ENERGISING SINGAPORE: BALANCING LIVEABILITY AND GROWTH

Lacking any indigenous energy resources, the Singapore government has had to grapple with the challenges of managing the trade-offs of the energy trilemma—balancing the need for economic competitiveness, environmental sustainability and energy security. From making electricity accessible, to providing a reliable and high-quality power supply to citizens and industry, and enhancing energy efficiency and tackling climate change, the energy landscape has changed significantly with Singapore's evolving priorities and challenges.

Drawing on archival research and interviews with pioneer practitioners and policymakers, *Energising Singapore: Balancing Liveability and Growth* offers an overview of Singapore's energy sector development over the past 50 years. This Urban Systems Study discusses major policy considerations and strategies, and the links between energy, planning and the built environment. It also explains how Singapore's approach in integrated planning and sound governance has contributed to a secure, competitive and sustainable energy supply for its people and businesses, and ultimately, the liveability of the city-state.

"Energy forms the backbone of a robust and vibrant economy that creates wealth for our society and good jobs for our people. Ensuring affordable, diverse, reliable and resilient energy supply is thus important."

Deputy Prime Minister Teo Chee Hean at the Singapore International Energy Week 2017

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URBAN SYSTEMS STUDIES

ENERGISING SINGAPORE: BALANCING LIVEABILITY AND GROWTH

CENTRE for LiveableCities SINGAPORE

First Edition, Singapore, 2018

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Set up in 2008 by the Ministry of National Development and the 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". The CLC's work spans four main areas—Research, Capability Development, Knowledge Platforms, and Advisory. Through these activities, the 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.

Research Advisors for the CLC's Urban Systems Studies are experts who have generously provided their guidance and advice. However, they are not responsible for any remaining errors or omissions, which remain the responsibility of the author(s) and the CLC.

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Cover photo: Aerial view of Singapore River, Civic District and Marina Bay.
Image courtesy of iStock.com/Stephane_Jaquemet.

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FOREWORD

Singapore is a sustainable and liveable city-state with a vibrant and growing economy today. Despite our lack of indigenous fossil fuels and limited renewable energy potential, we have secured stable and reliable energy supplies for our use.

This journey has not been easy. Working with industry, public stakeholders and citizens, the government had to make difficult decisions over the long term to achieve this outcome.

Energy policy requires the management of trade-offs, to balance the important goals of economic competiveness, environmental sustainability and energy security. In the 1960s, with extremely limited resources, we prioritised the provision of electricity to industries and public housing estates, to support economic development and lift the living standards of our people. As households' expectations rose, and more sophisticated industries required more stable and higher quality electricity supplies, we had to balance the need to upgrade and enhance our power generation, transmission and distribution systems, while keeping the cost of electricity as competitive as possible.

For a small nation like Singapore, it is imperative that we take a long-term view of integrated planning for our energy needs. Energy infrastructure can take many years to plan, commission and build, and has a long lifespan. The decisions we make on systems and technologies today will affect us for decades to come. To support a growing population and constant economic restructuring since the 1980s, our planners, economic development agencies and utility providers had to plan for Singapore's energy needs over a 10- to 20-year horizon, and coordinated the roll-out of new energy infrastructure with other developments to meet future demand. The construction of Singapore's Liquefied Natural Gas Terminal demonstrated the importance of long-term planning. It has strengthened our energy security by diversifying our sources of fuel, and supported the growth of our natural gas trading sector.

Critical national sectors such as energy have to be supported by sound governance and policies. Our decision not to introduce broad-based subsidies for energy consumption has facilitated energy conservation efforts, enabled sustainable financing of our energy infrastructure, and developed a competitive energy market. To improve efficiency and competition from the 1990s, we systematically liberalised the electricity sector, and provided regulatory certainty to generation companies and investors.

Climate change and technological advances have brought new challenges and opportunities to the energy landscape. Reductions in energy consumption and carbon emissions are needed to minimise the impact of climate change. Such reductions can be economically beneficial as electricity generated from renewables is increasingly more competitive compared to fossil fuel. To incorporate renewables such as solar into our electricity grid, we need to develop innovative solutions to manage fluctuations in solar power and maintain grid stability. We must be prepared to adapt to the changing context, encourage experimentation and innovation. We will need to foster closer collaboration between knowledge centres, industry and government, continue to upskill and develop our workforce, and engage our citizens to find sound and sustainable solutions for our future energy challenges.

Energising Singapore: Balancing Liveability and Growth gives an overview of Singapore's energy sector development over the past 50 years, the major policy decisions and strategies, and the links between energy, planning and the built environment. It explains how the provision of sustainable, secure and competitive energy services has enhanced Singapore's liveability for our people, businesses and investors. I hope that readers will find this publication useful.

Peter Ong
Former Head of Civil Service
Chairman of Enterprise Singapore

PREFACE

The Centre for Liveable Cities' (CLC) research in urban systems unpacks the systematic 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 within the last four to 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. *Energising Singapore: Balancing Liveability and Growth* is the latest publication from the Urban System Studies (USS) series.

The research process involves close and rigorous engagement of CLC researchers with our stakeholder agencies, and oral history interviews with Singapore's urban pioneers and leaders to gain insights into development processes and distil tacit knowledge that has been gleaned from planning and implementation, as well as the governance of Singapore. 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 of our urban achievements.

The CLC would like to thank all those who have contributed their knowledge, expertise and time to make this publication possible. I wish you an enjoyable read.

Khoo Teng Chye
Executive Director
Centre for Liveable Cities

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The Centre for Liveable Cities (CLC) gratefully acknowledges (in alphabetical order) Ananda Ram Bhaskar, Khoo Chin Hean, Ler Seng Ann, Puah Kok Keong, Soh Siew Cheong and Yeo Yek Seng for taking the time off to share their valuable insights and experiences through the interviews conducted as part of the research process.

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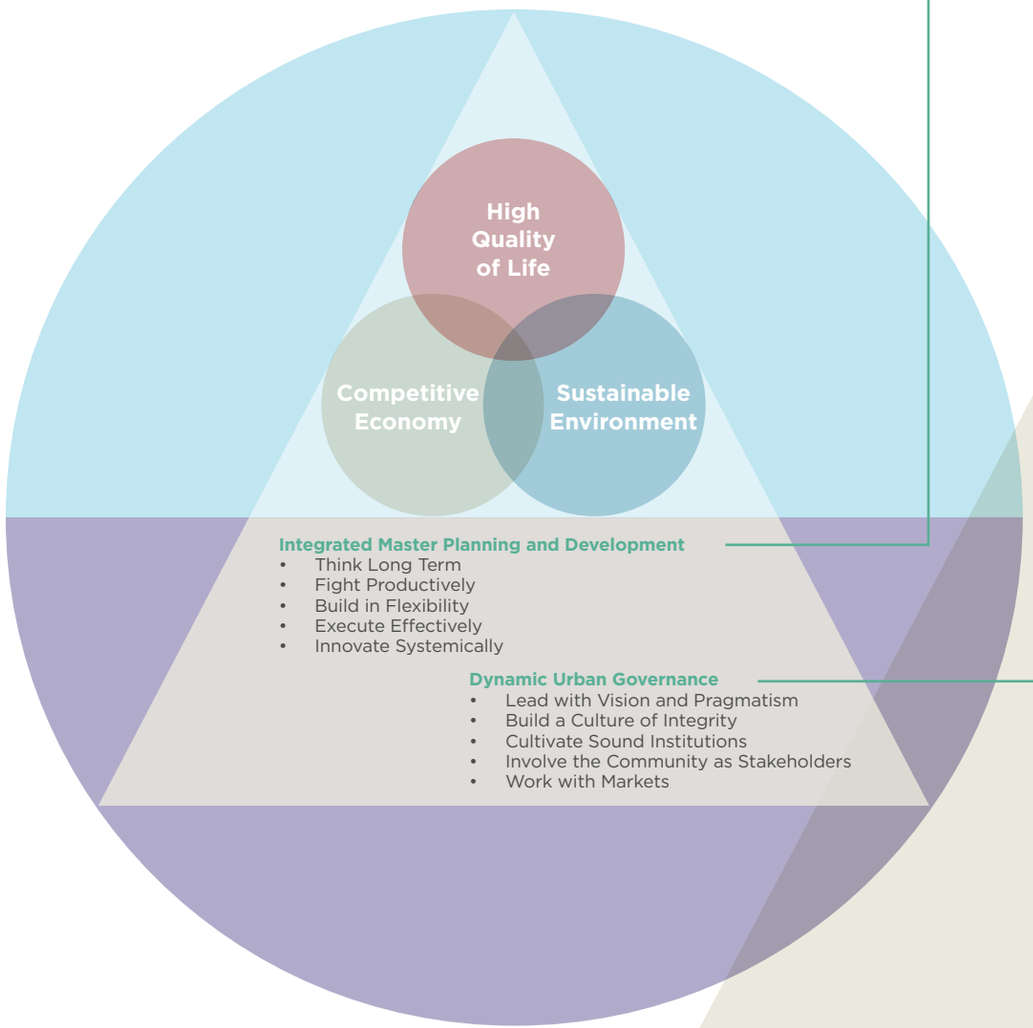
THE SINGAPORE LIVEABILITY FRAMEWORK

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 *Energising Singapore: Balancing Liveability and Growth.*



Integrated Master Planning and Development

Think Long Term

Over the past 50 years, Singapore was able to sustain continuous economic growth and development. This would not have been possible if planners had not undertaken careful long-term planning and forecasting, to ensure that Singapore's power capacity always kept up with development needs. It was important to think ahead, since it took five to 10 years to plan and build a power station. For example, planning for Tuas Power Station had already begun in the late 1980s, even though reclamation of the proposed site was only completed in 1991. Tuas Power Station became fully operational in 1999.

(See Staying Ahead of the Curve, page 20)

Innovate Systemically

As part of the vision to develop Marina Bay into a world-class business, financial and entertainment hub, state-of-the-art underground Common Services Tunnels (CST) were built. The CSTs house utility service lines such as power cables, water pipes, telecommunication cables and chilled water pipes for district cooling. By combining important service lines in a common tunnel, land use is reduced, utility supplies are more reliable and easily maintained, and road excavation works are minimised, which reduces traffic disruptions. This large-scale, system-level innovation has greatly benefited the development of Singapore's Central Business District.

(See Box Story: Creating a World-Class Utilities Network through Underground Tunnels, page 36)

Dynamic Urban Governance

Lead with Vision and Pragmatism

The government has always strictly avoided broad-based energy subsidies. Instead, energy is priced to reflect its true cost. Pricing energy right deters overconsumption and promotes efficiency. At the same time, it ensures that utility providers are able to generate sufficient revenues to cover operating and system costs, and ensures system reliability in the long run. While this pragmatic approach could be politically unpopular, it is important for the long-term sustainability of Singapore's energy supply.

(See Ensuring Financial Sustainability, page 17 and Pricing Energy Right, page 50)

Work with Markets

By privatising and liberalising the power generation sector, the government harnessed market forces to improve the efficiency and reliability of electricity supply. It created the right market mechanisms and regulatory framework to incentivise power generation companies (Gencos) to invest in more efficient natural gas-powered plants. In doing so, the Gencos stayed competitive without the need for public subsidies. These contractual mechanisms also encouraged Gencos to be reliable. For instance, in the event of a plant failure, a Genco had to buy more expensive electricity from other sources to fulfil its own power supply obligations.

(See Market Forces Ensuring Reliable Supply, page 51; Market Competition and The Switch to Natural Gas, page 52)

OVERVIEW

INTRODUCTION

"Energy forms the backbone of a robust and vibrant economy that creates wealth for our society and good jobs for our people. Ensuring affordable, diverse, reliable, and resilient energy supply is thus important."

Deputy Prime Minister Teo Chee Hean, Singapore International Energy Week 2017

Energy—whether in the form of primary energy sources such as oil, gas and solar, or secondary energy sources like electricity—is a vital resource that plays an indispensable role in Singapore's economy. As the foundation for every modern metropolis, energy makes possible the way people live, work, play and travel. It powers almost everything, from simple lighting, household appliances, mobile phones, computers and cars, to complex and large-scale railway systems, data centres, water processing plants, heavy machinery and so on. Modern life would come to a standstill without energy.

Singapore does not have any significant indigenous energy resources, and depends heavily on imported fuel to meet its energy needs. Despite this, it has grown and developed into an economically vibrant and highly liveable city-state. This would not have been possible without an affordable, reliable, and clean energy sector, and a modern and efficient energy infrastructure. To achieve these, the government carefully balanced the "energy trilemma": the three key goals of energy security, economic competitiveness and environmental sustainability.

THE ENERGY TRILEMMA: CHALLENGES AND TRADE-OFFS

The energy trilemma presents three important dimensions, which are often trade-offs that energy policymakers and planners have to grapple with, to achieve an outcome that meets the evolving needs and priorities of Singapore in different phases of its development.

The first dimension is that of economic competitiveness and competitive energy pricing. It focuses on the cost of energy, and its impact on both the cost of living and the competitiveness of Singapore's businesses and industries. For example, Singapore has one of the world's most reliable power grids. One challenge was how to liberalise and privatise the electricity sector, while ensuring that profit-making private operators would take all available steps to keep electricity competitive for users.

The second dimension is that of energy security and reliability. To achieve this goal, countries require secure and reliable supplies of energy that meet their power needs. For example, they can improve their energy security by having diversified sources of fuel and the means to maintain a stockpile for emergencies. Different sources of fuel can also come from having an energy mix such as coal, gas, oil and nuclear to create options for security, and this has to be guided by proper cost-benefit studies of the different options for security available to Singapore.

The third dimension concerns environmental sustainability. It is about reducing the environmental impacts of energy usage. For example, the government had to make a difficult decision on whether to and how to price carbon. This is a politically challenging decision that affects electricity pricing.

In addition to the lens of energy trilemma, there were also other pertinent national challenges that the government considered when making decisions on energy.

Singapore has neither a natural hinterland, nor sufficient vital resources such as water. It is a small island with a limited land area. Just 581 km^2 in 1965, the country had grown to 720 km^2 in 2017 through land reclamation. Meanwhile, its population has grown from 1.89 million in 1965 to 5.61 million in 2017. Being small with limited resources, Singapore undertakes integrated and long-term planning to balance competing land use needs. Planning for energy infrastructure such as power stations, the transmission and distribution (T&D) network and the siting of Singapore's energy industry had to be well-coordinated with other infrastructure critical for survival.

OVERVIEW OF SINGAPORE'S ENERGY SECTOR DEVELOPMENT

Singapore's energy landscape has evolved significantly over the decades, transitioning from the use of traditional wood biomass in the pre-colonial era to the country's first coal-fired power station in 1906, to today's highly efficient and clean combined-cycle gas turbine plants (CCGTs), solar photovoltaics and high-quality road transport fuels. It will continue to change according to the nation's needs and challenges.

This Urban Systems Study seeks to provide an overview of Singapore's energy sector development in the past 50 years—and how a reliable, affordable and clean energy sector, supported by a long-term and integrated approach in planning, contributes to making Singapore a more liveable and sustainable city.

It covers the following themes chronologically:

Chapter 1: Building the Foundation to Power the Nation: From Accessibility to Adequacy of Supply (1960s—1980s): captures Singapore's early efforts to achieve accessibility and adequacy of electricity supplies, and meet the rising needs of households and industries.

Chapter 2: Integrated and Long-term Planning for Singapore's Power Needs: focuses on the long-term and integrated approach of Singapore government in planning for the nation's power supply in tandem with urban development. Land resources were allocated strategically to minimise environmental pollution and to improve liveability.

Chapter 3: Enhancing Reliability and Quality (1970s—1980s): illustrates the shift in focus to reliable and good quality electricity supply to serve the changing needs of the people and industry.

Chapter 4: Harnessing the Energy Industry for Growth: From the First Refinery to an Energy Economy: highlights Singapore's historical involvement in and the significance of the oil industry, such as how Jurong Island developed into an integrated refinery and petrochemical hub during the 1990s—2000s.

Chapter 5: Growing Concerns for Rising Oil Prices and Climate Change: Quest for Efficiency (1990s—present): uncovers efforts in reforming the electricity sector and consolidating energy policies in an era of increasing uncertainty due to rising oil prices and climate change. Issues of sustainability, energy security and energy efficiency took centre stage.

Chapter 6: Navigating Change: Towards A Smart, Sustainable and System-Level Approach (2010s—present): highlights the measures Singapore took to be more innovative, resilient and sustainable as it joined global efforts to fight climate change.

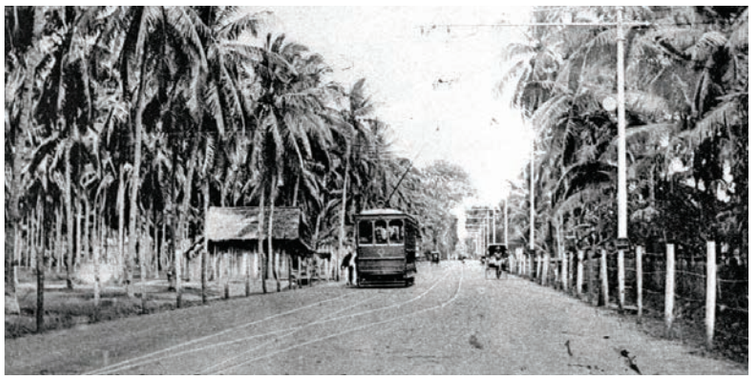
CHAPTER 1

BUILDING THE FOUNDATION TO POWER THE NATION: FROM ACCESSIBILITY TO ADEQUACY OF SUPPLY (1960s—1980s)

THE FIRST SPARKS OF ELECTRICITY: THE COLONIAL TIMES

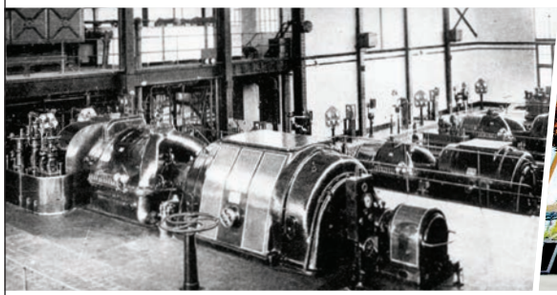
During its early decades as a British colony, Singapore relied on oil lamps, candles and gas for lighting and wood for cooking.[1] In 1878, electricity was first generated by the privately owned Tanjong Pagar Dock Company. This powered brighter lighting for the wharves, roadways and docks, prolonging operational hours after sunset.

Eventually, the demand for electricity in Singapore grew sufficiently to warrant the establishment of the country's first coal-fired power plant. This was built at Mackenzie Road and started operating in 1906. In the same year, the Singapore Tramway Company (later renamed Singapore Traction Company) installed a generator to run its trams. At this time, the Municipality purchased electricity in bulk from the Company, and laid down a distribution system in central areas. With its first public electricity supply, areas such as Raffles Place, North Bridge Road and Boat Quay were lit for the first time with electric lamps.



Road near the electric tramway terminus at Gayland (Geylang) in 1907.
Courtesy of National Archives of Singapore.

Demand for electricity skyrocketed when Singapore's entrepot economy took off in the 1920s. Large, newly established businesses required power, while street lighting was very much desired for its positive impact on public safety. To meet this demand, the Municipality took on the task of electricity generation, and started building St James Power Station in 1924 at Cape St James. This coal-fired plant commenced operation in 1926 with a capacity of two megawatts (MW).[2] Its proximity to the wharves meant that coal could be easily transported and unloaded by ships, and seawater



St James Power Station Turbine Room in 1930s (left) and the exterior of the power station (right).
Lee Kip Lin Collection, courtesy of National Archives of Singapore (left) and
The Little Red Dot Collection, courtesy of the National Library Board, Singapore (right).

could be used to cool its turbines. The St James Power Station was gazetted as a national monument in 2009, and converted into a buzzing nightlife hub frequented by partygoers.

