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Decarbonising The Power Sector Towards A Low-Carbon Future

Overview

With the power sector accounting for around 40% of total emissions in Singapore according to the Energy Market Authority ("EMA"), reducing carbon emissions in the power industry is crucial if Singapore wants to reach its 2050 net zero carbon climate goal. Transitioning towards a more sustainable future for the power sector will likely include an increase in energy production efficiency, the rise in solar power use and the importing of clean energy through regional power grids as some of the immediate trends in power generation. Future trends may include hydrogen power, carbon capture technology and nuclear power. There may also be possible risks during this transition period including the risk of stranded assets.

Industry overview

Singapore's power industry can be divided into three segments: generation, distribution, and transmission, and retailing of electricity.

Electricity is generated by power plants run by power generation companies. The seven main generation companies, or gencos, in Singapore include: Tuas Power, Senoko Energy, YTL PowerSeraya, Keppel Merlimau Cogen (jointly owned by Keppel Infrastructure Trust as well as Keppel Corporation Ltd ("KEP," indirectly via KEP' subsidiary)), Sembcorp Cogen (owned by Sembcorp Industries Ltd ("SCI")), PacificLight Power, and Sunseap.

Power distribution and transmission in Singapore is largely managed by Singapore Power Limited or SP Group and its subsidiaries ("SP Group"). SP Group is 100% owned by Temasek, an investment holding company that is in turn 100% owned by the Singapore government. SP PowerGas is the sole licensed gas transport and system operator. As the owner of all of Singapore's gas pipelines, they deliver gas to users through its gas pipe network. As the holder of the Transmission License and owner of Singapore's electricity transmission and distribution network, SP PowerAssets Ltd is the lone provider of electricity transmission and distribution services in Singapore. The electricity network is also managed and operated by another of SP Group's subsidiaries, SP PowerGrid.

In Singapore's electricity retail market, SP Services of SP Group sells electricity directly to non-contestable consumers while electricity retailers sell to contestable consumers. With the liberalisation of the Electricity Retail Market in 2018, one would expect an increase in competition. However, given the economies of scale and financial resilience required of retailers to ensure their ability to provide services over a long term, the market has developed in a way where the main players left in the market are the retail arms of power generation companies. Some retailers left in the market include: Geneco (by Seraya Energy Pte Ltd), Keppel Electric Pte Ltd, Sembcorp Power Pte Ltd, Senoko Energy Supply Pte Ltd, and Tuas Power Supply Pte Ltd.

Sustainability trends

Immediate trends

Over the last 50 years, Singapore has moved from oil to natural gas as its main source of power generation. Currently, around 95% of Singapore's electricity is generated from natural gas (EMA, 2022), which is already considered to be one of the cleanest forms of fossil fuels. Additionally, recent years have also seen a rise in the use of solar energy. Even with a large majority of Singapore's electricity generated from a relatively clean form of fossil fuel, and a falling Grid Emission Factor ("GEF"), which measures average CO_2 emissions emitted per MWh of electricity generated, the power sector still remains one of the major sources of carbon emissions.

With Singapore's vulnerability to the consequences of climate change, it comes as no surprise that Singapore has such a strong vested interest in tackling climate change. Nowhere is this interest more evident than in Singapore's participation in the United Nations Framework Convention on Climate Change. In 2009, under the Copenhagen Accord, Singapore pledged to reduce emissions by 16% from business-as-usual levels by 2020. In 2015 under the Paris Agreement, Singapore further pledged to reduce Emission Intensity ("EI"), the amount of greenhouse gasses emitted per dollar GDP, by 36% from 2005 levels by 2030 and stabilise greenhouse gas emissions, aiming to peak around 2030. In October 2022, Singapore announced that it would achieve net zero emissions by 2050, in line with the Glasgow Climate Pact signed at COP26 in November 2021.

In line with Singapore's climate goals, the Carbon Pricing Act ("CPA") and its accompanying regulations were introduced on 1st Jan 2019. Under the CPA, reportable facilities will have to pay a carbon tax from 1st Jan 2019 onwards for reckonable GHG emissions. The carbon tax is currently set at a rate of SGD5/tCO_2e from 2019 to 2023. The carbon tax rate is expected to be raised to SGD25/tCO_2e in 2024 and 2025, SGD45/tCO_2e in 2026 and 2027, with a view to reach SGD50-80/tCO_2e by 2030. Due to their status as reportable facilities under the definitions set out in the CPA, power generation companies and electricity retailers, the backbone of Singapore's power industry will have to bear these rising carbon taxes in the years to come, especially if they are unable to pass down the full cost to consumers. As such, with this rising pressure to reduce carbon emissions on the part of power generation companies, we can expect that the power industry will begin to pivot away from its current methods of electricity production towards low-carbon power generation methods and alternatives.

Energy production efficiency

Given the pressure that power companies face to reduce their carbon emissions, it may seem like low-carbon alternatives such as hydrogen, ammonia, and even nuclear should be the next step. However, there are gaps and uncertainties in the immediate adoption of some of these alternatives such as a lack of infrastructure, technological readiness, commercial viability, and security of supply of raw materials. With the industries of these low-carbon alternatives still in their infancy, natural gas is still needed, at least in the near future, to ensure a reliable supply of electricity as Singapore transitions to cleaner sources of renewable energy. In the meantime, we can expect a trend of power generation companies improving the efficiency and sustainability of their gas-fired power generation.

