patterns arising from climate change.[244] The desalination plant was to be opened in 2020,[245] but was delayed due to the Covid-19 pandemic.[246] The tender for the plant was awarded to the Tuas Power-Singapore Technologies Marine Consortium and co-located with Tuas Power's existing Tembusu Multi-Utilities Complex to "derive synergies in resources such as in seawater intake and outfall structures, and energy from the in-plant generation facilities".[247] The public-private partnership was important in delivering the project and achieving a win-win situation where PUB would "share its experience in terms of design and how to make the plant more efficient so that they [Tuas Power-Singapore Technologies Marine Consortium] could have the returns because they are the private sector. In return, Singapore would get affordable water".[248]

15. Artist's impression of the Jurong Island Desalination Plant.

PUB is currently studying the groundwater potential in Jurong Island, where infiltrated rainwater is accumulated within the reclaimed sand layers underground as a freshwater lens, like in the Maldives. Harry Seah shared the possibilities that groundwater could have, not just from a supply point of view. As it covers a large area, it can be tapped at convenient locations, therefore reducing the need to lay expensive pipes:

> We can make use of [the] freshwater lens to store excess water. If we dare to play around with the concept, that [the] freshwater lens itself can be a water conveying system…The conventional way is to lay a pipe to the factories' doorstep, then tap water from the pipe for water supply. Now you have the companies located on top of the freshwater lens. So basically, they can just run a pipe vertically down [to] draw the water. What we need to ensure is that whatever water that is drawn can be replenished so that we do not destroy the freshwater lens.[249]

Since Jurong Island is resource-intensive in terms of water, it also serves as a testbed for water security solutions that could be applied to the rest of Singapore. Jurong Island is an outlier at the upper end of issues, meaning that the issues it faces are typically more challenging, hence the saying, "if you can get everything working in Jurong Island, any other place is a breeze".[250]

Our Atmosphere and Water Bodies are not Dustbins

Chemical production on Jurong Island emits fumes and produces industrial effluent. If not managed properly, these could negatively impact the environment and the quality of life for the rest of Singapore. While preventative measures can be put in place, it is impossible to completely eliminate the "residual or fugitive emissions of smell, dust and noise".[251]

The choice of an offshore location like Jurong Island to host special industries helped ensure adequate buffer distances between residential and industrial land use, therefore establishing a precedence of minimising nuisances.[252] Loh Ah Tuan explained that whenever the EDB brought in potential investors for projects to Singapore, including Jurong Island, the projects would need the approval of the NEA, Urban Redevelopment Authority (URA) and Building and Construction Authority (BCA). The NEA adopted four guiding principles in evaluating such projects.[253]

> The first guiding principle is prevention, i.e., you use chemicals which are less hazardous or use cleaner technologies, where feasible. If that is not possible, the NEA then would require industries to incorporate measures and install equipment to treat and monitor air pollutants and waste effluents to comply with the prescribed limits, and to minimise/prevent chemical accidents—the second guiding principle of monitoring. The third guiding principle is enforcement and mandating industries to conduct chemical safety audits. Finally, the fourth guiding principle is training and education—the NEA together with petrochemical and chemical industries and their associations conduct training programmes on health and safety of handling hazardous chemicals for operators and workers in the industry, including their contractors.[254]

Stringent measures were put in place even before companies could set up their businesses in Singapore, and required continued compliance while companies were in operation. For example, companies have to submit a Pollution Control Study in the planning approval stage, which focused on companies' mitigation measures in controlling and dealing with industrial effluent and emissions to meet the standards.[255] On the ground, major emitters are also required to install stack emission monitoring systems in order to provide the NEA with real-time monitoring of pollutant emissions.[256] Furthermore, the government has committed to working with new investors or existing companies planning to expand to ensure they meet high standards of efficiency. Examples include SRC upgrading its Jurong Island infrastructure, resulting in greater energy efficiency and reduced sulphur oxide emissions; and ExxonMobil expanding its manufacturing complex to become one of the most efficient refineries in the world.[257] Companies on Jurong Island with substantial inventories of dangerous substances on-site also submit a quantitative risk assessment (QRA), which is a study of the risks the plant imposes on itself and its surroundings. Through the QRA, the companies are required to explain control measures in the prevention and mitigation of risks arising from possible scenarios arising from dangerous substances on-site.

The ecosystem of Jurong Island consists of specialised companies, which are licensed to manage integrated infrastructure solutions and a comprehensive host of shared third-party utilities and services such as waste treatment. One such company is Sembcorp Industries, which has centralised sustainability solutions such as industrial wastewater treatment and conversion of waste into energy. Sembcorp owns and operates two 100% waste-to-energy plants supplying steam to Jurong Island companies. In 2020, its initiative helped to treat over 3 million m^3 of industrial wastewater

and recover more than 340,000 tonnes of waste to generate energy. Around the same time, Sembcorp also embarked on various optimisation projects to save approximately 16,000 m^3 of water. The vertical integration on Jurong Island does not only apply to the chemical companies, but also to the specialist companies providing utilities. When waste is valued and fed back to the system, a circular loop for both energy and water is created.

16. The Sembcorp Energy-from-Waste plant is a trailblazing project that helps recover value from waste, and enhances the management of Singapore's scarce resources.

In addition, Loh Ah Tuan highlighted that the NEA licenses centralised industrial waste treatment facilities. Instead of providing on-site waste treatment plants, industries can send their waste to these facilities for treatment:

> Industries can either treat their hazardous waste on-site or send the waste to NEA-licensed hazardous waste treatment facilities. The NEA's preference is the latter. This is because licensed facilities are better designed and equipped to treat hazardous waste. Also, the facilities are operated by specialist professionals. By outsourcing the treatment [of] hazardous waste to licensed hazardous waste treatment facilities, industries could not only focus on their core business, but also save land and costs. For the NEA, enforcement becomes more efficient, as instead of having to carry out inspections on every industry, the NEA would need to carry out inspection on fewer centralised hazardous waste treatment facilities.[258]

By outsourcing to specialised companies, the chemical companies would be enabled to better focus on their core business and reap greater efficiencies in the management and treatment of waste. This would also benefit governing bodies in consolidating checks for compliance and enforcement, if necessary.

