

公務出國或赴大陸地區報告（出國類別：考察）

113 年度臺中市空氣污染防治執行空氣品質改善維護國外觀摩計畫-  
新加坡永續發展環保科技考察

服務機關：臺中市政府環境保護局

姓名職稱：詳出國人員名單

派赴國家：新加坡

出國期間：113.12.3-113.12.7

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## 壹、摘要：

此次參訪新加坡裕廊島長春石化廠、吉寶灣大樓、廢棄物焚化廠及濱海灣花園，深入瞭解了相關技術與管理經驗，並為未來政策制定與推廣提供了重要的參考依據。裕廊島作為新加坡的石化專區，其高效運行與污染防控具高度參考價值，值得借鏡。新加坡以許可證制度、定期檢測、自主化管理與科技化監控，實現空氣污染防治與產業發展的平衡。

吉寶灣大樓是新加坡首座獲得「綠色標章白金零耗能」認證的商業建築，運用太陽能發電系統實現能源自給自足，並採用智慧化空調系統、建築管理系統及創新水處理技術，展現節能環保的設計理念。

在廢棄物處理方面，新加坡的廢棄物焚化廠，如TuasOne和吉寶席格斯大士廢棄物焚化廠，以緊湊型設計、創新技術與高效能源回收，解決土地稀缺與廢棄物處理挑戰，同時提供可觀的電力供應。這些技術與運營模式對提升臺灣廢棄物焚化廠效率與環保效能有重要參考價值。

濱海灣花園以其獨特的擎天樹結合太陽能發電、廢氣排放與生態設計，展現了能源循環利用與美學融合的實現方式，提供了煙囪設計的新思路。

新加坡經驗強調整合環保與工業安全、自主管理政策與先進科技應用，對於臺灣在推動綠建築、廢棄物焚化廠更新與廢棄物處理等方面具有啟發性意義，並可助力實現資源循環與永續發展的目標。

## 貳、出國人員名單及行程表

### 出國人員名單

項次	單位	職稱	姓名
1	臺中市政府環境保護局	股長	劉祥兆
2	臺中市政府環境保護局	分隊長	杜旻霏
3	臺中市政府環境保護局	衛生稽查員	郭立德
4	臺中市政府環境保護局	技士	王榆超
總計		4員	



行程表

日期	星期	起訖地點	行程
12月3日	二	桃園機場- 新加坡樟宜國際 機場	搭乘班機(去程)
12月4日	三	新加坡	裕廊島(長春石化新加坡廠)
			吉寶席格斯大樓
12月5日	四	新加坡	吉寶席格斯大士廢棄物焚化廠
			TuasOne廢棄物焚化廠
12月6日	五	新加坡	濱海灣花園-擎天樹叢
12月7日	六	新加坡樟宜國際 機場-桃園機場	搭乘班機(回程)
合計		5日	

## 參、緣起與目的

在全球氣候變遷與能源危機的雙重挑戰下，各國積極推動綠建築、循環經濟及永續發展，以降低環境衝擊並提升資源利用效率。新加坡作為亞洲永續發展的標竿城市，透過創新政策與先進技術，在綠色建築等領域均展現卓越成果，值得借鏡。本次參訪旨在透過實地觀摩新加坡具代表性的環保基礎設施，深入了解其技術應用與管理模式，並探討相關經驗如何應用於本市環境治理與都市發展。

本次行程涵蓋多個設施，包括吉寶灣大樓、裕廊島長春石化廠、吉寶席格斯大士廢棄物焚化廠、TuasOne 廢棄物焚化廠及濱海灣花園。其中，吉寶灣大樓為新加坡首座獲得「綠色標章白金零耗能」認證的商業建築，其太陽能發電系統、智慧建築控制與節能管理模式，展現低碳建築的未來發展方向。裕廊島長春石化廠則採行提供產業節能與自主管理的參考模式。在廢棄物處理方面，吉寶席格斯大士廢棄物焚化廠與 TuasOne 廢棄物焚化廠皆採用高效能焚化技術與緊湊型設計，並透過公私合營（PPP）模式提升運營效率。此外，濱海灣花園運用三重熱電聯產技術與生質能發電系統，將環保設施與都市景觀結合，提供廢棄物焚化廠美學設計的創新思維。

透過本次參訪，期能學習新加坡的綠建築發展經驗。同時，藉由考察廢棄物處理與能源回收技術，為本市廢棄物焚化廠汰舊更新及資源循環策略提供參考。此外，透過對公私合營模式的研究，評估本市未來環保設施的最佳營運模式，以提升整體管理效能。綜合而言，本次參訪不僅提供綠色科技與環保政策的具體參考，亦可深化國際合作，推動本市邁向永續發展與低碳城市的目標。

## 肆、過程

### 一、考察新加坡環保低碳科技及綠美化

新加坡作為東南亞的島嶼城市國家，面積僅為 728.6 平方公里，卻擁有近 600 萬人口，是全球人口密度最高的國家之一。在國土面積受限的情況下，新加坡自 1965 年獨立以來，便將環境永續發展作為國家戰略之一，積極推動「花園城市」(Garden City)計畫，後來更進一步提出「花園中的城市」(City in a Garden)願景。這一路發展至今，新加坡已成功將自身打造成為兼具現代化都市機能與豐富生態環境的全球典範。

2021 年，新加坡政府更提出「新加坡綠色計畫 2030」(Singapore Green Plan 2030)，設定明確的永續發展目標，包括綠色建築應達到 80%、再植樹 100 萬棵等，彰顯其對於永續發展的堅定承諾。

臺中市作為臺灣中部的核心都市，面積達 2,215 平方公里，人口約 282 萬，近年來在城市發展與生態環境平衡方面面臨諸多挑戰。隨著工業化與都市化的快速發展，空氣品質、都市熱島效應、能源消耗等問題日益突出。尤其在空氣品質方面，臺中市因地理位置特殊且電廠與工業區集中，常面臨空污挑戰，這也促使市政府更加關注綠色基礎建設與永續發展戰略。

臺中市政府「永續淨零政策三部曲」因應，其中包括簽署「氣候緊急宣言」，以及發表「2023 臺中市自願檢視報告」並公布「2050 臺中市淨零碳排路徑」，設定多項具體目標，包括推動建築物節能減碳、增加再生能源的使用、綠建築標章推動及植樹綠化與造林等。特別值得一提的是，臺中市提出打造「宜居家園」的願景，與新加坡「花園城市」理念不謀而合，這也是促成本次參訪的重要因素之一，本次參訪針對新加坡主要獲得綠色標章建築物及指標性綠化公園濱海灣花園進行參訪。

### (1) 參訪吉寶灣大樓綠建築

吉寶灣大廈（Keppel Bay Tower，KBT）是吉寶集團可持續發展承諾的重要體現。吉寶灣大樓於 2002 年竣工，並於 2020 年進行改造，成為新加坡首座獲得建設局（BCA）「綠色標章白金零耗能」（Green Mark Platinum Zero Energy）認證的商業建築這項成就展示了如何透過現有建築的綠色升級來降低碳足跡。



圖、吉寶灣大廈之太陽能電板

與新建築可以從設計初期就融入最新節能技術不同，對於現有建築而言，升級過程面臨更大挑戰，包括如何在不影響日常運營的情況下進行改善工程。KBT 的升級工程成功克服了這些挑戰，除了該公司於屋頂中及其相鄰的平臺上安裝了超過 400 平方米的太陽能板，每年可產生約 100,000 度的電力外，並率先在新加坡實施了五大創新節能技術：

(一)配備空氣處理機組風扇的節能空氣分配系統，整合軸流風扇、驅動器與永磁電機，達到 80-85% 的效率，相比傳統的風扇技術（效率 60-68%）較佳。

此方案結合了高效能且易於整合的組件，包括專門為空氣處理機組（AHU）設計的 Novenco 軸流風扇、具備 ACMV(機械通風加上空氣調節)智能控制的 Danfoss 獨立馬達變頻驅動器（VFD），以及 IE5 永磁馬達，共同提升現有空氣處理機組的運行效率。該風扇技術靈感來自飛機噴射引擎優化的葉片設計，以提升空氣動力學性能其與傳統建築應用中的皮帶驅動風扇相比，其能效提高 25%。

透過這些技術的協同運作，最終實現 80-85% 的「電能到空氣（wire to air）」效率，顯著優於傳統離心風扇、直驅風扇及 EC（電子換向）風扇，後者的「電能到空氣」效率通常僅為 60-68%。

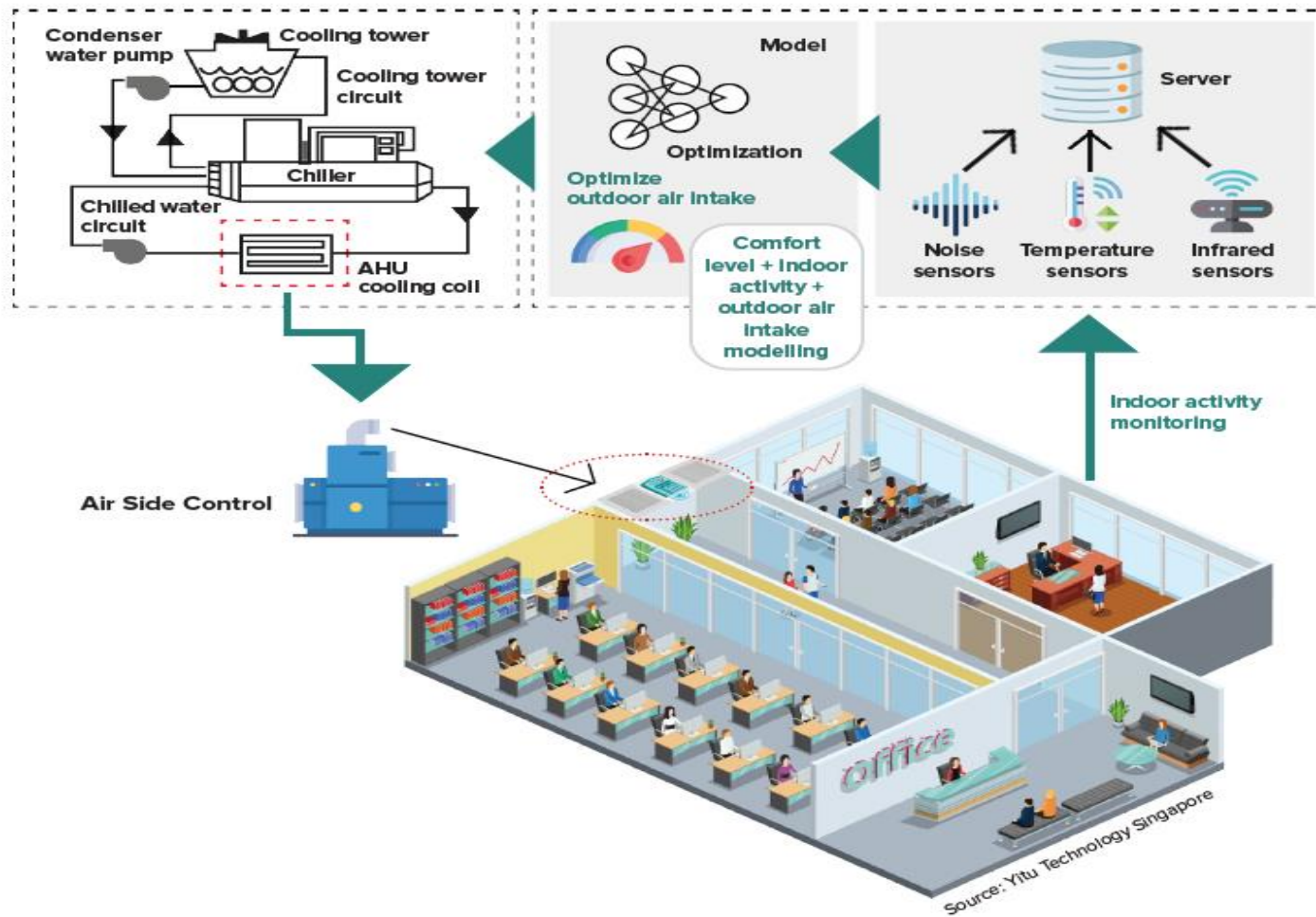
該風扇改造方案可廣泛應用於新建或現有的機械通風加上空氣調節系統，從而有效降低能源消耗與溫室氣體排放。在試驗成功後，KBT 隨即推廣至整棟建築，對其餘 21 台空氣處理機組進行相同技術升級，進一步優化整體能源使用效率。

(二)智慧空氣調節系統：透過傳感器和數據分析，根據室內活動的實時需求，調整新風進入量，最佳化冷卻效率及減少能耗(新風、室內活動和熱舒適度等變量與能耗進行關聯分析)。

為了確保室內工作環境的健康與舒適，持續引入新鮮空氣至關重要。然而，建築物的冷卻需求量會受到時間、天氣、使用情況等多重因素影響，呈現動態變化。因此，如何在不犧牲室內舒適度及空氣品質的前提下，盡可能降低冷卻能耗，便成為一項重要的挑戰。

為了解決此一問題，KBT 引入及開發了一套智慧空氣調節系統。此系統整合了多重感測器，能夠監測室內環境中的溫度、濕度、二氧化碳濃度、噪音等數據。透過這些數據，系統得以分析室內活動模式，並採精準調節新鮮空氣的引入量。

此系統的核心在於一套機器學習模型，此模型經過大量數據訓練，能夠準確預測不同情境下的冷卻需求，並在滿足室內空氣品質標準的前提下，優化新鮮空氣的引入量，進而降低冷卻負載。結果顯示，此系統成功降低了 12%的空調能耗，同時也提升了室內熱舒適度和空氣品質，為使用者創造了更健康、舒適的工作環境。



參考資料：吉寶公司提供資料

圖、智慧空氣調節系統

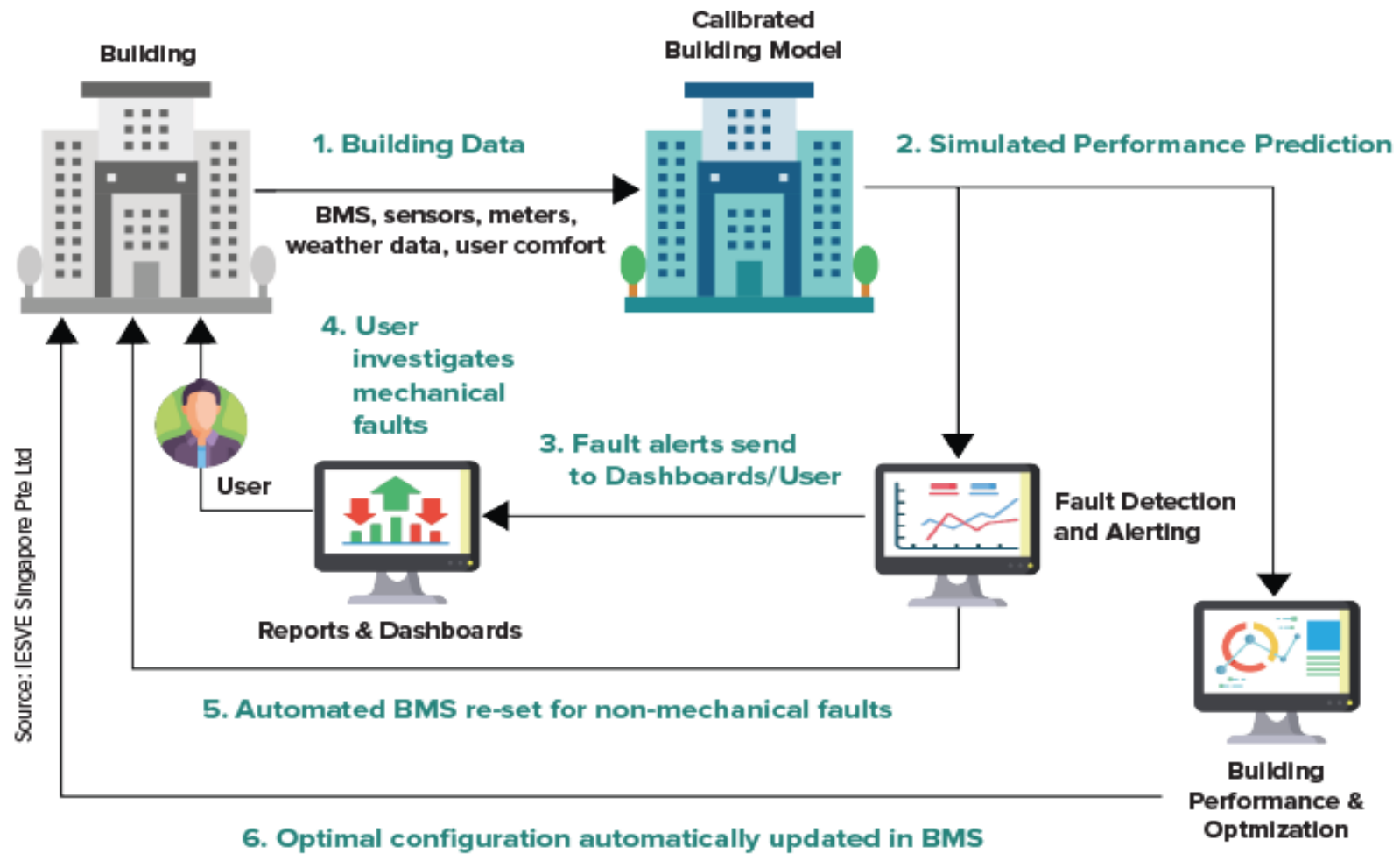
(三)智慧建築控制系統透過模擬與實際數據的對比驗證節能效果，並分析感測器和現有天氣數據，進一步改進並提升節能效果。

