This Version: 4 Aug 2016

THE STORY OF JURONG ISLAND

"We built this Jurong Island. It used to be a collection of little islands and atolls and coral reefs. We put them together, built Jurong Island and so enabled us to overcome our constraints and forge a leading position in the industry."[1]

ACKNOWLEDGEMENTS

This case study was written by Law Yi Ming and Chai Kah Hin for the module SSE1201 based on public materials. It is meant for classroom discussion only and does not imply effective or ineffective management.

We would like to express our utmost gratitude to the National Library Board, JTC, and Sembcorp Utilities for their assistance in providing the valuable information and resources, without which this case study would not have been possible. We would also like to thank the NUS professors, students and alumni who have taken the time to share their knowledge and provided feedback on the case study.

[1] Singaporean Prime Minister Lee Hsien Loong at the opening of ExxonMobil's chemical plant expansion on 8 January 2014.

INTRODUCTION

From its humble beginnings as a resource-scarce trading port, Singapore has evolved into one of the most developed economies in Asia. Despite having no oil and gas resources, one of the major contributors to Singapore's economic strength today is the chemicals industry, the centrepiece of which is Jurong Island[2]. The concept of Jurong Island was first publicly mooted in the 1991 concept plan and later turned into a reality by the Jurong Town Corporation (JTC), the Economic Development Board (EDB) of Singapore and many other government agencies. A man-made island formed from the amalgamation of seven smaller islands, Jurong Island has grown to become a thriving petrochemical cluster that is home to more than 100 companies with a total of S$47 billion worth of investments committed[3][4].

HISTORY OF JURONG ISLAND

BEFORE JURONG ISLAND

Before its current incarnation as a bustling petrochemical hub, Jurong Island was merely a group of seven small islands south of mainland Singapore. The names of the islands were Pulau Merlimau, Pulau Ayer Chawan, Pulau Ayer Merbau, Pulau Seraya, Pulau Sakra, Pulau Pesek and Pulau Pesek Kecil[5]. Before the 1960s, these islands were a far cry from what they are now. Instead of the imposing chemical plants that we see today, the islands were mainly occupied by laid-back fishing villages that had Malay-style wooden stilt houses with no power supply or proper roads[6].

It was not long before this quaint and rustic environment was to be transformed to meet Singapore's economic priorities. By the end of the 1960s, Singapore had four refineries from Shell, Esso, Mobil and the Singapore Refinery Company (SRC) scattered across the southern offshore islands, including Pulau Bukom[7][8][9][10]. These islands also saw early rounds of reclamation works, the first of which was to enlarge Pulau Seraya for a power station, then Pulau Ayer Merbau for the first chemical complex built by the Petrochemical Corporation of Singapore and, finally, Pulau Sakra and Pulau Bakau for other potentially interested parties[11].

This set the stage for Singapore to reap the economic benefits of the worldwide petrochemicals market boom during the 1970s[12]. By the end of the decade, Singapore had

[2] Carpenter, K., & Ng, W. (2013). Singapore's Chemicals Industry: Engineering an Island. *Chemical Engineering Progress , 109* (April), 56-60.
[3] Martin, C., Gandhi, R., Ang, S., Tan, W., Soh, A., & Teh, S. (1 December, 2014). *The making of Jurong Island*.
[4] Jurong Town Corporation. (2 September, 2014). *Jurong Island.*
[5] Hee, A. (1999). Jurong Island Experiences in Infrastructure Provision. *Dr Tan Swan Beng Memorial Symposium.* Singapore.
[6] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.
[7] Martin, C., Gandhi, R., Ang, S., Tan, W., Soh, A., & Teh, S. (1 December, 2014). *The making of Jurong Island*.
[8] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.
[9] Jurong Town Corporation. (5 September, 2011). *Jurong Island History*.
[10] Goh, W., & Tan, S. (2002). Vison and Guts: The Story of Jurong Island. In *Heart Work.* Singapore.
[11] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.
[12] Martin, C., Gandhi, R., Ang, S., Tan, W., Soh, A., & Teh, S. (1 December, 2014). *The making of Jurong Island*.

become one of the world's largest refining centres, able to produce more than 1.2 billion barrels per day. As a result of this refining capacity, Singapore began to attract potential petrochemical investors. Singapore's refineries were also attractive because of their ability to provide a variety of refined products (such as naphtha, paraffin, gasoline, oils, etc.), which were required by many petrochemical plants as feedstock[13]. Sumitomo Chemical Company was one of the first companies to recognize and tap into this opportunity, establishing a petrochemical complex in Singapore[14].

The 1980s was generally a period of uncertainty for Singapore's petrochemical sector. Although there was strong interest from petrochemical companies in increasing their footprint in Asia to feed growing demands for their products in the region, Singapore now faced serious competition from neighbouring countries that were able to offer more cost competitive alternatives. It was during this period of uncertainty that the concept of Jurong Island began to take shape[15][16].

Up to then, Singapore's post-independence economic growth strategy of being an export-driven economy had generally been successful. Apart from investing in local and government-linked companies to power the economy, Singapore relied heavily on foreign direct investments (FDI) from MNCs that set up operations in Singapore, creating tens of thousands of jobs in the process[17].

This strategy worked remarkably well for a couple decades and kept most of the country employed. However, by the mid-1980s, Singapore's economy was beginning to show signs of weakness. The traditional pillars of growth that churned out high volume and low value-added manufacturing output were starting to crumble under increased foreign competition and rising wage demands in Singapore[18].

Similarly, the petroleum refining industry also started to feel the heat. In the 1980s, petroleum refining margins were falling rapidly as neighbouring countries started to offer more competitive propositions — such as free land and berths, among other goodies — to attract refiners[19]. To keep Singapore ahead of her competitors, EDB made a concerted effort to expand the petroleum refining industry even further. Particular emphasis was placed on attracting investments for downstream operations that could produce high-margin petrochemicals[20].

The move towards higher margin petrochemicals made much economic sense as its capital intensive nature exerted less pressure on the limited human resources of Singapore. According to Tan Suan Swee, EDB's Director of Chemicals in 1999, "The chemicals industry is very capital intensive. It utilises a lot of technology, so the remuneration per capita and value added is very high." Indeed, the value added per worker in the chemicals sector added

---

13 Carpenter, K., & Ng, W. (2013). Singapore's Chemicals Industry: Engineering an Island. *Chemical Engineering Progress , 109* (April), 56-60.
14 Martin, C., Gandhi, R., Ang, S., Tan, W., Soh, A., & Teh, S. (1 December, 2014). *The making of Jurong Island*.
15 Martin, C., Gandhi, R., Ang, S., Tan, W., Soh, A., & Teh, S. (1 December, 2014). *The making of Jurong Island*.
16 Yeo, P. (2002). Passion Drives. In *Heart Work.* Singapore.
17 Singapore's "Mid-life Crisis" (2014).
18 Yeo, P. (2002). Passion Drives. In *Heart Work.* Singapore.
19 Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.
20 Yeo, P. (2002). Passion Drives. In *Heart Work.* Singapore.

up to eight times the national manufacturing average, while the figure of US$1 million of fixed investments per employee was roughly 35 times the average[21].

From a macro perspective, this increased focus on chemicals also helped to diversify the manufacturing sector in Singapore, which made up 23% of the country's economy in 1999. Of this 23%, half was made up of the electronics sector, which is very cyclical. Thus, by diversifying more into other manufacturing industries, the manufacturing sector could be made more resilient[22].

However, this was easier said than done in land-scarce Singapore. The existing petroleum refining plants had already taken up most of the viable offshore spaces. The obvious alternative of siting a large petrochemical plant on the mainland did not make sense either, as a chemical plant accident would have dire consequences for the general populace of Singapore[23].

CONCEPTUALISATION OF JURONG ISLAND

Even before the conceptualization of Jurong Island by EDB as a dedicated petrochemical cluster, Ong Geok Soo, who was the head of JTC's civil and structural department, had considered the possibility of combining all seven islands to form one big island, thereby creating a large bloc of land suitable for industrial use. In fact, by the late 1980s, JTC had already completed the theoretical plans to amalgamate these islands via reclamation[24].

The Jurong Island project took off in 1991 when Philip Yeo, who was EDB's Chairman then, had his "Eureka!" moment on a helicopter ride back from Karimun, Indonesia. As he and several guests flew over the cluster of seven small islands, his guests pointed out that the channels between the islands were shallow and commented that silting might be a problem for bunkering operations. He then began to put the pieces together in his mind and came up with the idea of creating a larger land area capable of housing petrochemical complexes and clusters by combining the seven little islands below[25]. The development of a chemical cluster would improve competitiveness by generating both vertical and horizontal linkages and integration among the petrochemical companies in the cluster[26]. With this seemingly crazy idea in mind, Philip Yeo then set about turning it into reality[27].

Creating a large island from seven small islands was a very intriguing prospect[28]. It was decided that Jurong Island would be formed by reclaiming land at the sea channels between the islands. In addition, the land area would be extended beyond the pre-existing coastlines into the open sea space. Through such effort, an additional 1,790 hectares of land could be

---

[21] Porter, B. (18 November, 1999). *Oil sector's self-sufficient home rises from sea, as Barry Porter reports*.
[22] Porter, B. (18 November, 1999). *Oil sector's self-sufficient home rises from sea, as Barry Porter reports*.
[23] Yeo, P. (2002). Passion Drives. In *Heart Work.* Singapore.
[24] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.
[25] Yeo, P. (2002). Passion Drives. In *Heart Work.* Singapore.
[26] Hee, A. (1999). Jurong Island Experiences in Infrastructure Provision.
[27] Yeo, P. (2002). Passion Drives. In *Heart Work.* Singapore.
[28] Yeo, P. (2002). Passion Drives. In *Heart Work.* Singapore.

added to the original 1000 hectares to create a total land mass of 2,790 hectares, which was equivalent to about 2.8% of the total land area of Singapore[29].