A Complex System Achieving Synergies and Constantly Evolving

Jurong Island is a complex system with many moving parts. Far from just a story about land reclamation and bringing in chemical companies, careful planning was needed to ensure that the appropriate transport, energy, water and waste systems were in place to support the companies and ensure that the environment and quality of life on the mainland would not be adversely affected. The fastidious integration of the many moving parts on Jurong Island has enabled savings of 25–30% of capital outlay and 10–15% of transport costs.[259] Furthermore, by the end of 2010, Jurong Island was home to almost 100 chemical companies that had invested over S$30 billion in fixed assets.[260] However, the story of Jurong Island does not end here, as Singapore continues to look for new ways of improvement.

CHAPTER 4

STAYING AHEAD OF THE CURVE

"A lot of companies are seeing that Asia is their most important market. And that is where we see that there are a lot more opportunities to go further downstream from petrochemicals into speciality chemicals. For specialty chemicals, it makes sense for Singapore because the innovation activities, which tend to be developing applications to meet the needs of the customers, benefit from being closer to where the customers are, and this fits with Singapore's push towards becoming an innovation-driven economy. Speciality chemicals are also less commoditised, higher value-added products that are less resource intensive, and are well suited to Singapore's resource and cost profiles.[261]"

DAMIAN CHAN
Executive Vice President,
Economic Development Board

Diversifying Further Downstream

Global megatrends, such as the rise of Asia, increased regional competition and greater attention on climate change, translated into opportunities as well as challenges for Singapore. The island-nation had to ensure that the energy and chemicals industry remained economically viable and competitive, which involved diversifying into specialty chemicals. Singapore was in the prime position to capitalise on this market due to its existing industrial base, as explained by former Minister for Trade and Industry, S. Iswaran:

> Building on our strong foundations in refining and petrochemicals, Singapore has also moved into high-value derivatives and specialty chemicals. This in turn creates demand for petrochemical feedstock and improves the overall resilience of our energy and chemicals industry through greater integration. Jurong Island will continue to be the centrepiece of our integrated strategy for the energy and chemicals industry.[262]

With specialty chemicals feeding into over a hundred end-markets, the EDB identified five focus areas: lubricant additives, oilfield and water chemicals, consumer care, agricultural chemicals, and animal health and nutrition.[263] Attracting and growing the cluster of chemical companies on Jurong Island would add greater depth and diversity such that the chemical hub would come to reflect the global chemicals industry ecosystem.[264] For Jurong Island to be well equipped to meet this vision, given its ageing asset base, various initiatives such as Jurong Island version 2.0 (JIv2.0) and the Industry Transformation Map (ITM) were launched to bring Jurong Island to the next level.

JIv2.0 and ITM

Launched in 2010, JIv2.0 brought together agencies such as JTC Corporation, the Economic Development Board (EDB), National Environment Agency (NEA), Energy Market Authority (EMA), Land Transport Authority (LTA), Maritime & Port Authority (MPA), PUB, Singapore's National Water Agency, Ministry of the Environment and Water Resources (MEWR) and Jurong Island companies to develop and implement system-level solutions to overcome resource challenges and ensure long-term competitiveness and sustainability. The initiative encompassed a review of five core areas—energy, logistics and transportation, feedstock options, environment and water.[265] David Tan, current Assistant CEO, JTC shared that JIv2.0 was part of Jurong Island's strategy of developing system level solutions to improve its competitiveness and sustainability:

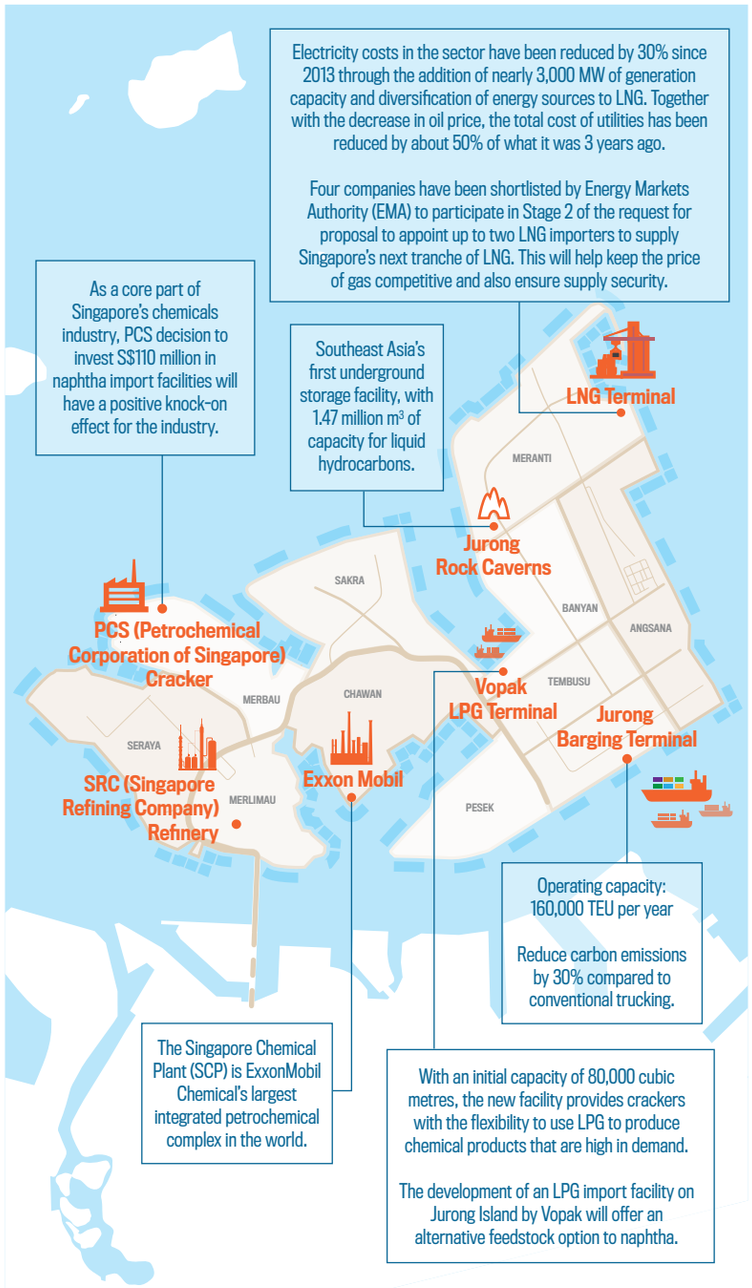
> When I talked about the right ecosystem, we asked the question if Jurong Island was competitive and sustainable enough? That is why we started to look at Version 2.0 to develop system level solutions such as feedstock options, logistics and transport, energy, water and environment to make Jurong Island a lot more competitive and sustainable in the longer term.[266]