隨著科技日新月異，建築物的智能化已成為趨勢。本專案所開發的智慧建築控制（IBC）系統，正是順應此趨勢的創新成果。它結合了建築模擬建模與即時數據分析，構建出建築的「數位孿生」，在雲端提供先進的建築性能預測、優化與診斷功能。

IBC 系統的核心在於其獨特的「數位孿生」技術。透過整合 IES Virtual Environment、IES SCAN 等專業軟體工具，以及自行開發的模型校準工具集，系統能夠建立建築物的精確數位模型。此模型不僅能模擬建築在不同條件下的能源消耗，更能與即時收集的建築數據進行比對分析，提供更準確的性能預測。

此外，IBC 系統還搭載了智慧控制演算法。這些演算法能夠分析建築數據、天氣資訊、以及使用者行為模式，自動調整建築設備的運作狀態，例如空調系統、照明系統等，以達到最佳的節能效果，實測結果顯示，IBC 系統成功預測並實現了約 7%的能源使用量減少。





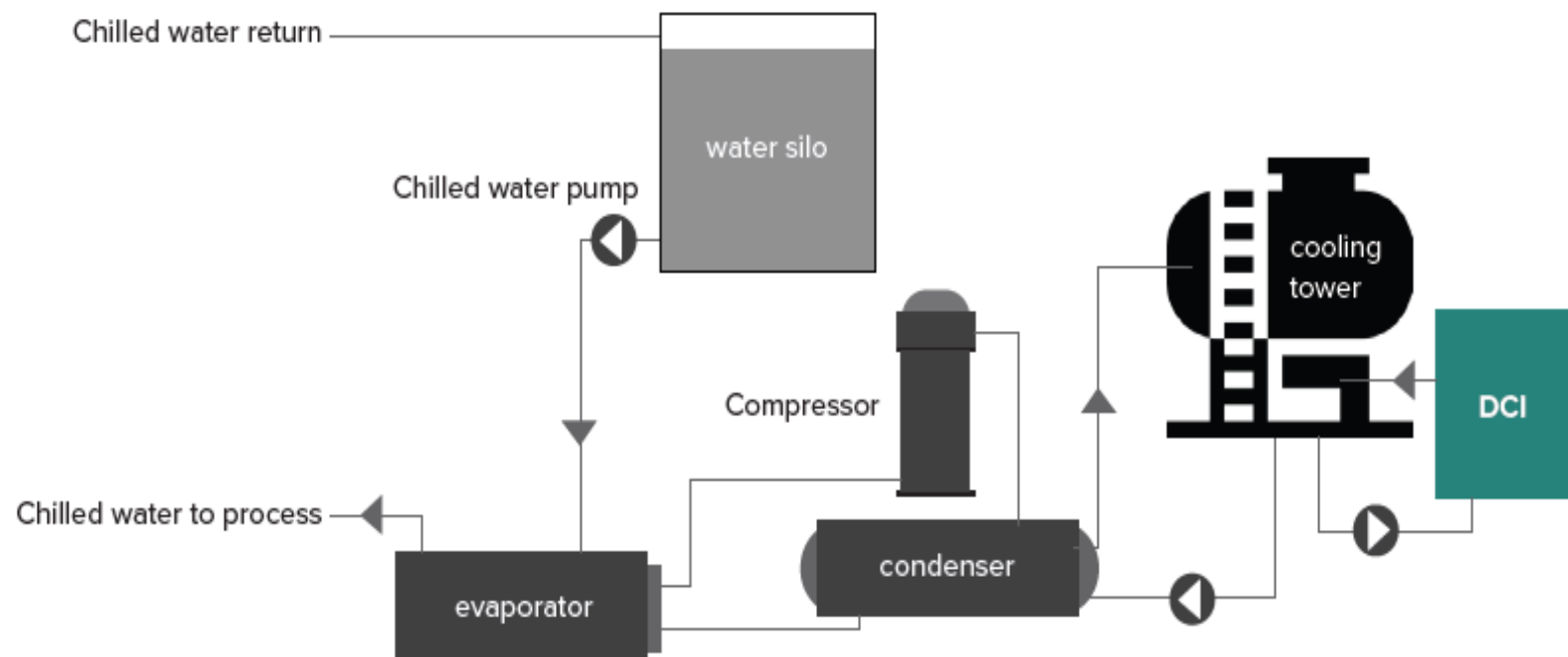
參考資料：吉寶公司提供資料

圖、智慧建築控制系統

(四)冷卻塔水處理系統採用專利系統(DCI)可以去除水中的溶氧，可以有效防止水垢形成並減緩腐蝕並增進冷卻水系統性能。

傳統冷卻塔的運行通常需要大量水資源、能源及化學藥劑，以維持系統的正常運作與設備保護。創新聚合物（Innovative Polymers）開發的 Decalon（DCI）系統則在提升冷卻效能方面帶來重大突破。該技術已獲得全球專利，能夠有效去除並防止水垢形成，並透過去除溶解氧顯著減緩腐蝕速率。此外，DCI 系統運用專利 CataGreen 技術進行水質消毒，取代傳統化學處理方式，有效抑制冷卻塔內藻類及細菌滋生，且處理效率優於市面上部分非化學處理技術（NCD），DCI 系統經過 12 個月運行後，冷卻機組系統效率提升 7%，而冷卻塔排污水量則減少 80%。

傳統冷卻水處理方法通常依賴化學藥劑來抑制水垢、減少腐蝕並抑制細菌生長，而 DCI 系統則無需投放有毒化學藥劑，不僅降低環境污染風險，還使排放水能夠直接安全排入環境，無需額外處理，實現更可持續的水資源管理，與其他 NCD (Non-Chemical Device)技術（如磁性、電子、流體動力及催化處理）不同，DCI 的電化學技術，能夠清除既有水垢、預防新水垢生成、降低腐蝕速率並進行水質消毒，實現更全面的冷卻水管理。該技術已獲得新加坡綠色建築委員會（SGBC）「卓越級」認證，並通過 ISO 9001、bizSAFE 3、TÜV Rheinland 及 CE 認證。



Source: Innovative Polymers Pte Ltd

參考資料：吉寶公司提供資料

圖、冷卻塔水處理系統

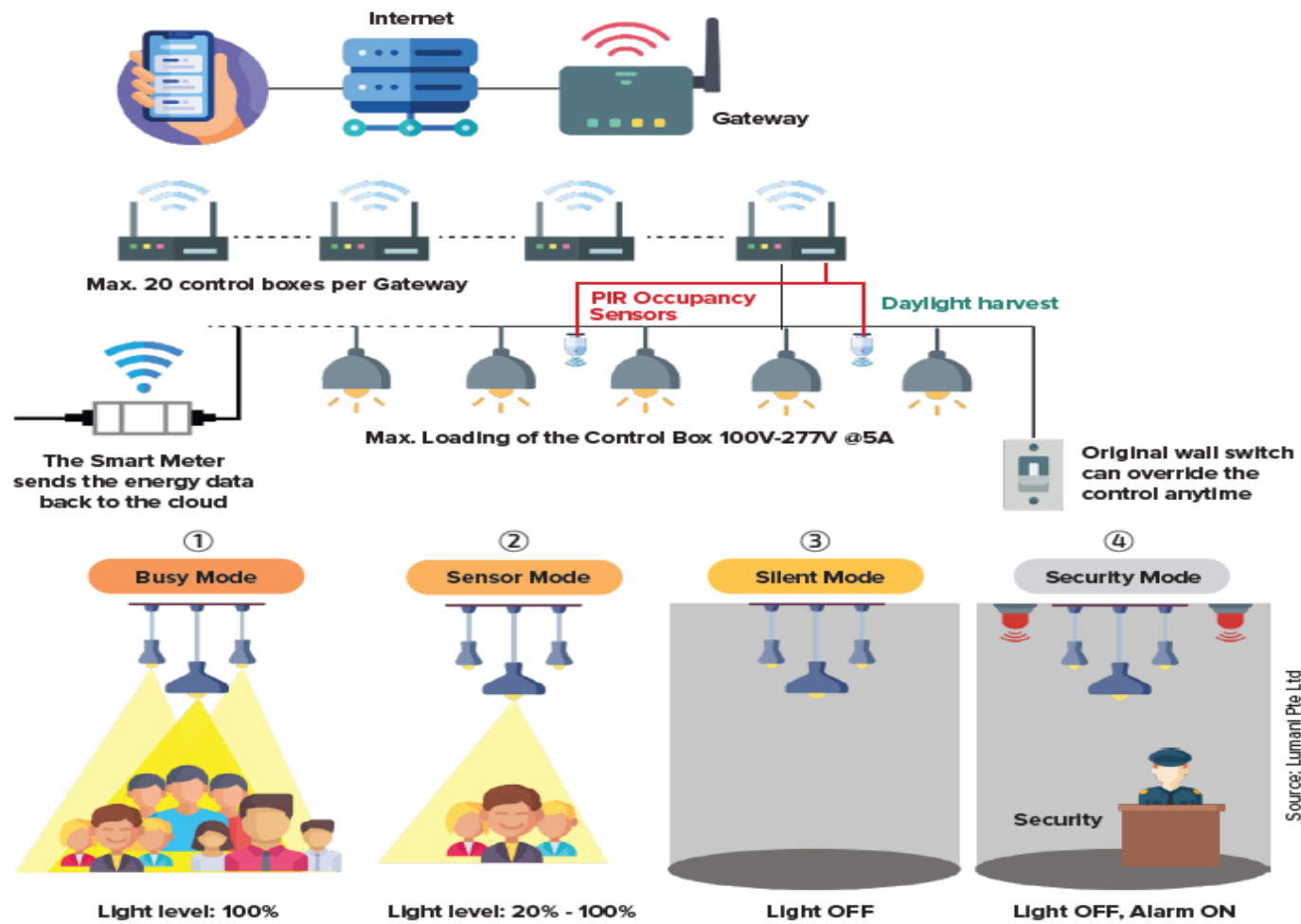
(五)智慧照明系統，微型感測器能根據室內人員的活動情況自動調整燈光亮度。通過 PIR 感測器計算活動數據，並將資訊傳輸到雲端分析，以選擇適當的燈光模式，實現高效能源管理與使用者舒適度的平衡。

這套照明系統利用感測器偵測建築物內人員的活動量，進而實現照明強度的調光。與一般辦公大樓的照明系統不同，本系統使用被動紅外線（PIR）動作感測器作為活動量的計數器，而非僅僅作為繼電器開關。照明控制器收集活動數據，然後將數據傳送到雲端，以決定燈光的運作模式，該照明系統已在 KBT 大樓 270 個區域安裝，可達成 13.4%的節能效果。：

繁忙模式：當偵測到高活動量時，切換到較高的調光亮度。

感測模式：高低亮度之間波動，以回應 PIR 感測器的觸發。

靜默模式：當一段時間未偵測到任何活動時，燈光會關閉。



參考資料：吉寶公司提供資料

圖、智慧照明系統

## 參訪照片



大樓應用科技介紹



吉寶集團設施介紹



大樓應用科技介紹



贈與吉寶公司代表禮物



雙方合照



吉寶灣大樓

參考資料：吉寶公司提供資料



## (2) 參訪濱海灣花園

本次參訪濱海灣花園，是位於新加坡濱海灣中央的公園，屬國家花園，也是當地和國際遊客至新加坡的首要園藝景點，係新加坡政府依據其國家永續綠色計畫打造出的夢幻大型花園，更被譽為「世界 10 大最佳室內花園」，新加坡國家公園管理局為實現打造花園城市的願景，由多個不同領域之國際及當地專業團隊共同參與開發設計及綠化工作，基於環境永續原則，整個花園之能源及水資源皆以永續循環規劃設計，並獲得 2012 年世界年度建築獎、2013 年新加坡總統設計獎等多項卓越獎項。

2012 年正式對外開放的濱海灣花園總面積達 101 公頃。其中面積最為廣闊的濱海南花園佔地 54 公頃；濱海東花園則設計為開放式綠地，提供市民運動休憩空間並供民眾騎乘自行車，同時可遠眺城市天際線；濱海中花園則自新加坡摩天觀景輪旁向北延伸，形成連續性的濱海長廊。

此花園代表新加坡成功樹立「花園中城市」(City in a Garden)的理念典範，並整合多項綠色能源技術，包括大規模應用再生能源系統、熱空氣對流與溫度調節循環系統、以及利用廢棄植物有機物質輔助環境溫度調節等創新技術，充分展現新加坡在環境保護及工程技術領域的卓越成就。

這座經過精心規劃與工程技術結合的濱海灣花園處處體現創新設計與工程傑作，其中最具代表性的建築為園區內的擎天樹叢 (Supertree Grove)。擎天樹叢採用鋼筋混凝土結構作為樹幹基礎，外部種植多種熱帶花草形成垂直綠化系統。園區內共設置 18 棵擎天樹，高度介於 27 至 78 公尺不等。每棵擎天樹的核心結構為強化混凝土，表面覆以植被牆板，外圍則以鋼鐵框架提供支撐。牆板系統上共種植超過 16 萬株植物，品種包括蘭花、蕨類植物、杉葉石松及多種藤蔓等熱帶植物品種。

擎天樹的傘蓋結構裝設有太陽能板，白晝期間收集太陽能並儲存於太陽能電池中，為園區提供所需電力。擎天樹樹心設計具有引導空氣流動的功能，通過地下管線系統將雲霧林和花穹兩處冷室產生的熱空氣進行有效排放，模擬自然界植物光合作用原理。此外，擎天樹結構設計亦能收集雨水，維持園區灌溉系統的水源供應。園區內適度播放的節慶音樂則營造出優雅且富有藝術氣息的环境氛圍。

為便於遊客欣賞園區景觀，園方於樹叢間架設一條位於 25 公尺高、全長 128 公尺的空中步道(OCBC Skyway)，提供遊客俯瞰濱海灣金沙酒店、新加坡摩天觀景輪及新加坡海峽等周邊景觀的絕佳視角。