Over the next five years, power plants that supply over one quarter of Singapore's total power generation capacity are expected to reach the end of their life span (Straits Times, 2022). Given the likelihood that Singapore will continue to remain reliant on natural gas as an energy source for now, investing in newer and more efficient advanced Combined Cycle Gas Turbines ("CCGTs") is crucial to Singapore's goals of reducing carbon emissions and improving generation efficiency, especially in the near term.

We are already seeing the EMA supporting the improvement of the overall generation efficiency of existing CCGTs, launching an Energy Efficiency Grant Call for Power Generation Companies ("Genco EE Grant Call") in 2018 and a subsequent round of grant call in 2021 (EMA, 2022). This grant call reimburses power generation companies up to 50% of the qualifying costs including equipment, materials and consumables, technical software, and professional services to improve overall generation efficiency and achieve carbon abatement.

In 2020, the EMA awarded four gencos a total of SGD23 million through the Genco Energy Efficiency Grant to take on energy efficiency projects to reduce their carbon emissions. It is expected that the completed projects would achieve carbon abatement of more than 30,000 tonnes per year, which is roughly equivalent to removing around 9,200 cars off roads annually. Additionally, in 2021, PacificLight Power was one of the recipients of the Genco Energy Efficiency Grant and was able to contract Siemens Energy to implement the latter's Advanced Turbine Efficiency Package ("ATEP") to its power plant. Siemens Energy claims that their ATEP is able to deliver higher operational efficiency and significantly reduce carbon emissions equal to around 18,100 tonnes of CO_2 a year, which would cement PacificLight Power's 800MW Jurong Island plant's status as one of the most efficient gas plants in Asia. Additionally, PacificLight Power also signed a long-term service agreement with Siemens Energy which would increase the operational life span of the plant through upgrades. PacificLight Power's CEO, Yu Tat Ming, claims that the ATEP, coupled with various other energy efficiency improvements that the company has implemented, is expected to reduce their annual carbon emissions by over 40,000 tonnes per year, which is roughly equivalent to supplying over 20,000 Singaporean households with carbon-neutral electricity. These upgrades were slated to be completed in 2023 and 2024.

While improving the efficiency of current gas plants contributes to the reduction of Singapore's carbon emissions in the short term, this trend has some limitations, one of which is that improvements in technology to bring about lower carbon emissions are not available for all of Singapore's current sources of energy. The Tembusu Multi-Utilities Complex ("TMUC") is the first and only coal-burning utility plant in Singapore and its supply makes up around 1% of Singapore's power generation capacity. The plant only employs a mix of both low ash and low sulphur coal (clean coal) and biomass to account for environmental concerns, but when compared to gas plants, the plant's method of power generation is significantly more carbon intensive, producing twice as much carbon dioxide to natural gas. While it is technically possible to reduce carbon emissions of the plant by switching to 100% biomass and phasing coal out completely, the lack of domestic biomass resources as well as the lower calorific value of biomass compared to coal makes phasing out of coal in the short term impractical and costly (CNA, 2021). While technology has the potential to help decrease Singapore's carbon emissions in relation to its gas plants as the nation pivots toward low-carbon alternatives, we have to acknowledge that the same improvements in energy efficiency are simply not feasible for all sources of power, particularly coal. It is doubtful if the improvement of energy production efficiency alone is sufficient to achieve carbon emissions reductions that is in line with the overall national target, especially when we also consider that the energy production efficiency of gas plants may eventually plateau.

Rising risk of existing plants becoming stranded assets

As much as technology is able to improve the efficiency of Singapore's energy production, we also need to acknowledge that this trend is merely a transition stage. With the two-fold pressure of rising energy demands and the rigid timeframe to reach climate goals, the transition away from natural gas toward low-carbon alternatives introduces one key risk, which is the risk of current gas and fossil fuel centric energy production assets becoming stranded assets. Singapore's stance on gradually phasing out the use of fossil fuels as a source of power and aiming to achieve net zero emissions by 2050, signals to us that the next 10-20 years may entail massive overhauls in the power sector with large shifts away from the use of natural gas toward renewables. Consequently, we could expect that Singapore will inevitably have to switch off its younger gas plants before they reach the end of their lifespan. With significant funds and resources diverted to improving the energy efficiency of these plants presently, the power sector is faced with the potential risk of having a significant proportion of its assets and the additional improvements invested in these assets becoming obsolete.

Solar power

Often touted as the most promising source of renewable energy in Singapore, it is no surprise that solar power has seen a meteoric rise here over the last few years. From 2015 to 2020, the installed capacity of grid-connected solar PV systems or the maximum amount of electricity able to be produced grew significantly from 59.3 MWp (megawatt peak) to 443.6 MWp. By 2030, Singapore plans to expand solar PV production to 2 GW, which is over six times that of the current installed capacity, making up around 3% of Singapore's total electricity demand in 2030 (EMA, 2022). These goals are backed up by a significant push in the development and deployment of solar power projects from not only the Singapore government but companies as well.

Singapore clean energy genco, Sunseap (now 91% owned by Euronext-listed EDP Renewables), managed to secure an SGD85mn green loan from DBS Group Holdings Ltd ("DBS") and United Overseas Bank Ltd ("UOB"), with each bank providing half of the loan for its SolarNova 4 project. This loan is not the first time either bank has provided green financing to the company. The project is the largest clean energy project in Singapore's history, and is estimated to generate more than 90,000 MWh, which is roughly equivalent to supplying power to 20,400 4-room HDB flats, potentially offsetting more than 68,583 tonnes of carbon emissions per year (Sunseap, 2022). The loan uses Sunseap's green financing framework and is in line with the International Capital Market Association's Green Bond Principles 2018, the Loan Market Association's Green Loan Principles 2018, and ASEAN Green Bond Standards 2018.