By 2012, all 10 developments under JIv2.0 had been researched completely and transitioned to the next phase of testing and implementation.[267] The JIv2.0 projects consisted of numerous infrastructure projects and innovative solutions, such as a gasification plant and a liquified petroleum gas (LPG) terminal.[268]

Building on JIv2.0, the ITM for the energy and chemicals sector was launched in 2017. The ITM was one of 23 roadmaps developed to address the challenges of different sectors upon recommendation by Singapore's Committee on the Future Economy.[269] It also emphasises Singapore's tripartite approach of government, industries and trade associations working together towards increasing the competitiveness and sustainability of the sector.[270] For the energy and chemicals industry, the ITM outlines a two-pronged approach: first, to transform Jurong Island's existing base in consideration of its ageing assets through adopting innovative technologies, and second, through diversifying into new growth markets and develop innovation capabilities to capitalise on the growth.[271] As the successor to JIv2.0, the ITM covered similar elements but also identified gaps and opportunities, as elaborated on by Damian Chan, current Executive Vice President and former Executive Director, Energy and Chemicals Cluster, EDB:

> The additional element[s] within the ITM—which may not have been [in] JIv2.0 because a lot of the elements in there were centred around infrastructure—is the manpower and productivity elements. Related to manpower is the productivity and attractiveness of the sector.[272]

Jurong Island's holistic strategy and roadmap are supported by four main pillars—productivity, innovation, skills and jobs, and trade and internationalisation—to ensure that the industry is competitive and sustainable.[273]



17. How Jurong Island's competitiveness is enhanced by the JIv2.0 initiative.

From Laboratory to Island

When Singapore planned to diversify into specialty chemicals in the early 2000s, its innovation ecosystem needed to be strengthened. Establishing a base of dedicated research institutes and skilled researchers to innovate new methods and technologies would allow Jurong Island to thrive. In 2002, the Institute of Chemical and Engineering Sciences (ICES) was established as an autonomous national research institute under the Agency for Science, Technology and Research (A*STAR),[274] and the ICES Jurong Island Laboratories was officially opened in 2004.[275] ICES would "play a critical role in spearheading research and development in Singapore's fast expanding chemical industry" and "nurture research talent as well as promote collaborations between industrial partners and institutions of higher learning".[276] The centre is also located on Jurong Island to promote greater opportunities for researchers to exchange ideas and build partnerships with their industry counterparts. Dr Keith Carpenter, then-Executive Director of ICES, shared the synergies obtained from locating the research institute on Jurong Island:

> Jurong Island companies [would] have direct access to our institute and our work, [and] our researchers [would] move into industry, thus renewing the research pool at [the] industry's disposal. More importantly, being on Jurong Island puts out research work in a real-life context, it encourages researchers to work in an environment that converts a great idea into a viable process.[277]

ICES has four research divisions—namely Formulated Products, Functional Molecules and Polymers, Process and Catalysis Research, and Scientific Infrastructure and Analytics—anchored by highly trained researchers.[278] ICES has collaborated with several corporate laboratories, such as with Mitsui Chemicals on catalysis research, such that the latter decided to establish its first research and development centre outside of Japan.[279] The congregation of public and private research institutes on Jurong Island has created a strong scientific base and foundation to support the energy and chemical companies in developing new products and processes.[280]

Under the ITM, the EDB and A*STAR have collaborated on a joint technology road mapping exercise in order to identify scientific and technological needs and gaps of companies to better support innovation in these domains.[281] As part of the strategy, A*STAR aims to position its research institutes and institutes of higher learning as choice innovation partners, and to facilitate consortiums across the research and development

value chain to develop market domain knowledge and key capabilities.[282] Some of the technology areas prioritised for focus by A*STAR, institutes of higher learning and industry players include Chemical Synthesis of Molecular Switches, Design and Synthesis of Polymer Structures, Target Release and Delivery, and Intelligent Formulations.[283]

18. ICES Jurong Island Laboratories officially opened in 2004.

The assemblage of top research institutions and highly skilled talent on Jurong Island contributes to Singapore's reputation as a global hub for research and development. Under the Research, Innovation and Enterprise (RIE) 2020 plan, Singapore has budgeted S$19 billion into research and development, which would contribute significantly to Singapore's economic growth, create further employment opportunities, assist industries in adopting new technologies, and translating research into concrete urban solutions.[284] Furthermore, by 2025, Singapore aims to have 20 new or expanded application development centres and an increase in business expenditure on research and development by S$55 million as part of the Energy and Chemicals ITM.[285]

JURONG ROCK CAVERNS

As the energy and chemicals industry continued to expand, innovative land use solutions had to be explored to meet the demand for industrial land. Although land reclamation was an option that might have been cheaper in the short term, but long-term prospects were considered for a more sustainable solution.[286] The idea was to maximise land use by storing liquid hydrocarbons underground and to prioritise land for higher value manufacturing activities.[287]

Faced with this issue, JTC began considering underground caverns. As MINDEF had already been utilising such caverns for ammunition storage, JTC began investigating whether they could be used similarly for industrial storage. In 2001, JTC commissioned a study on possible locations for such underground facilities in Singapore.[288] Site and marine investigations found suitable rock formations known as the Jurong Formation, underneath Banyan Basin.[289] Visits to similar underground facilities in countries like Japan and Korea were also conducted to learn from overseas experience.[290]

Deemed more secure and space-efficient than surface storage tanks, construction for Jurong Rock Caverns began in 2007 at Jurong Island's Banyan Basin.[291] Located 130–150 m below ground, the caverns are the deepest subterranean structure built in Singapore thus far. By comparison, most subterranean structures, including the Mass Rapid Transit and power cable tunnels, are built up to 50 m underground.[292]

Such a deep underground venture presented unpredictable geological conditions and technical challenges. To address them, systematic site investigations using probe holes were conducted with pre-grouting to reduce groundwater seepage. A mixture of drilling and blasting excavation methods were used to create the vertical access shafts and caverns, which were both reinforced using a variety of methods including ring-beamed diaphragm walls and shotcrete.[293]

Each cavern gallery is 27 m high, 20 m wide, and 340 m long, with a storage capacity of up to three times that of conventional storage tanks above ground.[294] Each cavern is also surrounded by "water curtains"—a lattice of water-filled tunnels and boreholes that provide hydrostatic pressure to prevent oil seepage.[295] In order to transport oil to the caverns for storage, a series of pipelines connect the storage facility to a few jetties.