With a land mass of such size, there would be sufficient space to house full chemical clusters and complexes, allowing companies to reap the full advantages of vertical integration in the chemical production chain. In the chemical industry, companies often specialise in the production of a specific component in an overall production chain. This means that one company produces the feedstock for another company to produce the intermediate, which is then fed to another company to produce the final product[30]. By being in close physical proximity to suppliers, customers and even competitors in the value chain, it is possible to generate synergies that provide significant cost savings through economies of scale, higher productivity and reductions in individual storage needs[31].

As the first hub to integrate vertically at such a scale, the arrangement on Jurong Island helped companies save as much as 25-30% on capital costs as well as 10-15% on transport costs. It also eliminated the need to transfer chemicals in tankers, thus rendering the operations on the island safer and more environmentally sound[32][33].

Furthermore, such an arrangement can yield further economies of scale through horizontal linkages. In an industrial cluster such as Jurong Island, common services and infrastructure can be put in place and shared among the tenants without them having to invest additional capital to build their own. This helped companies save as much as 20% on capital costs[34]. Using what is known as a Common Pipeline Service Corridor, companies can conveniently gain access to steam, electricity, utilities, raw materials and finished products by simply "plugging" themselves into the built infrastructure and not be bogged down by the pipeline laying and cable wiring otherwise required. With this plug and play concept, EDB and JTC hoped to lower the entry barriers for oil and chemical companies to invest in Jurong Island[35][36][37][38].

---

[29] Hee, A. (1999). Jurong Island Experiences in Infrastructure Provision.
[30] Yeo, P. (2002). Passion Drives. In *Heart Work.* Singapore.
[31] Porter, B. (18 November, 1999). *Oil sector's self-sufficient home rises from sea, as Barry Porter reports.*
[32] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.
[33] Yeo, P. (2002). Passion Drives. In *Heart Work.* Singapore.
[34] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.
[35] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.
[36] Goh, W., & Tan, S. (2002). Vison and Guts: The Story of Jurong Island. In *Heart Work.* Singapore.
[37] Yeo, P. (2002). Passion Drives. In *Heart Work.* Singapore.
[38] Tng, S., & Tan, S. *Designing our City: Planning for a sustainable Singapore.* Singapore: URA.

OVERCOMING CHALLENGES

SECURING THE ANCHOR TENANT

The reasons in favour of forming Jurong Island may have presented a compelling case, but many daunting hurdles still remained.

Firstly, the cost of putting everything in place was a hefty S$7 billion. Even though EDB managed to secure the budget in the end, they still had the unenviable task of trying to convince and sell “stretches of seawater, with only the promise of land” to prospective investors[39]. Secondly, Singapore had no oil or gas reserves, and had significantly higher land and labour costs compared to neighbouring countries. Thus, at first glance, the likelihood of Jurong Island actually materialising appeared bleak[40].

Although EDB received little interest from potential investors at the start, their perseverance eventually paid off. Several big petrochemical companies began to respond positively to the idea. From EDB’s perspective, the key to getting the ball rolling was to secure an anchor tenant with a strong enough reputation to inspire other companies to follow suit. Despite some of the shortcomings of Singapore as an investment destination for petrochemical plants, the capital-intensive nature of the industry meant it was critical that these companies invest in countries that were politically stable and business-friendly. Singapore’s stable investment climate made Jurong Island a convincing proposition[41].

EDB found the anchor tenant in DuPont, a chemical giant with a longstanding relationship with Singapore. Prior to the agreement to set up operations on Jurong Island, DuPont had already agreed to set up several chemical plants on the mainland in 1989. Not long after, in 1990, EDB was able to persuade DuPont to add another nylon production complex on Jurong Island. Having secured DuPont as the anchor tenant, interest from other companies began to rise. Companies providing ancillary support services and logistics, which were vital to the functioning of the ecosystem, also began to sign up. Soon, Van Ommeren, a Dutch company, signed up to be the first third-party logistics supplier on the island[42].

Having taken the momentous first step of securing investors for Jurong Island, EDB continued to work tirelessly in coordinating the effort to attract the “right” companies to make up the petrochemical ecosystem on Jurong Island. In the words of Tony Anderson, the CEO of the Singapore Refining Company (SRC) at that time, “The co-ordination has been tremendous. The EDB has been very active in finding companies that can feed off one another. Often these things evolve over 20 years but this is happening in a 10-year time-span.”[43]

[39] Yeo, P. (2002). Passion Drives. In *Heart Work.* Singapore.
[40] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.
[41] Yeo, P. (2002). Passion Drives. In *Heart Work.* Singapore.
[42] Goh, W., & Tan, S. (2002). Vison and Guts: The Story of Jurong Island. In *Heart Work.* Singapore.
[43] Porter, B. (18 November, 1999). *Oil sector's self-sufficient home rises from sea, as Barry Porter reports.* South China Morning Post

ENGINEERING AND DELIVERING RESULTS

The capacity of Singapore's engineers to work tirelessly, creatively and efficiently to overcome huge and often unprecedented engineering challenges cannot be understated. There is no doubt that the ability of the engineering team to deliver results in a timely fashion played a huge role in turning Jurong Island into a reality. As one of the largest reclamation projects of its time, engineers working on the Jurong Island project were challenged on a daily basis. Millions of tons of sand were brought in for the reclamation and hundreds of contractors had a hand in making Jurong Island possible. Emphasizing the challenges that engineers faced in orchestrating the entire project, then JTC Chairman, Lim Neo Chian, stated that "Jurong Island is one huge work site – every movement of every piece of equipment had to be coordinated."

In addition to the technical challenges, the engineering team needed to maintain a customer-focused orientation. They based their deadlines entirely on their customers' needs, and not on when they felt was suitable for them. In the words of Lim Chin Chong, the Director of Specialised Parks in JTC at the time, "We always said yes and then came back and figured out how to do it. We took a calculated risk because we knew we had a high performing team. Our position was that if we didn't deliver, we lose that client. And when you lose a client, you lose a whole cluster of clients. We knew we could not fail. We HAD to deliver."[44]

Of the many instances where engineers contributed in securing investors, one stood out in particular; it was even mentioned by former Prime Minister Goh Chok Tong in his 1998 National Day speech. The CEO of the Japanese chemicals company Teijin Ltd. was sceptical when the idea of transforming the "patch of seawater" was first presented to him, especially since similar efforts in Japan had been slow and tedious. Nevertheless, intrigued by the boldness of the plan, he decided to see that plot of "land" for himself several months later. All his scepticism disappeared when he found himself standing on the plot of reclaimed land that, a mere four months ago, had been seawater. The CEO gave the go-ahead for the investment not long after his trip to Jurong Island. This story is just one of many that shows there is no doubt that the engineers played a large role in making Jurong Island a possibility. To add further credence to all the work that engineers did for Jurong Island, the CEO of SRC Tony Anderson actually remarked, "I don't think it happens at this speed anywhere else in the world."[45][46]

ENGINEERING AND TECHNICAL CONSIDERATIONS

The undertaking of combining the islands was more than simply pouring sand into the water channels between them; many considerations had to be taken into account. Firstly, the depth of the water in the sea channels could not be too great or else the entire reclamation operation would prove too costly. Secondly, the engineers had to take care not to unnecessarily upset the physical environment. Thirdly, the interests of the existing petrochemical plants could not

[44] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.
[45] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.
[46] Goh, W., & Tan, S. (2002). Vison and Guts: The Story of Jurong Island. In *Heart Work.* Singapore.

be compromised. Many of the plants required access to the sea for logistics purposes, so reclamation had to be done in such a way that these plants did not end up being landlocked[47].

PRELIMINARY STUDIES FOR RECLAMATION PREPARATION

During the planning and development of Jurong Island, key participants from industry and multiple government agencies were engaged and constantly involved. Private sector input was received via a committee known as the Jurong Island Technical Committee that was formed in 1992. This committee was led by JTC and included representatives from other government agencies and industry. Master planning of Jurong Island was guided by three key principles[48]:

1. Investments by existing tenants must be safeguarded from disturbances and disruptions from reclamation and construction works. This is because the development of Jurong Island was meant to attract new investments from existing, as well as new tenants.

2. Accentuate the benefits of cluster development by planning and providing the necessary infrastructure in a cost-effective and time-efficient manner.

3. Minimise adverse environmental impact.

During the planning and development phase, various technical findings regarding the environmental impact, navigational safety, sedimentation, accommodating current infrastructure, and more, were identified and addressed[49]. (Refer to Exhibit 1 for more information on the specific findings)

DESIGNING THE JURONG ISLAND CAUSEWAY LINK

Prior to the grand plans for the reclamation of Jurong Island, the transportation of people and goods between the mainland and the islands was carried out via boats. Mr. Gan Seok Wee, who was then an engineer working on the island and is now the Chairman and managing director of ExxonMobil Singapore, still fondly recalls the boat journeys that he took early in the morning to get to the refinery on Pulau Ayer Chawan[50]. However, with the sharp increase in industrial activity expected after the formation of Jurong Island, it was no longer feasible to simply rely on sea transportation to satisfy all logistics and transportation needs.