園區裡也建造兩座冷室—雲霧林(Cloud Forest)和花穹(Flower Dome)，分別打造出熱帶山區及地中海花園景觀，介紹如下：

#### (一)雲霧林(Cloud Forest)

當天參觀園區時氣溫頗為炎熱，從炙熱的室外走進雲霧林冷室，立即感受到舒適涼意和涼爽水氣，其室內是一座 35 公尺高的人造山和瀑布，它占地約 0.8 公頃，模擬海拔 1,000~3,500 公尺的熱帶山區環境，溫度介於 23~25°C，可搭乘電梯或步行至 6 層樓高的原始叢林區欣賞蘭花、秋海棠、豬籠草、捕蠅草及眾多蕨類苔蘚植物。沿著樹園步道穿越人造山、瀑布，可以從上俯瞰冷室景觀，近距離觀賞攀附在山壁上的各式各樣花卉植物，還能欣賞鄰近的濱海灣金沙酒店的壯闊景色。

#### (二)花穹(Flower Dome)

它是目前世界最大的無樑柱玻璃建築物，且獲得金氏世界紀錄認證，它的室內溫度也是維持在 23~25°C，種植的植物種類大部分以地中海、南非、南美洲、美國加州及澳洲等不同國家的半乾燥地區的花卉草木植物為主，其中最特別的植物種類包括超過千年歷史的橄欖樹、極為罕見的非洲狒狒樹，以及許多造型奇特的寶瓶樹等等植物種類。



## 參訪照片



參訪濱海灣花園



參訪濱海灣花園

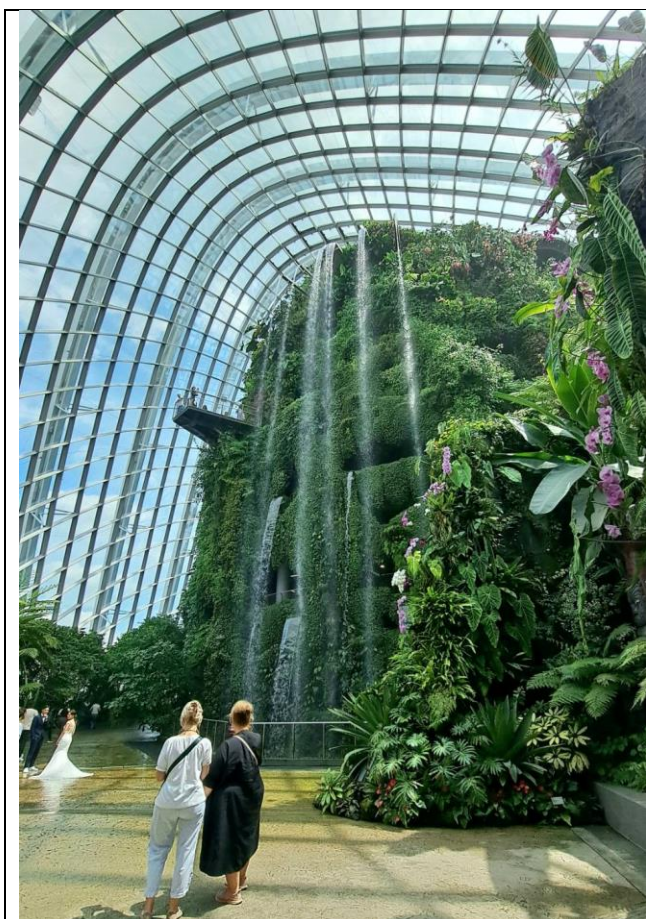


擎天樹叢

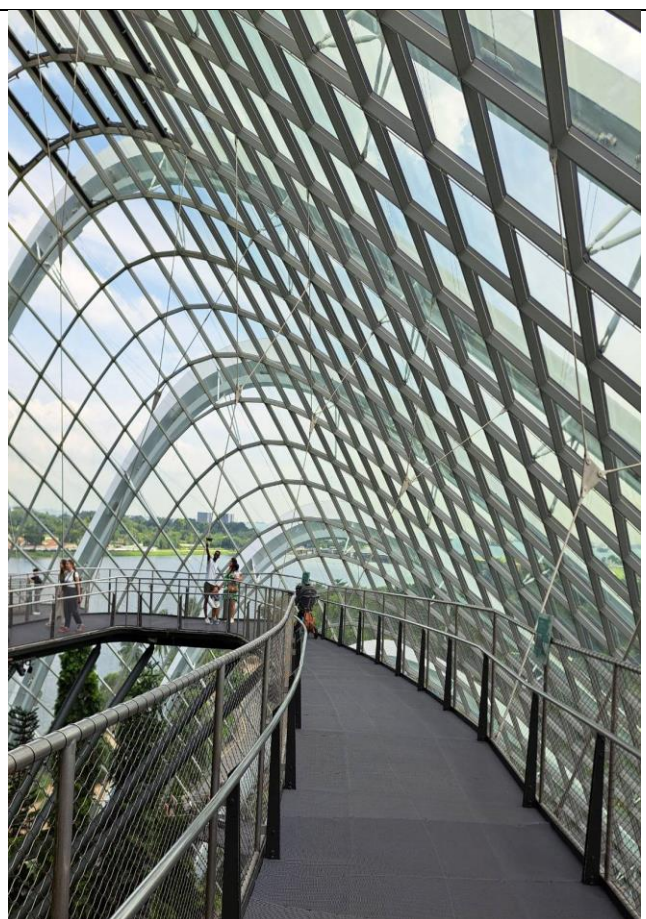


OCBC Skyway





雲霧林(Cloud Forest)



雲霧林(Cloud Forest)



參訪濱海灣花園



參訪濱海灣花園

### (三)濱海灣花園生質能發電系統

濱海灣花園的 18 棵擎天樹叢頂部除了有裝設太陽能板，以及雨水收集灌溉系統，提供園區內的雲霧林及花穹兩處溫室和污水處理設施必要的電力，以及雨水循環系統澆灌花草之外，其本身也是一座大型的生質能源發電廠。新加坡政府將其境內大部分的落葉及樹枝(包含園區內的落葉及樹枝)等生質廢棄物運送到濱海灣花園底層之生質能廢棄物焚化廠進行焚化處理，將其作為綠色燃料進行燃燒，過程中同時可產生蒸氣發電提供園區內相關設施及空間場域的電力需求。從蒸氣發電機排出的蒸汽也被引導到吸收式冷卻機，用以產生冷卻水提供生質能發電廠冷卻使用。

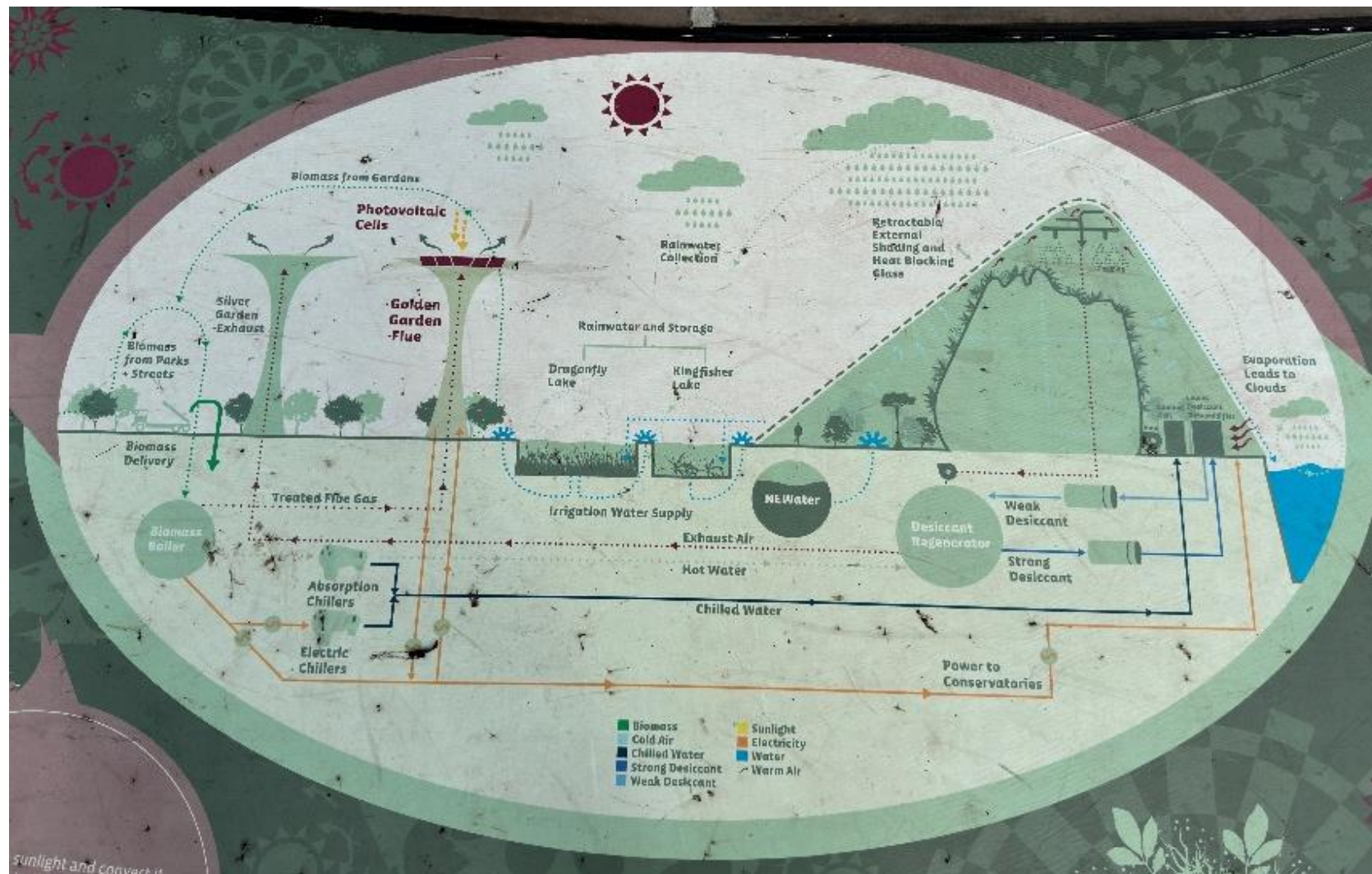
另外，焚化處理過程產生的廢氣經過處理後均符合新加坡國家環境局訂定的相關空污排放標準，再透過地面下的排煙管線連結地面上擎天樹叢結構包覆著的煙囪排放至大氣中，這支唯一的一根煙囪就藏身於 18 棵擎天樹叢的其中一棵結構體，來到園區參觀旅遊的遊客民眾也不會輕易察覺煙囪的存在，更不會聞到焚化燃燒排放的黑煙及異味；燃燒過程產生的飛灰跟底渣也經過回收再處理後製成綠色有機肥料，藉由生質能焚化處理及再利用等相關處理程序，讓生質廢棄物生成可再使用的綠色能源，同時減少生質廢棄物，如此源源不絕的資源循環再利用，成功達到零廢、減污、增能的環境永續目標。

新加坡每年產生約 50 萬噸之廢樹枝及園藝廢棄物，這些廢棄物透過蒐集、篩選、破碎等程序，作為能源中心之生質燃料轉化為再生能源，提供園區使用。

透過使用再生能源，每年可減少 1 萬 3,280 噸二氧化碳（CO<sub>2</sub>）排放，相當於：

- (1) 新加坡 4,502 戶家庭年度平均用電量。
- (2) 2,362 輛汽車年度平均溫室氣體排放量。
- (3) 511 萬 2,603 公升汽油。





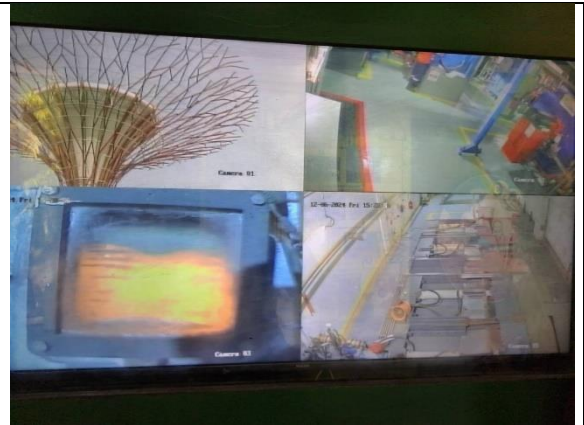
圖、園區循環能源循環系統



## 參訪照片



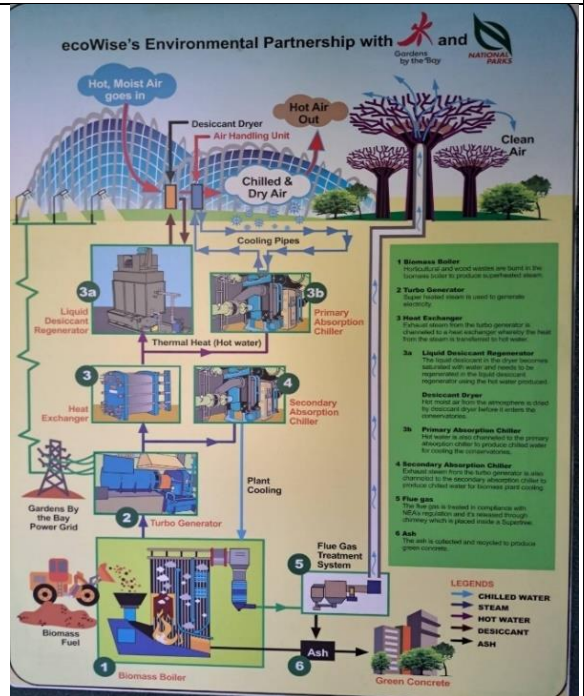
發電機組



焚化與煙囪監測畫面



轉廢為能效益



能源中心運作示意圖



發電廠外觀



隱藏在擎天樹的煙囪

## 二、 考察新加坡廢棄物處理設施

新加坡作為一個人口稠密的城市國家，僅有 730 平方公里的土地卻承載著 592 萬人口（截至 2023 年）；這種「地狹人稠」的特殊情況，為新加坡的廢棄物管理政策帶來了獨特的挑戰。龐大的人口意味著高垃圾產生率，然而，有限的土地卻難以容納如此大量的廢棄物。2023 年，新加坡的每日都市固體廢棄物產生量為 18,792 噸，每年總量為 686 萬公噸。

在土地資源有限的情況下，新加坡採取「減量（Reduce）、重複使用（Reuse）、回收再利用（Recycle）」為核心的廢棄物管理策略，並透過焚燒減少廢棄物體積後，再進行掩埋。根據政策，所有未被再利用或回收的可燃廢棄物皆會送往廢棄物焚化廠處理。2023 年，都市固體廢棄物總量達 853 萬噸，其中約 46% 經焚燒處理，52% 透過回收再利用，剩餘 3% 則直接填埋。

廢棄物焚化處理過程可同時發電，作為民生消費及工業生產等活動所需電力，因此新加坡政府考量國內因地狹人稠、能源生產及供給有限等因素，所以積極興建廢棄物焚化處理設施及發展相關技術，期望在提供更多電力能源的前提下，同時可解決因人口日益增加而相對衍生的廢棄物處理問題。所以新加坡政府自 1979 年(民國 68 年)起完成建造第一座廢棄物焚化廠開始，迄今已陸續建造完成六座廢棄物焚化廠設施，分別是 Senoko（1992 年啟用）、Tuas South（2000 年啟用）、Keppel Seghers Tuas WtE(2009 年啟用)和 TuasOne（2019 年啟用），Ulu Pandan(2009 年除役)及 Tuas(2023 年除役)，同時目前也正規劃設計第七座廢棄物焚化廠設施，預計 2026 年開始興建，2031 年落成完工使用，目前新加坡焚化處理設施主要由三菱重工與吉寶席格斯負責興建及營運。

然而，廢棄物焚化廠燃燒會產生大量的底渣與飛灰，目前每天產生約 1563 公噸，然而新加坡目前僅有一個實馬高(Semakau)垃圾掩埋場在運作，該掩埋場佔地 350 公頃，容量為 6300 萬立方米，於 1999 年啟用，預計僅可使用至 2035 年。

新加坡為改善垃圾掩埋問題在《2030 年綠色發展藍圖》中提出了具挑戰性的廢棄物管理指標：到 2030 年將整體廢棄物回收率提高到 70%，延長實馬高垃圾掩埋場的使用壽命至 2035 年後。