With the end of the Japanese Occupation in 1945, Singapore found itself liberated, yet plagued by acute shortages of skilled electrical workers. Many British electricians and engineers had left during the war, electricity was only available near the city centre, and supplies were sporadic. As before the war, most people relied on kerosene lamps for light, and charcoal and wood for fire.

Despite limited resources, local electricians undertook the arduous task of working within their means to provide more power. The Pasir Panjang Power Station was commissioned with a capacity of 150 MW in 1952 to meet post-war electricity demand. Despite this effort, electricity supply disruptions were common in those days. There were 142 hours of power outages in 1950, with an average of 2.44 hours per outage.[3]

Michael Khor, Former Chief Engineer of the Electricity Department, recounted his childhood life with limited electricity supply:

> *I remember well in 1952 when I was in the School Certificate class (now Secondary 4): I wrote to the Chief Electrical Engineer, appealing to him to leave the street lamp outside my house in East Coast Road next to Marshall Road out from the blackout. Surprisingly, he replied and left that street lamp out from the blackout list so that I could study and prepare for the exam. Otherwise, I would have had to depend on light from the kerosene lamp.*[4]

AFTER INDEPENDENCE: GETTING ACCESS TO ELECTRICITY

Following the Second World War, Singapore experienced a period of political and social unrest. It achieved self-government in 1959 amidst a tide of nationalism, anti-colonialism and political consciousness. Unemployment rose above 10% during this time, and Singapore's entrepot trade was insufficient to provide jobs for a burgeoning population. Housing was another issue: more than two-thirds of the population was living in overcrowded conditions, in slums and squatter settlements.[5]

The newly elected government sought to create more jobs, and to improve the quality of life of the people through home ownership, education and a better living environment. Under the leadership of Lee Kuan Yew, Singapore's first Prime Minister, the vision was to give Singapore's largely immigrant population a stake in their nation's future.

At the government's request, an industrial survey team, led by Dutch economist Albert Winsemius, visited Singapore in 1961. It formulated a 10-year development blueprint, recommending export-oriented industrialisation with a focus on labour-intensive manufacturing.[6] This blueprint also led to the establishment of the Economic Development Board (EDB) to spearhead job creation, investment and growth. At the same time, the Housing and Development Board (HDB) was set up to replace the Singapore Improvement Trust (SIT), and its task was to resolve the acute housing shortage by building affordable public housing more effectively and efficiently.

These major policies and programmes were instrumental to the success of bringing electricity to both people and industries.

Formation of the Public Utilities Board (PUB)

In May 1963, the Public Utilities Board (PUB) was established as a Statutory Board to take charge of supplying water, gas and electricity for Singapore. PUB was given the power and flexibility to operate its utilities, manage its finances and manpower, and drive infrastructure development. In 1995, PUB was corporatised whereby the gas and electricity undertakings were transferred to Singapore Power (currently known as SP Group), and PUB has now become the Singapore's National Water Agency. All mentions of PUB in this book refer to the organisation before corporatisation in 1995.

Singapore's Industrialisation Programme

The 1960s and 1970s were periods of rapid urbanisation and infrastructure construction. With demand for electricity rising at an unprecedented pace, there had to be accessible, efficient and reliable electricity supply in order for EDB's Industrialisation Programme to succeed and boost economic growth.

For example, electricity was needed for the Jurong Industrial Estate (JIE), Singapore's first industrial estate, which was established in 1961 to attract foreign investment and create jobs. In 1962, development began on the National Iron and Steel Mills, which required a substantially high power supply. Electricity was also crucial for other early industries such as timber, sawmilling, oil-rig fabrication, and shipbuilding and repair.

The Electricity Department of PUB soon had to expand their power capacity by building Pasir Panjang Power Station B next to Pasir Panjang Power Station A in 1962. Co-locating the power station with the existing one sped up the construction process and allowed sharing of common facilities like storage and bunkering.[7] Besides building power stations, engineers also worked hard to install and extend the transmission and distribution (T&D) network to areas designated for development.

Prioritising Power Supply with Limited Resources

With PUB's limited funding and resources at the time, it made the pragmatic decision to prioritise the supply of electricity to industries instead of households.

Their reasoning was simple: without electricity, there would be no investment, production or jobs. All of these were critical to Singapore's newly independent economy. On the other hand, households had other means of lighting and heating such as gas, charcoal and kerosene. Bringing electricity to households would improve their comfort, but was not essential in the short term. Focusing on growing the economy would improve jobs and wages, lifting the overall quality of life of Singaporeans.

After meeting industrial needs, the next most urgent priority was the supply of electricity to HDB public housing developments. The government was determined to resolve housing shortages and resettle slum dwellers and squatters, and drove this strategic programme with strong political will. HDB estates were high-density housing areas compared to rural villages, and supplying electricity to these estates would benefit more households more quickly. Early HDB housing estates such as Queenstown and Toa Payoh were completed, and the public housing programme grew.

Minister for Law and National Development E.W. Barker attends switching-on ceremony of newly installed street lighting in Macpherson Estate in 1966.
Ministry of Information and the Arts Collection, courtesy of National Archives of Singapore.

In order to meet demand in these priority areas, the electricity power system, particularly the T&D network, was expanded at least cost with reasonable reliability. For example, PUB made the decision to enable only the transmission networks of 22 kV and 66 kV to be centrally controlled from the System Control Centre housed in Pasir Panjang Power Station "A". The distribution networks of 6.6kV and low voltage were not centrally controlled.

Rural Electrification Programme

While HDB flats had an electricity supply, many people still lived in outlying, remote villages such as Bah Soon Pah village in Nee Soon and Jalan Tiga Ratus in Changi-10-Mile. Private operators ran diesel generators and sold electricity to households in the villages, but power capacity was very limited. Residents mostly used electricity at night for lighting.

Recognising the need to improve the living condition of these villagers, the government initiated the 10-year Rural Electrification Programme in 1963, which aimed to connect every "kampong" or village area to the electricity grid. Soh Siew Cheong, former Managing Director of PowerGrid and former Chief Transmission and Distribution Engineer in PUB's Electricity Department, recounted his days undertaking this project: "At that time people were at first suspicious, then later on they realised that it was for their own good that we were bringing in the supply."[8]

Under the Rural Electrification Programme, the Urban and Rural Services Committee (URSC) would identify and inform PUB of villages that were suitable for electrification.[9] To ensure financial sustainability of the programme, the revenue earned from each village resulting from the sale of electricity had to exceed or be equal to the capital investment in the project, over a seven-year period.[10] Priority was given to projects that yielded the greatest benefits at the lowest investment cost.

To keep costs manageable, less expensive power lines made up of bare copper conductors supported on overhead wooden poles were used to deliver electricity to rural households. However, there were occasional thefts of electricity and supply failures arising from short-circuits of the overhead conductors caused by tree branches and creepers. The government eventually had to replace the bare copper conductors with insulated aluminum wires to reduce theft and supply failures.

Public Utilities Board members visiting Kampong to check works carried out under the Rural Electrification Scheme in 1963.
Ministry of Information and the Arts Collection, courtesy of National Archives of Singapore.

By 1969, almost all the viable rural electrification projects were completed. The URSC then allocated about a million dollars each year to fund the remaining non-viable projects in sparsely populated areas so as to complete the Rural Electrification Programme.[11] The Programme lasted for 10 years until 1973, benefitting more than 200,000 people, at a cost of nearly $20 million.

NEXT CHALLENGE: FROM INACCESSIBILITY TO INADEQUACY OF POWER SUPPLY

The introduction of electricity to the rural areas brought many benefits to the villagers. Not only could kids study at night using electric lamps, home-grown businesses and small industries also had more options. Farmers began to mechanise their operations with water pumps; mechanics bought welding machines to repair bicycles; electric irons replaced charcoal irons; and cottage industries supporting garment and electronics factories were created. Housewives also had the opportunity to earn extra income by producing sub-assemblies for these factories.

Second Deputy Prime Minister and National Trades Union Congress Secretary-General Ong Teng Cheong (left) visiting a textile manufacturing factory.
Ministry of Information and the Arts Collection, courtesy of National Archives of Singapore.

But success brought further challenges. As people realised the benefits of electricity, demand soared, overloading the grid and causing low voltage supply.

> *They were happy for a while, until they found their voltage starting to dip. At night, the villagers had to compete to turn on their florescent lamps earlier while the load on the network was low and the voltage supply was normal. Their florescent lamps would not light up once the voltage dropped to below 200V. As a result, complaints kept coming in...*
>
> Soh Siew Cheong, First Managing Director of Power Grid, Former Chief Electrical Engineer of PUB's Electricity Department

By making electricity accessible to all, PUB faced the challenge of inadequate supply to meet their needs. It was a very hectic period as it tried to keep up with the increasing demand of its customers. For instance, it had to upgrade the older infrastructure (e.g. cables, transformers and switchgears) with replacements that could handle larger loads.

> *...we had to redo what we had done in the past 10 years because we couldn't just increase the capacity of existing equipment. We had to replace them with new and bigger capacity equipment and cables. It was part and parcel of the upgrading effort.*
>
> Soh Siew Cheong, First Managing Director of Power Grid, Former Chief Electrical Engineer of PUB's Electricity Department

Reorganisation of the Electricity Department

Demand grew from the industrial, commercial sectors as well as the the rural and urban residential areas. HDB continued to encourage homeownership in the early 1970s, and introduced a new accelerated building programme which called for building about 22,000 units per year, up from 7,000 units previously.

Given the exceptionally strong political backing of this programme, the Electricity Department was tasked to provide the utility infrastructural support without fail. Soh remembered being called into the office of Lee Yong Siang, then General Manager of Electricity Department, and being told: "this is politically sensitive, you cannot fail. In any politically sensitive project, no rational answer is acceptable. You cannot be let off the hook."

To meet the staggering load growth, the T&D infrastructure required extensive upgrading, and higher electricity generation capacity was needed. While the Electricity Department had done well in providing adequate supply to all new projects expeditiously and efficiently, the organisational structure of the Electricity Department was inadequate to undertake the massive increase in the workload.

Soh Siew Cheong, then Distribution Construction Superintendent, was given the authority to streamline the organisational structure of the Distribution Division to tackle this new challenge. The objective of the reorganisation was to streamline all aspects of work that were necessary to implement the distribution engineering projects expeditiously and efficiently under a single responsible office. The new restructured Distribution Construction Division had four Sections: Commercial, Project Engineering, Materials Management, and Distribution Construction.

This allowed better coordination and synergy between engineering staff within the Division, thus improving efficiency and work processes. The Distribution Construction Superintendent now had the oversight and control of the whole process, from the electricity supply application stage to the planning, materials procurement and the project construction and commissioning.

Overcoming Skilled Manpower Shortages and Improving Productivity

The expansion and reinforcement of the T&D network was a massive undertaking. At that time, PUB relied on its own Daily Rated Employees (DRE) workforce to carry out all construction works, such as cable jointing, switchgear and transformer installations. These were skilled works carried out by experienced, well-trained and competent artisans. However, PUB lacked the skilled manpower to cater for the sudden increase in workload. To ensure success, PUB made a bold decision to harness the manpower resources of the private sector when it came to construction work.

By the 1970s, many veteran PUB cable jointers and fitters had retired, and these skilled retirees could be deployed usefully to fill the shortage without further training. PUB encouraged those retirees to register new private companies and train new employees so that they could provide cable jointing services to them. It was a norm then for a jointer to be assisted by four workmen to complete a cable joint in a day while they were in PUB. But once the same jointers set up their own companies, they were incentivised to earn more profit and be more efficient. Two cable joints could be completed per day with the help of two workmen instead. This productivity gain was sufficient to meet needs of the HDB's accelerated building programme. The conscious effort by PUB to encourage the creation of a new cable jointing business in the private sector effectively resolved the skilled cable jointer shortage problem.

Electricians laying the underground cables.
Ministry of Information and the Arts Collection, courtesy of National Archives of Singapore.

The procurement policy for major power equipment was on a "Supply and Delivery" basis and had to be installed by skilled artisans. Instead of recruiting more artisans to cope with the increased workload, PUB introduced a new procurement policy based on Supply Delivery and Installation (SDI). Under this scheme, contractors had to supply, deliver, install and test the power equipment at the substation as and when required. These SDI contracts covered switch-boards, transformers, low tension and overground distribution boxes. In doing so, PUB was able to undertake large increases in the number of projects without increasing staff headcount.

Consequently, PUB began to outsource other electrical works, such as earthing of power equipment in the substation. This further reduced the number of staff needed, and improved output and productivity. To ensure quality, PUB introduced training programmes and certified the contractors before engaging them.

In the 1970s, power equipment required intensive maintenance to ensure their reliabilities. To release some manpower to cater for the construction activities, the PUB adopted a new class of power equipment that was relatively "maintenance free"; these included hermatically sealed air-cooled transformers, vaccuum circuit breakers and cross linked polyethylene insulated cables.[12]

A Pragmatic Decision to Oversize and Standardise Equipment

Another significant implementation was the decision to increase the transmission voltage from 66 kV to 230 kV in 1968, which enabled sustained growth until 1993, when PUB adopted 400 kV.

> *In 1968, we realised the 66 kV would soon be inadequate to meet demand, One school of thought was to step up to 132 kV or 175 kV, both British practices. We broke away and adopted 230 kV, the international practice.*[13]
>
> Michael Khor, Deputy Chief Electrical Engineer recalled the journey of transformers

The Electricity Department had many sizes of distribution cables and transformers. The practice then was to install the nearest cable or transformer sizes to meet the consumer's demand. For example, when a consumer applied for a supply of 250 kVA, a 300 kVA transformer would be installed. In a rapidly growing economy, the supply requirement by the customer could grow in steps to 400 kVA and 600 kVA. The Electricity Department would have to change the transformer to 500 kVA and 750 kVA to match the demand. With so many customers to serve, the demand on manpower increased: consumers had to wait for longer periods for supply to be given. Recognising the potential issue, the Electricity Department developed a stock index, standardised the rating of its transformers and cables, and reduced its range of power equipment. This enabled more efficient construction and installation works. For instance, a single size of 300 mm^2 was used for distribution cables. Moreover, the range of transformers used was reduced from eight to two models, rated at 1,000 kVA and 500 kVA. This meant that even if the load requirement was only 600 kVA, PUB installed a transformer with 1,000 kVA capacity in the consumer substation.

Both oversizing and standardisation of equipments resulted in a supply network with excess transmission and distribution capacity. While this seemed excessive at the time, it was a pragmatic approach that facilitated better services by PUB and growth of businesses.

Firstly, given that businesses had to apply for either supply extension or upsizing of supply capacity whenever their productions expanded, oversizing the transformers allowed the customers to grow their production capacities without constraint. Customers were also able to avoid the lead time needed from application to installation, which could result in a loss of business opportunities. This was especially important for a fast-growing economy in the 1970s. Secondly, as PUB's productivity improved significantly, it could concentrate its resources on providing more responsive services to new customers instead of offering repeated services to existing customers on a regular basis.

ENSURING FINANCIAL SUSTAINABILITY

Energy utilities are highly capital-intensive. In the face of rapid urbanisation and growth, it was critical that PUB grew its power system, and ensured the long-term financial sustainability of its operations.

In the initial phase of Singapore's development, the government took up loans from multilateral institutions such as the World Bank and Asian Development Bank. These loans financed the construction of infrastructure such as power stations.[14] For example, the government borrowed US$23 million in 1967 to expand the T&D system and water supply facilities. The loan agreement required PUB to ensure that the specified minimum Return on Total Assets (ROTA) was met.[15]

Under the leadership of Singapore's first finance minister, Goh Keng Swee, the government had institutionalised the ethos of financial prudence when developing its economic and social infrastructure.[16] Accordingly, it decided that non-subsidised public utilities should be delivered by statutory boards like PUB. Fees and charges were set at a level to yield sufficient revenue to cover operational costs, and also generate surpluses to finance future expansion and growth.[17]

In line with this approach, electricity tariffs and other energy prices were not subsidised to reflect their true market cost (see Chapter 5: Pricing Energy Right). While this was politically unpopular, such a pragmatic approach enabled PUB to operate and grow its power system to meet rising demand. Furthermore, it was able to fulfil the loan conditions imposed by the banks, and repaid its debts promptly.

Creating a Pro-Business Environment

Often, foreign investors in developing countries are deterred or crippled by the high additional costs of utility infrastructure needed to support their business operations. Many local governments in these countries do not have the finances to build and extend power lines and connections near to the factories.

Singapore sought to remove this burden from its investors by creating a business-friendly environment. The Jurong Town Corporation (JTC), established in 1968 to develop and manage industrial estates, worked closely with PUB to provide the necessary electricity and water infrastructure ahead of time, before the land and factories were leased to investors.[18] PUB's role was to build the necessary transmission and distribution network to provide electricity to the factories. It also absorbed the heavy upfront investment, while the developers and business owners only needed to pay a much lower cost to connect their factory buildings to the nearby consumer substation.

To safeguard PUB's financial interests, JTC and PUB signed a contract of guarantee, whereby JTC would ensure that the industrial estates were tenanted and leased, and the occupants' payments for electricity would exceed PUB's initial costs within an agreed timeframe. This allowed PUB to recoup its upfront investments over time.

This arrangement not only ensured PUB's long-term financial sustainability, but also gave JTC officers additional motivation to meet the minimum occupancy rates for industrial sites, to yield the required electricity consumption by companies. If the target was not met, JTC would have to pay the shortfall to PUB. Similarly, the contract of guarantee was also to be signed by large consumers of electricity to safeguard the investment made by PUB.

CHAPTER 2

INTEGRATED AND LONG-TERM PLANNING FOR SINGAPORE'S POWER NEEDS

STAYING AHEAD OF THE CURVE

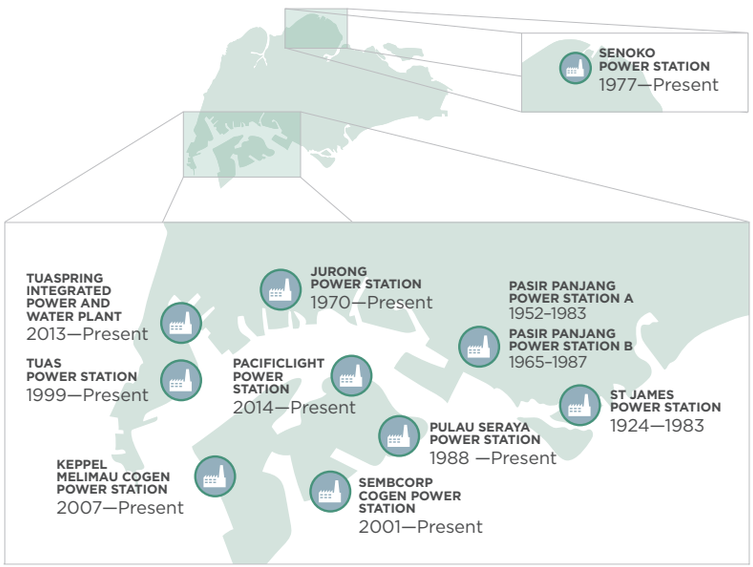
From the 1960s to 1980s, Singapore's industrialisation and urbanisation proceeded rapidly. The government engaged in long-term and integrated planning to ensure that energy infrastructure would always be ready ahead of time, to serve commercial, industrial and residential needs.

PUB worked closely with economic agencies such as the Ministry of Trade and Industry (MTI), JTC and EDB, and planning and development agencies such as URA and HDB. These agencies collaborated to plan the T&D network, and to forecast power demand based on development plans and economic growth projections. Long-term Power Station Development Plans were formulated to guide the location and construction of new power stations over a 10- to 20-year horizon.

In the drafting of these plans, agencies used comprehensive demand forecasting and mathematical models, based on variables such as historical load growth and the ratio of power system maximum demand to GDP. Their analysis took account of specific power-intensive projects

Exhibit 1

Major power stations in Singapore



or development programmes that might change the trajectory of demand growth, such as the iron and steel industry. They also considered the need for overhaul and maintenance of power turbines.