Thus, a causeway link connecting Jurong Island to mainland Singapore became necessary. This road linkage not only delivered cost savings to island users via reduction in the transportation costs of workers, but also in construction and maintenance costs. There were

---

[47] Reutens, L. (2000). *Building a Nation: The Story of Engineering in Singapore.* Singpaore: The Institute of Engineers, Singapore.

[48] Hee, A. (1999). Jurong Island Experiences in Infrastructure Provision. *Dr Tan Swan Beng Memorial Symposium*. Singapore.

[49] Hee, A. (1999). Jurong Island Experiences in Infrastructure Provision. *Dr Tan Swan Beng Memorial Symposium*. Singapore.

[50] Chia, Y. (24 December, 2014). *The engineer who became ExxonMobil S'pore chairman*.

also cost savings from the pooling of common infrastructure facilities (such as pipelines and cables from the mainland) among the tenants of Jurong Island[51].

TECHNICAL STUDIES FOR CAUSEWAY DESIGN

In order to better gauge the potential impact of building the causeway on the environment and to ensure that the development of the Jurong Island causeway proceeded smoothly, a comprehensive study was conducted where the following factors were considered:[52][53]

1. Influence of the causeway on the capacity of the existing navigational traffic;
2. Influence of the causeway on ship manoeuvring and berthing operations in the vicinity of the causeway;
3. Changes in the hydrodynamic condition of the current flow and sedimentation pattern due to the causeway;
4. Water quality changes (especially temperature changes) due to sea intake and outfall structures nearby;
5. Risks involved with having a public road within petrochemical complexes.

Baseline studies regarding the abovementioned issues were carried out in order to provide a frame of reference, calibration and validation for future modelling studies. Most of the studies were based on mathematical modelling, except those regarding the opening of the causeway where physical monitoring and modelling were used[54]. (Refer to Exhibit 2 for more details on the results of these studies.)

Despite all the preliminary studies, nothing could fully prepare the engineering team for the unforeseen challenges. In building the causeway, the team actually hit soft ground, which made the construction of the causeway harder. This added several months to the schedule and engineers had to work doubly hard to ensure that the causeway would be delivered on time. The engineers faced such challenges on a regular basis throughout the project, but their determination to live up to their responsibilities always kept them going[55].

[51] Pang, P., & Seow, K. (1999). The Design of Jurong Island Causeway. *Dr Tan Swan Beng Memorial Symposium*. Singapore.
[52] Hee, A. (1999). Jurong Island Experiences in Infrastructure Provision. *Dr Tan Swan Beng Memorial Symposium*. Singapore.
[53] Pang, P., & Seow, K. (1999). The Design of Jurong Island Causeway. *Dr Tan Swan Beng Memorial Symposium*. Singapore.
[54] Pang, P., & Seow, K. (1999). The Design of Jurong Island Causeway. *Dr Tan Swan Beng Memorial Symposium*. Singapore.
[55] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry*. Singapore: Jurong Town Corporation.

DESIGNING THE MAIN STRUCTURE OF THE CAUSEWAY

The causeway was designed to be able to handle a peak traffic volume of 5,000 passenger car units per hour once Jurong Island was fully developed. For this purpose, two options were considered. The first was to use a single dual 4-lane carriageway. The second option was to use a combination of dual 3-lane and dual 2-lane carriageways. In the end, a single dual 4-lane carriageway was chosen because it was the most economical solution and imposed the least disruption on existing tenants. The carriageway was then designed to connect Jurong Island to the Ayer Rajah Expressway[56]. (Refer to Exhibit 3 for more details on the reasons that led to the selection of the chosen design.)

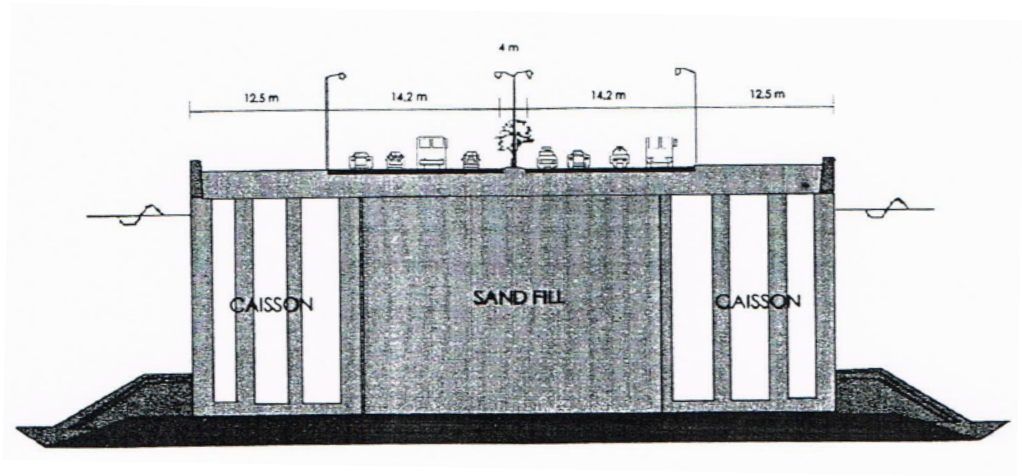

FIGURE 1: CROSS-SECTIONAL DIAGRAM OF THE CAUSEWAY STRUCTURE (PANG & SEOW, 1999)

DESIGNING THE CAUSEWAY OPENING

The design of the causeway opening posed a serious technological and engineering challenge to designers due to its unique requirements. While most openings in marine structures are frequently used and activated, the opening for the causeway was meant only for emergencies and special navigational circumstances. Thus, the opening must be reliable in times of need, but the construction and maintenance costs had to be kept low as it was not intended for regular use. The design requirements made building the opening an entirely unique engineering case with no precedent elsewhere in the world. Thus, the JTC engineers had to pool their creative juices to find the perfect solution to this problem[57].

[56] Pang, P., & Seow, K. (1999). The Design of Jurong Island Causeway. *Dr Tan Swan Beng Memorial Symposium*. Singapore.
[57] Pang, P., & Seow, K. (1999). The Design of Jurong Island Causeway. *Dr Tan Swan Beng Memorial Symposium*. Singapore.

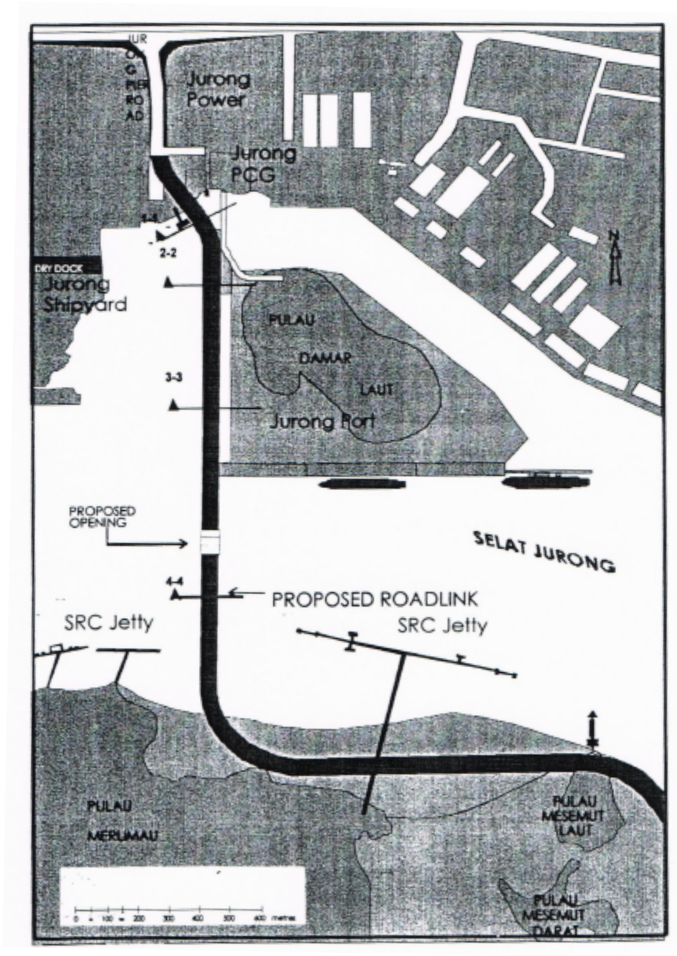

FIGURE 2: DRAWING SHOWING THE PROPSED LAYOUT OF THE CAUSEWAY LINK (PANG & SEOW, 1999)

Many options were considered during the brainstorm for the opening. The use of a deck was mooted, but there was a significant concern about the structural load on the deck across the 60m gap. In the end, the chosen option was to use an anchored pontoon as part of the causeway which had a floating mechanism when set above sea level. During an emergency, an opening could be created within 30 minutes by using eight mechanical pumps to pump water out of the pontoon so it could be floated away. This solution also mitigated concerns about the possible disruption of utilities, cables and pipes built along the causeway when it was opened, as the cables and pipes would be laid underneath the pontoon[58].

[58] Pang, P., & Seow, K. (1999). The Design of Jurong Island Causeway. *Dr Tan Swan Beng Memorial Symposium*. Singapore.