臺中市作為臺灣中部都會區的核心，面積約 2,215 平方公里，人口約 282 萬（截至 2023 年底），在廢棄物處理方面同樣面臨相當挑戰。臺中市平均每人每日一般垃圾產生量 0.66 公斤，每年總量達 68 萬噸，對城市的環境永續發展構成重大壓力。

臺中市目前共有三座廢棄物焚化廠：文山、后里及烏日。然而，隨著經濟發展及人口增長，臺中市的廢棄物處理系統已面臨飽和狀態。目前各廢棄物焚化廠設施老化問題日趨嚴重，迫切需要更新或改建，且其產生之空氣污染亦屢遭周遭民眾陳情。

臺中市每年平均焚化處理量約 72 萬公噸，經焚化處理後所產生之灰渣，每年平均灰渣產出量約 13 萬公噸，灰渣主要包含飛灰(Fly ash)與底渣(Botto mash)，底渣因性質較為穩定、無害，可回收處理再利用，而飛灰因含有毒物質存有污染環境疑慮，仍需經由固化(穩定化)處理後再進行掩埋之最終處置，目前近三年臺中市飛灰穩定化物掩埋量約 4.2 萬公噸，鑑於本市目前營運中公有垃圾衛生掩埋場使用量已趨近飽和且新闢掩埋場有其困難性，因此本次參訪新加坡吉寶席格斯及三菱重工建造之廢棄物焚化廠與了解新型底渣飛灰固化技術。

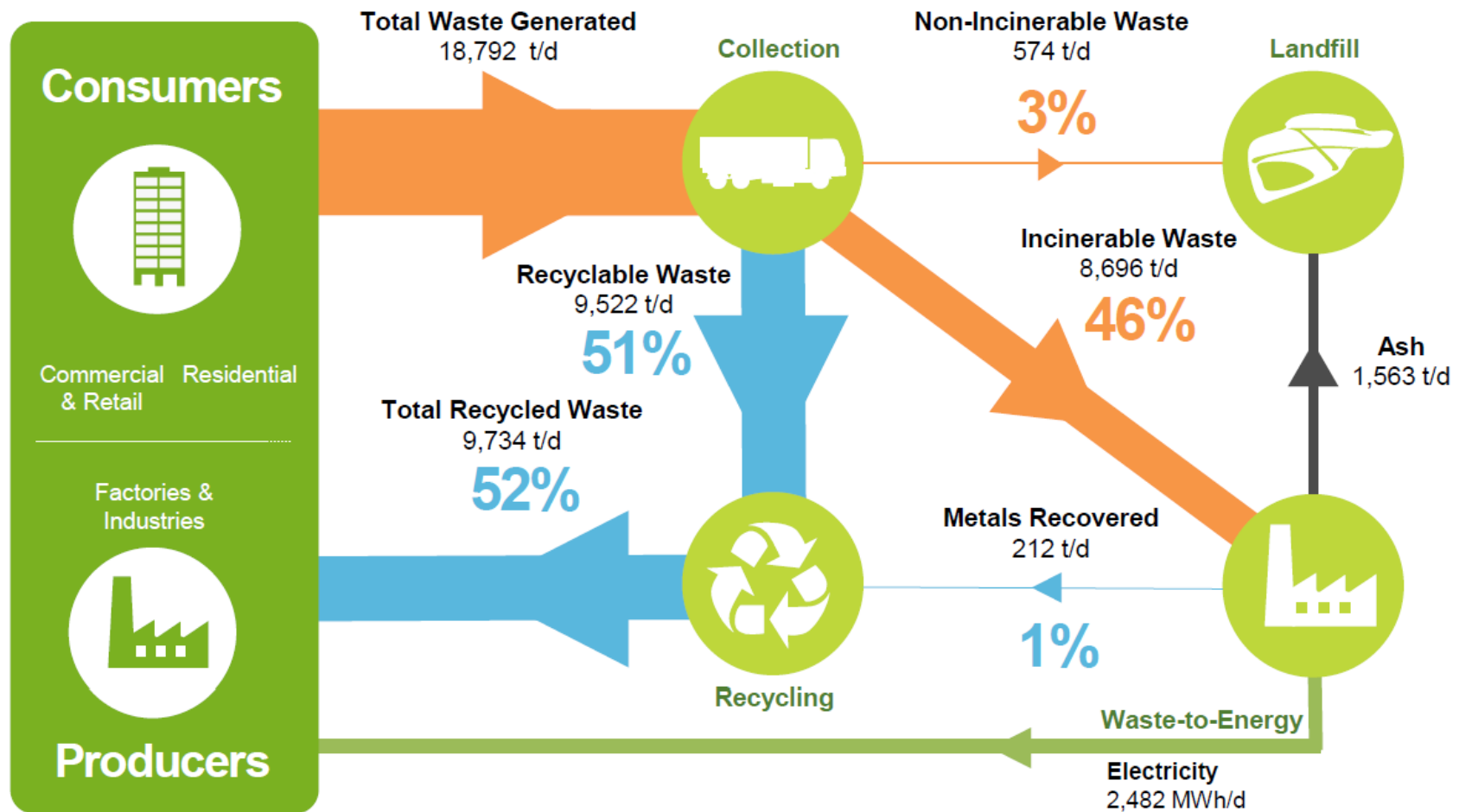




資料來源：新加坡 NEA 官網

圖、新加坡垃圾處理方針





資料來源：TuasOne 簡報

圖、新加坡廢棄物流向

4 WTE plants are in operation. 1 WTE plant is under construction.



資料來源：TuasOne簡報


圖、新加坡國內各廢棄物焚化廠興建歷程

### (1) 參訪吉寶席格斯大士廢棄物焚化廠

吉寶席格斯(Keppel Seghers)為新加坡跨國建置與營運環保設施之公司，旗下營運廢棄物焚化廠設計量可處理新加坡近 40%之垃圾量，在新加坡中有透過民間參與公共建設(PPP)收購及整改聖諾科廢棄物焚化廠並接續營運及維護的經驗，並有吉寶席格斯大士廢棄物焚化廠設計、建造、擁有及營運(Design-Build-Own-Operate DBOO)的經驗，目前有在 17 個國家完成 100 多個案件，分佈於歐洲、比利時、波蘭、澳洲、新加坡及中國與香港，吉寶席格斯目前部分承接新加坡綜合廢棄物管理設施 (IWMP) 第一期工程，設計焚化量達 2900 公噸/日與材料回收設施 250 公噸/日。

吉寶席格斯大士廢棄物焚化發電廠 (Keppel Seghers Tuas Waste-to-Energy Plant) 是新加坡第一座在新加坡國家環境局民間參與公共建設(PPP)下建造的廢棄物焚化廠。它是新加坡第五座廢棄物焚化廠，該廠由吉寶席格斯於 2006 年建造，並於 2009 年 10 月投入運營。廠內採用了吉寶席格斯自主研發燃燒技術(Sigmatix)，相關基本資料如下：

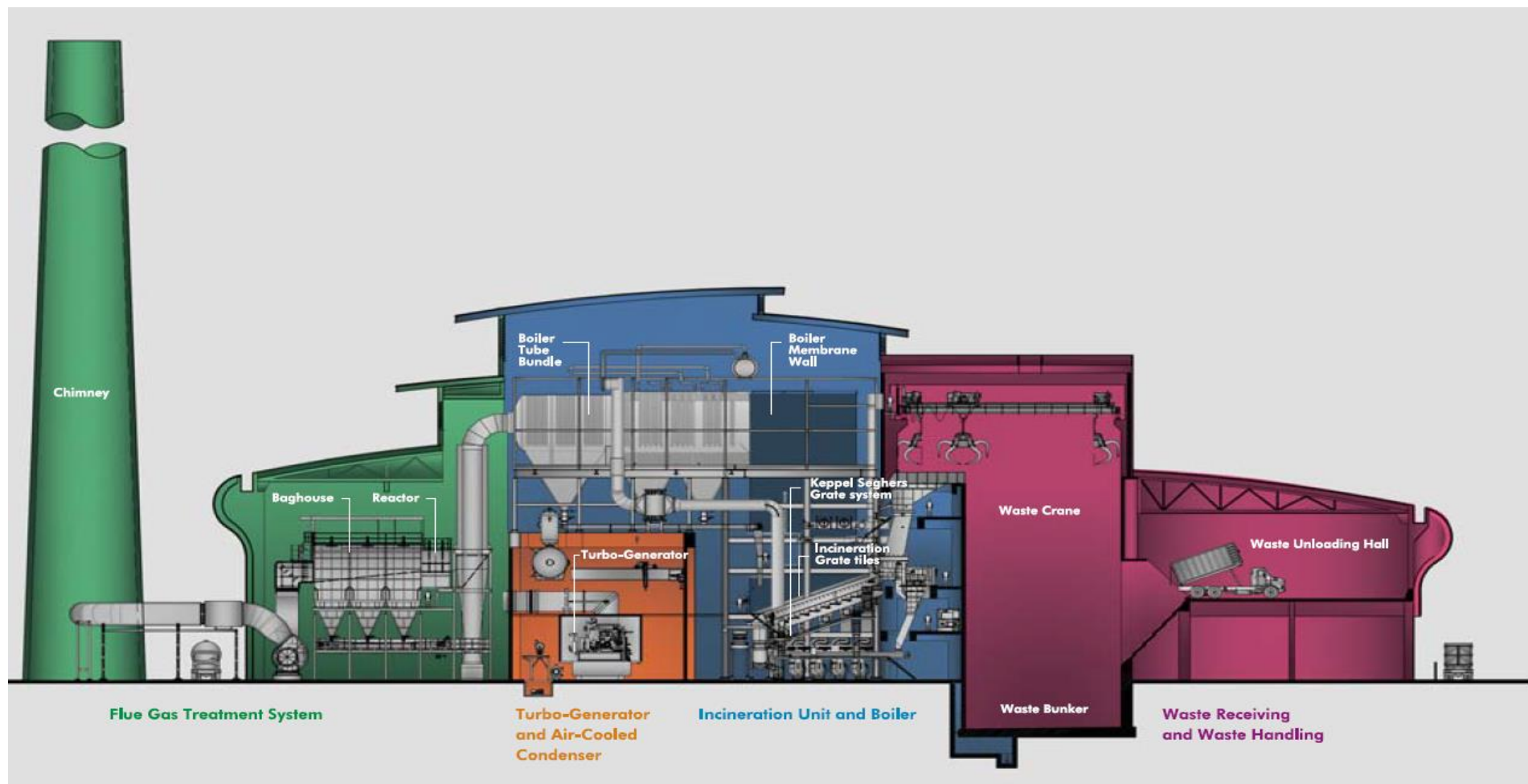
表、吉寶席格斯大士廢棄物焚化廠基本資料

	<ol style="list-style-type: none"><li>1. 每日處理能力：800 公噸/天</li><li>2. 渦輪機額定容量：22MW</li><li>3. 配置兩條焚化爐床</li><li>4. 廢氣處理技術：煙氣處理反應器 (石灰)</li><li>5. 廢氣處理技術：袋濾式集塵器</li><li>6. 1 座 100 米高的混凝土煙囪</li></ol>
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資料來源：新加坡NEA 官網

由於該廠空間限制於 1.6 公頃，在設計上做了全方位的考量，例如：地磅位於垃圾接收大廳的入口，維修車間和行政大樓位於接收大廳下面，以充分利用空間；發電機位於在鍋爐下，以方便維修和減少蒸汽管道的距離以增加效率，成為世界上最緊湊的廢棄物焚化廠之一。

**Sigmatix** 專利技術是利用滑動爐床透過推動垃圾進行燃燒，而翻滾爐床則攪拌垃圾以促進燃燒，可以解決不均勻的垃圾分佈導致的燃燒不完全。該系統具備多條爐床的靈活性，每條線的處理量可從 250 公噸/日擴展至超過 10,000 公噸/日。智慧燃燒控制通過調節垃圾進料率與獨立燃燒區的空氣供應，確保製程穩定與垃圾完全燃燒，同時最大化能源生產效率。



資料來源：NEA官網

圖、吉寶席格斯大士廢棄物焚化廠焚化處理設施流程圖



參訪照片：



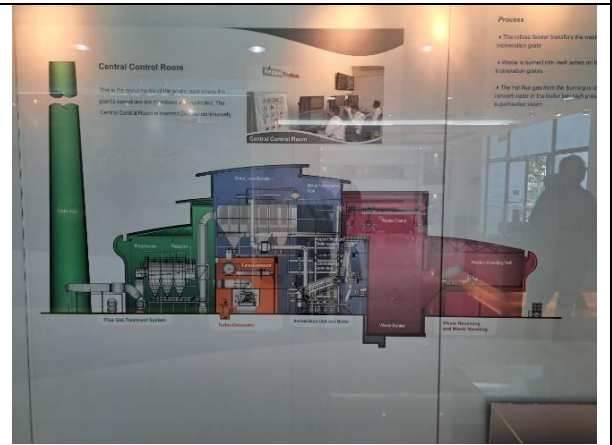
廢棄物焚化廠介紹



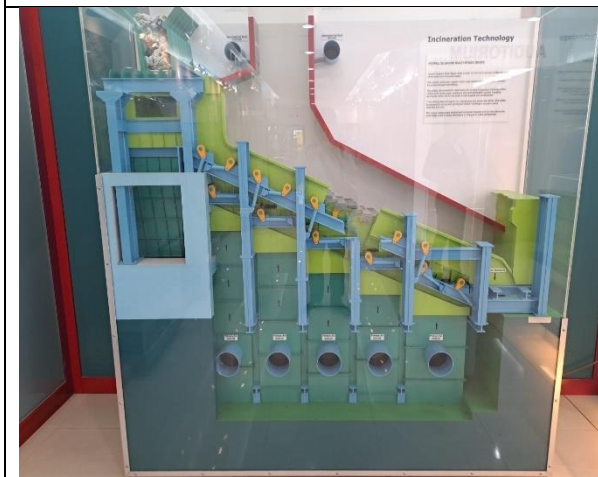
廢棄物焚化廠介紹



雙方合照



廢棄物焚化廠介紹



廢棄物焚化廠爐床介紹

備註：參訪現場刻正執行整改中，中控室及相關區域因涉及工安及商業機密無法拍攝

## (2) 參訪TuasOne廢棄物焚化廠

本次參訪的 TuasOne 廢棄物焚化廠是目前全世界透過民間參與公共建設(PPP) 營運模式的最大廢棄物焚化廠之一，該廠被新加坡國家環境局委任三菱重工環境化學工程 ECO Creation 新加坡有限公司（Mitsubishi Heavy Industries Environmental & Chemical Engineering ECO Creation Singapore）作為其長期運營與維護承包商。