Since the Pasir Panjang A Power Station began operations in 1952, PUB built another four power stations: Pasir Panjang B, Jurong, Senoko and Pulau Seraya. In a keynote speech during the opening of Jurong Power Station on 7 August 1970,[19] former Finance Minister Goh Keng Swee explained the importance and challenge of planning for power stations:

> *The opening of this handsome new power station comes at a time when economic expansion is much in evidence in Singapore. But it was planned when such evidence was less demonstrable. As you know, it takes some five years between conception and commissioning of the power station. It is no mean feat to make correct five-year forecasts in Singapore and no small nerve to commit a few hundred million dollars on the basis of one's judgement.*

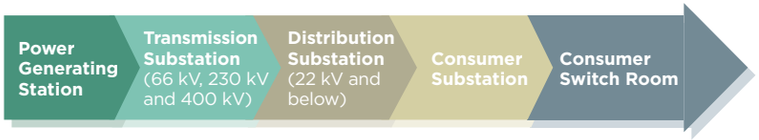
Indeed, it was a challenging and never-ending race for planners to ensure that Singapore's installed power capacity could keep up with the nation's needs. The pressure on electricity supply was only alleviated after Senoko Power Station officially opened in 1977. With a generation capacity of 1,610 MW by 1983, it was one of the largest power stations in the region.[20]

The government had always taken a long-term approach in developing the electricity infrastructure. For example, PUB decided to build Pulau Seraya Power Station as early as 1979, and the station was opened in 1988. Planning for Tuas Power Station had already begun in the late 1980s, even though reclamation of the proposed site was completed only in 1991. The construction work proceeded as planned. Tuas Power Station officially opened in 1999 and it now contributes about 20% of Singapore's electricity supply by generation capacity.

Securing Land for Energy

In Singapore, almost all electricity is generated in power stations, then transmitted via the power grid. Electricity is transmitted at higher voltages to reduce losses. The voltage is then stepped down through a series of substations, and reaches users at 230 V. These voltages are suitable for most small industrial, commercial and residential customers' use.

Exhibit 2
Electrical Infrastructure in Singapore



Excludes power cable network.

To supply the nation with electricity, a comprehensive network of energy utilities and grid infrastructure had to be built islandwide. Planners had to take Singapore's future energy needs into consideration, and to allocate and safeguard sufficient land to enable the construction of this infrastructure.

Since the 1960s, PUB was empowered under the Public Utilities Act to require that real estate developers set aside sufficient land on their sites for the installation of infrastructure to supply electricity to their buildings. If land was required for new substations to cater for system load growth, PUB would apply to the Land Office for State land, and work closely with URA, HDB and JTC to secure suitable sites for the construction of power stations and substations. After the privatisation and deregulation of the electricity sector (see Chapter 5), these responsibilities were vested in Singapore Power. The Land Office was merged with Singapore Land Registry, Survey Department and Land Systems Support Unit to form the Singapore Land Authority (SLA) in 2001.

The cost-sharing arrangements and responsibilities for building the utility infrastructure were set out at the early stages of a construction or development project.

High-rise buildings

In a high-rise development, the developer was required to provide land and build a substation building for PUB to house its electrical equipment necessary to provide electricity supply to the development. In such cases, PUB would pay for and owned the power equipment within the substation, and the developer had to give an irrevocable rights to the use of the substation building for as long as PUB required.[21]

Landed housing developments

In landed housing development, the developer would either vest the substation site and the building to PUB, or continue to own the land and building. In this case, the developer had to provide an irrevocable rights of use to PUB. In most cases, developers preferred to vest the land and substation building to PUB.[22]

Substations

In the 1960s and 70s, applicants for substantial power supply were required to provide standalone substation buildings and land at their own costs for PUB to install power equipment for the electricity supply. PUB was given the ownership of the land and building.

For HDB and JTC developments, they only needed to build the substation buildings at their own cost, and did not need to vest the land to PUB. Instead, they had to grant PUB the irrevocable rights to use the substation buildings.

The policy to require applicants to vest substation land posed difficulties to potential investors because of the loss of development potential of the substation land in the future.

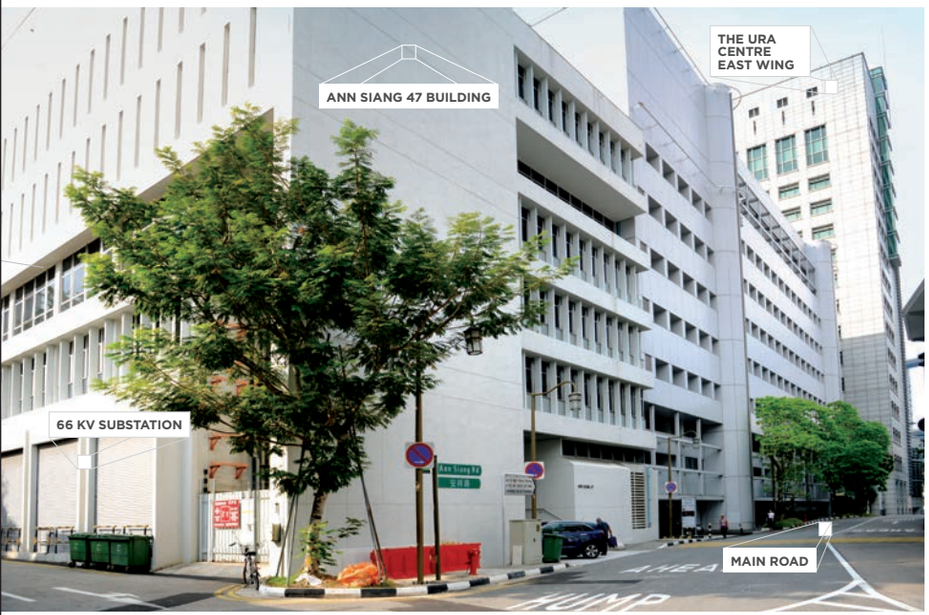
In a major change of policy in the 1980s, PUB discontinued the requirement for applicants to convey the substation land and furthermore, allowed applicants to provide rooms within the building to house PUB power equipment. This change of policy was welcomed by investors and developers alike.

With this new policy, PUB aimed to

1) make it easier for investors to obtain electricity supply;
2) better utilise land for the investors; and
3) achieve substantial cost savings by avoiding the need to pay property tax for thousands of substations

This policy change also gave developers more autonomy in integrating the substations within the building and the surrounding development, through architectural design.

Instead of standalone, plain-looking substation buildings, developers were required to observe certain design standards, to create an attractive streetscape. For example, in development areas such as the Downtown core covering the Central Business District (CBD), City Hall, Bugis and Marina Centre zones, URA made it a requirement for electrical substations to be fully integrated within the building envelope, if it is not possible to build them underground. It also encouraged the concealment of substations, and ruled that substation buildings could not be sited directly next to main roads, pedestrian malls, or public spaces.[23]



The Ann Siang 47 Building houses a 66 kV substation and office spaces on the higher floors. The building façade was designed to ensure that the substation is well-hidden at the rear of the building.
Photo courtesy of Cheong Kay Teck.

Transmission Substations above 230 kV and Power Stations

For the construction of large utility infrastructure such as transmission substations above 230 kV and power stations, PUB would pay for the land, and build and operate the infrastructure. In the case of major land development by government agencies which required the building of 66 kV and 230 kV substations, PUB would still require them to provide the land and the building.

BALANCING GROWTH WITH ENVIRONMENTAL PROTECTION

As industrialisation accelerated in the 1970s, the government agencies engaged in coordinated and careful planning to ensure that the increasingly dense living environment would remain comfortable, clean and healthy for all residents and visitors.

Even in the early years of development, the government had placed a heavy emphasis on mitigating the adverse environmental impacts of industrial activities and pollution. Its careful balance of environmental protection and growth can be seen in the planning and location of power stations in Singapore.

In the 1980s, more developments were introduced in the east of Singapore, such as in Tampines Town and Chai Chee Industrial Estate. In its Power Station 20-year Development Plan released in 1993, PUB had originally planned for Tekong Power Station to be built in the east of Singapore to support newer developments.

From the engineering perspective, locating power stations close to areas with a high level of electricity demand was the most economical and efficient, since PUB could avoid building a costly transmission network.

Despite this, the plan was never approved because the proposed site for Tekong Power Station did not meet the land zoning requirements of the Master Plan. The site, proposed by PUB, was only zoned for residential and light industrial use. Power stations were considered heavy industrial uses due to the possibility of emissions, pollution and noise. The tall chimneys of the power plant also exceeded the height control limit within the vicinity of Changi Airport. These stringent zoning criteria were put in place to safeguard public health and improve the liveability of Singapore's dense urban environment. As such, most power stations in Singapore are located in the periphery of the island, such as the industrial region in the western part of the island and Senoko Power Station in the northern industrial area.

Over time, technological advancements and the shift to natural gas for power generation substantially reduced environmental pollution, and removed the need for tall chimneys for power plants. As a result, the government granted the Energy Market Authority (EMA)'s proposal to earmark Lorong Halus and Punggol Barat in the north-east of Singapore for future power stations. These proposed sites had met the relevant authorities' requirements on environment considerations despite their closer proximity to residential areas compared to other existing power stations.

MAKING SPACE FOR ELECTRICITY IN THE CONSERVATION DISTRICTS

These substations bring about a 'lifeline' to these historic districts. If there is insufficient electrical power, people and businesses will not be able to move back there, and revitalisation will not be possible.[24]

Dr Cheong Koon Hean, Former CEO of URA, explained the importance of introducing electricity to the conservation districts

Conservation of Singapore's built heritage is an important part of urban planning and development. As the central agency responsible for conservation, URA oversees this process.

Districts such as Boat Quay, Chinatown, Kampong Glam and Little India are Singapore's oldest urban areas, and they possess significant historical and cultural meanings to the nation. They are characterised predominantly by shophouses—narrow, two- to three-storeys high, small terraced buildings—constructed between the 1840s and the 1960s. Today, these buildings also enrich the built environment with their diverse façades, rich ornamentation and unique architectural styles. Gazetted as conservation districts in 1989, strict guidelines are enforced to maintain the ambience and physical character of these areas.

When the shophouses were first built, they did not have any utility services such as water and electricity. Substations had to be built to supply electricity to the entire conservation district, which required vacant land plots of suitable sizes and locations. Each substation could only serve a specific catchment area within the district, and enough substations had to be built to ensure complete coverage. There was simply not enough vacant land for this purpose.

URA worked closely with PUB to coordinate infrastructure development, and came up with innovative solutions to overcome the challenges. For example, a typical shophouse has two storeys at the front but only a single storey at the rear. In the Tanjong Pagar area, URA selected a few shophouses and made space in their courtyards for PUB to build substations serving the entire estate.

Shophouses along Tanjong Pagar Road. Photo captured in the 1970s (left) and after revitalisation efforts (right).
Courtesy of Urban Redevelopment Authority (left).
Courtesy of Jnzl, https://flic.kr/p/qd7wt9 (CC BY 2.0) (right).

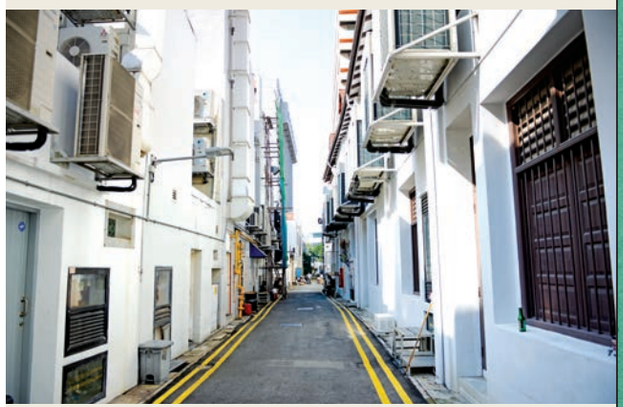
The substations had to be carefully integrated with their heritage surroundings through the use of sensitive aesthetic design and visual screening of the substations within the shophouses. Today, the substations in Tanjong Pagar supply electricity to the entire neighbourhood, yet most people do not even know of their existence.

The shophouses in Tanjong Pagar were originally built back-to-back, closely against each other. URA had to carefully demolish the rear of the shophouses to create a service back lane between the two rows of shophouses. With the service back lanes, the extension and maintenance of utility cables, piping, and air-conditioning condensing units are much easier. The back lane also serves as an emergency exit for the shophouse residents.

MAKING SPACE FOR ELECTRICITY IN THE CONSERVATION DISTRICTS

Continued...

The electrification and revitalisation of the Tanjong Pagar conservation district was more easily achieved because the shophouses were owned by the state. In the case of the Boat Quay conservation district where the shophouses are largely privately-owned, URA faced a greater challenge of rejuvenating the area. This rejunevation was deemed necessary since the government had already channeled substantial resources to clean up the Singapore River over a ten-year period. The government thus had to impose on the private owners to provide building setbacks by a designated deadline so that a service back lane could be built.[25] Besides a strong mandate, it also took planners from URA five years to persuade all 117 owners to see the value of conservation and restore their buildings.[26] Boat Quay was eventually successfully restored within six years after the mandate.



Service back lane created between two rows of shophouses at Tanjong Pagar.
Courtesy of Cheong Kay Teck.

CHAPTER 3

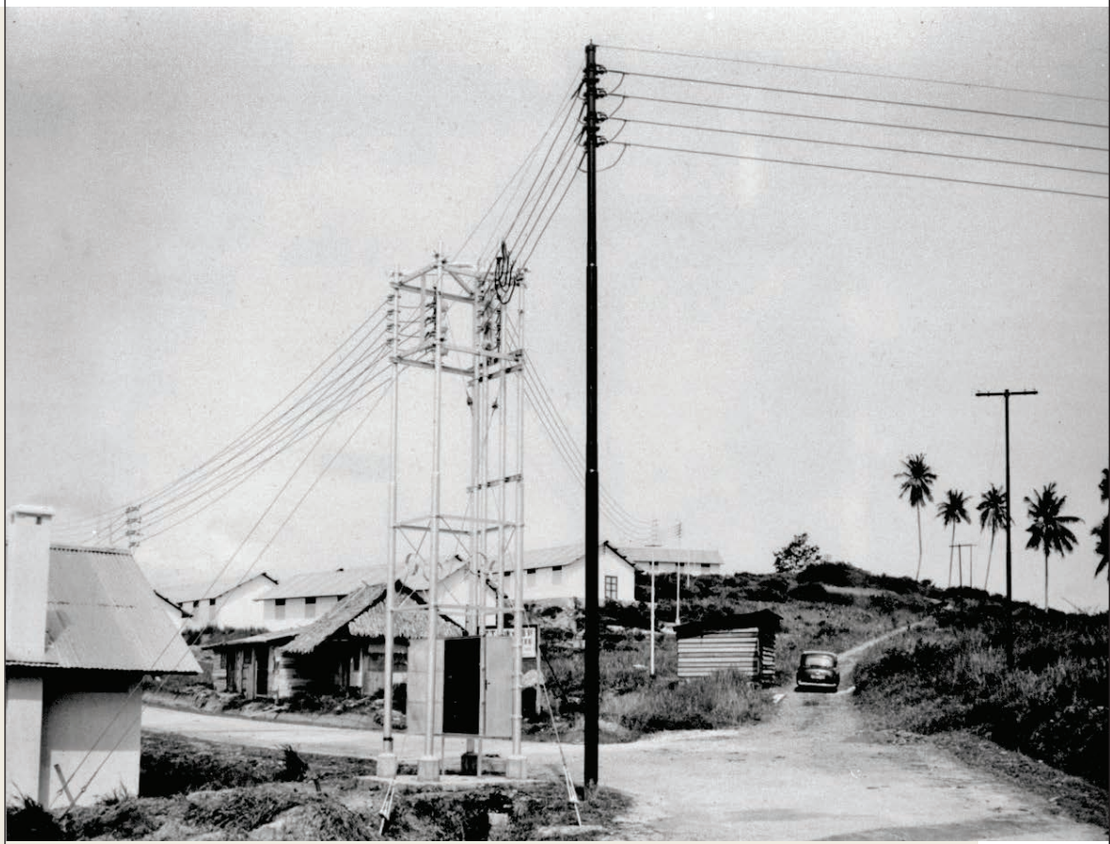
ENHANCING SAFETY, RELIABILITY AND QUALITY (1970s–1990s)

SHIFTING OVERHEAD CABLES UNDERGROUND

In the early 1960s, electricity cables were either buried underground or hung overhead. This was until Lawrence Estrop, former chief electrical engineer of PUB, proposed to have all cables buried underground.

Estrop had seen many cities whose skylines were marred by unsightly overhead cables. He argued that the government should invest in an underground cable network, which was much neater and more orderly.[27] Therefore, in the early 1960s, the government made the bold decision to bury both the power and telecommunication cables in the city centre, despite the higher cost of underground cables.

By the 1970s, overhead lines were only installed in lower-cost or low-density developments, such as in rural areas and private landed housing estates, to save costs. However, overhead lines were still susceptible to power outages caused by thunderstorms and lightning. PUB eventually dismantled the remaining ones and replaced them with underground cables. Today, only a few old private housing estates such as Opera Estate and Serangoon Gardens still use overhead lines.[28]



Overhead electricitcal distribution cables at Ulu Pandan in 1956.
Public Works Department Collection, courtesy of National Archives of Singapore.

As a result of these far-sighted decisions, Singaporeans can now enjoy beautiful urban spaces, landscaping and greenery, in the absence of cluttered and messy power cables.

SHIFTING THE FOCUS TO SAFETY, RELIABILITY AND QUALITY

> *Around the time when the Energy Market Authority was formed, several countries were running short of electricity. Some politicians from the Philippines made the point that there is no form of electricity that is more expensive than not having electricity. How true. Reliability and security of our power supply is important.*
>
> Khoo Chin Hean, Former CEO of Energy Market Authority

By the 1980s, PUB had succeeded in providing sufficient electricity supply to meet Singapore's needs. There was even excess infrastructure capacity, and that meant that any incoming investors could receive power and begin operations in Singapore promptly. The industrialisation programme gained momentum as foreign investment poured into the country. With companies such as Apple, Matsushita (now known as Panasonic), Seagate, Western Digital, IBM and Sumitomo Chemical setting up operations here, many jobs were created.

As Singapore prospered and its citizens' quality of life improved dramatically, power outages became much more unacceptable to the general public. Now that they had supplied electicity throughout the country, PUB's challenge and focus shifted to ensuring that these supplies were safe, reliable and of high quality.

Addressing Safety Concerns

During this period, the public was very concerned about the safety of electrical infrastructure. Fatal electrical accidents were not uncommon, but it was the 1972 fire at the Robinsons department store in Raffles Place that prompted the government to introduce legislation and regulations to ensure safety.

On 21 November 1972, nine people died in a blaze resulting from a short circuit on the first floor of the four-storeyed building.[29] Flames rose up to a height of more than 60 metres at one point, and were reportedly visible from as far away as Jurong.[30]

Before the Robinsons fire, there was no safety code for electrical work, but within the next few years following the fire, stronger laws and regulations were introduced to address safety issues. These included the Electrical Workers and Contractors Licensing Act and Electrical Workers and Contractors Licensing regulations in 1975.

Under the new law, people and companies had to engage a registered electrical contractor with licensed workers to undertake any electricity-related jobs. To facilitate the transition and in fairness to existing workers, licences were granted to existing electrical workers who had years of experience and a good safety record.

In 1985, the government further mandated that all new houses and apartments had to be fitted with high-sensitivity Earth Leakage circuit breakers, to further reduce the risk of electrocution. On top of these measures, engineers and electrical workers had to comply with the Code of Practice for Electrical Installations 1988, which raised professional standards and competency in the industry.

Improving Reliability by Reducing Cable Damage

One of the most common causes of power outages was cable damage resulting from negligent excavation and construction works. To tackle this problem, PUB stipulated that any earthwork by contractors or developers required prior approval from the Electricity Department.

PUB also introduced training and certification for a new profession in the industry: the licensed cable detection worker. All contractors and developers were required to engage a licensed cable detection worker to establish electricity cable positions and routes before commencing any earthworks. Heavy penalties were imposed on companies that flouted this rule. This successfully reduced the number of cable damage incidents.