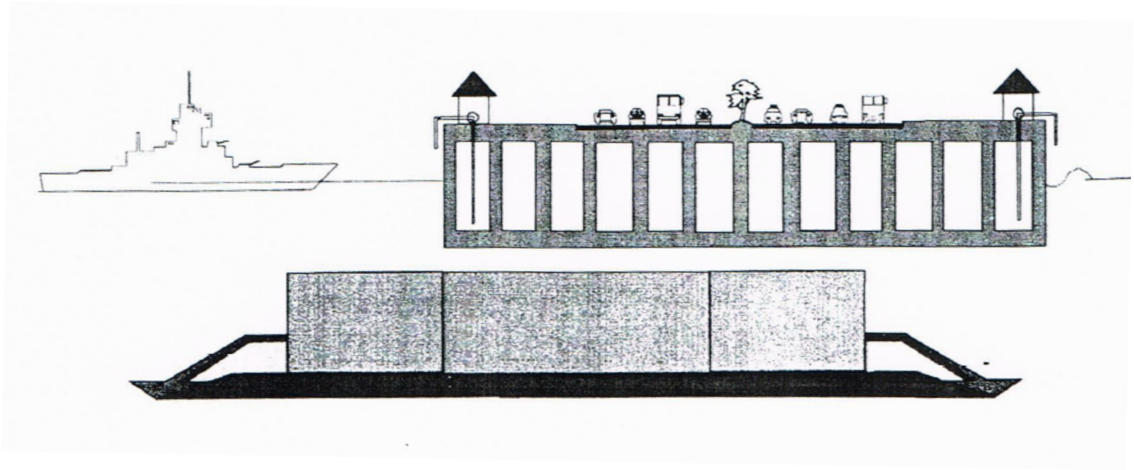

FIGURE 3: SCHEMATIC DIAGRAM SHOWING FLOATING PONTOON OPENING (PANG AND SEOW 1999)

ACCELERATION OF RECLAMATION PLANS

After much planning and deliberation, the work to put Jurong Island together finally kicked off in 1995. It was an ambitious project given the scale and complexity involved. To build the island, contractors such as Penta-Ocean and Koon Construction dredged sand and rock from seabed nearby, transported them by barge and deposited them onto newly-created sand keys around the Jurong site[59].

By 1999, some 682 hectares of land had been reclaimed[60]. As companies began to settle in, demand for a place on Jurong Island burgeoned. Interested clients started to queue for their land to be reclaimed and the engineers had to manage the pressure to deliver everything on time. Due to the influx of investors, engineers had to race against time to build the necessary infrastructure like drains and roads in order to meet the tight construction deadlines set by the clients[61].

EDB's success in marketing Jurong Island led to a demand so high that the plans were drastically accelerated. Between 1997 and 2000, more than 20 companies signed up for over 200 hectares of land (the equivalent of 300 football fields). By the year 2000, Jurong Island had received a sum of S$21 billion from 60 international companies, yielding a value added per worker of S$666,000 a year. This placed the chemical industry as the second largest contributor to Singapore's overall manufacturing output[62].

---

[59] The Oil & Gas Year. (n.d.) *The Oil & Gas Week: The Island*.

[60] Hee, A. (1999). Jurong Island Experiences in Infrastructure Provision. *Dr Tan Swan Beng Memorial Symposium*. Singapore.

[61] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.

[62] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.

FIGURE 4: ORIGINAL RECLAMATION PLAN SHOWING WHAT THE ISLANDS LOOKED BEFORE AND AFTER EACH PHASE OF RECLAMATION (NG, 2007)

As a result of the high demand, each reclamation phase was rescheduled and pushed forward in time. In 1997, Phase 3 began. This phase involved the reclamation of 1,011 hectares of land and was initially scheduled to be completed by 2030. The rush for land by clients forced the Jurong Island team to move the deadline forward all the way to 2001 instead. With demand continuing to build, another 550 hectares of land were added in another phase, called Phase 4, to be completed by 2005[63].

[63] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.

FIGURE 5: PHOTOS OF CURRENT RECLAMATION WORKS AROUND PULAU AYER CHAWAN TAKEN IN LATE NOVEMBER 2014 (COURTESY OF THE FIRST AUTHOR'S FRIEND)

WORLD-CLASS INTEGRATED PETROCHEMICAL HUB

Thanks to the efforts of the Jurong Island team, Jurong Island is now a fully-integrated petrochemical hub tied together by three networks. The first and most obvious is the infrastructure network. These facilities, which include service corridors, utilities, logistic services, power, roads, sewerage, telecommunications, a causeway, an amenity centre and a fire station, turned Jurong Island into a self-contained hub. The second network is the integration of the highly synergised chemical companies. The third is the IT network that enables the seamless transfer of information throughout the island[64].

Another factor contributing to the success of Jurong Island as a world-class petrochemical hub is its proximity to the best port infrastructure in the region. Having a mega-port within a close distance reduces the logistic costs that the chemical companies face in importing crucial raw materials or equipment, or in exporting products. The efficiency of the port also enables the companies to execute just-in-time delivery of manufactured products, thus improving their competitiveness against other chemical industries elsewhere in the world[65].

The transport of chemicals, most of which are highly hazardous, between the port and Jurong Island is by no means an easy feat. Specialised logistics services for the transportation of chemicals are provided by companies like Hoyer Global that transport the chemicals via roads in well-secured, pill-shaped iso-tanks. Such companies have extensive safety and precautionary measures in place to ensure that the potential hazards to the public are minimised. In addition, they are well-prepared to deal with potential mishaps, such as leakages[66]. This shows that preparation for the smooth operation of Jurong Island extends beyond the island's borders and requires commitment from all members of the ecosystem.

---

[64] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.
[65] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.
[66] Channel News Asia. (30 June, 2011). *SLA Moving Story - Episode 4, part 1 of 2.*

Case of Interest 1: Safeguarding Jurong Island from Terrorism Threats

At the turn of the millennium, a series of terrorist attacks (most notably the September 11 attacks) sent the entire world into a heightened state of security. While Singapore was fortunate enough to not go through the traumatic experience of a terrorist attack, it has spared no effort in ensuring that it remains safe. As part of the effort to better protect Singapore from such harm, the government instituted a host of security measures to protect facilities identified as key installations. These facilities include crucial national infrastructure such as water networks, power stations and, in particular, Jurong Island[67].

Due to its roaring success as a petrochemical hub, Jurong Island is an attractive potential target for terrorism. Furthermore, the fallout involved with a terrorism-induced chemical plant accident would be catastrophic not only for the economy, but also for the general well-being of the Singaporean populace. Wasting no time, in October 2001 Jurong Island was declared a 'protected area'. Singapore directed the Singapore Armed Forces (SAF), Police Coast Guard and commercial security forces to enact stronger security surveillance and controls around Jurong Island[68].

By enacting stricter security measures, the authorities were able to ensure that only authorised personnel were allowed onto Jurong Island. All employees on Jurong Island were given a computerised pass that was needed for entry onto the island. In addition, vehicle checkpoints with X-ray scanners were set up to screen all vehicles entering the island. To increase preparedness in case of any terrorist attacks, various agencies, such as the Singapore Civil Defence Force, JTC, Maritime Port Authority of Singapore, Singapore Police Force and SAF, have since conducted a number of emergency exercises in partnership with private companies on Jurong Island[69]. Establishing a comprehensive web of protection around Jurong Island was not an easy feat, but the government made it clear that Singapore was willing to do whatever it took to keep the general populace safe and secure.

[67] National Security Coordination Council. (2004). *The Fight Against Terror: SINGAPORE'S NATIONAL SECURITY STRATEGY.* Singapore: National Security Coordination Centre.

[68] National Security Coordination Council. (2004). *The Fight Against Terror: SINGAPORE'S NATIONAL SECURITY STRATEGY.* Singapore: National Security Coordination Centre

[69] National Security Coordination Secretariat. (2006). *1826 days: A Diary of Resolve.* Singapore: SNP International.

BUILDING A PIPELINE OF SUCCESS

DEVELOPING THE NECESSARY HUMAN CAPITAL

To ensure the smooth functioning of billions of dollars of infrastructure, it was vital to develop a sufficient skilled labour force to keep Jurong Island running. In 2004, the Chemical Process Technology Centre was set up on Jurong Island. It was the first training centre of its kind in the world and houses a full industry scale petrochemical plant on its premises to provide opportunities for education and training in chemical technology fields under real-life plant conditions[70].

In addition, 2004 saw the opening of Singapore's second university-level chemical engineering department at Nanyang Technological University. This added to the existing training capacity of the globally recognized chemical engineering department at the National University of Singapore, which has been producing approprimately 250 BEngs and 30 PhDs in chemical engineering per year since the 1970s[71][72].

As Singapore aims to move up the petrochemicals value chain, there is a growing need to bolster its capabilities in knowledge-intensive and high-tech research. To ensure that Singapore and Jurong Island remain relevant and innovative in the years to come, a national research institute called the Institute of Chemical and Engineering Sciences (ICES) was established by A*STAR and EDB in 2002. Once just a small, autonomous research centre at NUS, ICES now houses leading laboratories, pilot facilities and the necessary infrastructure to conduct world-class research in chemistry and chemical engineering[73]. In addition, the facility plays host to many corporate research facilities from world-renowned companies such as Mitsui Chemicals and BASF[74].

CREATING HOME-GROWN WORLD-CLASS COMPANIES – THE STORY OF SEMBCORP UTILITIES

While Jurong Island was conceived and built with the objective of attracting foreign investments in the field of chemical industry, its success has also led to the creation of many local companies. One notable example is Sembcorp Utilities.