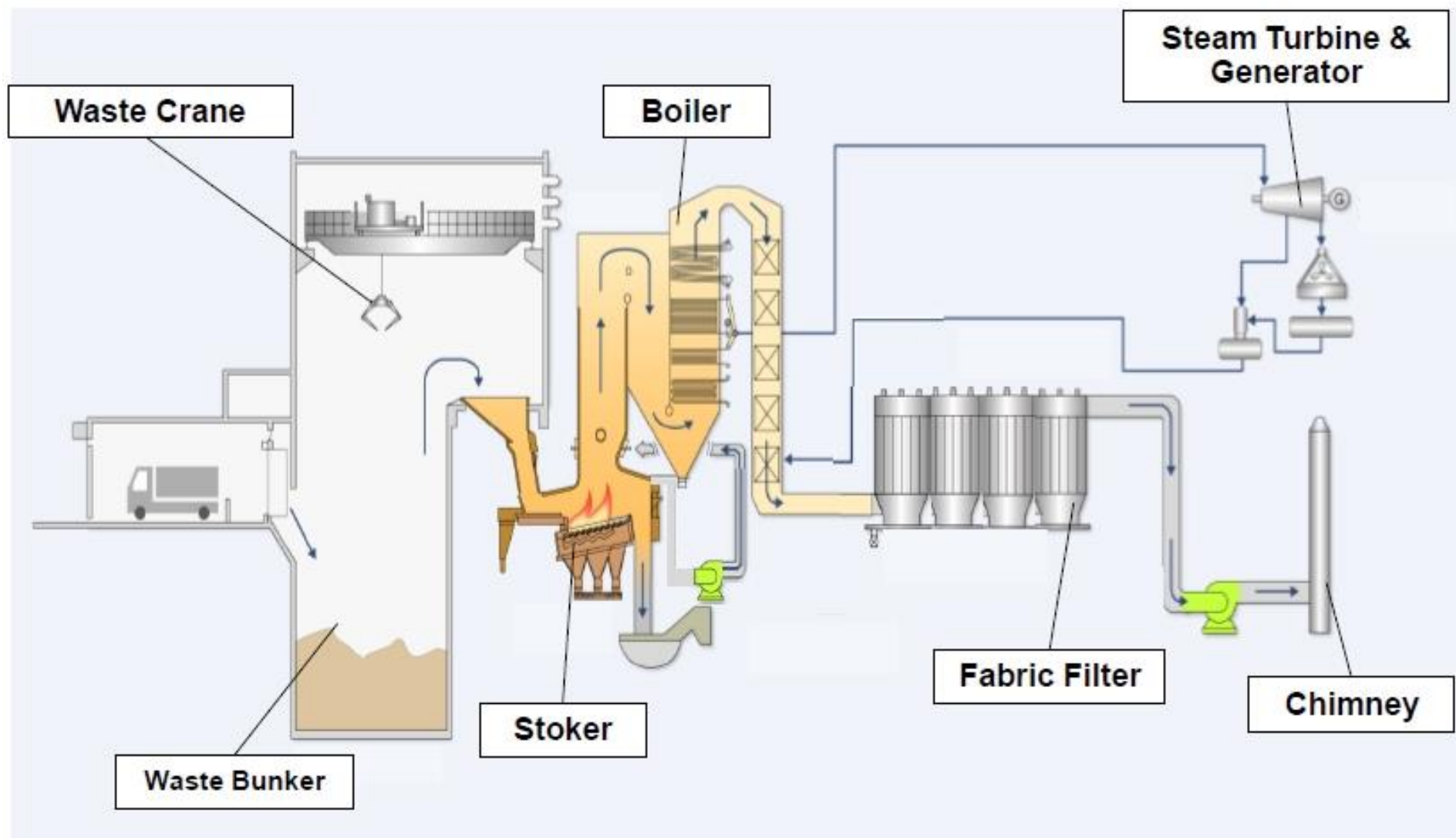
Public-Private Partnership (PPP)是一種公私部門合作的創新模式，透過政府與民間企業的策略性夥伴關係，共同投入公共建設與服務。此機制旨在整合政府的政策制定能力與私部門的資金、技術和管理專業，有效提升基礎建設的效率和服務品質。PPP 模式的核心在於風險與利益的共同分擔，涵蓋交通、能源、水利、醫療、教育等多元領域，常見的實施方式包括 BOT（興建-營運-移轉）、BOO（興建-擁有-營運）等。其主要優點包括加速公共建設、減輕政府財政負擔、引進創新技術，以及提高公共服務的整體水準。然而，PPP 也面臨複雜的契約談判、利益平衡及監管機制等挑戰，需要妥善規劃和管理，以確保公共利益得到充分保障。作為現代基礎建設發展的重要策略，PPP 為政府和私部門提供了一個互利共榮的合作平台。

該廢棄物焚化廠位於新加坡西南部的大士區，每日處理都市固體廢棄物數量約占新加坡全國廢棄物焚化總處理量的 35%，經焚化處理產生的發電量，約可供應 24 萬戶的家庭用電量，該設施相關基本條件如下：



1. 每日處理能力：4,200 公噸/日
2. 渦輪機額定容量：68MW\*2 台
3. 配置四條焚化爐床
4. 廢氣處理技術：煙氣處理反應器(石灰)
5. 廢氣處理技術：袋濾式集塵器

資料來源：TuasOne 簡報



資料來源：TuasOne 簡報

圖、焚化處理設施流程圖



## 參訪照片



廢棄物焚化廠介紹



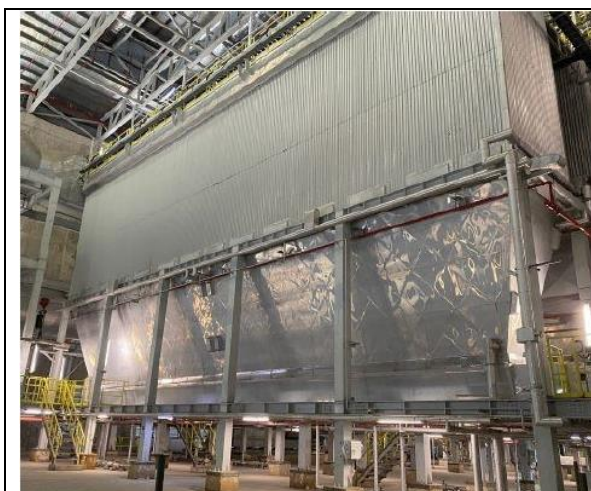
雙方合照



廢棄物焚化廠內部



廢棄物焚化廠爐排



防制設備



發電設備



廢棄物焚化廠設施外觀



垃圾車傾洩平台

備註：部分資料照片由TuasOne簡報提供



### (3) 參訪吉寶席格斯底渣與飛灰固化技術

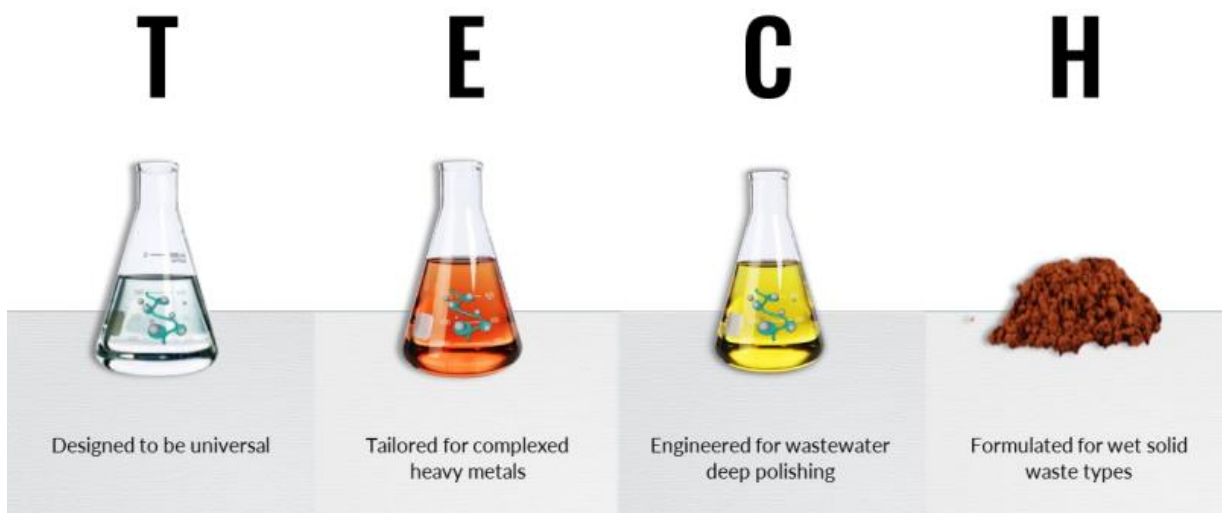
ZA (Zerowaste Asia Pte Ltd.) 是一家提供環保工程設計、建設及諮詢服務的高科技環保公司。由吉寶席格斯公司投資，提供客戶相關技術及方案解決廢棄物、廢水相關問題。公司專業領域範圍包含：焚燒底渣/飛灰處理與再利用、污染土壤整治、工業廢水處理、廢棄物/廢水貴金屬回收、廢物轉化為輕質骨料 (Artificial Aggregates)、環境影響評估、廢棄物特性與溶出研究等。

#### (一)底渣及飛灰處理技術

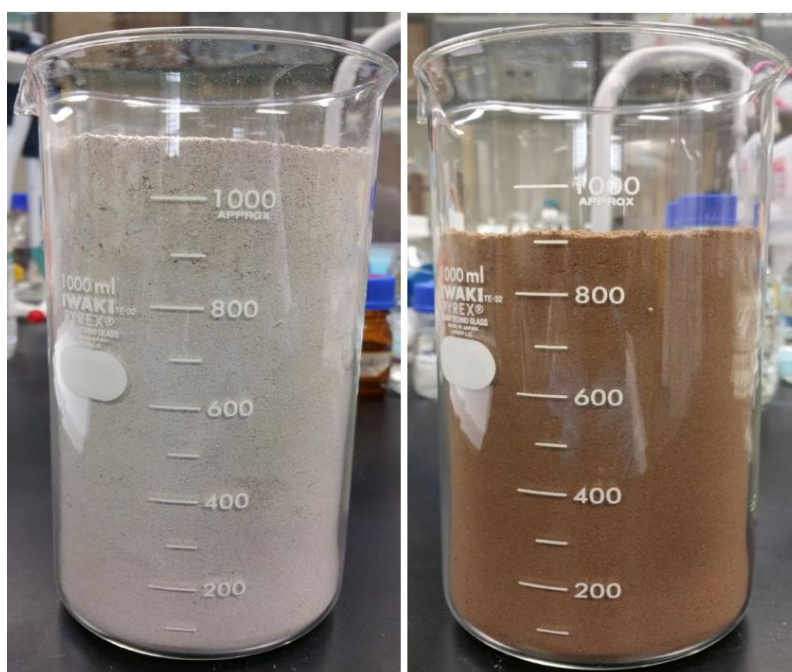
##### 1. CIP 飛灰化學鈍化技術：

生活垃圾焚化後飛灰含有大量重金屬（如鎘、銅、汞、鉛、鋅）、可溶鹽、戴奧辛等其他有機污染物，對生態系統及人類健康具危害性，因此歸類為有害廢棄物。傳統的飛灰處理方法是採用化學固化穩定化處理後掩埋。

CIP 技術基於化學鈍化原理，透過專利之重金屬捕獲藥劑 ZATECH™（圖）與飛灰混合，螯合飛灰中的重金屬，使其鈍化穩定後，送掩埋場最終掩埋處理。其螯合劑由多種配體組合，具有金屬特異性及選擇性，可作為高效重金屬捕捉劑，選擇性與有毒重金屬結合，且不受飛灰中大量無毒金屬（如鈣）的影響，形成無毒的產物（圖），於自然或浸出測試條件下具高度不溶性、穩定性及持久性，且可符合掩埋場掩埋標準。



圖、 ZA-TECH™ 重金屬處理特種藥劑



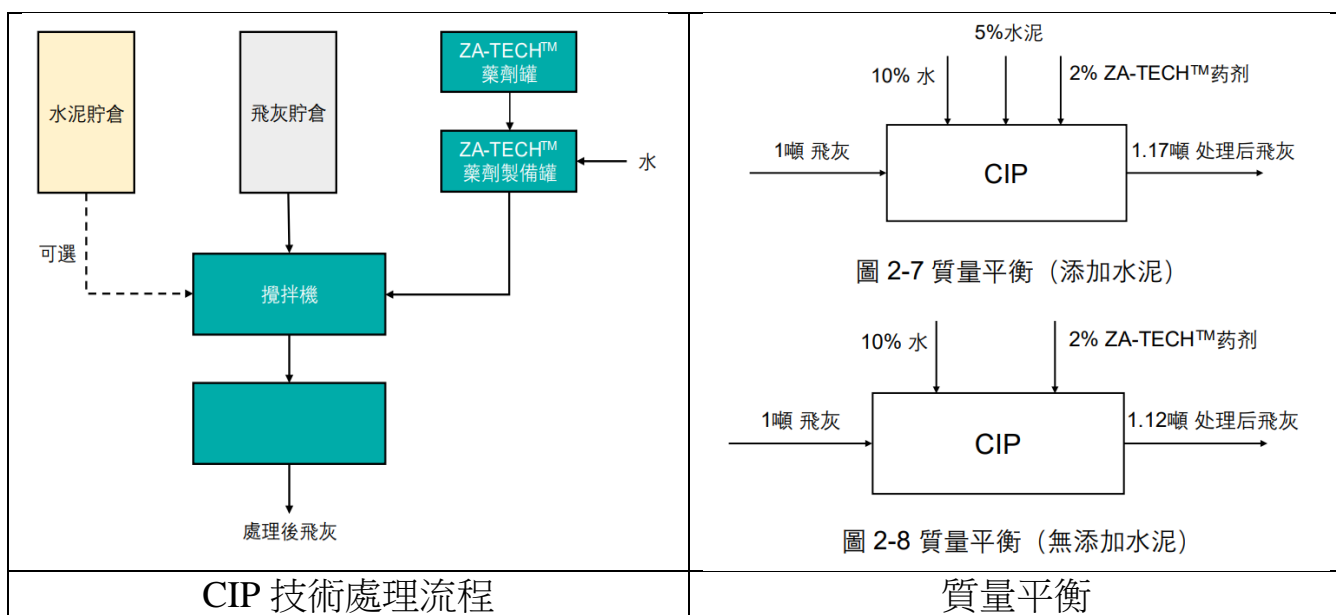
圖、 處理前（左）及處理後（右）飛灰

CIP 技術處理飛灰約以 10%水+1~3%藥劑+飛灰混和，並可選擇是否混拌水泥固化；水泥並非必要之添加物，經 ZA 試驗，添加水泥和藥劑處理後，飛灰的質量將增加 17%，將增加處理後飛灰重量，提高清運及掩埋場處理相關成本；只添加藥劑不添加水泥則增重 12%，可進一步降低後續相關打包、清運及掩埋處理成本。

CIP 技術每處理 1 噸焚化飛約產生 1.12~1.17 噸飛灰穩定化物，處理流程詳以下：



圖、飛灰化學鈍化工藝流程圖



圖、CIP 技術處理流程及質量平衡

## 2. CIP 技術處理特點及處理後飛灰各項檢測值

CIP 技術特點為 ZA-TECH™ 系列藥劑能有效地捕獲、固定、回收廢物廢水中的重金屬和金屬化合物，使處理後的廢物廢水具有高度環境安全性。具備經濟性、佔地面積小且操作簡便的特點，且不產生其他廢棄物或廢水，產出之飛灰穩定化物體機小，亦可有效節省掩埋空間，延長掩埋場使用期限。CIP 技術已成功應用於新加坡和中國大

陸，用於處理焚燒飛灰、焚燒底渣、污染土壤和其他工業廢物，經 ZA 測試處理後廢物可滿足當地的掩埋或廢物利用標準，與臺灣的飛灰掩埋標準相比，新加坡的飛灰經 CIP 處理所有限值均符合要求標準（測試結果詳下表）。

表、CIP 技術處理飛灰後各檢測項目值

檢測項目		新加坡		飛灰掩埋標準	
		飛灰處理前	飛灰處理後	臺灣	新加坡
戴奧辛毒性當量（ng I-TEQ/g）		0.84	未檢測	1.0	未監管
毒性特性溶出程式	總汞	0.0145	0.00058	0.2	0.2
	總鎘	0.00111	0.00079	1	1
	總硒	0.00263	0.00317	1	1
	六價鉻化合物	未 檢 測 ( $<0.083$ )	未 檢 測 ( $<0.0321$ )	2.5	未監管
	總鉛	47.34	$<0.0001$	5	5
	總鉻	0.083	0.0321	5	5
	總砷	0.00281	0.00241	5	5
	總銅	0.119	0.00805	15	100
	總鋇	6.168	5.708	100	100

備註：1.紅字表示超出臺灣標準；臺灣與新加坡浸出方法皆為 TCLP。

2.本項技術尚無臺灣實測資料。

3.參考資料來源：新加坡 ZA 公司提供之技術資料。

### 3. CIP 技術與本市廢棄物焚化廠現況比較

參考本市 3 座廢棄物焚化廠資料，現行飛灰均採添加穩定劑之水泥固化中間處理，再作最終之獨立掩埋處置。以處理每公噸垃圾將會產生約 0.036 公噸飛灰的比例(約 3.6%)、飛灰經穩定化處理後，以處理每公噸垃圾將會產生約 0.058 公噸飛灰穩定化物的比例(約 5.9%)推算，每公噸飛灰經處理後約產生 1.61 噸飛灰穩定化物，每年 3 座廢棄物焚化廠產生約 4 萬 5,000 公噸飛灰穩定化物（委外清運處理費用約 1 萬 9,499.55 元/公噸）。