In 2014, Jurong Rock Caverns were officially opened when two of the five caverns in Phase One of the project were completed. Three years later in 2017, Phase One was completed, freeing up 600,000 m^2 of land on the island and providing 1.47 million m^3 of storage space.

19. Jurong Rock Caverns.

Speaking to *TODAY*, then-JTC Chairman Dr Loo Choon Yong summarised the ambition that Jurong Rock Caverns represents:

> As a small city state, we are constantly pushing boundaries in our quest to overcome our scarce land resource. The Jurong Rock Caverns required us to venture into unfamiliar grounds and surmount engineering challenges never encountered before. Its success attests to our resolve to persevere and diligently deliver innovative and sustainable infrastructure solutions for Singapore.[296]

A massive engineering feat that balanced safety, technical, and economic considerations, Jurong Rock Caverns acts as a microcosm of Jurong Island itself in delivering innovative solutions to pressing challenges.

Digitalising Jurong Island

During the late 1990s and early 2000s, plans were made to usher in an age of information technology on Jurong Island. A broadband optical fibre network was installed on the island, but further planning and implementation was needed to take advantage of the hardware to make Jurong Island a more competitive environment.[297] In order to enable Jurong Island companies to "conduct business electronically, reduce cycle time and costs, and exploit e-business opportunities", the Jurong Island IT Masterplan Committee was formed, comprising JTC, the EDB, then-National Computer Board, and industry players.[298]

Initially, four modules were launched as part of the IT masterplan, namely integrated logistics, maintenance, repairs and engineering services, safety, health and environment, and information services.[299] The integrated logistics module would allow companies on the island to optimise their supply chain matching of routes, schedules and requirements, while the maintenance, repair and engineering module would allow companies to integrate these functions, source online for parts and services, and track maintenance jobs. In terms of safety, there would be island-wide emergency notification, response and evacuation systems. Lastly, there was the JurongIsland.com Internet Portal, which would provide all kinds of information with regard to Jurong Island, offer training programmes, and enable companies to conduct business.

Despite the ambitions to digitise Jurong Island then, the IT masterplan was not as successful as intended. David Tan shared more on the stumbling blocks in achieving this vision:

> At that point in time, we wanted to look at how to digitalise Jurong Island. I must say that it has not been really very successful, because we were too ahead of time. The technology was simply not available. But nevertheless, it started JTC to think about the digitalisation of manufacturing. And I think it started the ball rolling that allowed us today to adopt Industry 4.0.[300]

While the digital transformation that Jurong Island hoped for did not occur as intended back then, continuous efforts have been made to digitise the island. The ITM highlights automation, such as drones, and Industrial Internet of Things (IIoT), such as machine learning and virtual control rooms, as a means to improve energy management, optimise processes, and improve productivity and safety.[301] In order to greater support companies in adopting digitalisation, Damian Chan shared how agencies work to match solutions providers and demand drivers:

So [the] EDB would help to develop the ecosystem in terms of the technology providers and work closely with the major players, say, in the controls and automation space. Companies like Yokogawa, Emerson, for instance, which are leaders in the space of controls and automation, [provide] strong support to the energy and chemicals sector. In addition, [the] EDB also has incentive tools to help companies [looking] to develop and deploy advanced digitalisation tools, techniques and also need to recruit and train more digital experts, to enable higher productivity or even more energy efficiency within their plants using digitalisation.[302]

20. Demonstration of a drone inspecting chemical and utilities pipelines for leaks on Jurong Island. The drones will be equipped with multiple video cameras and sensors.

As a result of increased adoption of digitisation, companies have seen positive benefits. Chevron Oronite, for example, partnered with Emerson to install Pervasive Sensing Infrastructure, which is essentially a wireless "smart" platform to allow applications to be developed to improve plant operations and maintenance.[303] As a result, approximately 30,000 man-hours are saved each year in the first phase.[304]

The ITM's goal in the first phase was for 20 of the largest facilities on Jurong Island to be digitally enabled by 2020, while the second phase would then be for systems-levels optimisation.[305] This could possibly entail having third-party logistics providers developing solutions that integrate customers' operations with supporting systems, such as customs clearance and safety inspections, thus leading to time and cost savings for companies.[306]

The digitalisation process is still ongoing, and the potential for technology to benefit the sector in terms of productivity and sustainability is limitless. More effort is being made to increase awareness and enable companies, which include SMEs and those in process construction and maintenance, to adopt new technologies, such as in robotics and IIoT.[307] These efforts would ensure that Jurong Island will be able to ride the wave of Industry 4.0 and Industry 5.0 to remain competitive.

Humans of Jurong Island

Singapore lacks natural resources—with the exception of its people. Shortly after independence, Singapore's young workers and their English-speaking abilities proved attractive to foreign investors.[308] However, as other countries in the region started opening up, Singapore decided to undergo a structural shift, as it could not afford to compete on providing cheaper labour due to its smaller population base.[309] Between 1979 and 1981, the government pursued a wage correction policy that raised wages significantly with the intention of forcing companies to upgrade their labour productivity and operations.