However, cable damage incidents could not be eliminated completely. Investigations revealed that many of the cables were damaged by the contractors' hired foreign workers who operated the excavators. Since the contractors had already complied with the laws and regulations, it would be difficult, if not impossible, to press charges against them. Therefore, contractors and developers were required to engage only certified excavator operators.

To help the contractors and developers meet this new requirement, Singapore Power, which became responsible after PUB was corporatised in 1995, conducted training courses to equip excavator operators with the required earthwork skills. This measure proved effective, and was eventually adopted by other utility providers for telecommunication cables and water piping.

Enhanced Remote Control and Monitoring System

In 1979, PUB introduced the Supervisory Control and Data Acquisition System (SCADA), a computerised control system. This move represented a quantum leap in terms of enhanced remote control and monitoring of the transmission network.

The Supervisory Control and Data Acquisition System in 1979.
Courtesy of Energy Market Authority.

Enabling PUB to detect failures early and restore supply expeditiously, the SCADA system was extended to the 22 kV distribution network across the island. PUB additionally re-configured the network in closed rings so that any cable failure would not cause a supply interruption.[31] If one source failed, electricity from another source could be diverted to the users.

During this time, a special taskforce was formed. Its members worked incessantly, carrying out earthworks and installation of reinforced concrete pipes every night over a five-year period. Equipment was maintained or replaced with better versions, along with the reinforced pipes which offered added protection against cable damage. While these measures were costly, they were justified because a higher-quality power system would allow Singapore to win investments from companies that needed more stable power supplies. Such companies would generate higher value-added and create jobs.

These prolonged maintenance and upgrading efforts significantly reduced supply interruptions and enhanced power reliability for a large spectrum of customers. Over the years, cases of cable damages decreased steadily. Singapore now has one of the most reliable electricity grids in the world, with a System Average Interruption Duration Index (SAIDI) of less than 14 seconds (0.23 mins) per customer in 2016.[32] This was much lower compared to many advanced cities such as Osaka (4 mins), Hong Kong (23.4 mins), London (33.6 mins) and New York (20.53 mins).[33]

Quality versus Affordability

As part of the strategy to grow Singapore's economy, there was a shift from low value-added, labour-intensive manufacturing to capital- and technology-intensive industries in the 1980s. EDB took on the responsibility of attracting more sophisticated industries, such as chemicals, disk drive manufacturing, semiconductors and wafer fabrication, to set up businesses in Singapore.

Many of these industries shared a common trait—they used precision equipment and computer systems that were highly sensitive and had tightly controlled manufacturing environments, which depended on a consistent and high quality of electricity supply. Even a voltage dip of less than a second could cause some machinery to malfunction.

PUB soon faced the dilemma of how to address this issue. On one hand, these industries generated significant value-added, and were important for industrial development and job creation. On the other hand, only a small group of companies in Singapore required such high-quality electricity supply. Minor voltage fluctuations did not have any impact on the majority of electricity users, who would only experience a flicker on their computer screens, and might not even notice it.

To ensure high quality, many measures were put in place to reduce the number of voltage dips, such as the Condition Monitoring System which provided early warning to any incipient faults.[34] But the question of cost recovery and sharing arose. To what extent should the government pay for the sizeable cost of ensuring a high-quality electricity supply that benefited only a minority of consumers? And should the costs be shared among all users in the form of higher electricity tariffs?

After in-depth discussions, the government concluded that there was no strong justification for the majority of electricity consumers to indirectly subsidise the industries. The affected companies were asked to pay for the improvement measures, with some supporting co-funding from the government.

CREATING A WORLD-CLASS UTILITIES NETWORK THROUGH UNDERGROUND TUNNELS

While most countries lay utility services under roads or service verges, Singapore decided to build large underground tunnels to house the networks of pipes and cables.

One notable project was the construction of the state-of-the-art Common Services Tunnel (CST) network in Marina Bay. The CST is a purpose-built underground tunnel that houses and distributes utility service lines such as power cables, water pipes, telecommunication cables, and chilled water pipes for cooling buildings.

The CST represents a forward-looking and creative approach to utility infrastructure. It supports the development of Marina Bay into a 21st-century, world-class business, financial and entertainment hub. The idea was first mooted by URA following a 1997 study trip to Yokohama Minato Mirai 21 in Japan. A thorough feasibility study was then conducted to weigh the costs and benefits of CST.

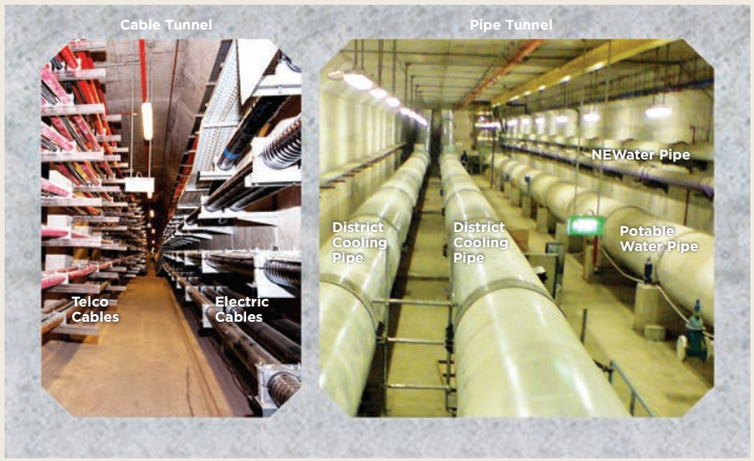
- With CST, traffic disruptions, noise and dust pollution caused by excavation or maintenance work could be avoided. Instead, any installation, maintenance and inspection work could be carried out in the tunnel.

- Accidental damage of cables and pipes from excavation works could be avoided. This enhanced the reliability of utility supply, which is especially important for high-value developments like Marina Bay.

Exhibit 3

Common Services Tunnel

Marina Bay Common Services Tunnel Utility Services Perspective.
Courtesy of Urban Redevelopment Authority.



Cross Section of Common Services Tunnel.
Courtesy of Urban Redevelopment Authority.

CREATING A WORLD-CLASS UTILITIES NETWORK THROUGH UNDERGROUND TUNNELS

Continued...

- Less land would be required. About 1.6 hectares (0.016 km^2) of land, which was initially set aside as road verges and carriageway for laying underground utility, was freed up for higher-value development.
- The extremely high capital expenditure required for the CST was a concern.

URA had several important tasks at hand. It had to determine the size of the tunnel, to ensure the possibility of installing additional service lines in the future. Once the tunnels were built, they could not be easily enlarged. URA also needed to facilitate stakeholder discussion and achieve consensus on this proposal. Discussions were elevated to the highest level in the government, and a Steering Committee involving utility, planning, transport and other agencies was formed. After careful deliberation, the government decided to approve the project, in recognition of the long-term benefits to Marina Bay and Singapore as a whole.

Besides the CST, Singapore Power, currently known as SP Group, also invested in a S$2 billion underground cable tunnel system which was built about 60 metres below the ground surface, and which stretched across the island. The tunnel infrastructure, completed in 2017, ensures sufficient room for expanding or upgrading Singapore's transmission and distribution network in the future.[35] As with the CST, the tunnels will enable SP Group to efficiently install and maintain underground cables, while minimising public inconvenience.[36]

CHAPTER 4

HARNESSING THE ENERGY INDUSTRY FOR GROWTH: FROM THE FIRST REFINERY TO AN ENERGY ECONOMY

Since Singapore's early years of self-government, its oil industry has played a significant role in growing the economy. Despite the country's small size and lack of any fossil fuel resources, Singapore is now one of the world's largest oil trading centres. As a significant regional oil storage hub, it is also an oil refiner which produces 1.5 million barrels per day in 2014.

The country's strategic geographical position, where half of the world's oil supply and a third of global trade passed through, enabled it to be a key hub for oil and maritime commerce. Its bunkering port topped the world, with bunker sales globally amounting to 50.6 million tonnes in 2017.[37]

Singapore's energy industry has adapted to the world's changing energy trends, as well as domestic energy policies such as the liberalisation and privatisation of the electricity sector, and the move towards liquefied natural gas (see Chapter 5).

SINGAPORE'S GROWING OIL ECONOMY IN THE 1900s

Singapore's oil story began as far back as the late 18th century when it served as a humble oil storage and bunkering centre for Shell. Shell's operations in Asia began with the distribution of imported Russian kerosene in the region via a petroleum tank depot on Pulau Bukom, one of Singapore's offshore islands.

In 1907, Shell merged with its competitor to form Royal Dutch Shell, which exerted major influence on oil markets in the Far East, directing reception, storage, blending and reshipment of oil in Pulau Bukom for Southeast Asia and nearby territories. It also opened Singapore's first petroleum refinery in 1961, channeling close to US$30 million worth of investment in the development.[38]

Singapore found favour with these global oil companies due to its geographical advantages, deep-water anchorage adjacent to the harbour, as well as lower municipal taxes and fewer regulations and restrictions in the colonial years. Petroleum imports thus grew from 0.7 to 1.3 million tons between the periods of 1925–1927 and 1937–1939 respectively.[39]

From the late 1960s to early 1970s, Esso, Mobil Oil and Singapore Refining Company set up three oil refineries on separate islands.[40] A total of four refineries had been built by late 1970, contributing more than 30% of the country's total manufacturing output.[41] The refineries enabled Singapore to import large volumes of crude oil from the Middle East, Africa and Asia. The crude was then refined and processed into petrochemical products

including liquefied petroleum gas (LPG), gasoline, naphtha, jet kerosene, diesel and fuel oil for re-export to other countries.[42] With its pro-business and free trade policies, Singapore was ranked one of the top three global oil refining and trading centres by the mid-1970s, alongside Houston and Rotterdam.[43]

JURONG ISLAND: AN INTEGRATED REFINERY AND PETROCHEMICAL HUB

To succeed as an international petrochemical hub, Singapore needed a decisive competitive advantage over its rivals as an investment destination. Petrochemical companies were looking for new ways to operate more cost-effectively, and also to raise their top line profitability. In the 1980s, EDB saw potential growth in the petrochemical and chemical industry within the Asia Pacific. Feedstock produced from the oil refinery could be integrated with the downstream petrochemical sector.

The idea of an integrated refinery and petrochemical sector drew on the concept of "cluster development". EDB and JTC envisioned a cluster of companies along the chemical production value chain co-locating in "a vertically integrated structure where the output from one plant becomes the input for another, allowing them to feed off each other symbiotically".[44]

The challenge was where to locate such a cluster. Petrochemicals and oil refining presented potential environmental or safety hazards in the event of an accident, and industrial land had become increasingly scarce. The site would also require infrastructure to support the import of crude and raw materials, and export of refined products and chemicals.

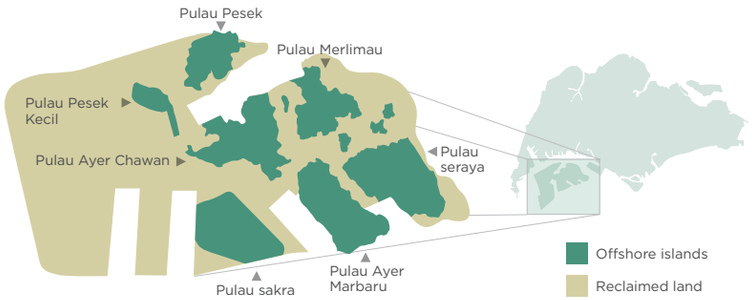
Finally, the government turned to land reclamation. The 3,000-hectare (30 km^2) Jurong Island was created by amalgamating a group of islands off the southwestern coast of Singapore (i.e. Pulau Seraya, Pulau Ayer Merbau, Pulau Pesek Kechil and Pulau Sakra).[45] JTC finalised the concept plans by the late 1980s, and in 1991 was appointed the responsible agent for the reclamation works. The whole reclamation project began in 1995 and was completed in 2009, with further expansion work ongoing until recent years.

A common pipeline corridor was developed to provide third-party logistics services to Jurong Island's tenants.[46] Sharing the cost of facilities and utility services enabled companies to lower their infrastructure and ancillary costs, while benefiting from economies of scale.[47] It was estimated that tenants' capital outlay fell by 30%, and their transport

costs were 15% lower.[48] Petrochemical plants were also able to operate with a 20% cost reduction. At the same time, siting the integrated hub close to Singapore's port enabled products to be easily exported, further improving operational efficiency.[49]

Exhibit 4

Formation of Jurong Island



In 2007, the government pushed for the construction of Jurong Rock Caverns, a commercial underground storage facility to be located 150 metres below the ground and 130 metres beneath Banyan Basin on Jurong Island. The first phase of the project was completed at a cost of $1.7 billion.[50]

The rock caverns are used for storing liquid hydrocarbons such as crude oil, condensate, naphtha and gas oil to support the future growth of the chemical sector. They are sited close to the industrial operations on Jurong Island. The rock cavern also freed up 60 hectares (0.6 km^2) of surface land for higher-value uses. This infrastructure plays an important complementary role in the existing network of facilities and services to support growth in the energy and chemicals cluster.

Beyond physical infrastructure, a concerted effort was launched to market Jurong Island, attract foreign companies, and engage them to ensure that their plants were established smoothly. By 2014, over 100 energy and chemical companies were set up on the island, a great increase from just five companies in 1995.[51] The refinery and chemical industries contributed significantly to Singapore's economy, accounting for about 34% of the nation's total manufacturing output in 2014.[52]

To ensure the long-term sustainability and competitiveness of Jurong Island, the Jurong Island Version 2.0 initiative was launched in 2010 to review five key areas: energy, logistics and transportation, feedstock options, environment and water.

CHAPTER 5

GROWING CONCERNS FOR RISING OIL PRICES AND CLIMATE CHANGE: QUEST FOR EFFICIENCY (1990s—PRESENT)

RISING OIL PRICES AND CLIMATE CHANGE

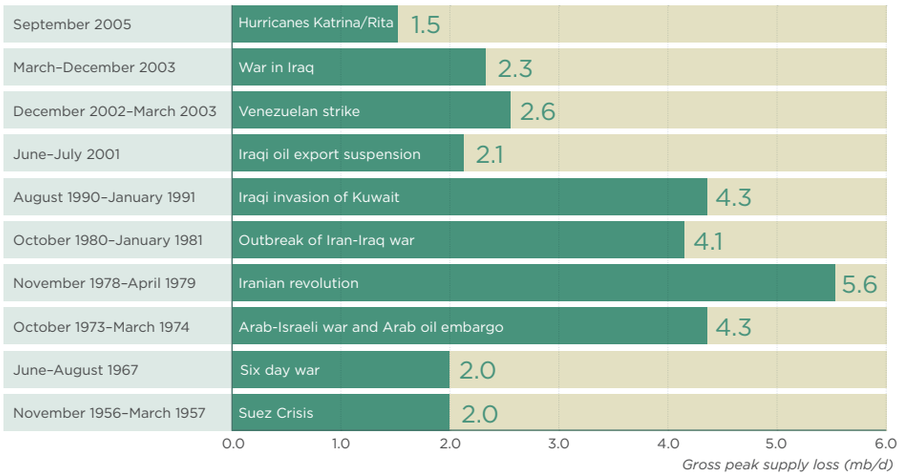
From the turn of the 20th century, two developments significantly shaped the energy policies of many countries worldwide, including Singapore.

First, global energy prices rose steadily. Oil prices moved persistently upwards from the 1970s until 2012, driven by both global supply and demand changes.[53] On the demand side, growing economies such as the USA, China, India, South Korea, Mexico and newly industrialising economies in Southeast Asia imported much more oil to meet their domestic needs. The 1970s and 1980s also saw rising demand for transportation fuels such as gasoline.

On the supply side, oil-producing countries in the Middle East continued to dominate the market. Supply disruptions became more common due to geopolitical tensions, terrorism, extreme weather events and sometimes industrial accidents. In the 1970s, the world encountered its first two significant oil disruptions: the Arab–Israeli war and Arab oil embargo in 1973; and the Iranian Revolution in 1978, with the latter being the most serious.[54] These oil supply shocks sent prices spiralling upwards, causing grave energy security concerns worldwide.

Exhibit 5

Major oil supply disruptions



Source: Oil Supply Security: Emergency Response of IEA Countries 2007, International Energy Agency (IEA).

Singapore was not spared. With no indigenous primary fossil fuels, it relies entirely on imported fuels to meet almost all its energy needs. As a price taker, its economy and society is vulnerable to oil supply disruptions. For instance, when the first oil crisis hit in 1973, oil prices in Singapore quadrupled, and inflation soared to nearly 30% in the first half of 1974.

Second, climate change became a global environmental challenge, leading to global warming, sea level rise and increasingly unpredictable extreme weather events. The burning of fossil fuels also contributed to air pollution and about two-thirds of global greenhouse gas emissions,[55] mainly in the form of carbon dioxide. Countries came together in 1992 to agree on the United Nations Framework Convention on Climate Change, and the Kyoto Protocol was adopted in 1995. Under the Protocol, developed countries committed to emissions reduction targets.

Singapore, being a low-lying and densely populated island state, is vulnerable to these external environmental impacts. It is projected that by the end of this century, sea levels here will rise by up to 1 metre, and daily mean temperatures will increase between 1.4–4.6 degrees Celsius. Over time, the contrast between wet and dry seasons will be more distinct with more intense and frequent heavy rainfall events.[56] The government recognised these vulnerabilities and committed to play its role in the global effort to fight climate change.

In the face of these deep shifts, Singapore needed to rethink its strategies for achieving energy security, environmental sustainability and economic competitiveness. The first step was to liberalise and eventually privatise parts of the electricity sector.

TRANSFORMING THE ELECTRICITY SECTOR

From the 1960s to the 1990s, PUB effectively served as the single provider of utilities in Singapore. It successfully overcame its initial challenges of ensuring sufficient and reliable electricity supplies, but it also made heavy investments in quality infrastructure to achieve these outcomes. To recoup the cost of these investments, PUB increased electricity prices over the decades. The oil price spikes of the 1970s and stubbornly high oil prices thereafter worsened the problem.

Higher electricity prices had an impact on Singapore's competitiveness. Some other countries in the region were able to attract investors and support their economic growth with much cheaper—but less reliable—electricity. Singapore's economy and workforce were highly reliant on foreign direct investment. If its competitiveness was blunted by rising costs, investors would turn elsewhere. By the mid-1990s, the key challenge for the government was to meet growing electricity demand without raising electricity prices excessively.

At this time, PUB was required to finance and build the utility infrastructure, and to recoup these investments through the sale of electricity. In countries where utility companies failed to manage their costs and risks on both ends, their governments needed to top up the shortfall, to keep the utility in operation. In the long run, this was a costly and unsustainable approach. For Singapore, the provision of subsidies would also run counter to the government's policy of selling energy at market prices. Passing on the full cost of electricity production to users encouraged more prudent and efficient use of energy.

PUB had limited options to keep costs down. Three of its major power plants were already using oil-fired steam generators, which at the time were efficient and cost-effective technologies. Renewable energy sources were either too expensive or had limited potential due to Singapore's physical constraints. While natural gas was the most cost-efficient generation option, there was simply not enough demand to justify the heavy capital investment of switching to natural gas. Furthermore, switching to gas-fired plants would result in the oil-fired steam generators becoming stranded assets with limited future use.

To address this challenge, the government decided to liberalise the electricity market progressively. Commercial discipline and competition would drive efficiency as the electricity system grew. A detailed feasibility study was conducted, which considered the experiences of the United Kingdom, Australia and New Zealand, which were among the first countries to adopt this approach.