以本市飛灰穩定化物處理現況與新加坡 CIP 技術比較，CIP 技術處理後產生之飛灰穩定化物量可減少約 0.44~0.49 噸(約減少 27%~

30%)，可減少約 30% 相關處理成本。新加坡 CIP 技術處理方式、處理後飛灰穩定化物量與本市現況比較詳如下表。

表、CIP 技術及本市處理焚化飛灰比較表

國家	焚化飛灰	螯合劑	水	混拌水泥	飛灰穩定化物
臺灣	1 噸	V	V	V	1.61 噸
新加坡 (ZA)	1 噸	V(1~3%)	V(10%)	V(5%)	1.17 噸
				X	1.12 噸

備註：參考資料來源：

1.新加坡資料：新加坡 ZA 公司提供之技術資料。

2.臺灣資料：本局「109 年臺中市垃圾焚化廠飛灰穩定化物吊掛及清運處理專案報告」、「112 年臺中市每年爐渣與飛灰處理方式、成本分析及未來規劃專案報告」。

#### 4. 飛灰水洗 (WCS) 結合固廢製陶粒技術 (MIL) 資源化

WCS 技術旨在處理垃圾焚燒飛灰無害化以實現資源化利用目的，通過深度洗滌高效去除垃圾焚燒飛灰中的可溶鹽和部分重金屬，以利於直接資源化或後續熱處理；包含的專利飛灰深度清洗設備可以大幅縮短清洗時間和降低用水量，從而降低後續水處理成本。清洗廢水經專利重金屬捕獲藥劑 ZA-TECH™ 處理後，可以安全排入海洋或污水處理廠，也可以進入 RO 或 MVR 進一步處理回用，實現廢水零排放。清洗後的飛灰結合固廢製陶粒資源化技術 (MIL)，在高溫 (1000℃ 以上) 下將廢物燒結並將其轉化為多孔陶瓷顆粒 (熱處理過程)，即輕質骨料 (LWA)。陶粒可用作高附加值的功能性建築材料或園藝材料，具有輕質、隔熱、隔音、蓄水和使養分緩釋等獨特功能，達成零廢棄物、廢水排放目標。

#### 5. 底渣水洗資源化技術 (WCI)

WCI 技術係通過深度洗滌高效去除垃圾焚燒底渣中的可溶鹽和泥沙，高效回收鐵和非鐵金屬，處理後廢水可回收使用或排放至下水道，處理後底渣可製成新生沙，應用於修路、混凝土或填海。



## 參訪照片

	
<p>處理前（左）、後（右）飛灰</p>	<p>金屬回收</p>
	
<p>處理後飛灰資源化-製作陶粒</p>	<p>陶粒牆板/磚</p>
	
<p>雙方人員交流及致贈本局宣導品</p>	<p>吉寶席格斯公司參訪</p>
	
<p>吉寶席格斯公司參訪</p>	<p>吉寶席格斯公司參訪</p>



### 三、 考察裕廊島長春集團石化廠

裕廊島 (Jurong Island) 位於新加坡西南方，是亞洲最大的石化工業基地之一，由 7 個離島(Pulau Seraya, Pulau Ayer Merbau, Pulau Sakra, Pulau Pesek Kecil, Pulau Pesek, Pulau Ayer Chawan and Pulau Merlimau) 填海造陸連接而成。新加坡政府於 1993 年提出開發計劃，並由新加坡貿易和工業部 (Ministry of Trade and Industry, MTI) 旗下的裕廊工業園區管理局(Jurong Town Corporation, JTC)主導開發，將裕廊島打造為化學工業聚落。

裕廊島填海工程於 1995 年啟動，原計劃於 2030 年完成，但由於石化產業對土地的需求快速增長，工程進度大幅提前，並於 2009 年完工，比原計畫提早 20 年。裕廊島總面積達 32 平方公里 (3,200 公頃)，並透過 2.3 公里長的裕廊島連接道 與新加坡本島相連，使其成為亞洲地區的重要石化產業中心。

裕廊島自 2000 年第一期啟用以來，已吸引殼牌(Shell)、埃克森美孚 (ExxonMobil)、巴斯夫(BASF)、住友化學 (Sumitomo Chemical)等全球知名企業進駐，至今超過百家跨國公司在此設立生產設施，能源與化學產業為新加坡貢獻 3% GDP，占總產值 20.4%，並提供 27,000 個就業機會。

裕廊島的成功得益於新加坡政府在工業區規劃與管理方面的創新做法。新加坡經濟發展局 (Economic Development Board, EDB) 與裕廊集團 (JTC Corporation) 為進駐企業提供從基礎設施、公共事業到安全管理(一站式工業生態系統 Plug and Play Infrastructure)，裕廊島內的企業可共用電力、蒸汽、冷卻水及污水處理設施，提升資源利用率並降低成本，透過產業鏈垂直整合與企業間的供應鏈聯繫，實現上游原料直接輸送至下游工廠。

裕廊島屬於高風險工業區，新加坡政府自 2001 年，將該島列為限制區，並實行嚴格的保安與管制作業，外人進出該島須由島內企業事先申請許可文件才能進出，並且不可拍照。

本次參訪長春石化在新加坡的工廠並協助進出裕廊島，長春集團於 2010 年投入 4.5 億美金啟動投資規劃，由於該廠建廠為自己興建，整個建設過程歷時約兩年時間較短，在 12 公頃的土地上建設三座專業化工廠，分別生產醋酸乙烯單體(VAM)、丙烯醇(AA)及異丙苯(Cumene)，長春集團在裕廊島主要優勢在於其完善的原料供應鏈體系。具體而言，殼牌公司透過一條 14 公里長的海底管線，可以直接從毛廣島將乙烯、丙烯等關鍵原料輸送至裕廊島，此舉顯著降低了原料運輸過程中的潛在風險且裕廊島其能源與相關措施均為租用方式，長春新加坡廠可向他廠租用蒸氣的方式減少能耗，其產品亦統一由儲槽公司存儲，可以減少相關資源浪費與能耗。長春新加坡廠致力於減少碳排，其在 2021 年 10 月舉行的能源效率國家夥伴獎 (Energy Efficiency National Partnership Awards) 中，長春新加坡廠因其通過蒸汽優化(熱整合，將製程餘熱導入其他製程中)減少碳排放的努力而獲得"最佳實踐"獎，而埃克森美孚、雅富頓化工 (Afton Chemical) 和新加坡石化公司 (Petrochemical Corporation of Singapore, PCS) 則因其在能源效率改進方面的努力而獲得了榮譽提名。

參訪照片：

	
新加坡長春石化廠大門	新加坡長春石化廠設施
	
新加坡長春石化廠設施	雙方合照

備註：裕廊島為新加坡管制區，不可拍照與錄影，製程與設備畫面為長春石化廠簡報提供

## 伍、心得：

### 一、 參訪吉寶灣大樓綠建築心得

本次參訪吉寶灣大樓，其作為新加坡首座獲得「綠色標章白金零耗能」認證的商業建築，展現了綠建築的前瞻設計與技術應用，透過現場人員的介紹，瞭解到未來面臨淨零碳排的挑戰下，必須考量到整合的重要性，該大樓利用太陽能發電系統實現能源自給自足，凸顯再生能源在商業建築中的可用性。其次，智慧化空調系統將高效設備與智慧控制相結合，且能即時調節新風量，在提升能源使用效率的同時，降低運維成本並保持室內空氣品質。再者，透過建築管理系統能使能源管理更加精準，為建築的永續運營提供科學支援。此外，其冷卻水塔使用創新水處理技術有效防止設備腐蝕與水垢形成，延長設備壽命並減少化學品使用，體現環保與效能兼顧的設計理念。而智慧照明系統則結合即時感測與後端分析，根據室內活動選擇最佳模式，比一般常見之感應燈可以更即時因地制宜的調整模式，提供節能且舒適的體驗。這些綜合措施充分展現了綠建築的未來發展潛力，並為臺中市在推動綠建築相關政策與技術應用方面提供了重要的參考與借鏡。

### 二、 參訪濱海灣花園(擎天樹)心得：

此次參訪濱海灣花園（Gardens by the Bay），既展現了其作為新加坡城市花園的自然美與綠意，更深刻瞭解其在永續設計與能源管理方面的創新理念與實踐成果。花園內「擎天樹」（Supertrees）的設計與功能展現了高度的創新與實用性，充分體現了新加坡在永續建築方面的卓越表現。這些高聳的人工結構樹頂安裝了太陽能板，用於為花園照明和設施供電，展現了太陽能利用的實際應用。同時，其中一座擎天樹被設計成煙囪，用於排放園區能源中心的生物質燃燒廢氣，將功能性與美學完美結合。而擎天樹外部的垂直花園，種植了鳳梨科植物、蕨類與胡姬花，不僅增添了自然美感，也強化了花園的生態意義。

濱海灣花園內的能源中心（ecoWise Marina Power）採用三重熱電聯產（Trigeneration）技術，實現了能源的高效利用。該系統

以園藝廢料和木材廢料為燃料，將發電過程中產生的廢熱收集起來，用於「花穹」與「雲霧林」兩大溫室供熱或冷卻需求，體現了資源循環利用的理念與內部植物創造了理想的生長環境。

濱海灣花園不僅是一座城市綠洲，更是一個將生態與科技深度融合的可持續發展典範。園區在空間設計、能源利用及廢棄物管理等各個環節，均充分體現了對自然資源的尊重與高效利用，其先進經驗值得本市在城市規劃與環境建設領域深入借鏡與推廣。

### 三、 參訪吉寶席格斯大士廢棄物焚化發電廠心得：

吉寶席格斯大士廢棄物焚化廠在空間設計上採用了垂直整合概念，充分利用有限的 1.6 公頃土地來打造每日可處理 800 公噸廢棄物的焚化設施。在垃圾處理技術方面，**Sigmatix** 燃燒系統的創新設計採用滑動爐排和翻滾爐排設計來解決垃圾燃燒的挑戰，其可確保垃圾均勻前進並通過攪拌確保垃圾完全燃燒，避免了傳統焚化爐床的燃燒死角問題；在空氣污染方面，該廠設有袋濾式集塵器與洗滌塔等設備，可充分處理空氣污染，使其符合國家設定的排放標準。

該廠其建廠面積與設計量均與文山廢棄物焚化廠相近，本次透過訪談了解到新加坡設計、建造、擁有和營運 (DBOO) 的好處，廢棄物焚化廠建造商與營運商若非同一單位，建造商可能僅考量營建與設計成本，而未顧及後續營運需求，導致營運成本與勞力需求增加。

### 四、 新加坡 TuasOne 廢棄物焚化發電廠心得：

此次實地參訪 **TuasOne** 廢棄物焚化廠為全球最大的民間參與公共建設(PPP) 廢棄物焚化廠之一，其設計、營運效能和環境效益，具有高度的參考價值及學習意義。

在營運模式方面，新加坡國家環境局與三菱重工環境化學工程的合作充分展現了民間參與公共建設(PPP)的優勢。透過引入私部門的專業技術和管理經驗，此模式在提升營運效率的同時，亦顯著改善了整體服務品質，為其他城市提供了具高度參考價值的典範。

就處理規模而言，TuasOne 每日處理量占全國廢棄物焚化總處理量的 35%，顯示其在新加坡廢棄物管理體系中的重要地位。更令人注目的是其能源回收效能，焚化處理產生的電力可供應 24 萬戶家庭使用，成功實現了廢棄物處理與能源生產的雙重效益。

此次參訪也凸顯了新加坡在環境管理方面的前瞻思維。透過採用先進技術、創新營運模式，以及注重能源效率，展現了其在都市廢棄物管理領域的領導地位。這些寶貴經驗對於推動永續發展具有深遠影響，同時為其他城市在廢棄物處理設施的規劃與實施方面提供了重要的參考價值。

## 五、新加坡參訪廢棄物焚化發電廠綜合心得：

廢棄物焚化廠自開始動工興建平均約花費 2-3 年期間即可興建完成，規劃興建之效率非常高，而且人民對於新加坡政府與民間企業公司共同攜手合作興建廢棄物焚化廠之環保設施也都抱持正面支持態度，可見廢棄物焚化廠對於新加坡國家整體發展而言是非常重要的國家基礎設施，同時可快速有效的處理都市廢棄物，減少廢棄物掩埋處理所需的土地空間及壓力，避免因廢棄物處理不當而產生的各種負面問題。

臺中市應借鏡及學習新加坡對於廢棄物焚化廠興建及營運等相關經驗及技術，積極加速及提升都市廢棄物焚化處理之執行政策及具體措施，尤其廢棄物焚化廠設施的規劃設計及興建更是刻不容緩，未來隨著城市經濟發展及科技進步，臺中市人口數勢將逐年遞增，同時亦將增加都市廢棄物焚化處理量能的需求及提升相關處理技術水準，針對現有 3 座即將屆齡除役的老舊廢棄物焚化廠進行重建或興建等工程已是當務之急，未來透過新穎高效及低污排放的廢棄物焚化處理技術，一定能有效解決臺中市的廢棄物處理問題，對城市環境保護注入新氣象，並帶動城市進步發展及繁榮。

新加坡廢棄物焚化廠之排放標準較本市寬鬆，導致其防制設備無法像本市之廢棄物焚化廠採用半乾式洗滌塔與常態噴氨，透過本次訪談，其也可以了解到在營運面理應降低營運成本，符合國家標

準即可或是契約訂定的標準，因此本市可在未來廢棄物焚化廠訂定的契約直接降低排放值，將可有效提升空氣品質。

此外，我國人口密集，廢棄物焚化廠多鄰近民眾居住區，高聳的煙囪長期被視為「鄰避設施」（NIMBY），引發在地居民的不滿。為降低民怨，過往多採取在大型煙囪上進行彩繪，以緩解視覺衝擊。然而，本次參訪濱海灣花園的擎天樹，為本市的煙囪設計提供了另一種思考方向。

擎天樹的外觀設計巧妙，若非特意了解，難以察覺其兼具煙囪功能。此種設計不僅美觀，更能有效減少煙囪對周邊居民造成的心理負擔與民怨。國際間亦有多座廢棄物焚化廠成功融入美學設計，例如 丹麥的阿馬厄山資源中心（CopenHill），將廢棄物焚化廠屋頂打造成滑雪場、登山步道與攀岩場，使其成為市民休閒運動的場所；奧地利施皮特勞廢棄物焚化廠（Spittelau），則透過鮮豔色彩、曲線造型與金色圓頂，使廢棄物焚化廠宛如藝術建築，成為都市地標；而 日本大阪舞洲廢棄物焚化廠（Maishima）則採用繽紛的童話風格，讓廢棄物焚化廠外觀彷彿宮殿，顛覆傳統工業設施的印象。

這些成功案例顯示，廢棄物焚化廠不僅能透過美學設計減少民眾抗拒心理，亦可轉型為兼具公共空間與城市景觀價值的基礎設施，值得本市借鏡與進一步探討。

## 六、參訪吉寶西格斯-底渣與飛灰固化技術

因新加坡腹地小且為海島，水、土地等各項資源珍貴，因此國家整體政策重視資源有效利用及相關技術開發，包含廢棄物處理後體積減少、各種水、重金屬等資源循環再利用等，於廢棄物處理設施之規劃，即以達到資源循環、零廢棄物產生之目標做整體考量，減少廢棄物處理後體積，不僅可節省所需掩埋之空間，節省土地資源及延長掩埋場壽命，同時，處理廢棄物之廢水循環再利用，廢棄物製成再生粒料用於陶藝、建築、道路工程，創造綠色循環經濟及