With the rise in green financing supported by the banks as well as the government through various schemes such as the Enterprise Financing Scheme-Green ("EFS-Green"), we will continue to see a rise in sustainable projects, which would include an increase in solar PV projects like the SolarNova 4. The availability of funding as well as grant eligibility for companies is a significant step forward when it comes to the large-scale development and deployment of solar PV systems due to the high upfront costs associated with solar projects. Most of the solar PV installation projects planned for 2019 to 2030 are under government efforts under the SolarNova project led by the Housing Development Board ("HDB") and the Economic Development Board ("EDB"), with the goal of achieving economies of scale and accelerating the growth of Singapore's solar industry.

Addressing technological constraints of solar: Land scarcity

Another contributor to the rise of solar power in Singapore would be advancements in technology that address previously held concerns regarding the wide-scale adoption of solar power such as land scarcity and solar energy storage. While most PV solar panels in Singapore currently are largely out of sight, usually placed on rooftops, the utilisation of vertical spaces for solar PV installations has become increasingly prevalent. With less land mass required to house solar panels, solar power is becoming increasingly feasible here in Singapore. For example, the newly opened PSA terminal at Tuas port is integrated with photovoltaics, with vertical solar panels cladding the building's façade. The building was awarded the Green Mark Award (Platinum) and categorised by Singapore's Building and Construction Authority as a 'Super Low Energy Building.' The Tuas Maintenance Base Admin Building in particular is estimated to use 58% less energy compared to other small-sized buildings annually due to its various energy-saving and energy-efficient features. It will also be one of the first net-zero energy buildings in Singapore due to its solar panel clad exterior and roof solar panels. Additionally, another way Singapore has overcome land constraints with respect to solar projects is by deploying solar PV panels over water bodies to create floating solar farms. Consisting of 122,000 solar panels and spanning 45 hectares, the 60 MWp floating solar farm on Tengeh Reservoir opened in 2021 and is one of the largest floating solar farms globally with the potential to offset over 4,000 tonnes of carbon dioxide annually. With advancements in solar technology, we can expect that solar power will be increasingly integrated into Singapore's cityscape.

Addressing technological constraints of solar: Storage

The storage of solar energy is another complication in the large-scale adoption of solar power in Singapore. Unlike traditional fossil fuels, solar energy is a lot less predictable in terms of production. Seasonal fluctuations or even hour to hour changes in the weather or even cloud cover can affect energy production, and not to mention that solar energy can only be produced in the day. Resultantly, energy storage and its associated costs are long considered to be the pitfalls of solar power. However, with game-changing technology in Energy Storage

Systems ("ESS"), Singapore is one step closer to not only addressing the issue of solar intermittency but also to enhancing power grid resilience to manage the mismatch between power supply and demand. Recently, SCI was awarded an expression of interest ("EOI") issued by the EMA to build 200Mwh of battery storage systems on Jurong Island and is expecting to complete the battery energy storage system ("BESS") towards the end of 2022. The energy storage system has the potential to serve different functions over the two phases of its lifespan. The EOI details that in the first two years of its lifespan, the battery storage system is expected to provide spinning reserves to free up CCGT for power demand and supply management as Singapore continues to be reliant on natural gas as a source of power during the transition towards renewable energy. Thereafter it is also expected be used to mitigate solar intermittency and ensure grid reliability by providing frequency regulation for the remaining of its lifespan (EMA, 2022). Advancements in ESS technology is key to addressing solar intermittency and crucial for the long-term success of large-scale adoption of solar power in Singapore. With the EMA promoting the development of ESS through various incentives like the EOI, the Accelerating Energy Storage for Singapore (ACCESS) programme, and the Energy Storage Grant Call, we can expect EES and consequently solar power adoption to increase over the next few years.

Promising source of renewable energy but comes with waste

As bright as the future of a solar powered Singapore may seem, the ramping up of solar energy deployment to meet Singapore's climate goals is not without a downside. The co-founder and chief executive of EtaVolt, a solar tech firm, Dr Stanley Wang estimates that within the next two years, an estimated 5,000 tonnes of photovoltaic waste may be generated. High quality solar panels typically have a lifespan of around 20 to 25 years. However, beyond the 10-year mark, they generally are around 10% to 15% less efficient. As such, solar panels are expected to be deployed now to be replaced within seven to ten years or even shorter if they are damaged (Straits Times, 2022). Solar panel waste is particularly concerning not only because it is difficult to recycle, given that the glass of most PV modules is tainted with problematic impurities such as plastics, lead and cadmium, but also because solar panels contain toxic materials that bleed out as they break down. The combination of solar panels' short lifespan, its delicate nature, the difficulty in recycling PV modules, and the toxic waste they leave behind creates a perfect storm to introduce a slew of new environmental problems (Forbes, 2022). With the world potentially facing up to 78 million tonnes of photovoltaic waste by 2050, there is a dire need for improvements in solar panel recycling technology and the recycling process to avoid the swapping out of one climate crisis for another due to the rising trend of solar power.