Sembcorp Utilities is one of the three divisions of Sembcorp Industries, a leading energy, water and marine group operating across six continents worldwide and workforce of over

[70] Carpenter, K., & Ng, W. (2013). Singapore's Chemicals Industry: Engineering an Island. *Chemical Engineering Progress , 109* (April), 56-60.
[71] Carpenter, K., & Ng, W. (2013). Singapore's Chemicals Industry: Engineering an Island. *Chemical Engineering Progress , 109* (April), 56-60.
[72] The NUS undergraduate degree programme in Chemical Engineering started in the Department of Chemistry in the Faculty of Science in 1975. The programme was transferred to the Faculty of Engineering in 1979.
[73] A*STAR. (2014). *About Us*.
[74] Carpenter, K., & Ng, W. (2013). Singapore's Chemicals Industry: Engineering an Island. *Chemical Engineering Progress , 109* (April), 56-60.

8,000 employees and total assets of over S$17 billion (as of 2015). Sembcorp Utilities has its origin as an engineering, procurement and construction specializing in chemical and petrochemical plant engineering. From the interactions with customers, Sembcorp realized that many of the customers spent a great deal of their time solving basic issues such a reliable utilities supply rather than their core operation. Identifying this as a potential business opportunity, the top management of Sembcorp decided to build, own, and operate (BOO) "centralized utilities" on Jurong Island that would provide a steady and recurring stream of income. These centralized utilities would provide energy, water and other onsite logistics to chemical and petrochemical customers on Jurong Island.

These centralized utilities bring many benefits to the companies operating on Jurong Island. By outsourcing these non-core activities to a one-stop provider such as Sembcorp Utilities, companies can focus on their core activities while Sembcorp can leverage on economies of scale to offer cost competitive solutions to their customers by centralizing such activities in a few infrastructures. Such "plug and play" concept is another advantage for plants operating on Jurong Island.

Fig 6. Sembcorp's facilities on Jurong Island serving companies at the Banyan, Sakra and Seraya areas (Source: Sembcorp)

There are 3 key services that Sembcorp Utilities offer:

1. Water,
2. Energy
3. Onsite logistics and solid waste management

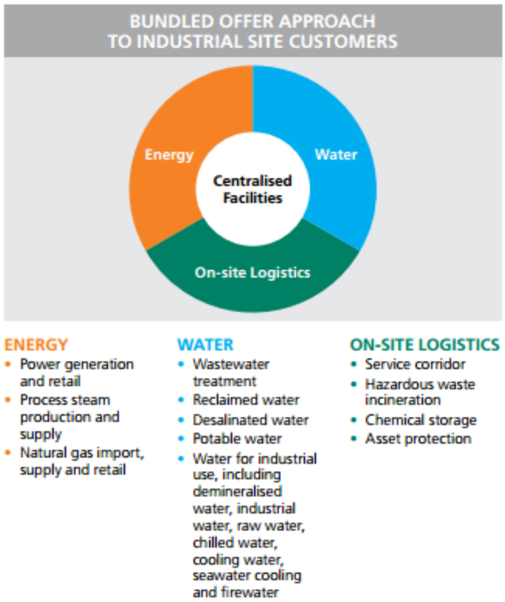

Fig. 7 Sembcorp Utilities' services to industrial site customers (Source: Sembcorp)

1. Water

As shown in Figure 7, Sembcorp Utilities's water business offers a broad range of areas. It embraces this in a "total water management" approach where water supply, wastewater treatment and water reclamation are integrated in a "closed-loop", minimizing liquid discharge and conserves water resources (see Figure 8). In fact, Sembcorp pioneered the commercial reclamation of municipal wastewater effluent into high-grade industrial water (HGIW) for industries on Jurong Island in 1999.

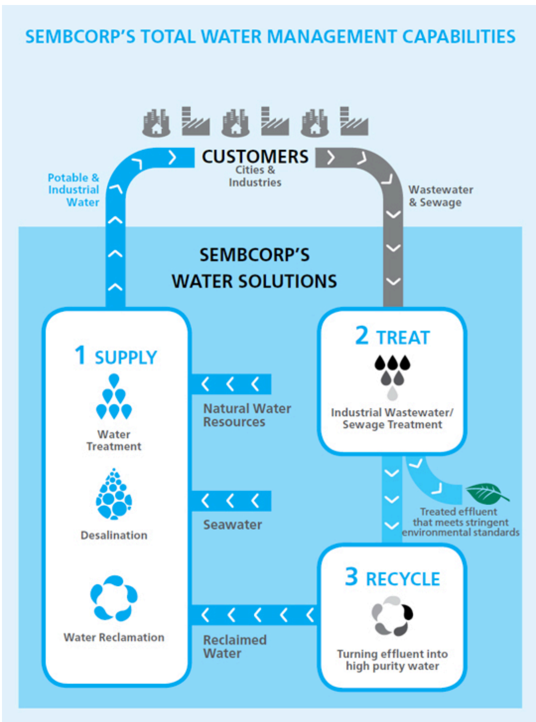

Fig. 8 Total Water Management Approach (Source: Sembcorp)

2. Energy

Sembcorp Utilities provides electricity, gas, steam and other form of energy to its customers on Jurong Island. It is also the first company to operate the first Combined-Cycle Gas-Turbine cogeneration[75] plant in Singapore. Situated on Jurong Island, the gas-fired plant supplies both power to the grid and steam to industrial users. It has a capacity of 815 megawatts and 700 tonnes per hour (tph) of steam.

In response to climate change concern, Sembcorp has also started to generate energy using alternative sources. In 2012, Sembcorp opened a Woodchip Boiler Plant that produces renewable energy from woodchip derived from waste wood. In addition, "Sembcorp is also developing an energy-from-waste facility which is targeted to begin operations in 2016. Located at the Sakra area, the S$250 million plant will be the first large-scale steam boiler on Jurong Island to be fuelled entirely by industrial and commercial waste to produce steam. The facility will produce 140tph of steam, using around 1,000 tonnes of industrial and commercial waste per day as fuel. This waste, collected by Sembcorp's solid waste management operations, is roughly 14% of Singapore's total daily tonnage of waste bound for incineration"[76]. The plant will be built by a consortium comprising Babcock & Wilcox Vølund, Halla Energy & Environment and Hyundai-HEC Joint Venture[77].

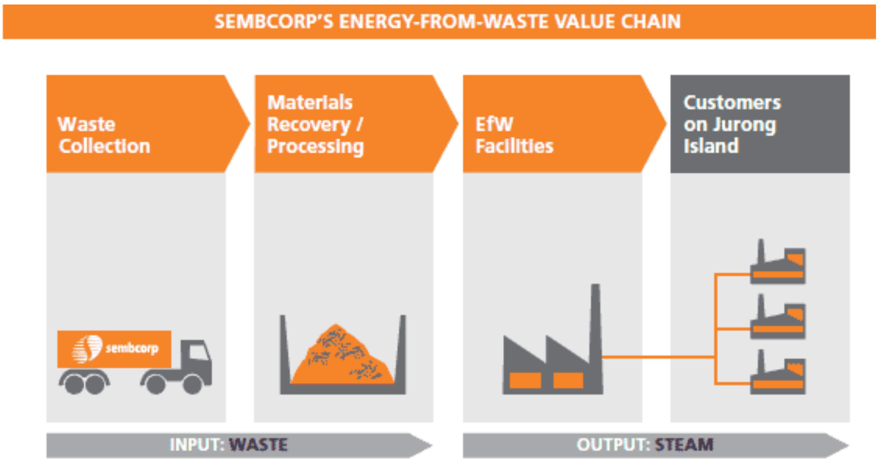

Fig 9. Energy-From-Waste Value Chain (Source: Sembcorp)

3. Onsite logistics and solid waste management

In addition to the water and energy businesses, Sembcorp also offers on-site logistics and services such as chemical storage, hazardous waste incineration services, and supply of industrial gases to their clients on Jurong Island. These services allow their client to focus on their core activities.

From the experiences and capabilities developed serving its customers on Jurong Island, Sembcorp Utilities has grown into a global player. Notably, it now:

---

[75] A cogent plant is a power station that generates electricity and also make use of the waste-heat (a by-product of the process). In this case the waste heat is used to generate steam which is supplied directly to plants on Jurong Island.

[76] "Sembcorp on Jurong Island", article provided by Sembcorp Utility

[77] State of Green (n.d.) *Waste-To-Energy Plant in Jurong Island, Singapore*.

- Provides total water management solutions in areas such as Zhangjiagang Free Trade Zone in China
- Operates Centralised utilities in 11 sites across Singapore, China, and the UK, with the latest being developed in the Dugqm Special Economic Zone in Oman

JURONG ISLAND VERSION 2.0

Despite all the amazing achievements that Jurong Island has attained, it remains a work-in-progress. The Jurong Island team continues to find ways to keep Jurong Island relevant and globally competitive. This is especially pertinent in the face of emerging fierce competitors, such as India and China. As part of the effort to continuously improve Jurong Island's competitiveness and prepare for the next growth phase in the chemicals industry, JTC continues to work closely with other key government agencies such as the EDB, National Environment Agency (NEA) and the Energy Market Authority (EMA) on initiatives to build Jurong Island version 2.0. Yet, the task has become even more challenging as land, energy and raw material resources grow even scarcer. As most of the shallower regions of Jurong Island have been reclaimed, there is increasing cost in reclaiming more land. In a bid to tackle these issues head-on, the Jurong Island 2.0 Master Plan was conceived[78].