達到資源利用最大化效益，同時也可符合相關環保標準，此經驗值得同為海島、土地資源有限的臺灣界借鏡參考。

## 七、參訪裕廊島長春石化廠心得

裕廊島為新加坡西南部由 7 座島礁與填海造陸所建置總面積約為 32 平方公里的人工島嶼，為政府所規劃之石化專區，依據新加坡國立大學（National University of Singapore, NUS）的學者估計，裕廊島的 2019 年排放量有 2,700 萬噸 MtCO<sub>2</sub>e，相當於全國總排放量的 54%（Max Tingyao Lin, 2021），細究其高排放量的原因在於整個新加坡逾七成發電容量、煉油量以及幾乎所有的石化廠與化工廠皆集中於裕廊島，其地理位置遠離新加坡住商混和區，以期對於環境受體的影響降至最低，也因此對於本次參訪的長春石化股份有限公司而言，幾乎未曾因環保事件招致當地主管機關進廠查核而有違規缺失遭受處分等情事。雖然採取新加坡專區管理能有效降低或解決受體之影響，但若無相對應之配套措施，空氣相互流通的特性亦將間接影響生活環境。經本次實地接觸當地業者，瞭解主管機關之管制策略主要區分為以下四個層面：

- (一)許可證制度：依據「空氣污染防制法」第 24 條及固定污染源設置操作及燃料使用許可證管理辦法第 23 條規定，公私場所應於取得固定污染源操作許可證後，始得操作，並應依許可證核定內容操作；綜觀新加坡空氣污染管制與上開所提「空氣污染防制法」許可證制度相類似，許可證效期皆為 5 年並得依規申請展延，僅有細節(如效期屆滿前之申請規定等)略有不同，皆向主管機關申請並經審核通過後，依許可證核定內容操作。
- (二)定期檢測：依據「固定污染源自行或委託檢測及申報管理辦法」第 6 條規定，公私場所應依空氣污染物排放檢測計畫執行固定污染源定期檢測，回顧新加坡之管理策略之一，每年擇特定時段至公私場所執行類似上開定檢之查核措施，此作法類似臺灣落實定期檢測的指引方針，藉由主管機關介入，以確保公私場所空氣污染防制設備相關效



能並無因長年操作而降低，且應自行落實設備(施)的檢點、保養與維護。但臺灣相較於新加坡，部分縣市(尤以本市)之地方主管機關常因需執行定期檢測義務之公私場所為數眾多，實難逐一共同執行定期檢測，著實讓定檢作業的落實度有所打折，此為本市目前管制實務上所浮現的問題之一。有鑑於此，地方主管機關於精進環境檢測管理策略時，可邀集檢測機構權責管理相關單位(如：國家環境研究院)執行固定污染源定期檢驗聯合稽查，以共同監督提升定檢品質。

(三)自主化管理：為避免揮發性有機物之製程、液體儲槽、裝載操作設施、設備元件洩漏致環境污染情事發生，臺灣訂有「揮發性有機物空氣污染管制及排放標準」相關規範及專章管理，新加坡則依據工業安全、環境保育以及能源管制等多面向設立專責單位強化自主管理，藉由工業安全相關法規落實揮發性有機物的收集與管理，並同步達到環境保育以及能資源循環利用的多贏政策，展現了全面且系統化管制的管理措施，此部分確為本市可予以借鏡的自主管理政策。

(四)科技化管理：除公私場所自主設置的空氣污染防制設施外，政府機關亦於該石化專區內部架設大量空氣品質微型感測器以及動態監控系統，除針對環保層面以外，亦可多方掌握包含工業安全等狀況，此部分科技化管理措施則與本市施政方針不謀而合。

## 陸、建議：

### 一、 本市建築物綠化可參考吉寶灣大樓經驗：

吉寶灣大樓的各項技術可以供本市各項借鏡。可以考慮各公有建築中納入太陽能光電，利用統一的空調與智能監控達成減少能耗的目標。

### 二、 本市廢棄物焚化廠汰舊整改，可參照國外技術及經驗：

(一)採用可充分混和及攪拌的爐床：良好的廢棄物焚化爐床燃燒效率可降低空氣污染物排放，並提高熱值產生更多能源。透過充分混合與攪拌，可促使垃圾與氧氣充分燃燒，提高燃燒效率，其中吉寶集團專利技術可提供本市一個參考，可透過選擇可充分混和與攪拌的爐床達成燃燒完全的目的。

(二)採用緊湊型廢棄物焚化廠設計：臺灣地小人稠，尤其土地珍貴，在市區中建造廢棄物焚化廠更為挑戰，本次所參訪之 **TuasOne** 及吉寶席格斯大士廢棄物焚化廠均為緊湊型廢棄物焚化廠，建議可參照吉寶席格斯經驗將地磅位於垃圾接收大廳的入口，維修車間和行政大樓位於接收大廳下面，以充分利用空間；發電機位於在鍋爐下，以方便維修和減少蒸汽管道的距離以增加效率，又或者參照 **TuasOne** 廢棄物焚化廠將爐床及儲坑儲存量增加，增加單位可焚燒的量即可增加土地利用效率。

(三)加嚴本市廢棄物焚化廠標準：有關各國空氣污染防制設備設計主要考量為符合當地空污法規或相關契約規範為主，經查新加坡排放標準較本國廢棄物焚化廠空氣污染物排放標準較寬鬆，導致空污防制設備較無全面，本市倘要更進一步降低空氣品質，應可加嚴廢棄物焚化廠標準，又因我國廢棄物焚化廠興建均由各縣市主管機關發包，可在規劃階段將廢棄物焚化廠排放值契約值訂定較嚴苛，將可增進空氣品質。

三、 引進國外技術減少廢棄物體積，延長掩埋場壽命：

臺灣土地有限，垃圾掩埋場容積亦趨於飽和，建議可引進國外廢棄物處理技術，減少燃燒後飛灰、底渣體積以延長掩埋場壽命，同時亦可減少委外處理清運之費用，節省公帑；底渣再利用，搭配政府政策規範及補助，實現資源循環再利用及零廢棄物排放目標。

四、 廢棄物處理設施設計加入美學設計並創造經濟效益：

目前臺灣焚化爐老舊，垃圾處理量能不足，有整改或興建需求，惟臺灣因地狹人稠，焚化爐處理垃圾容易有異味及，加上焚化爐外觀設計顯而易見一根大煙囪排放，有影響環境衛生及空氣品質疑慮，民眾觀感不佳，因此常成為嫌惡設施，容易遭當地民眾反對；建議可以參考新加坡濱海灣花園-擎天樹叢美學設計概念，美化焚化爐及煙囪外觀，並考量發展為特色觀光景點及收費，除讓民眾無法察覺煙囪存在外，還可以藉由發展觀光增加經濟收入，用於焚化爐相關設施維護。

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附件  
(新加坡攜回資料)



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# Foreword



Keppel Bay Tower (KBT) marks a significant milestone in Singapore's green building journey. It is a prime example of how an existing high-rise commercial building could be upgraded to be net zero.

I applaud Keppel Land's commitment in this outstanding accomplishment demonstrating how innovation both technological and financial can make high rise zero energy commercial buildings a reality. I hope Keppel Land's efforts will spur more building owners to make the decisive shift towards super low energy buildings and contribute to a low-carbon Singapore in line with the Singapore Green Building Masterplan.

This project is supported under BCA's Green Building Innovation Cluster programme. In collaboration with the industry, we are developing a series of publications on High-Performance Super Low Energy Buildings. These publications will help to raise awareness and facilitate knowledge sharing on green building solutions.

We hope that this publication on KBT, together with the subsequent publications, will be a useful and valuable resource for all built environment stakeholders in Singapore and the region.

**Mr. Kelvin Wong**

*CEO*

*Building and Construction Authority*

# Foreword



In line with Keppel's Vision 2030, Keppel Land places sustainability at the core of our strategy. We are committed to supporting the global fight against climate change as well as Singapore's sustainability efforts, including the Singapore Green Plan 2030.

Keppel Land has committed to halve our Scope 1 and 2 absolute greenhouse gas emissions by 2025 from 2020 levels, and achieve net zero by 2030. We are also contributing to greening the built environment with our suite of sustainable, smart urban space solutions.

With the support of BCA, we were able to test-bed and implement new emerging technologies under the GBIC programme, that were used to help transform the 20-year-old Keppel Bay Tower into Singapore's first BCA Green Mark Platinum (Zero Energy) commercial building. The initiatives implemented have enabled Keppel Bay Tower to be almost 50% more energy-efficient compared to typical office buildings in Singapore, and reduce over 2,400 tonnes of carbon emissions per year.

The transformation of Keppel Bay Tower is a showpiece of Keppel Land's Sustainable Urban Renewal initiative which aims to retrofit, future-proof and extend the lifespan of older commercial buildings. We believe that we have a scalable and innovative model through which Keppel Land can contribute solutions to advance sustainable development in Singapore as well as other key gateway cities in the Asia Pacific and beyond.

We will continue to push the envelope to redefine urban spaces for a sustainable future, harnessing the Keppel Group's diverse capabilities in energy and environment, connectivity and asset management to create greener and smarter solutions.

**Mr. Louis Lim**

*CEO*

*Keppel Land*

# Introduction

## Background

Keppel Land provides innovative and multi-faceted urban space solutions, including quality homes, offices, malls as well as large scale integrated developments, that enrich people and communities.

A prime showcase of Keppel Land's sustainability efforts is Keppel Bay Tower (KBT), which was completed in 2002. KBT was retrofitted and became the first commercial building in Singapore to be awarded with BCA's Green Mark Platinum (Zero Energy) certification in 2020. It exemplifies how companies can play a part to reduce the built environment's carbon footprint through the greening of brownfield assets and providing sustainability as a service to investors and like-minded asset owners.

While a new building can be designed with new energy-efficient technologies from the onset, there are more challenges in implementing these technologies for an existing operating building where the infrastructure is already in place. This includes the need to carry out the improvement works without disrupting the building's ongoing operations.

KBT is a good demonstration of the effective implementation of five emerging energy efficient technologies: a high-efficiency air distribution system, an innovative cooling tower water management system, fresh air intake control system, smart LED lighting solutions, and an intelligent building control system.

KBT's upgrading is the first time all five systems have been implemented in a development in Singapore, representing a milestone in the nation's history in its push towards sustainability. In addition, the installation of more than 400 square meters of solar panels at KBT allows the property to tap on renewable energy for its operations.

This publication captures KBT's unique journey in becoming a net zero building.

## Timeline

Keppel Land has long been committed to running its business in a sustainable manner, and continually strives to create real estate solutions that mitigate climate change. KBT's upgrading journey began in 2017, when Keppel Land

and the Building and Construction Authority of Singapore (BCA) jointly launched the BCA-Keppel Land Super Low Energy initiatives for KBT.

In 2018, Keppel received a grant from BCA's Green Buildings Innovation Cluster (GBIC) programme to pilot the aforementioned five systems at KBT, with a target annual 20% improvement in energy efficiency. In February 2020, with the completion of the pilot programme and the deployment of the five systems, KBT was able to achieve a 22.3% reduction in its annual energy consumption, exceeding its original goal.

After passing the pilot phase, some of the technologies under these five systems have been deployed to the rest of the building. A 400 square-meter solar panel installation, yielding 100,000 kilowatt-hours per annum, has been installed on the roof of the 18-storey Keppel Bay Tower, as well as its six-storey podium block.

KBT's annual energy consumption has been reduced by some 30%, or 2.2 million kilowatt-hours a year, compared to its 2017 Green Mark Platinum level. At this stage, KBT's annual energy consumption is half that of a typical office building in Singapore, resulting in electricity cost savings of around \$400,000 annually. The remaining energy use is offset through the purchase of renewable energy certificates through Keppel Land's electricity retailer, Keppel Electric, which are generated from PV panels installed at Keppel Offshore & Marine's yards in Singapore.



### 5 emerging energy efficient technologies:



High efficiency  
air distribution  
system



Innovative cooling  
tower water  
management system



Fresh air  
intake control  
system



Smart  
LED lighting  
solutions



Intelligent  
building control  
system



# Keppel Bay Tower

Singapore's first Green Mark Platinum (Zero Energy) commercial building



**Energy Use Index (EUI) of <115 kWh/m<sup>2</sup> per year**

Almost 50% more energy-efficient compared to typical office buildings in Singapore.



**Overall energy savings of over 30% or 2.2 million kWh/year**

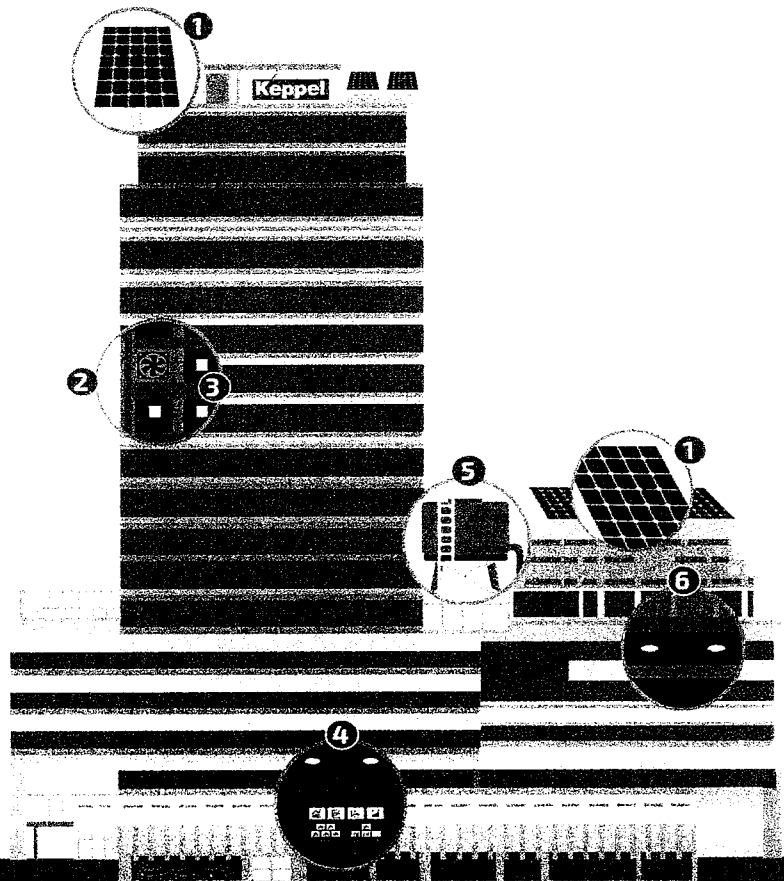
Equivalent to the amount of energy required to power more than 400 five-room HDB flats in Singapore for a year.



**Reduction of over 2,400 tonnes of carbon emissions per annum**

The purchase of renewable energy certificates generated from PV panels installed in Keppel Offshore & Marine's yards in Singapore, together with the installation of onsite PV panels at Keppel Bay Tower, result in a reduction of over 2,400 tonnes of carbon emissions per annum. This amount would otherwise require about 12,000 trees to absorb over approximately 50 years.

Source: Keppel Land Limited



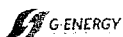
## Smart Eco-Features of Keppel Bay Tower

- ① **PV Panel System** will generate about 100,000 kWh of energy per annum
- ② **Energy-Efficient Air Distribution System** with air handling unit fans that are about 45% more energy-efficient than other best-in-class technologies
- ③ **Demand Control Fresh Air Intake System** utilises integrated sensors to regulate fresh air intake according to indoor activities, optimising energy usage for better thermal comfort and indoor environmental quality
- ④ **Intelligent Building Control System** employs a high precision physics-based simulation engine to improve data analytics and control
- ⑤ **Cooling Tower Water Management System** utilises a patented solution that reduces cooling tower water usage and eliminates the need for chemical water treatment
- ⑥ **Smart Lighting System** utilises occupancy sensors which allow seamless transition in lighting levels according to building occupancy



**Keppel Land**

**Keppel Bay Tower** is conveniently located at HarbourFront and within five minutes' drive from CBD. It offers excellent connectivity via the HarbourFront MRT station, major roads and expressways. Tenants enjoy a wide array of dining and lifestyle choices with the building in close proximity to VivoCity and Resorts World Sentosa. The 18-storey office building has approximately **394,000 square feet of overall floor area**.