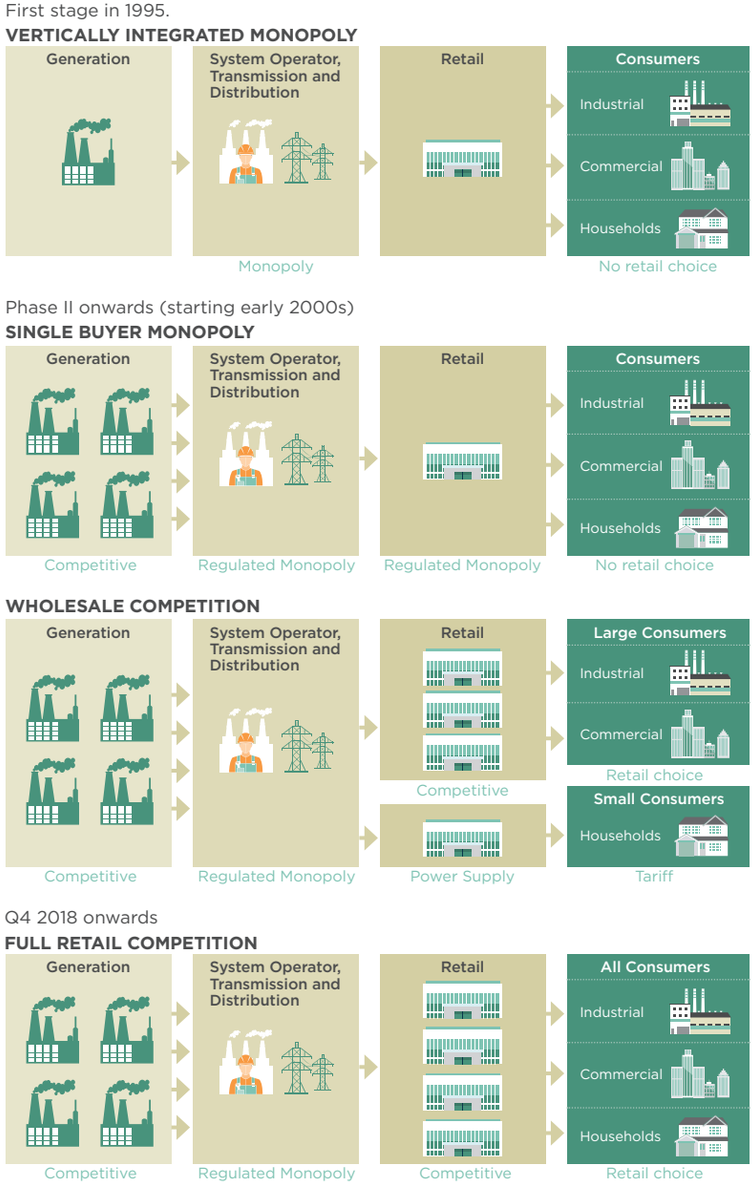
LIBERALISATION OF THE ELECTRICITY MARKET

Phase One (Late 1990s)

The liberalisation of Singapore's electricity market was guided by one objective: to deregulate and allow competition in the contestable segments of the market, such as electricity generation and retail, while tightly regulating the transmission and distribution network, which was a natural monopoly.

Exhibit 6

Phases of the liberalisation of the electricity sector



This process began in 1995. PUB's electricity and gas undertakings were corporatised under a vertically integrated government monopoly known as Singapore Power. It owned two power generation companies (Gencos), namely PowerSenoko and Power Seraya, as well as a T&D company (PowerGrid), a gas company (PowerGas) and an electricity retail company (Power Supply). In the meantime, PUB assumed the role of regulator for the electricity and gas sectors.

To introduce competition in the power generation segment, Tuas Power was formed as a wholly-owned subsidiary of Temasek Holdings to develop Tuas Power Station. The government also allowed the entry of independent power producers (IPPs) and co-generators, without setting any limits for the market.[57] Shortly after, the Singapore Electricity Pool (SEP), administered by PowerGrid, commenced operations in 1998 to allow wholesale trading of electricity. Gencos had to compete to sell electricity they generated at the SEP.

Despite these substantial reforms, the market lacked a level playing field. Progress had been made through ring-fencing Singapore Power's generation, T&D and customer services segments, and keeping the subsidiaries' operations and financing management separate from each other. However, Singapore Power was vertically integrated, and owned and operated both the power grid and the Gencos. The market had been deregulated, but true competition did not yet exist.

Phase Two (2000s)

The industry was only fully liberalised in 2001, with the further restructuring of Singapore Power to allow the two Gencos to become wholly-owned subsidiaries of Temasek Holdings. This ensured a level playing field, with the competitive sectors of electricity generation and retailing separated from the natural monopoly of the power grid.

The Energy Market Authority (EMA) was formed in 2001 to take over the regulatory functions of PUB, and the Energy Market Company (EMC) was incorporated, to serve as the wholesale market operator. With the regulatory and market mechanisms in place, the wholesale electricity market was revamped and the National Electricity Market of Singapore (NEMS) commenced operations in 2003.

Since 2001, EMA has progressively opened up the retail electricity market to competition. This liberalisation of the retail electricity market aims to promote the supply of competitively-priced electricity and allow greater consumer choice. Over the years, the threshold for consumers who are allowed to buy electricity from their preferred electricity retailer has been gradually lowered.

Currently, commercial and industrial consumers with a minimum average monthly consumption of 2,000 kWh can choose their electricity retailer. EMA also conducted a soft launch of Open Electricity Market for households and businesses in Jurong to provide them with a choice to buy electricity from a retailer of their choice at a price plan which best met their needs. On 21 September 2018, EMA announced that the Open Electricity Market will be extended to all consumers across Singapore by zones starting from 1 November 2018. About 1.4 million households and business accounts will have the option of buying electricity from a retailer on a price plan to suit their needs.

In any electricity supply system, the transmission and distribution (T&D) network is critical infrastructure. It is the backbone of the electricity system, and links power generation plants with all electricity users. The government decided to entrust the responsibility of T&D operation and maintenance to Singapore Power. Its experience and track record, and its status as a company wholly owned by Temasek Holdings, gave the government confidence in its abilities and reliability. As an independent and neutral party, EMA regulates grid charges, and sets performance standards for Singapore Power. EMA also manages the Power System Control Centre (PSCC), the nerve centre of the electricity generation and transmission system.

In Infrastructure Investment, Regulatory Certainty is Key

With the progressive liberalisation of the electricity market, Singapore has a competitive power generation and retail sector, and a highly regulated power grid to ensure reliability and efficiency. With a liberalised market, it is the private sector that makes investment decisions and builds the highly capital-intensive power plants to meet the nation's electricity needs.

> *It's always got to do with investments, and whether investments keep up with demand. So, there is a very key lesson here, which is that for investments to be made, the people who make the investments must have certainty of recovering their cost. And that certainty can only come from regulatory certainty. If the regulators do not provide the certainty, the industry will underinvest, and you will run into all kinds of problems.*
>
> Khoo Chin Hean, Former CEO of EMA

Because regulatory certainty is so important, the government faced the key task of establishing sound regulatory institutions, and creating a stable regulatory environment, to give private firms the confidence to invest in energy infrastructure.

CREATING THE RIGHT MARKET BEHAVIOUR

Governments often work with markets to deliver public value, and achieve social and economic objectives. This requires the right set of regulatory and incentive structures, to encourage private firms to make pricing, investment and allocation decisions that meet broader national needs.

Pricing Energy Right

One important aspect of Singapore's energy market has been the use of competitive markets, to allow market forces and price signals to allocate energy resources. By pricing energy correctly, without subsidies or other market distortions, consumers become aware of the true cost of energy production. This encourages households and businesses to use energy more efficiently.

This approach was demonstrated in 2012, when the government decided not to provide subsidies for solar power generation. At the time, solar power was relatively more expensive than fossil-fuel-based technologies. Some countries in Europe and elsewhere sought to encourage the development and use of solar power, through direct subsidies in the form of feed-in tariffs.

Under a feed-in tariff, the government would price solar power at a premium relative to regular electricity prices, to compensate producers for the higher cost of producing solar power. Some countries believed that this would incentivise solar generation, bringing down solar prices in the medium term, and supporting mass adoption in the longer term.

Singapore does not implement feed-in tariffs, as this might raise electricity costs for many users, and risk locking in subsidy commitments for less efficient solar technologies over time. This would not have been fair and sound economically. The cost of solar eventually declined over time, and this facilitated the adoption of solar in Singapore.

While pricing energy right is key to establishing a healthy and competitive market, the government also had to ensure that lower-income households could afford to pay market prices for electricity, especially when prices rose. To achieve this, the Utilities Save (U-Save) Rebate Scheme was implemented to give each HDB household a fixed dollar amount to offset their utility bills. Households living in smaller HDB flats—for example, 1- and 2-room flats—received higher rebates, while those in 5-room flats received less.

Although some higher-income families choose to live in smaller flats, the subsidy tier system used by U-Save was sufficiently reliable and cost-effective. It allowed the government to focus the bulk of subsidies on needy households.

U-Save was designed using sound economic principles, to preserve the incentives for households to save energy. The rebate reduces a household's utility bill by a fixed dollar amount, so it will still enjoy the cost savings if it chooses more energy-efficient appliances, or uses electricity more prudently. Households also continue to see the true cost of electricity, as the electricity tariffs remain unchanged. In contrast, if a rebate took the form of a discounted price per unit of energy consumed, the cheaper energy prices could have the perverse effect of encouraging more electricity use.

Market Forces Ensuring Reliable Supply

In a competitive market system, Gencos have a strong commercial interests to maintain and operate their power plants reliably. Plant outages could result in lower quantities of electricity generated, thus impacting their generation market shares and earnings.

Singapore's electricity market is designed to preserve and enhance these market incentives, to improve system reliability and uptime. In a scenario where a Genco bids to supply a specific amount of electricity, but is unable to deliver on its commitments due to a plant breakdown, the market operator would activate the reserves to meet the shortfall at that point. Simultaneously, the electricity wholesale market prices would rise to reflect the supply and demand.

To incentivise Gencos to maintain their plants reliably, the reserves costs are allocated, taking into account the reliability of the units. That is, plants which trip more would be allocated a higher proportion of the reserves cost.

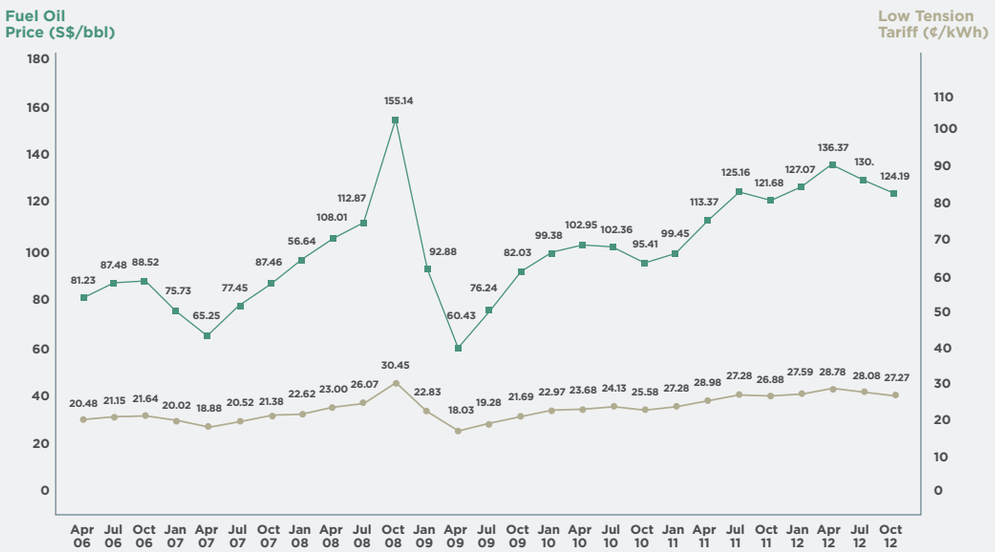
Market Competition and the Switch to Natural Gas

Before deregulation of the electricity sector, most of Singapore's electricity generation used oil-fired sets, which had a thermal efficiency of less than 35%. After deregulation, each Genco sought to lower their costs and improve productivity, to improve their chances of outbidding other Gencos to supply electricity in the competitive market.

To encourage greater innovation and productivity, the government left the choice of power generation technology to the market. The Gencos invested in more Combined Cycle Gas Turbine (CCGT) plants powered by natural gas. These units had an overall thermal efficiency of 53–55% and were more efficient compared to oil-fired power plants.

Exhibit 7

Fuel Oil Prices versus Low Tension Tariff



Source: SP Services, 2012.

The benefits of market liberalisation and competition were apparent. The deployment of more efficient CCGT plants meant that less fuel is needed to generate the same amount of power. As a result, CCGT technology enabled the Gencos to cut costs, and offer lower electricity prices. Even though oil prices increased from US$15 per barrel in 2001 to US$110 per barrel in 2007, electricity prices did not rise in proportion. The use of natural gas continued to increase: in 2001, 26% of Singapore's fuel mix for electricity generation came from natural gas.[58] This jumped to 74.7% in 2005, and 95.2% in 2017.

According to Singapore Energy Statistics 2018, Singapore has registered generation capacity of 13,614.4 MW (as of March 2018) with peak demand of about 7,370 MW in June 2018. Khoo Chin Hean, former CEO of EMA, recalled the times when people criticised the apparent overinvestment in power infrastructure and the substantial increase in wasteful excess capacity. But they did not understand that this was the result of a properly operating market, which drove the private sector instead of the government to invest in CCGT plants, in addition to keeping their existing oil-powered plants. The government created a competitive electricity market supported by an appropriate regulatory framework, giving the private sector the confidence and incentives to invest in efficient and cleaner generation technology. In turn, this helped to curb the upward pressure on electricity prices, and ensured that power demand could be met ahead of time.

LIBERALISATION OF THE GAS MARKET

With natural gas becoming the major source of fuel for power generation, the gas sector had to be competitive. This led to the restructuring of the natural gas industry. The gas transportation segment was separated from the businesses of gas import, shipping and retail at the ownership level. PowerGas, a subsidiary of Singapore Power (now known as SPGroup), served as the natural monopoly responsible for maintaining the reliability of Singapore's gas transportation network. PowerGas is regulated by EMA, and not allowed to participate in gas import, shipping and retail, to preserve a level playing field.

Singapore presently imports gas both in the form of LNG, and through pipelines from neighbouring countries. There are two gas pipeline networks in Singapore, both owned and operated by PowerGas, and two types of gas. Town gas, produced by City Gas Pte Ltd, is mainly used for cooking and heating by residential and commercial customers. Natural gas, imported by licensed gas importers, is mainly used for electricity generation and industrial feedstock.

ENERGY SECURITY THROUGH DIVERSIFICATION OF ENERGY SOURCES: THE DEVELOPMENT OF AN LNG TERMINAL

Singapore's ability to ensure a secure supply of energy is of strategic importance to the nation's economy and survival. Without any indigenous fossil fuels, the country is highly reliant on imports to meet its energy needs. This also means that Singapore is a price taker for energy, and is vulnerable to global energy supply disruptions. As global energy demand continues to rise in the coming decades, Singapore cannot assume that its current sources of fuel imports will be sufficient to meet its own growing needs.

Because Singapore has fewer renewable energy options than many countries, it remains largely reliant on fossil fuels such as natural gas. In such a situation, the best way to improve energy security is to diversify its sources of gas. [See Chapter 6 Alternative, Cleaner Energy Sources].

LNG Terminal.
Courtesy of SLNG Corporation Pte Ltd.

Shortly after independence, the government switched from coal to fuel oil for power generation. After deregulation in the 2000s, the Gencos switched to natural gas-fired power plants, which were cleaner and more efficient than fuel oil. Pipelines were used to import natural gas from Malaysia and Indonesia under long-term contracts.

Using piped natural gas for electricity generation increased Singapore's vulnerability to supply disruptions. First, any intentional or accidental damage to the pipeline infrastructure would interrupt the gas supply. Second, Malaysia and Indonesia would naturally need to prioritise their own rapidly growing domestic demand for gas, given their lack of major new gas field discoveries in recent years.[59] If these contracts were not renewed, Singapore's gas supplies would have been at risk.[60]

To strengthen energy security, the government turned to Liquefied Natural Gas (LNG), which is transported by specialised tanker ships. In 2006, Singapore decided to build its first LNG receiving terminal, to gain access to natural gas imports from all over the world.

Construction of the S$1.7 billion LNG terminal began in 2010. By 2013, the first phase was complete, with two storage tanks, a jetty and regasification facilities with throughput capacity of 3.5 million tonnes per annum (Mtpa). The terminal's location, at the southernmost tip of Jurong Island, made it convenient to supply natural gas to the power generation plants and petrochemical industries situated on the island. To enhance the future economic potential of the terminal, it was equipped with facilities for re-export and LNG trading, and the flexibility for expansion.[61] The LNG terminal has since been expanded: a fourth storage tank was completed in 2018, raising the terminal's capacity to at least 11 Mtpa.[62]

Singapore currently imports LNG mainly from three different regions: the Mexican Gulf, North Africa and Australia. These broadly diversified sources are also different from its major sources of oil imports such as the Middle East, reducing the country's vulnerability to fuel supply disruptions. At the same time, EMA also made it a requirement for Gencos to stockpile fuel reserves to cover at least 60 days of their normal operations for emergency back-up.

The investment in the LNG terminal, coupled with Singapore's strategic geographical location, could facilitate the nation's development into a regional LNG trading hub, allowing gas to be brought in at a more competitive price. The advent of LNG has also allowed the government to strike a balance between cost effectiveness, environmental sustainability and energy security.

FORMATION OF THE ENERGY POLICY GROUP: WHOLE-OF-GOVERNMENT POLICY COORDINATION

A key milestone for Singapore's energy policy was the formation of the Energy Policy Group (EPG) in 2006. The EPG was an inter-ministerial committee looking at energy policy at the whole-of-government level for the first time. It was chaired by Peter Ong, then-Permanent Secretary of the Ministry of Trade & Industry (MTI), and comprised representatives from MTI, the Ministry of Finance, Ministry of Foreign Affairs, Ministry of the Environment and Water Resources, Ministry of Transport and other agencies responsible for energy-related infrastructure, economics and research.

The National Energy Policy Report published in 2007.
Image courtesy of Ministry of Trade and Industry Singapore.

The EPG allowed the government to develop a more coherent and coordinated position on several major issues related to energy. Singapore acceded to the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) in 2006. At the same time, oil prices had rebounded following the Gulf War, and technological developments enhanced the promise of renewable energy worldwide. Singapore's environmental, economic and security agencies thus came together to discuss these new opportunities and challenges.

The agencies agreed that a new coordination platform was needed to formulate clearer frameworks and goals for Singapore's energy policies—one that would allow the government to look at energy holistically, and better manage trade-offs between economic competitiveness, environmental sustainability and energy security. The discussions led to the publication of the National Energy Policy Report in 2007, which communicated principles and perspectives on Singapore's energy policy, from various angles. The Report also outlined six strategies to achieve its goals. (Some policies related to these strategies are discussed in Chapters 5 and 6.)

1) Promote competitive markets
2) Diversify energy supplies
3) Improve energy efficiency
4) Build energy industry and invest in energy R&D
5) Step up international cooperation
6) Develop a whole-of-government approach

ENERGY EFFICIENCY FOR THE ENVIRONMENT, SECURITY AND ECONOMY

Energy efficiency is integral to Singapore's energy policy. Improving energy efficiency supports the nation's three fundamental energy policy objectives of security, economic competitiveness and environmental sustainability.

Increasing energy efficiency reduces energy demand, which helps decrease both greenhouse gas emissions and air pollutants like sulphur dioxide and particulate matter. This gives rise to cleaner air and a more liveable environment, and helps mitigate global climate change. With increasing awareness of climate change following the various countries' commitments to reduce emissions under the UNFCCC, the issue of energy efficiency is gaining interest. Many nations, including Singapore, seek to contribute to the well-being of the global community by improving their energy efficiency.

More efficient use of energy also helps to slow the increase in Singapore's total energy demand, even as its population and energy needs grow. The city-state has limited options to diversify its energy sources, and is heavily reliant on fossil fuel imports. However, with greater efficiency and slower energy demand growth, Singapore's dependence on energy imports can be managed more easily in the long term.