The purpose of the Jurong Island 2.0 Master Plan is to spearhead the development of innovative and systematic solutions to solve the ongoing issue of resource constraints[79]. Due to growing concerns about Jurong Island's environmental impact, plans have been put in place to reduce its carbon footprint[80]. Sustainability and efficiency are two core foci of the Jurong Island 2.0 Master Plan. The Jurong Island 2.0 plan entails a comprehensive review of five core aspects, namely energy, logistics and transportation, feedstock options, environment and water. As part of the plan, system-level optimisation of valuable resources, such as energy, water and land, will be done. Additionally, the plan aims to develop integrated innovative solutions to enhance energy and resource-use efficiency, e.g., the ability to tap wasted heat to power productive processes. With these initiatives in place, it is hoped that Jurong Island will continue to be seen as an innovative platform for future-ready solutions that can transform the chemicals industry[81].

One initiative is to use alternative feedstocks for existing chemical production processes, such as liquefied petroleum gas, syngas (a combination of carbon dioxide and hydrogen from coal) and even bio-renewables. Energy initiatives include tapping unused "cold" energy from the LNG terminal. To improve logistics and transportation efficiency, the building of a second road link to the mainland has been proposed. The construction of a coal gasification plant is also being evaluated; the plant is expected not only to supply utilities, but to also produce syngas. In fact, EDB has studied the use of "green" materials, including crops like palm oil, sugars and bioethanol, to produce chemicals and industrial polymers that currently rely mainly on naphtha and other petrochemicals produced by refineries[82].

[78] Lim, R. (21 March, 2012). *All projects studied under Jurong Island 2.0 initiative completed*.
[79] Jurong Town Corporation. (2013). *Jurong Island: HOME TO LEADING GLOBAL CHEMICAL COMPANIES*.
[80] Lim, R. (21 March, 2013). Tender called for re-greening of Jurong Island: Consultant to study vegetation to sop up contaminants. *The Business Times*.
[81] Jurong Town Corporation. (2013). *Jurong Island: HOME TO LEADING GLOBAL CHEMICAL COMPANIES*.
[82] Lim, R. (21 March, 2012). *All projects studied under Jurong Island 2.0 initiative completed*.

Another example of "green" efforts is the 2013 tender for the re-greening of Jurong Island. The re-greening plan is not for an aesthetic purpose but a functional one: it would utilise the natural capacity of plants to remove contaminants in soil and water that have been polluted by the oil, petrochemical, chemical and power facilities on Jurong Island. This natural cleaning process is known as phyto-remediation. It uses plants' natural metabolic, absorption and transport processes to sop up contaminants (including carbon dioxide) and clean up Jurong Island[83].

Under the Jurong 2.0 Master plan, a Green Campus has also been established to help companies to reduce the use of energy. See Case of Interest 2.

Case of Interest 2: McKinsey's Green Campus on Jurong Island

The rising cost of energy, coupled with the increase in concerns for climate change, had led to many petrochemical companies to place great emphasis on energy efficacy. In many petrochemical plants, energy cost may constitute 50% or more of their operating cost. A small improvement in energy efficiency may translate into hundreds of thousands dollars saving, given the large-scale nature of these plants. According to Oliver Tonby, a McKinsey consultant, "Energy efficiency is becoming a strategic imperative for companies. It offers huge potential cost savings, together with a vital reduction in global greenhouse emissions. Our experience working with companies in Singapore and across the region has led us to conclude one important thing: there is real scope for players in the region to transform their operations to become more energy efficient and competitive"[84]. It is for this reason that, McKinsey, a top management consulting firm, with the support of EDB and NEA, has established a "Green Campus" on Jurong Island in 2012. The main purpose of this "campus" is to train executives and front line operations managers across a range of core operations in areas from water cooling system to operational furnace. Located within the Chemical Process Technology Centre, the centre is run by Petrofac and is a live and fully operational refinery.

According to Mr Quek Swee Kuan, Assistant Managing Director at EDB, "The Green Campus is McKinsey's first process model factory in the world. This is a strong validation of Singapore's status as a globally competitive manufacturing hub, with an existing base of knowledge intensive manufacturing operations. Consulting firms like McKinsey can centralise their Asian knowledge resources in Singapore and leverage the base of sophisticated lead demand here to develop new consulting solutions and serve their growing base of clients throughout Asia."[85]

Mr S. Iswaran Minister in Prime Minister's Office and Second Minister for Home Affairs and Trade & Industry said this during the opening of the green campus,

[83] Lim, R. (21 March, 2013). Tender called for re-greening of Jurong Island: Consultant to study vegetation to sop up contaminants. *The Business Times* .
[84] Press release by 25 Oct McKinsey 2012
[85] Singapore Economic Development Board. (2012). *Driving energy efficiency: Mckinsey establishes Singapore's first green campus*.

> "Global energy demand is projected to grow by 28 per cent from 2009 to 2035, and energy market gyrations are exacerbated by the increased volatility and uncertainties in global energy markets and oil prices. There is also rising pressure for global action to reduce greenhouse gas emissions and to mitigate climate change. As a small country with a relatively large industrial footprint, Singapore is also studying how we can reduce our energy demand and carbon footprint as part of our sustainable economic growth. To this end, the Singapore Government has invested in various efforts to encourage more efficient energy use and to build up capabilities in energy management.
>
> In this regard, Jurong Island is a good example of our focus. In our master planning for Jurong Island Version 2.0, government agencies collaborated with multiple partners – including McKinsey – to uncover energy efficiency opportunities, develop best practices in energy management, and explore innovative infrastructure planning. These are aimed at optimising energy use and lowering utility costs. Several system-level opportunities, such as harnessing cold energy from LNG and utilising waste heat for desalination, emerged as possible projects for us to pursue." [86]

JURONG ISLAND 3.0

Even before the completion of the Jurong Island 2.0 project, the Singapore government started planning for the next phase of development – Jurong Island version 3.0. In Jurong Island 3.0, Jurong Island aims to continue its move up the value chain - initially from refining to petrochemicals, and now from petrochemicals to speciality chemicals. This has been lauded by experts as the right strategic move in the face of increasing global competition in the petrochemical industry[87].

There are also thought to be greater synergies in this respect, as Jurong Island now possesses sufficient production capacity for petrochemicals feedstock to supply a viable specialty chemicals industry. Furthermore, Singapore is attractive to potential specialty chemicals companies because speciality chemicals production requires robust intellectual property protection. Thus, Singapore's emphasis on strong intellectual property protection gives Singapore an edge over rivals in the region[88].

[86] Opening Speech, Mr S. Iswaran Minister in Prime Minister's Office and Second Minister for Home Affairs and Trade & Industry, at the Opening of McKinsey Green Campus, Thursday 25 October 2012, 9.45am, Jurong Island

[87] Soh, A. (24 November, 2014). New plan, rethink for Jurong Island. *The Business Times, Singapore*.

[88] Soh, A. (24 November, 2014). New plan, rethink for Jurong Island. *The Business Times, Singapore*.

Case of Interest 3: Jurong Rock Caverns (JRC)

Click the link below to watch CNN's "Why Singapore is putting its oil back into the ground"

http://edition.cnn.com/2015/06/16/asia/going-underground-in-singapore/index.html?iref=obinsite

Although not technically under the Jurong Island 2.0 plan, the JRC is yet another initiative that shows the aptitude of the Jurong Island team to evolve with the times. As surface land becomes increasingly scarce, one alternative is to go underground. This is exactly what JTC has done. Situated 130 metres below the seabed of the Banyan Basin on Jurong Island, the Jurong Rock Caverns (JRC) will be Singapore and Southeast Asia's first underground facility for hydrocarbon storage.

The JRC will help to meet the burgeoning demand for storage capacity by the petrochemicals clusters on Jurong Island. Chemicals that will be stored in the JRC include liquid hydrocarbons such as crude oil, condensate, and naphtha. The use of subterranean space for low value-added functions such as storage will free up to 60 hectares of surface land (which could house up to six petrochemical plants) that can now be dedicated to higher value-added projects[89].

The creation of the JRC is quite the engineering undertaking. It is designed to be below the groundwater table at around 120m to 150m deep, which is unprecedented in Singapore. In contrast, most of Singapore's man-made subterranean structures are at most 50m underground. The caverns also use water pressure from the groundwater table to keep the stored oil inside the caverns. Digging at such depths presents significant challenges. One of the major challenges is the unpredictability of geological conditions while digging due to water inflow tendencies. Should water seep into the caverns, it will be pumped out and collected automatically to prevent water from accumulating in the caverns[90].

While the JRC is the first underground oil storage facility in South-East Asia, it is not Singapore's first attempt at a large-scale underground storage. The Underground Ammunition Facility was officially opened in 2008 by the Singapore Armed Forces to store the military's munitions and explosives, freeing up to about 400 football fields of space[91].

[89] Png, C. (2014). *Development of Jurong Rock Caverns.* Singapore: Jurong Town Corporation.
[90] Png, C. (2014). *Development of Jurong Rock Caverns.* Singapore: Jurong Town Corporation.
[91] "Five Things to Know about the Jurong Rock Caverns." The Straits Times. Singapore Press Holdings Ltd. Co., 2 Sept. 2014. Web.

TAKING STOCK OF ACCOMPLISHMENTS & PREPARING FOR FUTURE CHALLENGES

Jurong Island has come a long way from when it was first mooted in the 1991 Concept Plan. From nothing more than a figment of imagination, Jurong Island has become the centrepiece of Singapore's position on the global stage as an integrated chemicals hub. Jurong Island now plays host to many world-class chemical companies that have collectively poured in $47 billion in investments[92]. Considering that the oil refinery and petrochemical industries in Singapore were once considered a sunset industry, Jurong Island has truly beaten all odds[93].