Regional power grids

With no hydro resources, low wind speeds and mean tidal range, and limited land capacity, many traditional renewable options such as hydro power, wind power and geothermal energy are less viable in Singapore. However, there is still a way for Singapore to be able to access these cleaner forms of energy to stay in line with its national climate goals - Regional power grids. Singapore recently began importing renewable energy through the Lao PDR-Thailand-Malaysia-Singapore Power Integration Project (LTMS-PIP) for the first time and will continue to do so over the next two years. The LTMS-PIP currently imports up to 100MW of hydropower from Lao PDR to Singapore, which is roughly equivalent to 1.5% of Singapore's 2020 peak electricity demand (Straits Times, 2022). The purchase agreement between local electricity retailer and licensed importer Keppel Electric Pte Ltd (wholly owned subsidiary of KEP), and Lao's state-owned Electricite du Laos (EDL) marks the first multilateral cross-border electricity trade between four ASEAN countries. The integration project has the potential to further facilitate the development of a regional energy market and acts as a stepping stone towards the broader goal of an ASEAN power grid ("APG"), allowing for multilateral electricity trading in the region beyond neighbouring countries.

Beyond the LTMS-PIP, Singapore's effort to expand access to renewable energy in the region also includes conducting two rounds of Request for Proposal (RFP), RFP1 and RFP2, to import up to four gigawatts (GW) of renewable energy by 2035. Solar, wind, hydro, and geothermal power from countries in the region such as Indonesia, Laos, Malaysia, and Thailand are estimated to supply up to 30% of Singapore's projected electricity needs in 2035 (EMA, 2022). Under the second round of RFP (RFP2), the potential importers are required to demonstrate their ability to supply and manage the carbon output of their power generation, ensuring that emissions do not exceed 0.15 tCO_2e/MWh per year within five years of operations. To put this reduction in carbon emissions into perspective, Singapore's current average emission intensity is around 0.4080 tCO2e/MWh. Additionally, over the last two years, the EMA has been working with various partners aside from KEP on trials to import electricity, which helps EMA in the assessment and refinement of the frameworks and processes of importing electricity, ensuring that Singapore is ready to ramp up the importing of energy on a larger scale. Singapore may import power from Australia in the future via an undersea cable. As of November 2022, an Australian solar energy infrastructure company called Sun Cable has submitted a proposal for discussion with EMA (CNA, 2022).

The recent efforts in establishing frameworks for the importing of clean energy signals to us that we can expect regional power grids to play a larger role in Singapore's future of renewable energy. Moreover, with gencos like Keppel Electric Pte Ltd, YTL PowerSeraya Pte Ltd, and PacificLight Power Pte Ltd assuming the role of importers of energy from regional power grids, we can also expect that Singapore gencos will continue to expand and develop their infrastructure to better prepare for the ramping up of clean energy imports.

One of the distinguishing features of tapping into regional power grids as a source of clean energy is that the importing of energy is cost effective from Singapore's perspective. Regional power grids allow countries that have a surplus of renewable energy to trade with countries that lack the resources. With limited land mass and a lack of natural resources putting a cap on Singapore's ability to generate enough energy from renewable sources to meet its energy demand, Singapore is a prime example of a country that would benefit greatly from regional power grids. Given that increasing the carbon efficiency of natural gas plants is only expected to reduce carbon emissions by 10% (MTI, 2022) at best and that even if Singapore were to maximise all available spaces for solar deployment, Singapore would not be able to meet its energy demand, only relying on local sources of clean energy to meet climate goals could result in a strain to energy supply, inadvertently driving energy prices up. With the ability to import clean energy, Singapore would be able to tap on the abundance of clean energy from renewable energy powerhouse neighbours.

<u>Regional power grids can potentially provide energy consistency and reliability</u>

Regional power grids also have the potential to provide Singapore with energy consistency and reliability that simply cannot be achieved by only relying on local sources of clean energy. Given Singapore's resources, the only feasible local source of renewable energy is solar energy and considering both solar power's proclivity to be unreliable and less effective under certain weather conditions such as overcast and high temperatures and that solar energy systems only operate during the day, a lack of diversification in Singapore's clean energy sources introduces variability and systematic risk to energy supply. Importing energy however allows for Singapore to tap into the different advantages each country has in their renewable sources and technologies. Within the South-east Asia region itself, countries such as Laos, Indonesia and Vietnam generate a large proportion of their energy from various sources such as hydropower, geothermal energy, and wind power. Having access to a diverse mix of clean energy sources and consequently energy imports is crucial in ensuring that energy supply is kept consistent and reliable as Singapore transitions towards low-carbon energy sources.

<u>……however, exposes Singapore to supply shocks</u>

It should be noted that relying on cross-border trade for energy could expose Singapore to supply shocks in the case where export bans are put into place. In October 2021, Malaysia announced that they were barring exports of renewable energy to Singapore citing the need to develop its local renewable energy industry in order to meet their domestic sustainability targets (Straits Times, 2022). At that point in time, the EMA was weeks away from finalising plans of a two-year trial agreement to import 100 megawatts of low carbon electricity from

Malaysia. This sudden ban in exports of renewable energy illustrates how reliance on imports to meet renewable energy supply exposes Singapore to the risks of supply shocks stemming from export bans from key trading partners and illustrates the limitations of regional power grids in Singapore's future of renewable energy. This could drive Singapore to export more than what is necessary to ensure a reserve of energy supply to avoid supply shocks.

Long-term trends

Singapore's current efforts in reducing carbon emissions are insufficient to meet its long-term goals of achieving net zero emissions by 2050. With the power industry focusing on a switch towards low carbon alternatives and with 2050 still some time ahead, we can expect that the switch to low-carbon energy sources will only happen in the medium-to-longer term. However, Singapore has started to explore the use of new low-carbon sources of energy, particularly in hydrogen power, carbon capture technology, and nuclear power. We expect a higher level of development in these areas in the coming years.