Moreover, improved energy efficiency translates to lower electricity bills for businesses and consumers, and cushions the impact of rising energy costs. This will raise the competitiveness of businesses in the long run, especially when full life-cycle costs are taken into consideration.

The government began focusing on energy efficiency and conservation around the year 2000. Prior to that, the Ministry of National Development (MND) was responsible for curbing energy demand from buildings, while PUB set up an Energy Conservation Unit to conduct walk-through audits and provide energy-saving recommendations.

After PUB was restructured, no single agency was responsible for improving energy efficiency. Therefore, in 1998, MND convened an Inter-Agency Committee on Energy Efficiency (IACEE), comprising 11 infrastructures, transport and economic ministries and agencies. The IACEE was tasked to curb rising energy consumption and recommend measures to improve energy efficiency.[63] Chaired by Associate Professor Koo Tsai Kee, then Senior Parliamentary Secretary of MND, the committee produced the National Energy Efficiency Report which was presented to Parliament in 1999. Its recommendations focused mainly on energy efficiency in households and buildings, and less so in factories and industries.

This led to a discussion on which government agency should be responsible for energy efficiency and conservation. Finally, the Ministry of the Environment (later became the Ministry of the Environment and Water Resources) was tasked with the role, on the basis that this issue was more closely linked to environmental protection than anything else. This resulted in the establishment of the Resource Conservation Department.

> *The argument to push for efficiency in how just one resource—energy—is consumed is hard to make since Singapore is a net importer of many resources. So why focus only on energy? Why not push to be efficient in steel consumption, for example? The reason for the focus on energy is the link between energy use and production, and the impact of that on the environment. So energy efficiency came under the then Ministry of the Environment.*
>
> Ananda Ram Bhaskar, Director-General of the National Environment Agency

In the early days, the government concentrated on gathering data to better understand energy consumption patterns and emissions levels across the various sectors. Building on the earlier National Energy Efficiency Report, the Resource Conservation Department initiated the formation of a National Energy Efficiency Committee involving all relevant agencies.

In 2007, the National Environment Agency (NEA) established the Energy Efficiency Programme Office (E2PO), a multi-agency committee co-chaired by NEA and EMA, to develop a comprehensive plan that would raise awareness and emphasise energy efficiency.

Households

In 2005, electricity use by households made up 18% of total national consumption.[64] Its major consumers of electricity are air conditioning and refrigeration appliances. There was hence scope to lower household electricity use by promoting more efficient electrical appliances. Households were hence encouraged to adopt energy-efficient behaviour through awareness-raising, and the introduction of labelling schemes and standards for electrical appliances.

In 2004, NEA established a voluntary energy labelling and performance standard, but it was met with limited success. At the time, this was deemed as low-hanging fruit that could be implemented quickly. However, under the voluntary approach, companies chose to label only those products that were more efficient. This was later replaced by a Mandatory Energy Labelling Scheme (MELS) in 2007 for high energy consumption appliances such as air conditioners and refrigerators, to help consumers make informed purchasing decisions. Subsequently, Minimum Energy Performance Standards (MEPS) were imposed to improve the average energy efficiency of regulated appliances.

It was challenging at first as many suppliers were unhappy about the financial penalty imposed on them for not meeting standards, despite their products being cheap and popular. Significant efforts were made to convince the manufacturers, suppliers and major retailers. The voluntary programme in the early phase also contributed to the smooth transition when mandatory and stringent regulations were eventually introduced.

In an era of information overload, NEA's public messaging has focused on encouraging energy efficiency and environmentally friendly behaviours, instead of general statements about sustainability. Mr Bhaskar also recalled the importance of timeliness and being opportunistic:

> *Around 2008, energy prices suddenly shot up. Oil prices moved beyond 100 dollars, leading to higher prices for other fuels such as natural gas and coal. As energy prices went up, home electricity bills also went up. These circumstances helped us to push energy efficiency as a message, and the labelling scheme became important to households.*
>
> Ananda Ram Bhaskar, Director-General of National Environment Agency

In addition to NEA, several other government agencies and utility providers also encouraged energy efficiency. For example, in 2012, EMA and SP Group started the SP Electricity Efficiency Centre to raise awareness about electricity efficiency, reaching approximately 7,500 visitors annually through these learning journeys. Additionally, an interactive Mobile Exhibition unit programme was developed—since 2015, it has reached more than 17,000 upper primary and lower secondary students every year. EMA and SP Group also redesigned and launched a hardcopy utility bill and mobile application that provides consumers with feedback and peer comparison data to encourage energy savings.

Buildings

More emphasis was placed on the environmental sustainability of buildings in the early 2000s. For instance, in 2005, BCA launched the Green Mark Scheme, offering a comprehensive framework for assessing the environmental performance of new and existing buildings. It also featured a green building rating system suited for the specific environmental conditions of the tropics and sub-tropics. Green Mark sought to promote sustainable building design, construction and operations. [For more information: see CLC's Urban Systems Study, *Built By Singapore: From Slums to a Sustainable Built Environment*]

Marina One—A Green Mark Platinum non-residential building.
Courtesy of M+S Pte. Ltd.

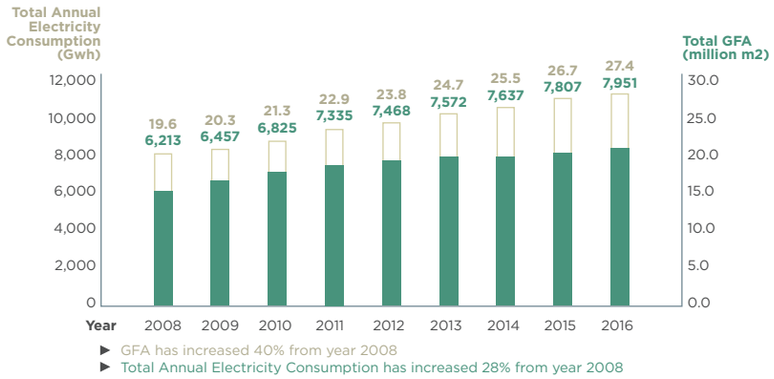
One important aspect of Green Mark assessment is energy efficiency. Buildings account for about half of Singapore's electricity consumption. In non-residential buildings, 60% of electricity used is for cooling, followed by 15% for lighting.[65]

It is thus important to invest in systems and processes that reduce energy demand for air-conditioning. On this front, Singapore is one of the forerunners in improving cooling efficiency. There is a matrix that measures the efficiency of the air-conditioning at the system level, rather than the efficiency of each component. Coupled with regulatory requirements and incentives, developers are encouraged to build and retrofit chiller plant systems with higher efficiency.

The Green Mark Scheme has shown promising results. From 2008 to 2016, the annual electricity consumption of new buildings and those that recently completed major renovations and redevelopment increased more slowly than the growth rate of building Gross Floor Area.[66] This indicates that buildings are becoming more energy efficient (see the following diagram).

Exhibit 8

Total Gross Floor Area (GFA) & Annual Electricity Consumption Trend of Buildings[67]



Source: Building and Construction Authority, BCA Building Energy Benchmarking Report 2017.

The BCA's Green Building Masterplan has expanded, from focusing on new buildings to including existing buildings. The third Masterplan aims to make Singapore a global leader in green buildings.[68] Under the Building Control Act, new and existing buildings undergoing major retrofits are required to achieve a minimum environmental sustainability standard, periodically audit their cooling systems, and submit their energy consumption and related data.[69] BCA's goal is to green at least 80% of building Gross Floor Area by 2030.[70] The government has taken the lead by aiming to attain the more stringent Green Mark Platinum Standard for new public sector buildings of substantial air-conditioning area, and at least Green Mark Gold Standard for existing public sector buildings.

Industry

Industries are the largest consumers of energy, accounting for almost two-thirds of Singapore's final energy consumption, both in the form of petroleum products and electricity [see Appendix A for Total Final Energy Consumption by Sectors and Energy Products in 2016].[71]

Industries present a unique challenge for energy efficiency regulators. Households and buildings have largely similar components like cooling, lighting and façades, which standards and guidelines can be developed for. However, industrial buildings and facilities are a lot more heterogeneous. Each factory is often different, and customised to support its own production and operations. In contrast to households, there will be fewer one-size-fits-all regulations or solutions for improving energy efficiency in industries.

For the purposes of electricity and energy efficiency, the industrial sector can be categorised into three tiers. The first consists of the power generation, refining and petrochemicals industries. This tier is highly energy-intensive, and plays an important national and economic role. Electricity generation has critical national functions, while the refining and petrochemicals industries are largely export-oriented, create good professional and technical jobs for Singaporeans, and contribute substantially to Singapore's economy. Because of strong external and internal competitive pressures, this first tier has natural incentives to be more productive and improve energy efficiency over time, so as to reduce costs and stay competitive.

The second tier mainly comprises large electricity consumers, such as electronic manufacturing plants, wafer fabrication plants and pharmaceutical factories. Under the Energy Conservation Act enacted in 2012, NEA requires these energy-intensive companies, both from the first and second tier, to introduce proper energy management practices, such as tracking and reporting their energy consumption, and developing an Energy Efficiency Improvement Plan. These companies are further expected to appoint an Energy Manager to monitor energy use and implement improvement plans. The government has additionally introduced Energy Efficiency Grant schemes to encourage owners and operators of companies from the first and second tiers to become more energy efficient.

The third tier of industries encompasses all the remaining small energy consumers. Their businesses are not energy-intensive, and electricity bills are usually not a major percentage of their overall business costs. Because of this, such firms generally need motivation to improve their energy efficiency. Currently, third-tier companies are not regulated through binding standards, but the government encourages more energy-efficient practices through education and engagement.

Land Transport

Land transport accounts for 13% of the nation's energy consumption, mainly from the use of petroleum.[72] As a densely populated city-state with limited land, Singapore needs a sustainable and energy-efficient land transport system.

To satisfy the increasing demand for transport, and reduce energy usage and environmental impacts, the Land Transport Authority (LTA) has made sustained efforts over the years to expand and improve public transport services as the most efficient way to serve Singaporeans. If a passenger

can switch from a car ride to taking a bus or train, energy usage per kilometre can be reduced by 9 and 12 times respectively.[73] LTA aims to increase the percentage of peak-hour trips made using public transport to 75% by 2030.

To achieve this, the existing rail network will be extended from 138 km in 2008 to 280 km by 2020. Another 800 buses will also be introduced by 2022 with higher capacity, better services and improved connectivity.[74]

To alleviate traffic congestion and curb emissions and energy use arising from private cars, Singapore implemented the Vehicle Quota System (VQS) in 1990 to control the annual growth in vehicle numbers. The government will cut the growth rate for private passenger cars and motorcycles to zero in 2018, to steer Singapore towards a car-lite society.[75]

In terms of fuel for transport, land transport users mainly consume petrol and diesel. Private cars are responsible for the largest share of transport sector carbon emissions, at 35%.[76] This is followed by 26% from commercial vehicles, 17% from taxis, 15% from buses, 4% from the Rapid Transit System and 3% from motorcycles. On top of carbon emissions, the combustion of transport fuels emits harmful fine particulate matter, which has an adverse impact on air quality and public health.

To address these issues, the government introduced a Fuel Economy Labelling Scheme (FELS) designed to help potential vehicles buyers make informed decisions in choosing cleaner, more fuel-efficient cars.

In the early 2000s, there was a push for the adoption of compressed natural gas (CNG) for taxis, private cars and buses. While CNG was cost competitive at that time, CNG adoption did not take off mainly because of insufficient CNG refuelling stations. In terms of carbon emission and pollutions, CNG was not much cleaner than petrol. As such, the government decided that there was no strong justification to warrant public investment on gas refuelling stations and pipelines to accelerate the adoption of CNG.

Instead, the Carbon Emissions-based Vehicle Scheme (CEV) was introduced in 2013, to encourage the use of lower emissions cars, irrespective of the fuel or technology used. This technology-neutral approach rewards all kinds of innovations to improve emissions efficiency. The CEV was enhanced in 2018 to incentivise the reduction of other pollutants as well, and is now known as the Vehicular Emission Scheme (VES).

CHAPTER 6

NAVIGATING CHANGE: TOWARDS A SMART, SUSTAINABLE AND SYSTEM-LEVEL APPROACH (2010s—PRESENT)

RETHINKING ENERGY: FUTURE CHALLENGES AND MANAGING TRANSITIONS

By the 2010s, the key foundations of Singapore's energy landscape and markets had been laid. The electricity sector had been successfully deregulated and liberalised, and the construction of the LNG Terminal enabled greater diversification of natural gas supply sources.

Despite these successes, there was no time for complacency. The global energy landscape continued to evolve quickly and dynamically. Oil prices became more volatile, peaking at US$150 per barrel in 2008, and falling sharply in the years following the US financial crisis. Slowing global growth and lower oil prices further blunted the urgency of renewable energy research and adoption.

Climate change remained a priority on the global agenda as more drastic and frequent extreme weather events impacted agriculture, water supplies, cities and ecosystems. On 12 December 2015, for the first time in history, 195 countries at the United Nations Framework Convention on Climate Change (UNFCCC) agreed in Paris to fight climate change through mitigation actions, adaptation measures, and investments in low-carbon technologies.

These major developments shaped various aspects of Singapore's energy policies. The Inter-Ministerial Committee on Climate Change, led by Deputy Prime Minister Teo Chee Hean, was set up in 2007 to improve coordination on climate change policies across the whole of government. The National Climate Change Secretariat (NCCS), currently under the Strategy Group of the Prime Minister's Office, was also established in 2010 to develop and implement the country's domestic and international policies and strategies on climate change, and to facilitate strategy-making and planning on cross-agency issues.

Despite its resource scarcity and geographical constraints, Singapore committed to play a role in the global community's climate change efforts, and pledged to reduce its emissions intensity by 36% from 2005 levels by 2030. Meanwhile, Singapore's energy demand is projected to rise at a compounded annual growth rate of between 1.2% to 1.8% in the next 10 years.[77]

Enhancing Singapore's Energy Efficiency

Energy efficiency continues to be a key strategy to reduce carbon emissions, manage growing demand for imported energy, and strengthen economic competitiveness. As individual Ministries' earlier efforts to improve energy efficiency bore fruit, agencies have adopted an inter-agency perspective and coordinated their efforts more closely, to further enhance energy efficiency across sectors.

The industry sector continues to be the largest energy consumer, accounting for about two-thirds of the nation's energy demand, as well as 60% of greenhouse gas emissions in 2014.[78] The government aims to increase the energy efficiency improvement rates from 0.6% in 2015 to 1–2% annually, on par with the results achieved by other developed countries.[79]

While the government is actively supporting system improvements and technology adoption to enhance energy efficiency in industry, achieving a more energy-efficient system alone is insufficient. Prime Minister Lee Hsien Loong explained this in 2010.

> *Efficiency gains are important for more efficient cars, better ways to produce electricity, more energy-efficient homes and so on, e.g. greener air-conditioners. But efficiency gains alone are not sufficient because of the rebound effect. Because if the air conditioner consumes less electricity and it is cheaper to operate, you may decide to run it for more hours or you might decide to set the room cooler and therefore overall consumption will go up. Economists tell us so and our experience confirms that this is what actually happens. Therefore, there is a need to impose a charge to induce consumers to change their behaviour so that they feel the cost of the consumption and they make the right choices.*[80]

The government will implement a carbon tax by 2019 on large emitters such as Gencos based on their emission of greenhouse gases.[81] The tax—initially set at $5 per tonne of emissions, and rising in later years—will send a clear market signal on the price of carbon, and ensure that emitters bear the social and environmental cost of emitting greenhouse gases. This will nudge companies to improve energy efficiency, as well as manage energy demand.

Through consultations with relevant stakeholders, the government will have to carefully determine the optimal carbon price that produces the desired behavioural change, without destroying the economic competitiveness of industries. Ultimately, the carbon tax aims to transform Singapore into a low-carbon economy, and fulfil Singapore's commitment to tackle climate change.

ALTERNATIVE, CLEANER ENERGY SOURCES

While Singapore has adopted natural gas, the cleanest form of fossil fuel, as the main fuel for power generation, harnessing renewable energy can help Singapore move closer towards a low-carbon future.

Globally, the adoption of renewable energy is on the rise. In 2016, the world added an estimated 165 GW of power capacity, two-thirds of which came from renewable sources. The use of renewables is expected to continue rising through 2022,[82] driven by falling costs, R&D investments, and growing support from governments. Among renewable options such as wind, solar, hydropower and bioenergy, solar photovoltaic capacity grew the most, by about 74 GW or 50%.[83] In particular, China is one of the key leaders in driving renewables, contributing over 40% of global growth in renewable energy capacity.[84]

Singapore also recognised the promise of renewable energy. In the mid-2000s, the Energy Policy Group looked closely at options to diversify Singapore's energy sources and mitigate greenhouse gas emissions.

However, Singapore's renewable energy options are limited. It does not have geothermal energy sources or large rivers suitable for generating hydroelectric power. Although it is an island, the potential for tidal and oceanic energy is limited by its calm seas. With its location on one of the world's busiest shipping lanes, much of Singapore's waters are needed for ports, anchorage and maritime passage. Wind energy potential is likewise limited, with a low average wind speed of about 2 m/s—far below the 4.5 m/s required by commercial wind turbines.[85] In terms of bioenergy, Singapore's high population density and lack of an agricultural sector limit the potential for locally produced biofuels. Burnable waste is sent to incineration plants, which provided 1.9% of Singapore's generation capacity in 2017.[86]

Among renewable energy options, solar power is currently the most technically and economically viable. Singapore receives 50% more solar radiation than temperate countries. With the cost of solar power approaching grid parity, the private sector has been willing to invest in more capacity.[87]

The government has stepped up efforts to encourage the adoption of solar energy. The SolarNova Programme, launched by the EDB, aims to increase solar deployment to 350 MWp by 2020.[88] The Programme promotes and aggregates solar demand across the public sector, so that locally based companies can reap economies of scale through bulk tenders. Beyond 2020, Singapore plans to further raise the adoption of solar power to 1 gigawatt-peak (GWp). This would be equivalent to powering 200,000 4-room HDB flats for a year.[89]

Government agencies have actively promoted solar PV. To date, the Housing and Development Board (HDB) committed a solar capacity of 190 MWp for 3,350 housing blocks, and is on target to raise solar PV capacity to 220 MWP—equivalent to the annual electrical consumption of 55,000 4-room flats.[90,91] To overcome the constraint of Singapore's limited land, PUB, Singapore's National Water Agency is testing the installation of floating solar panels on the surface of reservoirs. A pilot project at Tengeh Reservoir found that floating panels performed better than rooftop solar systems, and had no observable impact on water quality or biodiversity.[92]

PUB's floating solar PV testbed at Tengeh Reservoir (left).
Solar panels at Treelodge@Punggol (Record Date: 2017) (right).
Courtesy of PUB, Singapore's National Water Agency (left).
Image courtesy of the Housing & Development Board (right).

The use of solar power in Singapore is limited by its intermittency. Solar electricity generation fluctuates due to environmental factors, such as cloud cover and shadow, common in tropical countries. If solar energy output suddenly dips, the power system operator must ensure that conventional generators have sufficient capacity to instantaneously meet demand, to avoid a power failure.

Battery storage is one promising technology that could overcome the intermittency problem of renewables. Though still at its nascent stage, EMA and SP Group have jointly awarded $17.8 million to two Singapore-led consortiums to implement a utility-scale Energy Storage System (ESS) test-bed. The ESS technologies deployed redox flow and lithium-ion batteries, which will be evaluated for their performance under Singapore's hot and humid environment, and help establish clear guidelines for such deployment. Singapore is also exploring how to couple energy storage with solar forecasting capabilities to help our power system operator better manage the impact of solar intermittency as more solar energy is integrated into the grid. For example, the National University of Singapore (NUS), with the grant support of EMA, is looking into improving the accuracy of solar PV output forecasts and grid management, in collaboration with the Meteorological Service Singapore.