Yet, all these accomplishments do not mean that Jurong Island can now rest on its laurels. As shown in the recent shutdown of the Teijin Polycarbonate[94][95] (started in 1999) due to factors such as soaring energy cost, dwindling customer demand, and low cost competitors in China, Jurong Island will see closures of plants. In the ever-changing and fiercely competitive global landscape that we live in today, Jurong Island will have to continue evolving to keep up with – or possibly get ahead of – its competitors. Notwithstanding external uncertainties such as global terrorism threats, oil prices and macroeconomic conditions, Jurong Island will also have to cope with challenges posed by domestic constraints, such as higher labour costs due to the tightened supply of foreign workers as well as ever-rising land costs due to land scarcity[96][97].

Another important issue to tackle is the growing concerns about the environmental impact of Jurong Island. The 2013 Parliamentary Budget debate saw S Iswaran, the Second Minister for Trade & Industry, reemphasise Singapore's commitment to meet its unconditional pledge of reducing greenhouse gas emissions 7% to 11% below current levels by 2020. As a booming petrochemical hub, Jurong Island is a major contributor of greenhouse gases in Singapore. Thus, any effort to reduce the carbon footprint of Jurong Island would make a significant contribution to the reduction of the national carbon footprint as well[98].

Nevertheless, if there is anything to learn from the Jurong Island case, it is perhaps that the Jurong Island team can never rest on their accomplishments. To maintain its legacy as a chemical hub, Jurong Island has to keep reinventing itself with new technologies to take advantage of new opportunities and overcome new challenges. With that in mind, the Jurong Island team is constantly exploring new ideas and options by going on study visits to modern high-tech petrochemical complexes in the region, such as in China and India, to stay abreast

---

[92] Jurong Town Corporation. (2 September, 2014). *Jurong Island.*
[93] Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.
[94] Chan, Yi Wen. "Chemicals Giant Teijin to Close Jurong Island Plant, Sell the Site." The Business Times. Singapore Press Holdings Ltd. Co., 16 June 2015. Web.
[95] Massive Industrial Site in Jurong Island Put up for Sale as Teijin Polycarbonate Exits." Singapore Business Review. Charlton Media Group, 15 June 2015. Web.
[96] Prime Minister's Office Singapore. (10 January, 2014). *TRANSCRIPT OF SPEECH BY PRIME MINISTER LEE HSIEN LOONG AT THE OPENING OF EXXONMOBIL'S CHEMICAL PLANT EXPANSION ON 8 JANUARY 2014, 11.30AM, AT JURONG ISLAND.*
[97] Martin, C., Gandhi, R., Ang, S., Tan, W., Soh, A., & Teh, S. (1 December, 2014). *The making of Jurong Island*.
[98] Lim, R. (21 March, 2013). Tender called for re-greening of Jurong Island: Consultant to study vegetation to sop up contaminants. *The Business Times*.

of current developments. Indeed, the only way to do justice to all the milestones of success in the past is to never stop striving for more success in the future[99].

[99] Ho, J. (2011). Moving Towards Jurong Island 2.0. In *Heart Work 2* (pp. 37-45). Singapore: Straits Times Press.

DISCUSSION QUESTIONS

The following questions are meant to be answered with information from both the case and your own knowledge. You are fully encouraged to share your own viewpoints and perspectives.

1. What were the inherent shortcomings that Singapore had in terms of being an oil refinery and petrochemical hub?
2. How did Singapore mitigate these shortcomings? What were Singapore's strengths?
3. What do you think was the greatest challenge to making Jurong Island a reality?
4. What were the roles of engineers in creating Jurong Island?
5. Do you think it was the right decision to have a dedicated island for the petrochemical industry? Why?
6. If you were a member of the senior management of a large petrochemical company, would you have chosen to invest in Jurong Island in view of cheaper alternatives in the region? Qualitatively explain how you arrived at your decision.
7. What are the challenges that Jurong Island will face in the future? Can you share some ideas from your own knowledge as to how Jurong Island may be able to overcome these challenges?

APPENDIX

EXHIBIT 1 [EXCERPT FROM [HEE 1999[100]]

IMPACT OF THE RECLAMATION ON THE ENVIRONMENT:

To assess the impact of the reclamation on the surrounding environment, numerical modelling was used. The results show that there was no significant impact on environment found[101].

CLOSURE OF SOUTHERN ENTRANCE OF SELAT PESEK:

During reclamation, the sea entrance to Selat Pesek would need to be closed. This would affect users of the berthing facilities along the channel. This closure presented major engineering issues which required careful analysis, study and planning in order to overcome these problems. In particular, the closure of the entrance would bring about concerns of navigational safety, berthing efficiency and berth utilisation[102].

The existing operators of the berthing facilities imposed that the closure of the southern entrance was only allowed if the sea current velocity at the northern entrance is reduced to 0.5 knots or 0.25m/s. Numerical analysis showed that these conditions imposed could indeed be met with the closure of the southern entrance. To further ascertain the exact timing of closure, a constant current monitoring was carried out at the northern entrance in order to supplement data from the numerical analysis[103].

IMPACT ON WATER INTAKE AND OUTFALL STRUCTURE:

Existing and potential plant operations would require the intake of cold seawater and discharge/outfall of hot wastewater. Existing outfall and intake structures located along the channels are expected to be affected when the channels are closed or reclaimed. Numerical simulations were carried out to study the suitable locations for both cold water intake and hot water discharge points. Using the results from the analysis, a cold and hot water zone was mapped out to guide future development. As development took place, there was also a need to build more water intake and outfall structures so as to ensure that operation efficiency of the existing and future intake structures would not be affected by the reclamation works[104].

EXISTING UTILITIES, INFRASTRUCTURE, AND SERVICES:

Existing companies on the islands consumed a large amount of water and electricity that were supplied from the mainland via undersea pipelines and cables. Many of the existing

[100] Hee, A. (1999). Jurong Island Experiences in Infrastructure Provision. *Dr Tan Swan Beng Memorial Symposium*. Singapore.
[101] Hee, A. (1999). Jurong Island Experiences in Infrastructure Provision. *Dr Tan Swan Beng Memorial Symposium*. Singapore.
[102] Hee, A. (1999). Jurong Island Experiences in Infrastructure Provision. *Dr Tan Swan Beng Memorial Symposium*. Singapore.
[103] Hee, A. (1999). Jurong Island Experiences in Infrastructure Provision. *Dr Tan Swan Beng Memorial Symposium*. Singapore.
[104] Hee, A. (1999). Jurong Island Experiences in Infrastructure Provision. *Dr Tan Swan Beng Memorial Symposium*. Singapore.

companies, by nature of their operations, were also interconnected with many pipelines and utilities, while some of them had their own marine facilities such as ramps and jetties. Since these existing infrastructures were crucial to daily operations and extremely expensive to divert or replace, extra attention was paid to these installations. The following options were considered on a case-by-case basis when it comes to handling these existing installations[105]:

- Replacement of facility – when the existing infrastructure did not fit into the proposed Jurong Island master plan.
- Protection of facility – when the cost of replacement of the existing infrastructure was extremely high and the infrastructure did not fit into the master plan.
- Avoidance of facility – when cost of replacement was extremely high or impractical due to severe disruption to daily operations.
- Strengthen the structure – Helps to shore up the strength of support structures when reclamation is carried out in the vicinity of support structures for the infrastructure.

SEDIMENTATION AROUND JURONG ISLAND

Due to the reduction in current velocity of the Jurong Fairway, excessive sedimentation due to lower current flow in the Jurong Fairway was a concern. Numerical analysis revealed that the sedimentation rate during stage 1 reclamation (phase 1 – 3A) was only about 5 cm/yr and was acceptable. The study also showed that when stage 2 (phase 3B) is completed; the siltation over a large area at the west entrance however is around 10 cm/yr. While this was a rather high rate of sedimentation for navigational safety through the channels, it may not be undesirable in the long term as the area could be a potential site for reclamation[106].

[105] Hee, A. (1999). Jurong Island Experiences in Infrastructure Provision. *Dr Tan Swan Beng Memorial Symposium*. Singapore.
[106] Hee, A. (1999). Jurong Island Experiences in Infrastructure Provision. *Dr Tan Swan Beng Memorial Symposium*. Singapore.

EXHIBIT 2 [EXCERPT FROM [PANG AND SEOW 1999[107]]

DETAILS ON PRELIMINARY STUDIES FOR THE BUILDING OF THE JURONG ISLAND CAUSEWAY

The hydrodynamic studies showed that the currents in the Selat Jurong would be decreased significantly due to the causeway while flow conditions in the surrounding areas were not very affected. The initial mathematical model showed that the stream velocities through the opening of 30m were deemed to be too high. To achieve a lower flow velocity that would be acceptable for safe navigation through the opening, the opening size was decided to be 60m instead of the 30m[108].

Sedimentation caused by the causeway in Selat Jurong was not deemed to be a problem with an estimated 2-10 cm/year over most areas. While navigation and berthing of vessels in the area would be affected during the construction of the causeway, the calmer waters after completion of the causeway would actually benefit navigational and berthing activities. Water quality studies also indicate that the water would be affected by the shifting of intake and outfall points due to the reclamation works[109].

As for risk assessment, a quantitative study revealed that the fatality risk to an average road user of the causeway is 4.1×10^{-6} per year, while societal risk (measures danger to general public) is $10^{-6} – 10^{-8}$ per year, which were both very low and acceptable[110].