Hydrogen power

Hydrogen power involves the use of hydrogen or hydrogen compounds to generate electricity, while only producing water as a by-product. Since the process does not emit any CO_2, hydrogen power is expected to be pivotal in the decarbonization of power. Like oil or gas, hydrogen can be piped and transported, but it has a higher energy density meaning than it contains approximately three times more energy compared to oil and gas. About 70 million tonnes of hydrogen are produced each year, largely used in oil refining, and making ammonia fertiliser. While the process of generating electricity using hydrogen is carbon free, the carbon emissions of producing hydrogen largely depend on the type of production used.

The main types of hydrogen are green, blue, and grey hydrogen. Green hydrogen is produced through the electrolysis of water using renewable energy, without producing any harmful greenhouse gases and is therefore a carbon-free process.

Currently, green hydrogen only makes up a small proportion of overall hydrogen. As a whole, hydrogen production is generally still a carbon generating process. Blue hydrogen is produced from natural gas by steam reforming, where natural gas and heated water are combined to produce steam, with carbon dioxide as a by-product. The carbon dioxide is then trapped and stored. While blue hydrogen is considered to be 'low-carbon hydrogen', the process of producing blue hydrogen is still carbon emitting. Grey hydrogen is essentially produced in the same way as blue hydrogen, but the carbon is not trapped and stored during the process. Blue and grey hydrogen make up 95 percent of all hydrogen produced today.

Since hydrogen power does not emit carbon when generating electricity, many regard it as the 'ultimate clean fuel.' Coupled with the fact that it is more efficient than many other energy sources, it is a promising method of energy production as Singapore seeks to reach net-zero emissions by 2050. Singapore has already begun directing its resources toward hydrogen fuel. In early-2020, with the support of the National Research Foundation ("NRF") and the Maritime and Port Authority of Singapore ("MPA"), five Singapore and two Japanese companies signed a signed a memorandum of understanding ("MoU") agreeing to develop new ways to use hydrogen as an energy source (Straits Times, 2022). The five Singapore companies are PSA Corporation, Jurong Port, City Gas, SCI, Singapore LNG Corporation, and the two Japanese companies are Chiyoda Corporation and Mitsubishi Corporation. The five Singapore companies will focus on evaluating and developing a business case for the feasibility of hydrogen imports and use in Singapore. Additionally, publicly funded researchers will also be working with the companies to study how technologies can be further developed for the large-scale use of hydrogen as an energy source.

Beyond research, Singapore has also begun investments in hydrogen power infrastructure. By the first half of 2026, Singapore is expected to have its first hydrogen-ready power plant ready. The Keppel Sakra Cogen Plant is slated to be built on Jurong Island and is expected to produce up to 600Mw of electricity, which is approximately 9% of Singapore's 2020 peak electricity demand and can be run completely on hydrogen in the future (Straits Times, 2022).

Though the KEP-owned CCGT power plant can be run entirely on hydrogen, it is expected to run on natural gas for now, and possibly on 30% hydrogen in the future. The ability to adjust the proportion of hydrogen used in current methods of energy production underscores the ease at which hydrogen can be easily incorporated into current energy production processes.

Hydrogen is efficient but green hydrogen is expensive

The general consensus is that one of the biggest threats to the success of large-scale adoption of hydrogen power is the current lack of infrastructure and high costs of manufacturing green hydrogen. While hydrogen can be imported through pipelines, it can only be done over short distances, and while it is possible for hydrogen to be converted into a liquid chemical carrier and then be transported, more research needs to be done to extract the hydrogen from the carrier (Eco-Business, 2022). Additionally, given Singapore's lack of local green hydrogen production, importing green hydrogen will yet again expose Singapore to supply shocks from export bans similar to regional power grids. Attempting to produce green hydrogen locally will again call into question Singapore's ability to produce energy from renewable sources, keeping in mind that green hydrogen is produced from renewable sources only. Singapore's ability to scale up its supply of green hydrogen is hindered by the limitations in hydrogen transportation technology and lack of domestic renewable sources of energy required to produce green hydrogen. Singapore's lack of green hydrogen supply chain infrastructure is the bottleneck in the large-scale adoption of hydrogen power.

The future of hydrogen fuel is particularly encouraging given that it can be easily incorporated into the current methods of energy production. The ability to gradually increase the use of hydrogen as an energy source without the need for a complete overhaul of infrastructure limits the risks of stranded assets, and also allows for a smooth shift towards zero-carbon sources of energy in line with Singapore's transition timeline. Though promising, the hydrogen power industry is still in its infancy. With a steady and reliable source of green hydrogen not yet established, a lack of hydrogen power generation infrastructure, and limited research and technology in the transporting and handling of hydrogen, it is likely that we will only see hydrogen power play a larger role in Singapore's clean energy supply further into the future. The future of hydrogen power in Singapore is reliant on the developments of the green hydrogen supply chain.