Besides renewable energy sources, some countries are looking towards nuclear energy as a low-carbon energy source. Newer nuclear power plant designs that are being developed and tested have the potential to be much safer than many of the plants in operation today. However, most of these newer technologies are still at the testing phase and have not been operationally proven. In Singapore, the government is monitoring the progress of these nuclear energy technologies, and considering these energy options for the future.

DEVELOPING A CLEAN ENERGY SECTOR AND INVESTING IN RESEARCH, DEVELOPMENT AND DEMONSTRATION (RD&D)

In order for Singapore to overcome future energy challenges, it has to transform itself into a green and low-carbon economy. As such, the government is developing capabilities in science and technology, and encouraging companies and research institutes to test-bed innovative solutions adapted for the tropics. It further provides support for the commercialisation and adoption of these technologies. Apart from creating jobs, Singapore will benefit from the energy and urban solutions developed through RD&D.

> *The world needs more research into new and sustainable energy solutions. So far, the research into energy technologies has been episodic. Each time oil prices shoot up, there is a surge of new initiatives and monies. But when oil prices come down, funding peters out and the efforts are abandoned. What we need is a sustained research effort to develop and improve new technologies, to drive down costs and to accelerate the deployment of promising new techniques and solutions. And only then can we make significant breakthroughs to transform the world's entire energy system.*[93]
>
> Prime Minister Lee Hsien Loong

The NCCS and National Research Foundation (NRF) commissioned seven Technology Roadmaps on carbon capture and storage, solar photovoltaic, green data centre, building energy efficiency, industry energy efficiency, waste management and e-mobility, to guide pathways in RD&D, and deployment of technologies. Each roadmap was developed by a leading government agency in consultation with stakeholders from the government, private sector and academia. The aim was to address industry-relevant challenges and opportunities, which would lead to long-term solutions for Singapore's energy challenges.

To support sustained research, the government also committed $19 billion to the Research, Innovation and Enterprise (RIE) 2020 plan for the period 2016–2020. Under this plan, $900 million was set aside for Urban Solutions and Sustainability, which includes competitive grant calls to catalyse applied RD&D of innovative energy technologies and solutions. Over the past few years, EMA has awarded over $60 million to over 25 companies and 11 Institutes of Higher Learning/Research Institutes under the RIE2015 Energy Innovation Research Programme (EIRP). Under RIE2020, EMA will build on the momentum and focus RD&D efforts in three areas: power utilities, energy storage and smart grids that will meet Singapore's energy needs.

The National Energy Transformation Office (NETO) was set up within EMA to better synergise efforts across agencies and steer Singapore towards its long-term energy objectives. NETO adopts a whole-of-government perspective in planning and coordinating energy RD&D funding and initiatatives, and in enabling policies for the adoption of transformational energy solutions.

While many new technologies and energy services could potentially benefit consumers and the energy sector, they often do not comply with existing regulatory requirements. In addition to the government's efforts in providing infrastructure for technology test-beds, EMA, as industry regulator, also constantly reviews the regulations and works in close consultation with the industry. In 2017, EMA launched a Regulatory Sandbox to encourage innovations.[94] Under this initiative, innovators can carry out experimentation in the electricity and gas market and be subject to less stringent regulatory treatment.

Besides catalysing the various R&D innovations, it is imperative to ensure that these developments are backed by a competent pool of professionals, and that the existing and future workforce are continually trained with emerging technical skillsets and competencies to stay relevant. Hence, the government continues to forge new and strengthen existing partnerships with the industry, union and institutes of higher learning, to build capacities and capabilities in the sector, and ensure a ready pipeline of professionals for the energy sector. As of 2016, the green economy has generated 60,000 jobs and contributed $6.2 billion to the nation's GDP.[95]

TOWARDS INTEGRATED SYSTEM-LEVEL SOLUTIONS

In the search of effective energy and urban solutions for Singapore, the government has increasingly recognised the need for an integrated, system-level approach.

The Urban Solutions and Sustainability domain of the RIE 2020 Plan seeks to harness synergies arising from the nexus between energy, water and land, to optimise resource and energy efficiency at the systems level rather than in separate subsystems and sectors.[96] For instance, treatment facilities for waste and water can be co-located to reap benefits such as reduced land use, and sharing of feed and waste streams.[97] The government, in collaboration with NUS, also looked into harvesting cold energy from LNG to desalinate water, which would otherwise be wasted if not utilised.

On the land-energy nexus, the government is looking into better use of underground space. For example, Singapore will be building its first 230 kV underground substation at the former Pasir Panjang Power District, integrated with a commercial building above it. Such integrated development, if applied to more substations in the future, will collectively free up substantial land space. In the past, there was a lack of a systematic approach to the use of underground space. The infrastructure, electricity cables and water pipes underground were mostly developed and laid on a first-come-first-served basis. As a result, the underground space is not well-optimised.[98] On this front, the government is developing a 3D Underground Master Plan to facilitate planning and development of above and underground infrastructure more holistically and seamlessly.[99] This will also ensure that underground space can be better optimised by building more supporting infrastructure for utility, storage and transport purposes, and as a result, free up above-ground land for homes, amenities and greenery, which are intrinsic to good quality of life.

SMART NATION VISION

Singapore launched its Smart Nation initiative in 2014, a movement to harness technologies as the means to improve citizens' quality of life, strengthen community cohesion and create more opportunities for the people and economy to prosper.[100] In the energy sector, the use of data analytics, networks, and information and communication technologies (ICTs) can provide opportunities to improve services by the utility providers, facilitate the adoption of renewable energy sources, support energy efficiency, and enable people to lead more sustainable and comfortable lives. More broadly, it can result in a cleaner energy system for Singapore, where risks and trade-offs between reliability, cost competitiveness and environmental sustainability can be assessed and managed more intelligently and robustly.[101]

In the RIE 2020 Plan, the government channelled funding on RD&D to advance the Smart Nation Vision, and promote smart and clean energy systems. As a case in point, the Energy Grid 2.0 programme was launched to create a more robust, flexible and responsive energy grid of the future. The programme will look to adopt and integrate multiple sources of energy, including renewables, across electrical, gas and thermal networks, as a single intelligent, reliable and resilient system.

Digitalisation can also benefit multiple end-use applications from the demand side—in areas such as homes, buildings, transportation and manufacturing sectors—to promote optimised use of energy.[102] For example, EMA launched the Project OptiWatt, a pilot programme involving 16 partners, which examines how ICTs, coupled with studies on energy pattern usage, can help retailers explore incentive schemes. These include compensation to nudge consumers to avoid consumption during peak periods. In this way, consumers can benefit from lower electricity bills while operators can achieve peak shaving.

A SYSTEM-LEVEL SOLUTION: DISTRICT COOLING IN MARINA BAY

The underground District Cooling System (DCS) in Marina Bay is an example of a system-level solution that contributed to Marina Bay's transformation into a world-class business, financial and entertainment hub. DCS provides cooling to a district of buildings, using a network of underground piping to distribute chilled water from a centralised plant.

Currently, the Marina Bay DCS—the world's largest underground DCS—comprises two centralised chilled water plants connected to a five-kilometre network of chilled piping. The underground chilled piping is housed in the Common Services Tunnel for ease of maintenance and operation.

The plants together produce 600 tonnes of chilled water per hour, serving customers in the Marina Bay Sands integrated resort (MBSIR), the Marina Bay Financial Centre and One Raffles Quay. The first DCS plant is located at One Raffles Quay, and the second plant, at MBSIR, is the deepest in the world. Both enable the use of less productive or otherwise unusable underground space.

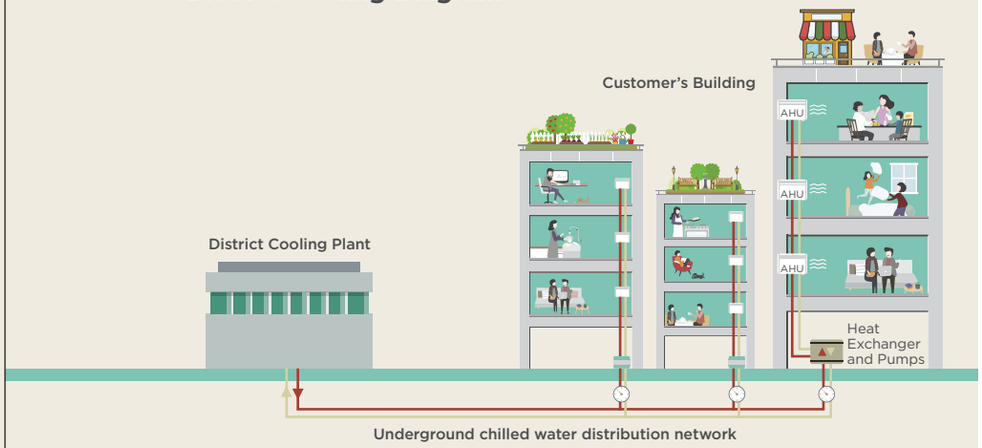
There are three main benefits to using DCS in Marina Bay.

1) **Freeing up valuable space in buildings and rooftops**

   Prior to the introduction of DCS, buildings were mostly cooled using conventional In-Building Chiller Plants. Each building would have its own chilled water system, consisting of a chiller plant room within the building, and cooling towers located on the rooftop for heat removal.

Exhibit 9

District Cooling Diagram



DCS removes the need for each building to have its own cooling towers and chillers. Instead, an exchange station allows heat transfer between chilled water from the DCS and the building's air-conditioning system.

This frees up valuable floor and rooftop areas within the building for more productive uses. For example, rooftops can be transformed into creative and social spaces for people to enjoy. MBS's iconic infinity pool is an example of how DCS made it possible for Marina Bay to have a more distinctive ambience and beautiful skyline, with consideration that some users are counted as Gross Floor Area.

2) **Lower capital investment and maintenance costs**

   Without the need to install cooling towers and chilled water plants in individual buildings, developers can cut down on capital expenditure. Building owners and operators enjoy lower maintenance costs, and can use smaller electricity supply systems. Each building operator pays the DCS supplier for cooling services.

A SYSTEM-LEVEL SOLUTION: DISTRICT COOLING IN MARINA BAY

Continued...

3) **Asset and energy efficiency due to flexibility and economies of scale**

DCS is more energy-efficient than the typical direct expansion air-conditioning systems in most buildings with lower demand. However, DCS tends to be less energy-efficient compared to the newer, individual building chiller plants which are properly operated and well-maintained.

Despite this, from an overall perspective, DCS has greater economies of scale, and the cooling capacity of the central plant can be raised incrementally when cooling demand from the network increases. In practice, developers or building owners often have difficulty choosing the most efficient technologies for their individual building chiller plants or operate them optimally, as tenant and business models tend to change overtime. They may also install higher-capacity chillers than initially needed, to prepare for anticipated future cooling demand. This results in lower efficiency.

Other benefits of the DCS system-level approach includes the use of thermal storages to provide continuous and reliable supply in cooling even in the event of electricity disruption, and harnessing of the waste heat from the DCS chiller at MBSIR to heat water for the 2,500 hotel rooms and kitchens.

DCS has significant overall benefits in terms of saving land and building space, particularly in a dense city like Singapore. With its integrated nature, the Marina Bay DCS is a good example of a system-level solution. Sound governance, implementation and regulation were critical for the DCS to succeed. URA worked with the operator to develop a good public–private partnership to manage risks, while appropriate regulations under the purview of EMA ensured stability and fairness for the suppliers, developers and end users.

CHAPTER 7

CONCLUSION

Energising Singapore: Balancing Liveability and Growth gives an overview of Singapore's journey in providing good energy services to its people and industries. A reliable energy supply is critical to both quality of life and a competitive economy—as well as a city's liveability. While energy is intangible, the infrastructure and systems that allow its generation, transmission and distribution to the businesses and households, as well as the facilities that enable the import and processing of fuels and feedstocks, are physical, and they constitute a key part of Singapore's built environment and critical infrastructure.

Over the decades, government agencies have worked hard to build up these infrastructures and engineering systems while carefully managing the trade-offs between energy security, affordability and environmental sustainability. These achievements did not come easy as Singapore, being an island city-state, is uniquely constrained by its limited land space and lack of natural resources. Over time, the energy sector has evolved significantly, in response to new government policies and the nation's changing needs.

Back in the 1960s, Singapore was underdeveloped and many areas had little or no access to electricity. The focus then was to prioritise resources to ensure areas planned for industrialisation and public housing could be plugged into the electricity grid with reasonable reliability. At the same time, the government was determined to provide electricity supply to people in the rural areas progressively. With access to electricity, businesses grew and Singapore's economy prospered. Then, in the 1970s, the issue for Singapore shifted to supply inadequacy. PUB had to increase the capacity of the energy systems and overcome manpower shortages while ensuring proper financing of energy infrastructure projects in order to catch up with the rapidly growing demand. But moving into the 1980s, Singapore's focus shifted to improving citizens' quality of life and restructuring the economy—this translated to higher expectations for reliable and good-quality electricity supply.

During this time, the government had to strike a balance between improving system reliability and maintaining the affordability of electricity for households and businesses. From the 1990s till the present, many countries are responding to the global issues of energy supply disruptions and climate change by adopting energy efficiency as part of their energy policies and strategies. Singapore itself now employs a more holistic and integrated approach to looking at energy policies across the whole-of-government.

To date, Singapore has overcome the various energy challenges that have accompanied its different stages of development. Its achievements would not have been possible if not for the government's long-term integrated planning approach, sound governance and policies to support the growth of energy systems.

POST-SCRIPT

Energy plays an indispensable role in our economy and in our everyday life. With limited energy resources of its own, Singapore has always had to grapple with this energy trilemma—how do we ensure a secure supply of energy that is not only competitively priced and affordable, but also sustainable in the long term? Our task has been made more challenging by changing geopolitical forces, rapidly developing technology trends, and rising demands of a growing economy and population.

In response, we have transformed various aspects of our energy sector over time. One of the most significant shifts was the change to our energy sources. In the 1990s, we began switching from fuel oil to natural gas for electricity generation. Today, about 95% of Singapore's electricity is generated using natural gas.

To diversify our sources of natural gas, we built our first Liquefied Natural Gas (LNG) Terminal in 2013 so that we can import natural gas from around the world. The LNG Terminal successfully expanded its capacity to 11 million tonnes per annum (Mtpa) in 2018, and it is capable of fully meeting the nation's current total gas demand. With Singapore's strategic location and LNG infrastructure, we are working to establish ourselves as a regional gas trading hub.

We have also transformed our electricity market. This began in 1995 with the corporatisation of the electricity industry and the establishment of the electricity wholesale market in 1998. In our drive for competitive energy prices and to improve efficiency, the retail electricity market was progressively liberalised from 2001. Consumers in the commercial and industrial sector have been able to buy electricity from a retailer of their choice, enjoying choice and flexibility in their electricity purchases to better manage their consumption.

These benefits will be extended to the rest of Singapore when market liberalisation enters its final phase with the rollout of the Open Electricity Market. Starting from 1 November 2018, about 1.4 million consumers, mostly households, will get to enjoy more choices and competitive pricing in electricity price plans. At the same time, they will continue to receive the same reliable electricity supply from the national power grid.

The impact of technological developments and new business models has led to changes in the way the Energy Market Authority (EMA) regulates and develops the energy sector. One example is the solar industry. EMA took the lead to streamline regulations and worked with multiple agencies such as the Economic Development Board and Housing and Development Board to drive solar adoption. The SolarNova programme has catalysed our solar photovoltaics (PV) industry by aggregating solar demand across government agencies. Our efforts have contributed to the rapid growth in solar adoption, reaching around 162 megawatt-peak (MWp) today—up from 0.4 MWp in 2008. Beyond 2020, we aim to raise solar adoption to 1 gigawatt-peak (GWp), enough to power about 200,000 four-room HDB flats for a year. This will help meet our climate change pledge to reduce our emissions intensity by 36% from 2005 levels by 2030.

Technological advances are fast changing the energy landscape. While Singapore has one of the world's most stable and reliable power systems, this cannot be taken for granted. Emerging trends, such as distributed generation of energy and smart grids, are altering the traditional roles of power generators and consumers in the way we generate, distribute and use energy.

To support sustained research and innovation to enhance our energy security, the government will focus research and development (R&D) efforts on smart grids, power utilities and energy storage. We have also been building up Singapore as a "living lab", where companies can partner energy players to test-bed and pilot innovative urban solutions, including future energy technologies. For instance, the urban micro-grid at the Singapore Institute of Technology's new campus will integrate gas, electricity and thermal energy in a unified smart energy network. Such solutions may enable more renewables to be integrated into our power grid and optimise energy use, while maintaining system stability.

We will also continue to facilitate the growth of the clean energy sector by investing in research, development and demonstration (RD&D), facilities and manpower development. Various government agencies are working with the private sector to develop research focused on areas such as solar PV, energy storage and utilisation, energy efficiency and waste-to-energy. To better align these efforts, the National Energy Transformation Office (NETO) was set up in 2017. NETO will be taking on a whole-of-government perspective in planning and coordinating energy RD&D funding and initiatives.

Inevitably, emerging technologies and energy services may not comply with existing regulatory requirements. Hence, EMA works closely with the industry to review our regulatory frameworks. In 2017, EMA launched a regulatory sandbox to encourage energy innovations. This will give innovators a "safe space" to test their energy solutions. The sandbox will complement ongoing energy R&D initiatives, while allowing EMA to assess their impact before deciding on the appropriate regulatory treatment.

New developments and innovations in the energy sector also mean that we need our people to deepen their skills and stay ahead of the curve through continuous learning. We have put in place a national skills framework to ensure our workforce is equipped to handle the challenges of the energy sector in the future. We are also working closely with various partners such as SkillsFuture Singapore to create multiple alternate pathways and encourage lifelong skills deepening.

The energy sector will continue to change and transform. The government will need to work with industry, academia and the community to find solutions to our current and future challenges. Together, we can co-create innovative solutions to build a vibrant economy with cheaper, cleaner energy with the same level of reliability, and make Singapore a better home for Singaporeans.

Ngiam Shih Chun
Chief Executive Officer
Energy Market Authority

ENERGISING SINGAPORE: BALANCING LIVEABILITY AND GROWTH

Before 1960

1906
- Street lighting was first introduced in a few selected places in the central part of Singapore.
- Beginnings of bulk electricity supply: Singapore Electric Tramway Company's power station supplied electricity in bulk to the Municipality, which then sold it to consumers.

1924
- Construction of Singapore's second power station: St James Power Station.

1952
- Commissioning of Pasir Panjang "A" Power Station, which was critical to meet post-war demand for electricity.

1960s

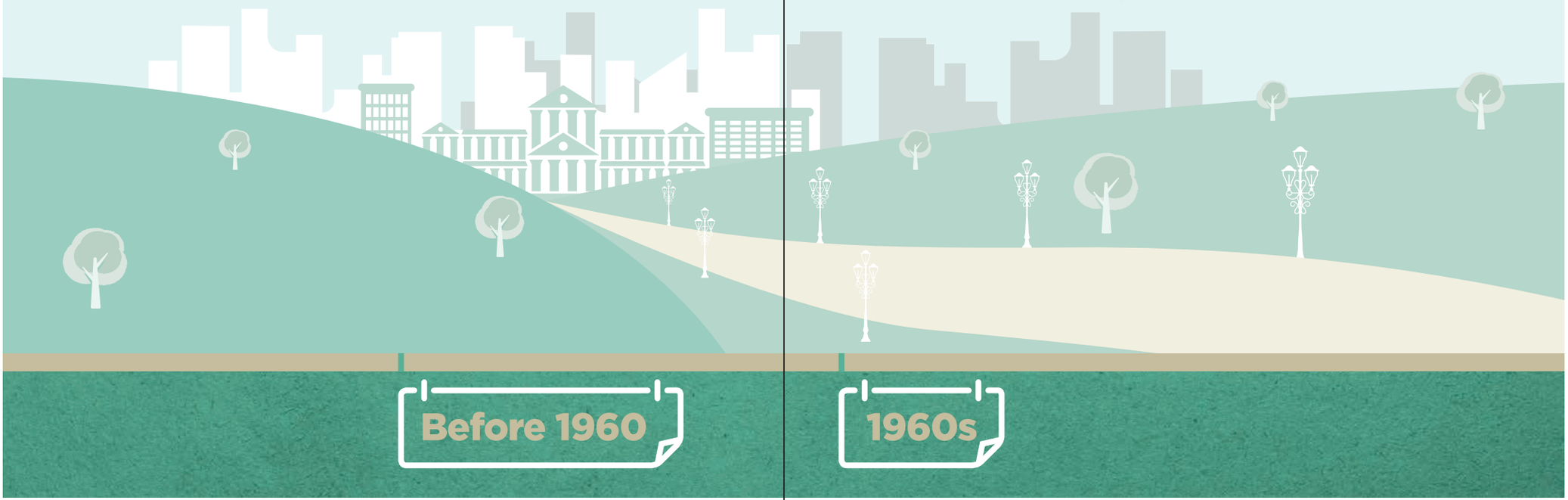
Early 1960s
- Approval of proposal by Lawrence Estrop, then-Chief electrical engineer, to shift overhead cables underground.