---

[107] Pang, P., & Seow, K. (1999). The Design of Jurong Island Causeway. Dr Tan Swan Beng Memorial Symposium. Singapore.
[108] Pang, P., & Seow, K. (1999). The Design of Jurong Island Causeway. *Dr Tan Swan Beng Memorial Symposium*. Singapore.
[109] Pang, P., & Seow, K. (1999). The Design of Jurong Island Causeway. *Dr Tan Swan Beng Memorial Symposium*. Singapore.
[110] Pang, P., & Seow, K. (1999). The Design of Jurong Island Causeway. *Dr Tan Swan Beng Memorial Symposium*. Singapore.

EXHIBIT 3 [EXCERPT FROM PANG AND SEOW 1999]

CAUSEWAY DESIGN

In coming up with the design for the causeway, a number of alternatives were considered[111]:

1. Dual 4-lane with opening bridge
2. Dual 4-lane , 35 m high viaduct
3. Dual 4-lane underwater tunnel
4. Dual 4-lane causeway with an "opening"

Alternative 1 and 2 were considered inappropriate because studies showed that a bridge would restrict and endanger navigation as it would create a strong current pattern in the vicinity. Additionally, Alternative 2 would also require a huge land intake at the shores for the ramps, which was very costly. Alternative 3 was deemed to have the least impact on the environment. However, it was also the most economically costly option. Furthermore, there would be significant safety concerns regarding the transportation of potentially hazardous chemicals in the tunnel. Lastly, Alternative 4 was thought to be the cheapest option. However, such a proposed system has never been done before in the world and required significant creativity and engineering nous to work. Despite the lack of precedents, JTC decided to go with Alternative 4 and sought to come up with an innovative solution for the problem[112].

In the construction of the causeway, many constraints had to be taken into account, such as the limited sea space, the limited land space for connection to the AYE, the need for continued operation of industries in the vicinity and the demand for navigational sea space in the busy Selat Jurong channel. The construction also had to work around existing facilities like the Jurong Police Coast Guard Base, Jurong Pier Jetty and Jurong Power Station[113].

Due to these constraints, construction methodology used played a very important role in the design of the causeway. Several types of causeway were considered. The rock-filled causeway was the most economical option but presented many construction difficulties on the site. Eventually, pre-cast concrete caissons were chosen to form the sides of the causeway as it would minimise the sea space occupied and enable construction activities to be carried out off-site. Sand was then used as filling for the space in between the caissons to form the structure of the causeway[114].

RECOMMENDED WEB LINKS FOR MORE INFORMATION

For more information on history and timeline of EDB:

http://www.edb.gov.sg/content/edb/en/about-edb/company-information/our-history.html.

[111] Pang, P., & Seow, K. (1999). The Design of Jurong Island Causeway. *Dr Tan Swan Beng Memorial Symposium*. Singapore.
[112] Pang, P., & Seow, K. (1999). The Design of Jurong Island Causeway. *Dr Tan Swan Beng Memorial Symposium*. Singapore.
[113] Pang, P., & Seow, K. (1999). The Design of Jurong Island Causeway. *Dr Tan Swan Beng Memorial Symposium*. Singapore.
[114] Pang, P., & Seow, K. (1999). The Design of Jurong Island Causeway. *Dr Tan Swan Beng Memorial Symposium*. Singapore.

http://eresources.nlb.gov.sg/history/events/509d1656-8fc5-405f-8eec-ad058d8a540c.

For more information on history and timeline of JTC:

http://eresources.nlb.gov.sg/history/events/9206cd21-7c6f-44fa-bd8d-c46e15cbbee3.

http://www.jtc.gov.sg/about-jtc/pages/our-history.aspx.

BIBLIOGRAPHY

A*STAR. (2014). *About Us*. Retrieved 4 December, 2014, from https://www.ices.a-star.edu.sg/corporate-profile/about-us.aspx

Carpenter, K., & Ng, W. (2013). Singapore's Chemicals Industry: Engineering an Island. *Chemical Engineering Progress, 109*(April), 56-60.

Channel News Asia. (30 June, 2011). *SLA Moving Story - Episode 4, part 1 of 2*. Retrieved 27 November , 2014, from https://www.youtube.com/watch?v=9Ffwq0fMlsI

Chia, Y. (24 December, 2014). *The engineer who became ExxonMobil S'pore chairman*. Retrieved 26 December, 2014, from http://business.asiaone.com/news/the-engineer-who-became-exxonmobil-spore-chairman

Goh, W., & Tan, S. (2002). Vison and Guts: The Story of Jurong Island. In *Heart Work.* Singapore.

Hee, A. (1999). Jurong Island Experiences in Infrastructure Provision. *Dr Tan Swan Beng Memorial Symposium.* Singapore.

Ho, J. (2011). Moving Towards Jurong Island 2.0. In *Heart Work 2* (pp. 37-45). Singapore: Straits Times Press.

Jurong Town Corporation. (2000). *The making of Jurong Island: The right chemistry.* Singapore: Jurong Town Corporation.

Jurong Town Corporation. (5 September, 2011). *Jurong Island History*. Retrieved 20 November, 2014, from http://www.jtc.gov.sg/Industries/Chemicals/Pages/Jurong-Island-History.aspx

Jurong Town Corporation. (2013). *Jurong Island: HOME TO LEADING GLOBAL CHEMICAL COMPANIES.* Retrieved 30 November, 2014, from http://www.multinine.com.sg/CCDS%20Editorial%202013_JTC%20Corporation.pdf

Jurong Town Corporation. (2 September, 2014). *Jurong Island* . Retrieved November 27, 2014, from http://www.jtc.gov.sg/RealEstateSolutions/Jurong-Island/Pages/default.aspx

Lim, J. (13 April, 2010). *My islands in the sun*. Retrieved 4 Decemeber, 2014, from https://thelongnwindingroad.wordpress.com/2010/04/13/my-islands-in-the-sun/

Lim, R. (21 March, 2012). *All projects studied under Jurong Island 2.0 initiative completed*. Retrieved 30 November, 2014, from http://wildsingaporenews.blogspot.sg/2012/03/all-projects-studied-under-jurong.html#.VHvlePmUc0O

Lim, R. (21 March, 2013). Tender called for re-greening of Jurong Island: Consultant to study vegetation to sop up contaminants. *The Business Times*.

Martin, C., Gandhi, R., Ang, S., Tan, W., Soh, A., & Teh, S. (1 December, 2014). *The making of Jurong Island*. Retrieved 1 Decmeber, 2014, from http://www.businesstimes.com.sg/in-depth/special-feature-jurong-island#/pre-1960

National Security Coordination Council. (2004). *The Fight Against Terror: SINGAPORE'S NATIONAL SECURITY STRATEGY.* Singapore: National Security Coordination Centre.

National Security Coordination Secretariat. (2006). *1826 days: A Diary of Resolve.* Singapore: SNP International.

Ng, S. (April, 2007). *Introduction to Jurong Island*. Retrieved 20 November, 2014, from http://chemistryofjurongisland.blogspot.sg/

Pang, P., & Seow, K. (1999). The Design of Jurong Island Causeway. *Dr Tan Swan Beng Memorial Symposium.* Singapore.

Png, C. (2014). *Development of Jurong Rock Caverns.* Singapore: Jurong Town Corporation.

Porter, B. (18 November, 1999). *Oil sector's self-sufficient home rises from sea, as Barry Porter reports*. Retrieved 2014 December, 22, from http://www.scmp.com/article/299969/oil-sectors-self-sufficient-home-rises-sea-barry-porter-reports

Prime Minister's Office Singapore. (10 January, 2014). *TRANSCRIPT OF SPEECH BY PRIME MINISTER LEE HSIEN LOONG AT THE OPENING OF EXXONMOBIL'S CHEMICAL PLANT EXPANSION ON 8 JANUARY 2014, 11.30AM, AT JURONG ISLAND*. Retrieved 30 November, 2014, from http://www.pmo.gov.sg/content/pmosite/mediacentre/speechesninterviews/primeminister/2014/January/transcript-of-speech-by-prime-minister-lee-hsien-loong-at-the-op0.html#.VHwlWMnslws

Reutens, L. (2000). *Building a Nation: The Story of Engineering in Singapore.* Singpaore: The Institute of Engineers, Singapore.

Singapore Economic Development Board. (2012). *Driving energy efficiency: Mckinsey establishes Singapore's first green campus*. Retrieved 24 April 2015 from https://www.edb.gov.sg/content/edb/en/news-and-events/news/news-archives/2012/driving-energy-efficiency-mckinsey-establishes-singapores-first-green-campus.html

Singapore's "Mid-life Crisis" (2014).

Soh, A. (24 November, 2014). New plan, rethink for Jurong Island. *The Business Times, Singapore*.

State of Green (n.d.). *Waste-To-Energy Plant in Jurong Island, Singapore*. Retrieved 23 July 2015 from https://stateofgreen.com/en/profiles/babcock-and-wilcox-voelund/solutions/waste-to-energy-plant-in-jurong-island-singapore

The Jakarta Post. (11 January, 2011). *Indonesia begins natural gas exports to Singapore from West Natuna*. Retrieved 23 July 2015 from http://www.thejakartapost.com/news/2001/01/11/indonesia-begins-natural-gas-exports-singapore-west-natuna.html

The Oil & Gas Year. (n.d.) *The Oil & Gas Week: The Island*. Retrieved 24 April 2015 from http://www.theoilandgasweek.com/191212/article.html

Tng, S., & Tan, S. (n.d.). *Designing our City: Planning for a sustainable Singapore.* Singapore: URA.

Yeo, P. (2002). Passion Drives. In *Heart Work.* Singapore.