Quality workers are key to Jurong Island's success and contribute substantially to the economy, with a value-add of over S$650,000 per worker—more than eight times the national manufacturing average in 2000.[310] In order to help companies enhance their manpower and capability development, numerous schemes were introduced to improve workers' skillsets. Under the Initiative in New Technology (INTECH), the EDB would subsidise a portion of companies' training costs for their workers.[311] The EDB also launched the Local Industry Upgrading Programme (LIUP) in 1995 to upgrade the capabilities of contractors who offer key supporting services for Jurong Island. The programme would "ensure that the petroleum and chemical industries would be able to enjoy better and more cost-efficient engineering and maintenance services".[312]

In 2004, Singapore officially opened the Chemical Process Technology Centre (CPTC) on Jurong Island, a training facility that provided pre-employment and in-employment training to support the chemicals industry. The CPTC was the first training facility in the world to feature an industrial-scale, live distillation plant to provide realistic hands-on training for workers.[313] The centre, managed by Petrofac on behalf of the EDB, delivered courses in operations and technical training, health and safety, and competence assurance management, among others. The courses

helped ensure that the workers of Jurong Island were competent, practiced safe measures and were efficient.[314] The centre also benefited from the cooperation of the private sector, which included chemical giants such as ExxonMobil, Shell and DuPont, along with technology providers such as Honeywell, Yokogawa and Singapore Aviation Academy.[315] Following a joint review undertaken by the EDB, Singapore Workforce Development Agency and Ministry of Education, it was determined that the chemicals industry in Singapore had matured such that plants were able to provide their own in-house training customised to their needs. In addition, the CPTC's continuous process was becoming less relevant for specialty chemical plants, which were the main new entrants to the industry and used batch processing. As such, the CPTC was closed in 2016.

21. Workers learning process technology skills at the Chemical Process Technology Centre, 2015.

Over the years, the energy and chemicals industry continued to face manpower challenges. These included attracting and maintaining a strong pool of technicians, as well as ensuring that workers possessed relevant skills as technologies and production methods changed over time.[316] The private sector has taken an active role in supporting the transformations that the energy and chemicals industry faces. The Chemical Industry Manpower Advisory Committee (CHIMAC)—co-chaired by the EDB and the Singapore Chemical Industry Council (SCIC), the latter of which comprises private sector members—is constantly working to develop manpower initiatives specific to the sector, whether it is regarding capability building or hiring practices.[317]

The ITM highlights several strategies on enabling Singapore's workforce in meeting the evolving needs of the industry, one of which was the Skills Framework for the Energy and Chemicals Industry that was elaborated on by former Minister for Trade and Industry, Lim Hng Kiang, in 2017:

> Developed by SkillsFuture Singapore, Workforce Singapore and [the] EDB, with inputs from industry stakeholders and unions, the Skills Framework provides valuable information about career pathways, occupations and job roles for this industry. To support our workers to be future-ready, the Skills Framework also highlights emerging skillsets in areas such as robotics and internet-of-things.[318]

22. The Chemical Industry Experience–ChemEx 2019.

Numerous opportunities have been created by the industry to engage potential employees, to enlighten them on the sector and clear up any misconceptions that they may have. Chemical Experience Day, for example, is an industry-led outreach organised by SCIC to provide students with first-hand industry experience and to share the possible prospects in joining the industry.[319] Industrial attachments are also offered by Chevron Oronite, Shell and Sumitomo for students to gain exposure and experience in the industry.[320] Beyond industry, institutes of higher learning have also played key roles in launching relevant programmes such as the Advanced Diploma in Chemical Engineering offered by Singapore Polytechnic from 2016.[321] These programmes would contribute to a steady supply of skilled technicians across different tracks in the energy and chemicals sector.

GREENING JURONG ISLAND

As construction of Jurong Island was underway in the 1990s, the project team was careful not to let the petrochemical hub become another humdrum industrial estate, as highlighted by Lim Neo Chian, former Chairman of JTC:

> We try to make the island a nice place to work in. You see that actually we put in a lot of the green...there were nice roadside landscaping and greenery and all that.[322]

23. Jurong Island today, where nature and industry coexist.

Guided by the Garden City concept of mainland Singapore at the time, extensive efforts were put in place to improve the landscaping of Jurong Island, as detailed in the 1997 landscaping masterplan.[323] The landscaping was carried out in stages where trees and flowering plants were planted along main roads, and pockets of land were kept as green lungs to soften the physical industrial landscape of pipes and tanks. The landscaping efforts served to make Jurong Island a better working environment.[324]

Over the years, Singapore's own greening strategy evolved to envision a City in Nature, where community engagement and the use of biophilic designs to restore habitats are pursued.[325] Among these efforts are the intensified greening of streetscapes, including industrial estates, and the "One million trees" movement that seeks to massively increase tree planting across Singapore.[326] Much like the transition from Garden City to City in Nature, Jurong Island's greening initiative has also evolved from merely improving the aesthetics of the working environment in the 1990s, to the current approach of greening the environment.

JTC, in collaboration with National Parks Board (NParks), will be planting approximately 170,000 trees, adding 1,000,000 m^2 of new green spaces in parks and roadside greenery in industrial estates by 2030.[327] The first hundred trees of this initiative were planted on Jurong Island as part of the Greening Jurong Island Project, the result of a public-private partnership between JTC, NParks and the Jurong Island community.[328] Funding for the project is also supported by the public-private partnership, where corporations can raise funds under NPark's Garden City Fund.[329] Altogether, over 70 companies, organisations and individuals from the Jurong Island community have raised over S$740,000 to support the tree planting initiative.[330] This includes the contribution of the Association of Process Industry (ASPRI) and its members, as well as ExxonMobil, which was the single largest contributor.[331]

Teams from JTC and NParks worked together to analyse ground conditions to plan strategic planting techniques that ensured the well-being and longevity of trees on Jurong Island. A multi-tier planting process mimicking a forest structure was adopted to add diversity, vibrancy and colour to the industrial island's streetscape. Tree species were also meticulously selected for their hardiness and drought tolerance to thrive on Jurong Island's industrial landscape, as well as their ability to provide shade, colour and vibrancy.

The continued and intensified greening of Jurong Island shows Singapore's commitment to realising its City in Nature vision, setting an example of how industry and nature can coexist to further distinguish Singapore as a liveable city.