1961
- Formation of the Economic Development Board.
- First oil refinery opened in Pulao Bukom by Shell Refining Company (Singapore) Limited.

1963
- Rural Electrification Programme was implemented to increase accessibility of electricity to rural areas.
- The Public Utilities Board was formed to take care of Singapore's water, gas and electricity needs.

1965
- Pasir Panjang "B" Power Station was opened by then-Prime Minister Lee Kuan Yew. This was an expansion of the Pasir Panjang "A" Power Station to generate more electricity for Singapore's rapid industrialisation.

1969
- The government spent $1 million yearly to subsidise remote kampongs that were far from the power grid, to bring power and light to every home.



1970
- Jurong Power Station was opened by then-Minister for Finance, Dr Goh Keng Swee.

1972
- Electrical fire broke out at Robinsons Department Store. This kickstarted the introduction of stricter safety regulations.

1973
- Rural Electrification Programme was completed with a total spending of nearly $20 million and benefiting more than 200,000 people.

1975
- Enacting of Electrical Workers and Contractors Licensing Act, Electrical Workers and Contractors Licensing Regulations, Licensed Installations Regulations, Electricity Supply Regulations and Electricity Regulations.

1977
- Senoko Power Station was opened by then-Minister for Foreign Affairs S. Rajaratnam.

1979
- Setting up the nerve centre. The PUB installed a new computerised energy management system at the Ayer Rajah substation.
- PUB introduced the Supervisory Control and Data Acquisition System (SCADA) for remote control and monitoring of power networks.

1970s

1983
- St James and Pasir Panjang "A" Power Stations were decommissioned.

1985
- Mandatory for all new homes to be fitted with high-sensitivity Earth Leakage circuit breakers.

1988
- Pulau Seraya (now a part of Jurong Island) became home to Singapore's first offshore power plant with three 250MW generating steam plants.

1980s

1995
- PUB's electricity and piped gas undertakings were corporatised on 1 October 1995, to introduce competition into the energy market.
- Singapore Power incorporated as a commercial entity to take over the business of supplying gas and electricity from the PUB.
- Reclamation project to form Jurong Island started.

1998
- Power Grid Ltd started the Singapore Electricity Pool as a wholesale electricity market to facilitate competitive bidding between generation companies.
- Formation of Inter-Agency Committee on Energy Efficiency.

1999
- National Energy Efficiency Report was presented in Parliament.
- Tuas Power Station commenced operations.

1990s

2001
- Energy Market Authority was set up to oversee the liberalisation of the electricity and gas industries.
- About 250 consumers with electricity demand of 2 MW and above became contestable in July 2001 and could choose which supplier to buy their electricity from.
- The Energy Market Company (EMC) was formed to oversee the operation and administration of the electricity market.

2003
- Fuel Economy Labelling Scheme was implemented.

2004
- Vesting contracts were introduced by the EMA to prevent private energy generators from abusing market power.

2005
- Launch of BCA's Green Mark Scheme.

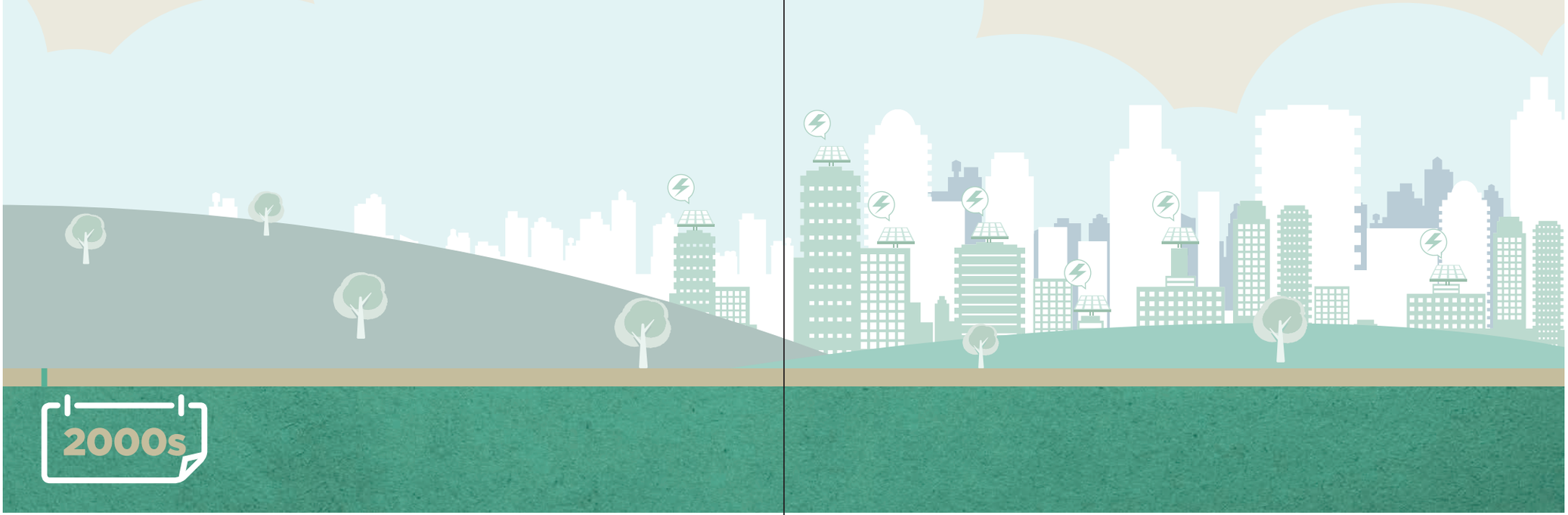
2006
- Formation of Energy Policy Group, the first inter-ministerial committee looking at energy policy at the whole-of-government level.

2007
- National Environment Agency set up an inter-agency Energy Efficiency Programme Office E2PO in six priority areas: power generation, industry, transport, buildings, the public sector and households.
- Mandatory Energy Labelling Scheme (MELS) was introduced.

2008
- Tuas Power announced it would build a steam-and-electricity plant running on biomass (plant matter, mostly wood chips and palm kernels) and coal from the region.
- Start of the Singapore International Energy Week, an annual platform involving energy professionals and policymakers to discuss and share best practices on pertinent energy-related issues.

2009
- EMA introduced new system of pegging electricity tariffs to the average of fuel prices in the previous three months.
- EMA set up Singapore LNG Corporation Pte Ltd in June to build, own and operate Singapore's first LNG terminal.
- Start of EMA's Intelligent Energy System towards an integrated smart grid in Singapore.
- EMA and LTA co-chaired a taskforce to oversee the Electric Vehicle test-bedding programme and assess the viability of EVs in Singapore.

2009–2011
- HDB announced and began a $31 million, five-year trial of solar power at 30 HDB precincts; solar energy will power lights at common areas such as stairwells.



2000s

2010

- Construction of Singapore's first LNG terminal.
- EMA and EDB co-chaired the Energy Innovation Programme Office (formerly the Clean Energy Programme Office) to promote research and development in the energy sector.
- EMA and the National Research Foundation co-chaired the National Innovation Challenge in Energy Resilience for Sustainable Growth to promote the development of cost-competitive energy solutions to help Singapore improve energy efficiency, reduce carbon emissions and increase energy options.

2012

- Singapore Power announced a $2 billion infrastructure project to build a 60-metre underground cable tunnel.
- Energy Conservation Act was enacted.
- Formation of an industry-led Power Sector Manpower Taskforce to identify and recommend strategies to build up manpower capacities and capabilities, to address an ageing workforce in the power sector.

2013

- Singapore' first Liquefied Natural Gas (LNG) Terminal became operational.
- Carbon Emission-based Vehicle Scheme was introduced.

2014

- EMA announced a $20 million Energy Training Fund to help build a strong core of local technical professionals for the power sector.
- Launch of SolarNova Programme.

2015

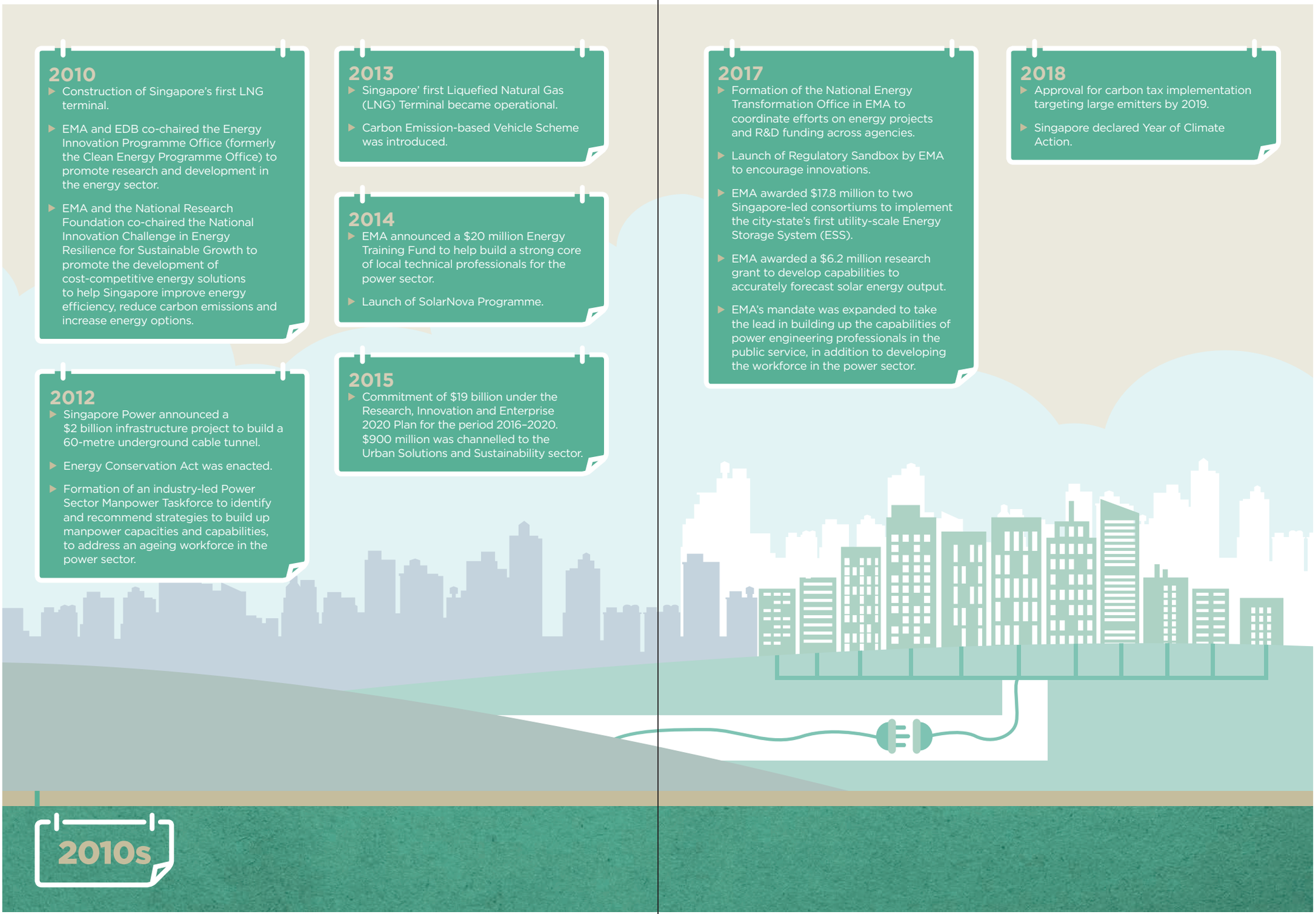
- Commitment of $19 billion under the Research, Innovation and Enterprise 2020 Plan for the period 2016–2020. $900 million was channelled to the Urban Solutions and Sustainability sector.

2017

- Formation of the National Energy Transformation Office in EMA to coordinate efforts on energy projects and R&D funding across agencies.
- Launch of Regulatory Sandbox by EMA to encourage innovations.
- EMA awarded $17.8 million to two Singapore-led consortiums to implement the city-state's first utility-scale Energy Storage System (ESS).
- EMA awarded a $6.2 million research grant to develop capabilities to accurately forecast solar energy output.
- EMA's mandate was expanded to take the lead in building up the capabilities of power engineering professionals in the public service, in addition to developing the workforce in the power sector.

2018

- Approval for carbon tax implementation targeting large emitters by 2019.
- Singapore declared Year of Climate Action.



2010s

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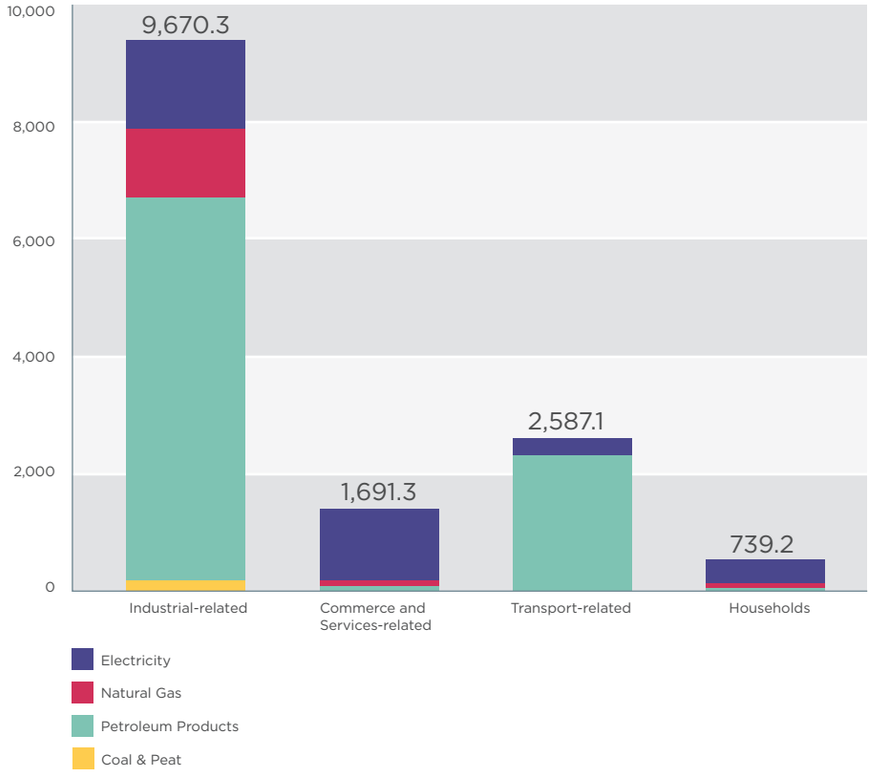
APPENDIX A

Total energy consumption by sector and energy product, 2016

Unit: kilotonne of oil equivalent (ktoe)



Each component in the chart above is ordered according to the legend.

Source: Singapore Energy Statistics 2018.

APPENDIX B

Governance Tools of Singapore's Energy Story

(I) Legal Instruments

Tool	Description
Energy Market Authority of Singapore Act 2001	The act enables the Energy Market Authoriy of Singapore to be conferred the powers to regulate the electricity industry.
Electricity Act	An act to create a competitive market framework for the electricity industry, to make provision for the safety, technical and economic regulation of the generation, transmission, supply and the use of electricity, and for other matters connected therewith, to repeal the Electrical Workers and Constractors Licensing Act, and to make consequential amendments to certain written laws.
Energy Conservation Act	An act to mandate energy efficiency requirements and energy management practices to promote energy conservation, improve energy efficiency and reduce environmental impact, and to make consequential and related amendments to certain other written laws.

(II) Executive Policies

Tool	Description
National Energy Policy Report Energy for Growth announced by the government in 2007	Aims to carry out three main policy objectives: Economic competitiveness, Energy security and Environmental sustainability. Policy objectives were translated into six strategies: Promote competitive markets; Diversify energy supplies; Improve energy efficiency; Build energy industry and invest in R&D; International cooperation and Whole-of-Government Approach.
National Climate Change Strategy 2008 and 2012	The strategy report presents Singapore's current and future efforts to address climate change in vulnerability and adaptation, and mitigation of greenhouse gas emissions.
Singapore's Climate Action Plan (2016)	This action plan sets out the strategies to make Singapore more carbon-efficient.
Sustainable Singapore Blueprint 2009 and 2015	The blueprint outlines the national vision and plans for a more liveable and sustainable Singapore.

(III) Institutions

Tool	Description
Energy Market Authority (EMA)	EMA is a statutory board under the Ministry of Trade and Industry. The EMA's main goals are to promote effective competition in the energy market, ensure a reliable and secure energy supply, and develop a dynamic energy sector in Singapore. Through its work, the EMA seeks to forge a progressive energy landscape for sustained growth.
Public Utilities Board (PUB)	In 1963, the Public Utilities Board (PUB) was established to take over the responsibilities of the City Council in supplying electricity, water and gas in Singapore. It "turned on" the lights in kampongs with the rural electrification plan from 1963 to 1969. It also oversaw much of the country's growth in electricity usage in the post-independence years.
Energy Division, Ministry of Trade and Industry	The Energy Division (ED) of the Ministry of Trade and Industry develops and manages Singapore's overall energy policy, with the aim of supporting economic growth and addressing energy security, economic competitiveness and environmental sustainability. ED also oversees the development of the energy industry and energy research and development, and performs energy economics analysis. It works closely with EMA, Economic Development Board, Agency for Science, Technology and Research, and Enterprise Singapore, as well as external agencies such as the Ministry of Environment and Water Resources, Ministry of Foreign Affairs, National Environment Agency, Land Transport Authority and Building & Construction Authority. ED also works closely with EMA in setting the strategic direction and policies for energy security and the electricity and gas markets. In addition, ED oversees bilateral and international energy engagements in key multilateral forums such as ASEAN, the East Asia Summit and APEC.
Energy Policy Group (EPG)	EPG is responsible for the formulation and coordination of energy and energy-related policies and strategies. It comprises senior representatives from the Ministry of Finance; Ministry of Foreign Affairs; Ministry of the Environment & Water Resources; Ministry of Trade and Industry; Ministry of Transport; Agency for Science, Technology and Research; Building and Construction Authority; Economic Development Board; Energy Market Authority; Land Transport Authority; and the National Environment Agency. Since March 2006, the EPG has studied a wide range of energy issues, including the power and transport sectors; energy efficiency; climate change; energy industry; energy R&D; and international energy cooperation.
National Climate Change Secretariat (NCCS)	NCCS was established in 2010 under the Primie Minister's Office to develop and implement Singapore's domestic and international policies and strategies to tackle climate change.
National Environment Agency (NEA)	NEA is the leading government agency responsible for keeping Singapore clean and green. It implements a range of environment-related programmes and initiatives, which includes promoting energy efficiency and energy conservation.
Energy Efficiency Programme Office (E2PO)	The E2PO is a multi-agency committee, led by NEA and EMA, to promote and facilitate the adoption of energy efficiency in Singapore.
Singapore Power (Currently known as SP Group)	Singapore Power is the corporatised entity of the former electricity and gas departments of the PUB. It now owns and operates electricity and gas transmission and distribution businesses in Singapore and Australia.

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