Carbon capture technology

Other than reducing the amount of carbon emitted during the power generating process, another way of reducing carbon emissions in line with Singapore's longer term climate goals is through carbon capture technology. There are two main uses of carbon capture technology in the reduction of carbon emissions, Carbon Capture and Storage ("CCS") and Carbon Capture, Utilisation and Storage ("CCUS"). Both processes start with carbon dioxide being separated from other gasses emitted during the energy generation process, then compressed to be transported. In CCS, the carbon dioxide is transported to a storage site where it is finally pumped underground to be permanently stored where geologically suitable. In CCUS, the carbon dioxide is transported to be re-used in industrial processes. CCS and CCUS are unique when compared to the other methods of carbon emission reduction we have explored in that they have the potential to remove carbon from the atmosphere and generate 'negative emissions' on a large scale.

Largely still in the R&D phase

By 2030, Singapore is targeting to realise up to 2 million tonnes of carbon capture potential, but the general consensus is that the processes and technology of CCS and CCUS are still in the beginning stages of development (NCCS, 2022). In Singapore, discussion around both CCS and CCUS are limited to feasibility studies and research projects, far removed from any concrete investment plans thus far. This indicates that the reduction in overall carbon emissions due to CCS and CCUS technology is more likely to be realised further into the future. Nevertheless, Singapore has increased its efforts in the development of carbon capture technology through conducting various feasibly studies and funding research and development of carbon capture technology in 2022. For example, KEP, Air Liquide, Chevron and PetroChina signed an MoU in September 2022 to evaluate and advance the development of large-scale CCUS solutions and integrated infrastructure in Singapore.

According to the study 'Carbon Capture, Utilisation, and Storage: Decarbonisation Pathways for Singapore's Energy and Chemicals Sectors,' which was jointly commissioned by the National Climate Change Secretariat (NCCS) and the EDB, one potential hurdle for Singapore when it comes to CCS would be the lack of sub-surface carbon dioxide sequestration options, meaning that Singapore lacks suitable underground storage sites to store compressed carbon. Consequently, Singapore will eventually have to turn to neighbouring ASEAN countries like Indonesia, Vietnam, and Thailand to export carbon dioxide for sequestration. When considering the export of carbon dioxide, it is important to keep in mind that cross-border transport of carbon dioxide can be expensive, and that for the export of carbon dioxide for sequestration to be cost-effective, there needs to be a secure supply of carbon dioxide. The under-utilisation of transport and storage assets can easily drive-up costs and threaten the commercially viability of CCS deployment. As such, the cost-effectiveness of CCS will largely be dependent on the secure supply of carbon dioxide. Additionally, the transport of carbon dioxide is a complex process, and more research needs to be done on safe and effective modes of carbon dioxide transport. The study also documents similar issues of cost-effectiveness in CCU technologies. Most CCU technology projects with substantial abatement potential require large amounts of hydrogen and ammonia and the availability and costs of these low-carbon commodities in the future are largely uncertain. Additionally, the study also determined that there needs to be significant cost reductions and technological developments of current CCU technologies before it can be commercially viable. From the feasibility study, it is clear that the large-scale deployment of CCS and CCU technologies is not commercially viable for now, and will not be for some time, and that the largest barriers that CCS and CCU technologies face are the high up-front costs, cost-ineffectiveness, and limitations in research and development.

There have yet to be any concrete steps taken in the development and deployment of CCS and CCUS technology, and not without good reason. The unestablished supply chain of low-carbon commodities such as hydrogen and ammonia that are required for most CCS and CCUS processes, the limited amount of research that has been done on CCS and CCUS technology, and cost ineffectiveness of current technologies prevent the large-scale adoption and deployment of CCS and CCUS. As Singapore transitions towards net-zero carbon emissions, the role of CCS and CCUS technology will be contingent on the success of current research projects in the long term.

Nuclear power

Once thought unsuitable for Singapore due to safety and reliability concerns, nuclear energy in more recent times has been identified as another potential source of clean energy that Singapore can tap on. Nuclear power plants heat up water to produce steam. The steam is then used to spin the blades of turbines which in turn produce energy. The water is heated up in a process called nuclear fission, which is a reaction where atoms, usually uranium atoms, are split apart to form smaller atoms which releases energy. Nuclear plants then cool the steam back into water, which can be reused to produce steam.

Nuclear power plants do not produce greenhouse gases during the energy generation process, making nuclear power a potential source of energy moving forward as Singapore transitions toward net-zero carbon emissions. Additionally, nuclear plants are able to generate large amounts of energy consistently for months at a time without interruption, operating at a much higher capacity factor (measures the percentage of time a power plant produces electricity) than most renewable energy sources and fossil fuels. In the United States in 2021, nuclear power's capacity factor ranked the highest among all energy sources, at 92.7% (U.S. Energy Information Administration, 2022), meaning that nuclear power plants were able to produce electricity 92.7% of the time. Other sources of alternative energy lagged behind, with geothermal power, hydro power, and solar power at 71%, 37.1%, and 24.6% capacity factors, respectively. Even when compared to fossil fuels, with coal and natural gas combined cycle at 49.3% and 54.4% (U.S. Energy Information Administration, 2022) capacity factors respectively, nuclear power was the most reliable source of energy. Furthermore, given the extreme density of nuclear fuel, nuclear energy has a smaller land footprint when compared to other sources of clean energy, being able to generate the same amount of power as solar facilities with 31 times less land, and wind farms with 173 times less land (NEI, 2022). The reliable source of clean energy and the small land mass required of nuclear power makes it a viable choice of clean energy for land and resource scare Singapore.