"We Don't Rest"[332]

Jurong Island cannot afford to be static while the rest of the world moves. As an important sector of Singapore's economy, continuous review and examining ways to improve the island is the way forward, as it always has been. Partnerships and collaborations need to be forged and strengthened to ensure that the workforce is productive and has the relevant skills, to foster an innovative environment to develop solutions and to drive the adoption of digitalisation. This will allow Jurong Island to remain competitive and sustainable as it advances towards a more innovative future.

CHAPTER 5

THE FUTURE OF JURONG ISLAND

"The Singapore chemical industry contributes significantly to the gross domestic product and we create jobs for 27,000 workers. ...But I think we need to continuously improve and look at innovative ways to see how we can continue to grow that ecosystem and attract foreign direct investment for Jurong Island. Jurong Island will probably become a circular economy. And because it is circular and sustainable, I would think there will be a lot more environmentally conscious companies who will want to set up businesses on Jurong Island."[333]

DAVID TAN
Assistant Chief Executive Officer,
JTC Corporation

The Elephant in the Room

Climate change is one of the most pressing issues that countries around the world are facing, and Singapore is no exception. The Centre for Climate Research Singapore has projected that Singapore will experience an increase in daily mean temperature of between 1.4°C and 4.6°C, an increase in frequency and intensity of rainfall extremes, and an increase in mean sea level of up to one metre by 2100.[334] Recognising this and the need for Singapore to play a part in the collective global effort against climate change, Singapore has pledged to peak its emissions at 65 million tonnes of carbon dioxide equivalent ($MtCO_2e$) around 2030, and aspires to halve emissions from its peak to 33 $MtCO_2e$ by 2050, with a view to achieving net-zero emissions as soon as viable in the second half of the century. In realising our aspirations and commitment towards sustainable development, Singapore has implemented various initiatives such as increasing the adoption of renewable energy and increasing energy efficiency.[335] However, critics have lamented about the carbon-intensive nature of Jurong Island, and that a shift away from fossil fuels is needed for Singapore to be truly effective in its fight against climate change.[336]

From an economic and environmental standpoint, this is not exactly desirable or feasible at the moment. Melissa Low, research fellow at the NUS Energy Studies Institute, highlighted how Jurong Island is a key pillar of Singapore's economy and simply removing the entire chemical and energy industry will have dire ramifications on other sectors:

> If you want full divestment from fossil fuels, if you want Jurong Island to cease to exist, then you would reasonably need to find an alternative industry for which Singapore can build its reputation, economic tariffs, its adjacent and very much interlinked financial [...] sector, legal sector, maritime logistics sector. You would need to find another industry that would be able to support all of that and the jobs [that] accompany it...[Jurong Island] seemed to make sense for Singapore at the time that decisions were made.[337]

Furthermore, even if Singapore was to shift to another industry altogether, the companies on Jurong Island would shift their operations elsewhere and global emissions will likely increase due to the difference in environmental standards, as explained by Damian Chan, Executive Vice President, Economic Development Board (EDB):

> Most other countries, at least in the region, probably will not have such high standards. So the argument is that even if we were then to relocate the energy and chemicals sector to the region, it is probably going to make emissions as a whole worse for the world.[338]

Singapore's prospects as an energy and chemicals hub will likely continue to remain strong in the future,[339] especially as chemicals are vital to the production of low-carbon solutions. For example, the fabrication of solar panels requires the use of sodium hydroxide and hydrofluoric acid.[340] In order to demonstrate that chemicals can be produced in a more sustainable manner, Minister Chan Chun Sing at the Committee of Supply 2021—Joint Segment on Sustainability, expressed that the key was in transforming the energy and chemicals sector and "partnering companies that are developing cleaner products and decarbonisation solutions".[341]

From the very start, Singapore has set high environmental benchmarks and put in place measures at every juncture to mitigate the adverse impacts from the energy and chemical industry. The Carbon Pricing Act came into effect on 1 January 2019.[342] Facilities that emit ≥25,000 tonnes of greenhouse gas annually will be subject to the carbon tax and required to submit a Monitoring Plan and an Emissions Report annually.[343] In 2018, the government announced that the tax rate would be set at S$5 per tonne of greenhouse gas emitted between 2019 and 2023.[344] It was estimated that the carbon tax would generate S$1 billion dollars in the first five years.[345] The tax is not meant to generate revenue but will be redirected to support the industry in investing in carbon reduction and energy efficiency improvements.[346] In 2021, in response to the increasing global momentum to address climate change, the government announced that the post-2023 trajectory and level of the carbon tax would be reviewed. In consultation with industry and expert groups, this review seeks to spur the reduction of Singapore's carbon footprint, promote industry innovation, and encourage green growth, all the while maintaining its economic competitiveness. The outcome of the review will be announced in 2022.

The Next Lap: Circularity and Innovation at the Forefront

Businesses nowadays realise the importance of sustainability as part of their business strategy and have ramped up efforts, such as optimising resources in their own plants. However, there are limitations to individual efforts as no single player has a monopoly on all the solutions and some solutions are only feasible if they are deployed at a systems level to achieve economies of scale.

In order to move in this direction, JTC Corporation, with the support of other government agencies including the Agency for Science, Technology and Research (A*STAR), EDB, Energy Market Authority (EMA), National Environment Agency (NEA) and PUB, Singapore's National Water Agency, has partnered with 51 companies on Jurong Island in 2019 for a Circular Economy study.[347] The study, which involves consultants Witteveen+Bos and Metabolic, aims to map out the current water, energy and waste flows on Jurong Island in order to identify existing gaps and potential opportunities to optimise resource use at the systems-level.[348] While the idea of a circular economy for Jurong Island is not new, considering the vertical and horizontal integration where one company's product is another company's feedstock, the Jurong Island Circular Economy Study places a larger emphasis on the resource loop. Jurong Island is gearing up for sustainable growth in the future economy, where resource optimisation will take centre stage, to seize new opportunities to drive advances in the circular economy on the island, and to boost competitiveness, as shared by Cindy Koh, Director, Energy and Chemicals Cluster, JTC:

> The Jurong Island Circular Economy Study is important in showing us if we are on the right track in terms of resource use and pointing us to areas where more work is needed. The joint study is also key in promoting a shared responsibility among the Jurong Island community and in building a collaborative ecosystem where key supporting companies, MNCs and research academia can come together to develop industry solutions that will help Jurong Island remain both competitive and sustainable in the years to come.[349]

Beyond the Circular Economy Study, Jurong Island will also continue to play a key role as a testbed to host trials for innovative and pioneering technologies that can help stakeholders achieve breakthroughs in productivity and service delivery. The benefits of the solutions are not limited to Jurong Island, with potential positive ramifications for the mainland.

In January 2018, JTC kickstarted the first phase of its SolarLand pilot initiative to utilise temporarily vacant industrial land for solar farms.[350] The unoccupied 39,000 m^2 site at Jurong Island was identified as a suitable pilot site due to its large contiguous footprint which can accommodate the large-scale deployment of solar PV panels as an interim use. Unlike conventional fixed designs, these systems are designed to be modular and flexible, and can be redeployed when the land is needed for other uses. The plant became operational in May 2019, with the ability to generate up to 6.6 GWh of renewable energy annually—equivalent to powering 1,475 units of 4-room flats for a year.[351] This will result in an estimated reduction of around 2,700 tonnes of carbon emissions per annum. Along with its solar operator, Terrenus Energy, JTC is working to experiment with other renewable energy sources as an extension of this project, going beyond solar to include wind and even tidal energy.

24. Aerial view of the SolarLand installation on Jurong Island. The system is modular and flexible, allowing JTC to maximise land that is temporarily vacant and to deploy the land when needed.

In January 2021, the Emerging Stronger Taskforce's Alliance for Action on Robotics, comprising industry participants in collaboration with JTC, deployed on-demand autonomous bus services on Jurong Island.[352] After the pilot ends, the results will be evaluated before it could be potentially scaled up domestically and abroad. Such public-private partnerships will continue to strengthen the ecosystem of Jurong Island and the direction that it takes in the future.

The Right Chemistry

Jurong Island has come a long way from its past as several small islands tucked away at the south of Singapore. The story of the energy and chemicals industry in Singapore is complex, featuring the collaboration of the public and private sectors in planning the island, the process of land reclamation, implementing horizontally and vertically integrating

companies, putting in place the urban systems, and continuously innovating to stay competitive and sustainable without compromising the mainland. As summarised succinctly by Prime Minister Lee Hsien Loong:

> Today, we are the third largest oil refining centre in the world, and [a] petrochemical centre, with all the major oil companies having significant investments here. It is a huge achievement considering that we have no energy supplies of our own, not much land area, nor any other natural advantages except that we had the idea, we could execute and implement, and we made it happen.[353]

Jurong Island is home to over 100 leading global petroleum, petrochemical and specialty chemical companies.[354] The chemicals and energy industry in Singapore is ranked among the top 10 globally, contributing S$81 billion to the nation's total output in 2015, or a third of its total manufacturing output, and approximately 25,000 good quality jobs.[355] While Jurong Island will continue to face new challenges as it strives to be more competitive and sustainable, Singapore will continue with its tradition of innovation and adaptation to address them head on in the years to come.

25. Jurong Island today—the cornerstone of Singapore's energy and chemicals industry.

POST-SCRIPT

What makes Jurong Island? Historically a cluster of smaller islands in the south-western part of Singapore, it was inconceivable several decades back that Jurong Island would, in a short space of 20 to 30 years, become the premier energy and chemicals hub it is today.

Jurong Island is a flagship development of Singapore, developed in large part by JTC Corporation. A cornerstone of success stories in Singapore's energy and chemicals sector, Jurong Island serves as the home for more than 100 international leading petrochemical companies. These companies are all inter-connected in a complex ecosystem, sharing significant infrastructure such as pipe-racks, storage terminals and jetties, and third-party utilities for wastewater treatment and co-generation power. This architecture of Jurong Island is unique in its own way, and enables companies to reap significant economies of scale, share many resources, and contribute to Singapore's position amongst the top refinery and chemicals exports hubs.

For a small nation, with limited land and a lack of natural resources, how did the vision of Jurong Island come into being? Thanks to this Urban Systems Studies on Jurong Island by the Centre for Liveable Cities, we now have a comprehensive archive of this journey — from Jurong Island's conceptualisation and infancy, to the world class energy and chemicals hub that it is today. The journey from the past to present has not always been straightforward. Beyond the many infrastructural, technological and business initiatives put in place by government agencies and business stakeholders that led to making Jurong Island a success, the largest factor driving the continued success of Jurong Island stems from the single-minded focus and perseverance of our early pioneers in driving the vision and development of Jurong Island. The continuous ambition and innovative spirit of subsequent generations made the dream of Jurong Island a reality for today, and one that will endure for tomorrow. I believe that this unwavering, "dare to go against the odds" spirit is an essential ingredient as Jurong Island continues to innovate and transform into a sustainable and green island in the coming years, driven by a circular economy that involves all stakeholders on the island.

With all stakeholders working together, JTC and its sister agencies will continue to ensure Jurong Island's relevance not only in Singapore, but also in the region as a leading sustainable energy hub. Indeed, the Jurong Rock Caverns, situated within the confines of the island, represent one of the many innovations undertaken, which the island will continue to strive and push for in the years to come. One thing is certain for Jurong Island—it is not static, and never will be. Jurong Island will continue to transform as global shifts and trends shape the future of the energy and chemical industries worldwide. It is our aspiration that Jurong Island continues to play a leading role in spurring game-changing technologies and be a role model for the world in sustainable chemical production and solutions.

Tan Boon Khai
Chief Executive Officer
JTC Corporation

TIMELINE

JURONG ISLAND: DEVELOPMENT MILESTONES

1851

Peninsular and Oriental Steam Navigation Company secures a British government contract to provide shipping services to India, China and Australia, leading to new port facilities in Singapore in 1851.

1891

Establishment of Singapore's first oil storage facilities by M. Samuel and Co. on modern-day Pulau Bukom.

1907

M. Samuel and Co. form Shell Transport and Trading, eventually merging with the Royal Dutch Petroleum Company to become Royal Dutch Shell in 1907.

1945

Destruction of oil facilities on Pulau Bukom during the Second World War. These facilities were rebuilt in 1950.