Recently, a report commissioned by the EMA highlighted nuclear power could make up to 10% of Singapore's energy mix by 2050. Over the years, there have been significant advancements in nuclear technology and safety to make the energy process safer and more reliable. According to the World Nuclear Association and United Nations Environment Programme, an individual is exposed to more radiation during an x-ray than being in close proximity to a nuclear power plant. Studies also have shown that death rates from the production of nuclear energy are somewhat comparable to modern renewables like solar power, wind power, and hydropower and are much lower than that of fossil fuels (Nanyang Technological University, 2022). Moreover, the number of accidents in nuclear plants have been low and steadily declining (World Nuclear Association, 2022). The total death estimates, both direct and indirect, as a result of nuclear energy is 0.07 deaths per terawatt-hour, which is significantly lower than the four deaths per terawatt-hour that natural gas has. (Our World in Data, 2022).

Much like CCS and CCUS technology, nuclear power, in Singapore at least, is still in the research and development phase. Back in 2014, Singapore launched a programme for research and education in nuclear safety, science, and engineering, setting aside a total of SGD63 million for the programme. Singapore's Energy 2050 Committee also projected that by late 2030s, commercial small modular reactor designs and units will be developed abroad and made available worldwide. These developments could allow Singapore to deem nuclear power as a viable source of energy and begin developing domestic generation capacity by the 2040s. (EMA, 2022)

Negative public perception of nuclear power

One of the largest hurdles that nuclear power faces in Singapore is the issue of negative public perception. While statistics have shown that nuclear power has become one of the safest forms of energy production in recent years, there is still a generally negative sentiment towards nuclear energy in Singapore which is likely a result of the 2011 Fukushima incident as well the Chernobyl incident in 1986 given the severity and long-lasting negative implications. Additionally, nuclear waste is a major environmental concern along with concerns over potential for misuse and impact on national security. It is worth noting that many sustainability and green bond frameworks currently explicitly exclude nuclear power generation from the use of proceeds, a reflection that this energy source is perceived as controversial by countries and investors. A study done by NTU Singapore's Wee Kim Wee School of Communication and Information found that more than half of the survey respondents were against the idea of nuclear energy (NTU,2022). The study found that safety was the key concern affecting the public's support towards nuclear power, and that the construction of a nuclear power plant with enhanced safety and reduced production of radioactive waste could garner greater support from the public (NTU, 2022). The success of nuclear power usage in Singapore is partly contingent on the support of the general public. Hence, alongside developments in nuclear power technology, there should also be an effort to change the negative perception that the general public has pertaining to nuclear power.

Nuclear power's high-capacity factor and small land footprint required makes it a potentially consistent and reliable source of clean energy for Singapore. However, limitations in nuclear power technology as well as the need for further feasibility studies to be done makes it likely that we will not see Singapore adopt nuclear power until 2040s, if at all. It should be highlighted that nuclear power does not share the limitations of many clean energy alternatives such as the need to constantly import raw materials, large amount of land mass required, and the issue of intermittent energy production.

Risks and considerations

Stranded asset risks are no longer theoretical

Beyond looking forward into Singapore's clean energy, it is also important to look at what the major changes in the power industry leaves in its wake. Throughout this piece, the idea of stranded assets was brought up as it is one of the largest potential threats the world faces in its transition to clean energy. A stranded asset is an asset that has suffered from an unanticipated or premature write down, devaluation or a conversion to liabilities. With rapid changes in the power industry due to growing environmental concerns, it is observed that many power-generating assets are beginning to or have already begun suffering unanticipated or premature write downs, devaluations, or a conversion to liabilities.

As the world phases out coal as a power source, we are seeing in real time a large number of coal plants becoming stranded assets. For decades, coal infrastructure was seen as a relatively safe investment, with banks putting up trillions of dollars to finance new fossil-fuel assets. However, in more recent times, this trend has reversed. The costs to finance new fossil-fuel assets, particularly coal projects are rising with some banks announcing policies to stop funding coal plants completely while certain insurers are reducing their insurance underwriting exposure to coal plants. The combination of the pressure to sell off coal assets (before values decline further) and the higher cost of funding for high-carbon projects has resulted in companies divesting from coal assets. While at first glance it may seem that the divestment from coal assets is a step forward in the fight against climate change, we have to consider how the breakneck pace at which companies are selling off their coal assets have unintended consequences to the environment.

As larger and more reputable companies bow to the pressure of investors to divest from their coal assets, these assets usually do not end up properly wound down. Instead they are usually bought by unlisted companies that may not have the same environmental priorities.

The risks of stranded assets are not limited to coal plants. While most current examples of stranded assets are of coal plants, it is reasonable to expect that other fossil fuel plants or even inefficient solar panels will become stranded assets in the future. Considering that most of Singapore's gas plants are relatively new, the oncoming pivot towards low-carbon energy sources may result in heightened risk of stranded assets in Singapore where these newer plants are not used for their designed lifespan.