1959

Singapore gains self-governance and faces problems of high unemployment, poverty and a lack of critical services.

1960

Arrival of Dr Winsemius and the United Nations Development Programme Team.

1961

Building of a new refinery on Pulau Bukom by Shell at a cost of $30 million.

Founding of the Economic Development Board (EDB).

1963

1963 Ring Plan is proposed by UN experts Otto Koenigsberger, Charles Abrams and Susumu Kobe.

1964

Development of Jurong Port and the resettlement of villagers on Pulau Merlimau.

1968

Founding of Jurong Town Corporation, now JTC Corporation.

1968–69

Start of the British withdrawal, and discussions on the future of the Southern Islands take place.

1969

Setting up of the Esso refinery on Pulau Ayer Chawan.

Initial facilities (piping and transportation) to the islands are established.

1971

Launch of Singapore's first Concept Plan. The West and Southern Islands are zoned for heavy industry.

1973

First Oil Crisis.

Decision is made to reclaim Pulau Seburus Luar and Pulau Seburus Dalam to form Pulau Seraya.

1976

Rehousing of villagers from the Southern Islands.

1977

The government considers building a "clean" coal power plant on Pulau Seraya to cater to growing energy needs. Construction is planned to start in 1981 and end in 1986.

1979

Second Oil Crisis.

1981

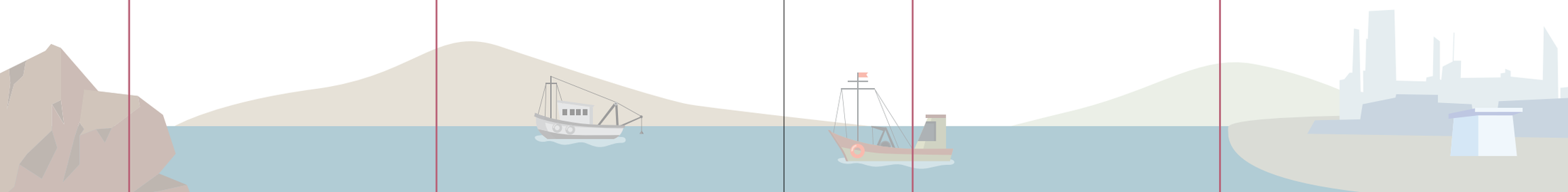
Resettlement of islanders from Pulau Semekau and Pulau Seking.

1982

Feasibiltiy studies start on merging Pulau Merlimau, Pulau Mesemut Darat, Pulau Mesemut Laut, Pulau Meskol and Pulau Seraya, with the intent of creating industrial land for petrochemical industries.

1985

Singapore experiences its first post-independence recession.



1988

Opening of Singapore's first offshore power station—Pulau Seraya Power Station.

A refinery fire breaks out on Pulau Merlimau on 25 October 1988, which was considered the worst offshore fire at that time.

Late-1980s

JTC completes the Concept Plan for the amalgamation of Jurong Island.

Early-1990s

Philip Yeo proposes linking up the seven islands to create a large offshore island for petrochemical complexes.

1991

1991 Concept Plan zones Jurong Island for petrochemicals.

1995

The government approves a $7-billion budget for the reclamation of land for Jurong Island.

1997

Announcement of the Landscaping Masterplan for Jurong Island.

1997-1999

Construction of Jurong Island Road Link.

1998

Opening of the first fire station, following the 1988 Pulau Merlimau Fire.

1999

Opening of Oasis@Sakra.

Creation of the JurongIsland.com online portal.

2000

Announcement of the Jurong Island IT Masterplan.

Official Opening of Jurong Island Road Link.

Official opening of Jurong Island by then-Prime Minister Goh Chok Tong.

2001

Jurong Island is gazetted as a protected area, and troops from the Singapore Armed Forces are deployed to guard the island.

2002

Official opening of ChemGallery@Jurong Island.

2004

Opening of the Institute of Chemical and Engineering Sciences Jurong Island Laboratories.

2007

Ground-breaking ceremony for Jurong Rock Caverns.

2009

Completion of Banyan Fire Station, which allows response to calls within eight minutes.

2010

Jurong Island Version 2.0 Initiative.

Construction starts for Singapore's liquefied natural gas (LNG) terminal.

2012

Launch of Singapore's first LNG terminal.

2013

Opening of the Tembusu Multi Utilities Complex to generate steam, chilled water and electricity, and treat industrial waste.

2014

Opening of the first two of five Jurong Rock Caverns.

2017

Unveiling of the Energy & Chemicals Industry Transformation Map.

2019

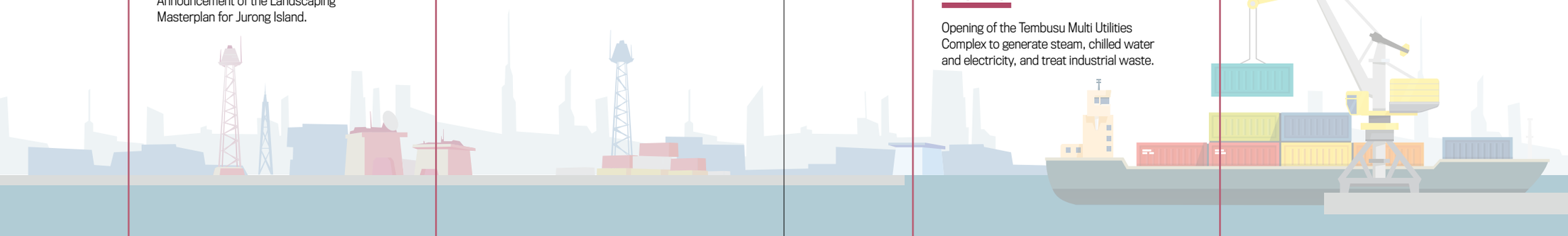
First phase of Jurong Port Tank Terminals is officially opened.

Jurong Island Circular Economy Study is kicked off by JTC, EDB, Agency for Science, Technology and Research, Energy Market Authority, National Environment Agency, PUB, Singapore's National Water Agency and companies on the island.

JTC SolarLand on Jurong Island becomes operational.

2020

Launch of the Greening Jurong Island project by JTC and NParks.



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