Case study: SCI – Committed to turning from brown to green with consequences

Recently, SCI transferred its Sembcorp Energy India Limited ("SEIL") unit to Tanweer Infrastructure Pte Ltd at USD1.47 billion where the transaction was structured as a divestment. SEIL is one India's largest power producers, operating two coal-fired plants, generating a total of 2,640 MW of power, supply power to nearly 2.5 million households. SEIL has not announced any plans to wind down the coal plants and will likely continue its 12-year agreement commencing in 2023 to supply 625 MW of power to power distribution companies in India. Many equity investors have lauded SCI for the sale of the unit, calling it a step in the right direction, with SCI's share price soaring to a 4.5-year high of SGD3.50 per share after the transfer of the assets. However, the transaction has received negative attention from the sustainability bond market where the company had been an active issuer of green and sustainability-linked bonds. It remains to be seen if the company will be able to continue accessing the green, social, sustainability and sustainability-linked corporate credit market. While on paper, SCI has managed to turn its portfolio from 'brown to green', the divestment in the unit ultimately allowed the company to offload carbon emitting assets to other owners instead of properly winding down or transforming the asset for a new use. SCI's portfolio may be greener, but the coal plant will continue to produce greenhouse gases. This case study begs the question – Is it enough for companies to simply off load their high carbon assets, and in turn the environmental responsibility, to others? Furthermore, with the sale being funded by a deferred payment note, this essentially allowed SCI to shift the physical carbon emitting asset to a financial asset, earning a greener balance sheet only on a technicality. This transfer is an example of how the developing sustainability-linked bond market could incentivise distortions in the way companies choose to manage their high-emitting assets. A bigger question and perhaps the main one from recent events is that the arbitrage between public versus unlisted companies remains an unresolved issue in many countries globally. Until such time governments decide to make it mandatory for all owners to wind down their highly emitting facilities overtime or enforce the proper pricing of carbon emissions, the arbitrage is likely to continue given that this business is still profitable otherwise.

Case study: Enel – Decommissioning and transforming plants into new uses but not all exits were green

As the world transitions to clean energy, the ideal scenario is that companies will be able to either transform their fossil-fuel assets into clean energy assets using technology or ensure that their fossil-fuel assets are properly wound down, and there are some companies that have taken efforts to do so. Italian electricity company Enel Spa ("Enel"), one of the largest owners of coal plants in Europe, is an example of a company that has begun pivoting away from fossil-fuel plants, embracing sustainable sources of energy. In September 2022, with the disconnection of the Bocamina II coal plant, Enel became the first company to exit from coal completely in Chile, with plans to exit coal worldwide completely before 2025 (S&P Global Commodity Insight, 2022). Additionally, Enel has also committed itself to the transformation of coal plants for new uses, such as creating renewable energy hubs. In Spain, Enel has plans to transform the Andorra thermal power plant into Europe's largest solar power plant, with additional wind power and battery storage onsite (Enel, 2022). Enel's efforts to create a more sustainable portfolio through not only the decommissioning of their coal plants but also the transformation of former plants into green assets represents the ideal path that power generation companies can take moving forward. However, given the tight timeline, it is unsurprising that not all of Enel's efforts to exit from coal have been as responsibly managed from an environmental perspective.

Enel has also divested some of its coal plants instead. In June 2022, Enel sold its stake in their 327MW gas plant, the Central Geradora Termeletrica Fortaleza facility, to Brazilian energy company Eneva SA. With this sale, Enel officially became 100% renewable in Brazil. Additionally, in October 2022, Enel finalized the sale of its stake in PJSC Enel Russia to PJSC Lukoil and the Closed Combined Mutual Investment Fund "Gazprombank-Frezia", successfully disposing all of its Russian power generation assets that consisted of approximately 5.6 GW of fossil fuel capacity. The buyers have yet to announce any plans to decommission the power plants and are likely going to continue operating these fossil fuel plants. If even a company like Enel, that has a proven track record of successfully decommissioning and transforming their fossil fuel assets, struggles to avoid offloading the responsibility of winding down their fossil fuel through divestment, we can expect that many energy companies will choose divestment as the primary method of removing fossil fuel assets from their portfolio. As pressure mounts for companies to clean up their portfolios in a short amount of time, we can expect more companies to choose divestment over sustainable decommissioning or transformation of fossil fuel assets.

Explanation of Issuer Profile Rating / Issuer Profile Score

Positive ("Pos") – The issuer's credit profile is either strong on an absolute basis or expected to improve to a strong position over the next six months.

Neutral ("N") – The issuer's credit profile is fair on an absolute basis or expected to improve / deteriorate to a fair level over the next six months.

Negative ("Neg") – The issuer's credit profile is either weaker or highly geared on an absolute basis or expected to deteriorate to a weak or highly geared position over the next six months.

To better differentiate relative credit quality of the issuers under our coverage, we have further sub-divided our Issuer Profile Ratings into a 7-point Issuer Profile Score scale.

IPR	Positive		Neutral			Negative	
IPS	1	2	3	4	5	6	7

Please note that Bond Recommendations are dependent on a bond's price, underlying risk-free rates and an implied credit spread that reflects the strength of the issuer's credit profile. Bond Recommendations may not be relied upon if one or more of these factors change.

Explanation of Bond Recommendation

Overweight ("OW") – The bond represents **better relative value** compared to other bonds from the same issuer, or bonds of other issuers with similar tenor and comparable risk profile.

Neutral ("N") – The bond represents **fair relative value** compared to other bonds from the same issuer, or bonds of other issuers with similar tenor and comparable risk profile.

Underweight ("UW") – The bond represents **weaker relative value** compared to other bonds from the same issuer, or bonds of other issuers with similar tenor and comparable risk profile.

Other

Suspension – We may suspend our issuer rating and bond level recommendation on specific issuers from time to time when OCBC is engaged in other business activities with the issuer. Examples of such activities include acting as a joint lead manager or book runner in a new issue or as an agent in a consent solicitation exercise. We will resume our coverage once these activities are completed.

Withdrawal ("WD") – We may withdraw our issuer rating and bond level recommendation on specific issuers from time to time when corporate actions are announced but the outcome of these actions are highly uncertain. We will resume our coverage once there is sufficient clarity in our view on the impact of the proposed action.

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