**G-Energy** offers a wide array of integrated energy and project management services, acting as the System Integrator in the Keppel Bay Tower project.



**IES** are leading global innovators in integrated performance based analytics, and home to the largest building analytics team in the world.



**Innovative Polymers Pte Ltd** specialises in providing advanced technological chemical free cooling water management system for air-conditioning and mechanical ventilation system (ACMV).



**Lumani** uses its expertise to reduce energy consumption with intelligent algorithms that contribute to sustainability.



**Danfoss and Novenco** provide engineering solutions that utilise resources to drive sustainable transformation of tomorrow.



**YITU** integrates state-of-the-art AI technologies with industrial applications for a safer, healthier and faster world.

(A video feature: <https://www.youtube.com/watch?v=f0Tz2ON6ECY>)

# Design Strategies & Features of Emerging Technologies

All five technologies exhibit positive returns in energy savings as compared to their pre-retrofit energy usage

Technologies	Test-Bed Area	Pre-Retrofit Energy Consumption (MWh per year)	Measured Energy Savings	Achieved Energy Saving (kWh per year)
Danfoss AHU Fans	Level 12	43.8	46.8%	20,500
DeCalon Cooling Towers Management	Whole building (2 running chillers)	1,679	7.0%	117,500
Yitu Integrated Sensors	Level 12	62.5	12.0%	7,500
IES Intelligent Building Control	Whole building	5,102	7.0%	357,200
Lumani Smart Lighting	Level 2, 5, 6, 10, 11, 12 & 18	17 (from LED)	13.4%	2,300 (level 12 only)



# Keppel Bay Tower - Design & Innovation

## High Efficiency Air Distribution System

### Technology Introduction

The solution combined highly efficient and easily integrable components such as the Novenco's axial fans especially designed for air handling unit (AHU) applications, Danfoss's motor independent variable frequency drives (VFD) with ACMV intelligence and IE5 permanent magnet motors to the existing AHU. The fan technology employs an optimised design of blade profiles, taking inspiration from the aircraft jet engines, and delivers high performance of aerodynamics. It is 25% more efficient than the standard belt driven fans used for building applications. The Danfoss VFD utilises motor independent technology that makes integration to the high efficiency permanent magnet motor (IE5 motors) an easy task and delivers highest levels of Motor-VFD efficiency. By integrating these technologies together, the solution resulted in the "wire to air efficiency" (Fan + Motor + VFD) of 80-85%. This is significantly higher than the belt driven conventional centrifugal fans and the direct driven plug fans or the EC (electronically commutated) fans that typically have "wire to air efficiency" of 60-68%.

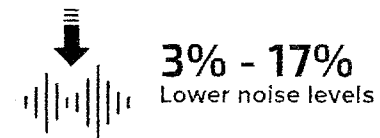
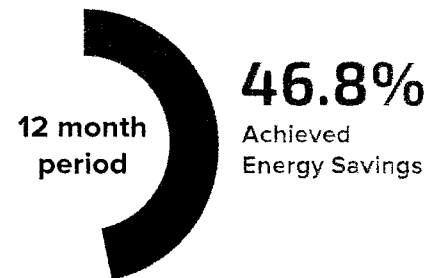
### Project Implementation

A Novenco ZerAx® axial flow fan, Danfoss VLT®-HVAC-FC102 VFD and Domel IE5 motor were installed in an existing air handling unit over a 12-month period and achieved energy savings of 46.8%, compared to the pre-retrofitted system comprising a conventional belt driven centrifugal fan. In addition, the new fan operates at 3-17% lower noise levels, noticeably reducing noise within the building.

### Outcomes

The success of this fan retrofit can easily be replicated with new or existing ACMV systems, to reduce power consumption and greenhouse gas emissions.

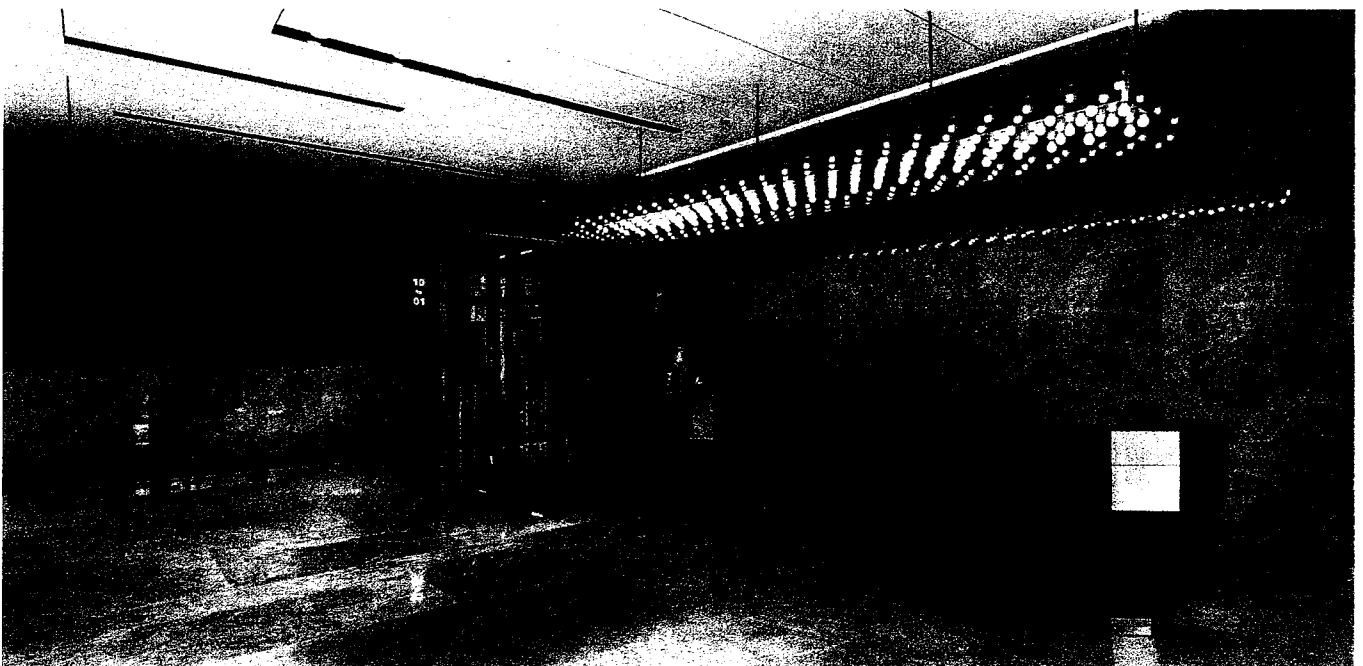
Following the successful pilot, KBT retrofitted its remaining 21 AHUs to Danfoss low-power systems in a similar fashion, minimising energy usage throughout the whole building.



#### Websites:

<https://www.danfoss.co.uk/en/markets/buildings-commercial/dds/drives-for-fans/#tab-overview>  
<https://www.novenco-building.com/solutions/ecplus-concept/>

Before Improvement	After Improvement	Achieved Savings
0.533 W/CMH 13.53 kW	0.230 W/CMH 6.96 kW (Jan-Dec 2019)	46.8%

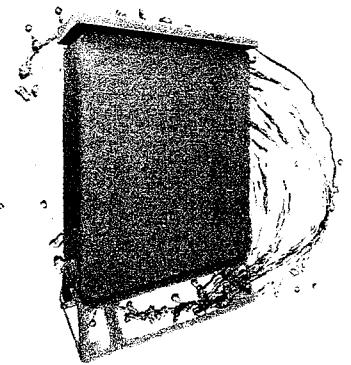


## Cooling Tower Water Management System

### Technology Introduction

A typical cooling tower requires significant amounts of water, energy and chemical treatments to function.

Innovative Polymers' Decalon (DCI) system represents a significant breakthrough in improving the efficiency of cooling energy. Its worldwide patented technology is able to remove and prevent scale formation and greatly slow corrosion by removing dissolved oxygen from the water. The DCI system also disinfects water through its proprietary CataGreen technology, removing the need for complex chemical treatments to deal with algae and bacteria build-up in KBT's cooling towers more efficiently than some other Non-Chemical Device (NCD) technologies available in the market. Unlike other NCD, such as magnetic, electronic, hydrodynamic and catalytic, DCI uses scientifically proven electrochemical technology to remove the existing scales, to prevent future scaling, to reduce the corrosion rate and to disinfect the cooling water.

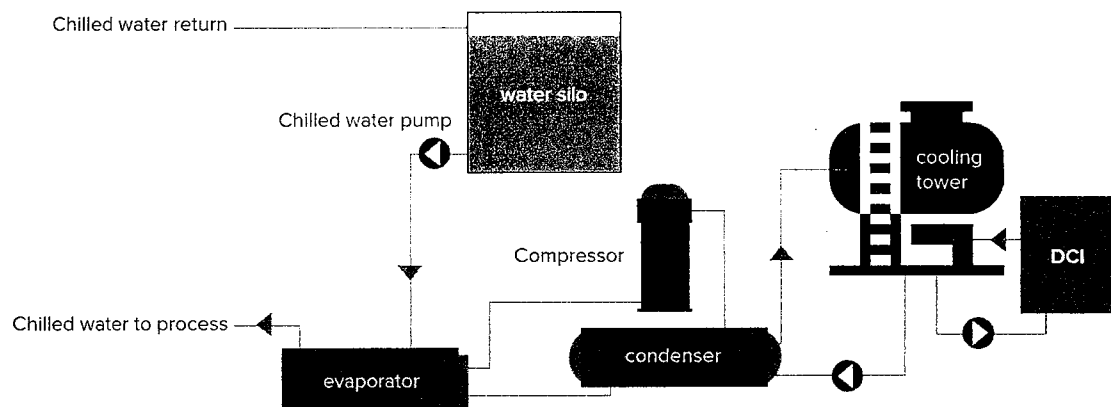


DCI is SGBC certified with "Excellent" status, certified by ISO 9001, bizSAFE 3, TUV Rheinland and CE too.

### Project Implementation

This system was implemented throughout the entire building in December 2018. Average chiller plant system efficiency over a 12-month period in 2019 improved by 7%. The system also enjoys an 80% reduction in cooling tower blowdown water usage.

#### How It Works



Source: Innovative Polymers Pte Ltd



## Outcomes

The system replaces the environmentally unfriendly chemical treatment method that is commonly used in the cooling-water process. It does not dose any toxic chemicals into the cooling tower water, typically used to prevent scaling, corrosion and reduce bacteria buildup. As a result, water drained from the system can be safely be discharged into the environment without treatment.

Before Improvement	After Improvement	Achieved Savings
0.620 kW/RT	0.575 kW/RT (Dec 18 - Feb 20)	7%

### Website:

[http://innovativepolymers.com/sub\\_decaion.html](http://innovativepolymers.com/sub_decaion.html)

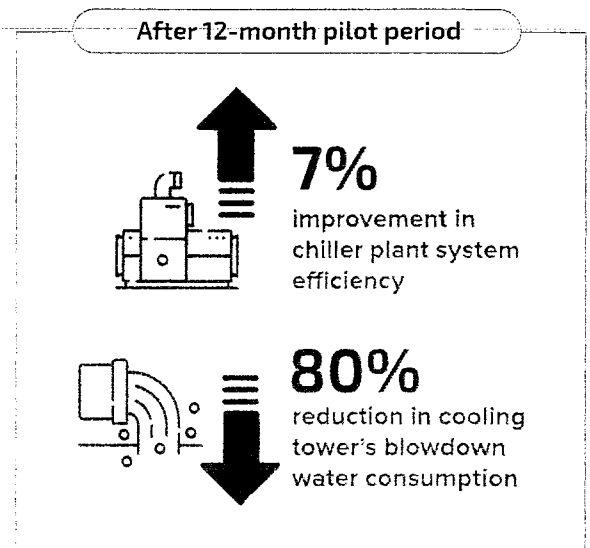


Photo: Keppel Land Limited



## Fresh Air Intake Control System



### Technology Introduction

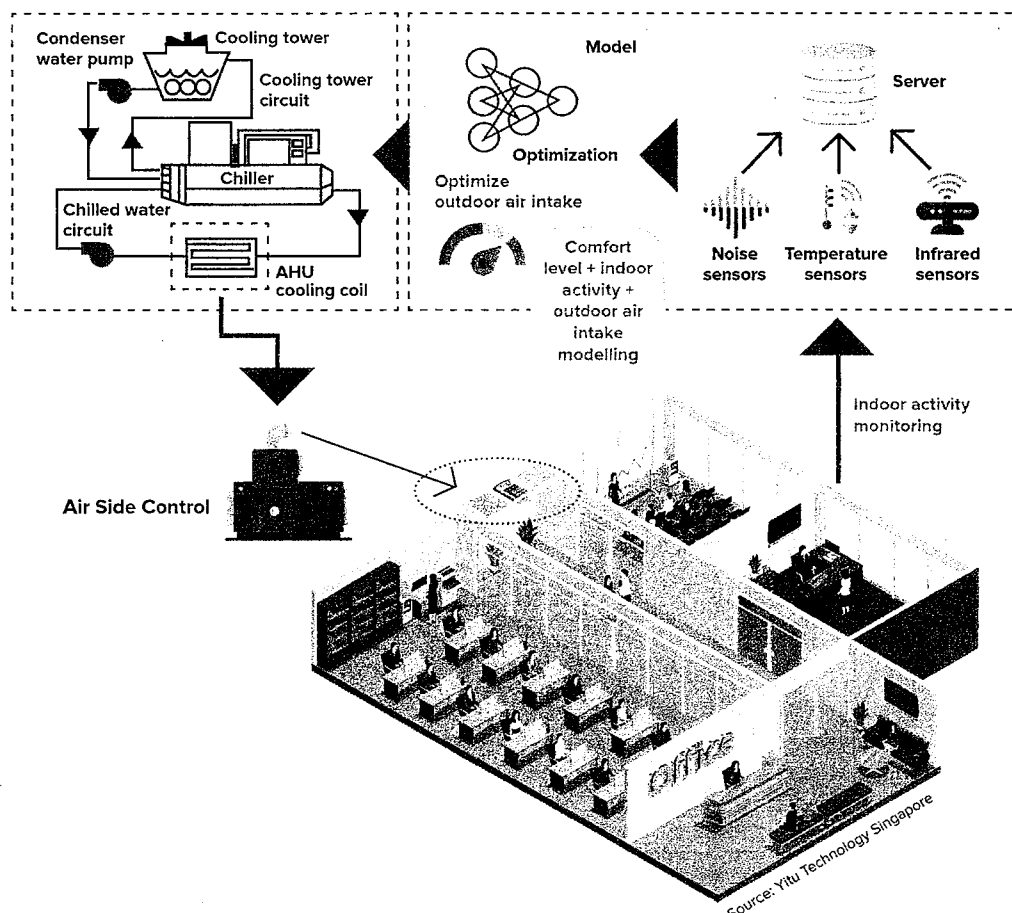
The constant flow of outdoor fresh air is vital to maintaining a healthy, pleasant indoor working environment. However, cooling demands are constantly changing every day, throughout the day, and there is a need to find a solution to minimise cooling energy usage without compromising indoor comfort and air quality.

This air system utilises integrated sensors to optimise fresh air intake based on indoor activities through a data driven demand control fresh air optimisation method. The aim is to reduce cooling load by optimising fresh air intake based on demand analysis via indoor activity modelling, while maintaining acceptable indoor air quality. This is through a regression model based on both independent variables (fresh air quality, indoor activity modeling and thermal comfort), and dependent variable (energy usage) that were developed as part of this project. These data driven models allow us to optimise the energy consumption dependent variable by fine-tuning the independent variables while meeting indoor air quality constraints.

### Project Implementation

The deployment of demand control fresh air optimisation system was carried out on Level 12 in KBT over a six-month period, in which sensor arrays were positioned to monitor air temperature, noise, carbon dioxide and infrared levels.

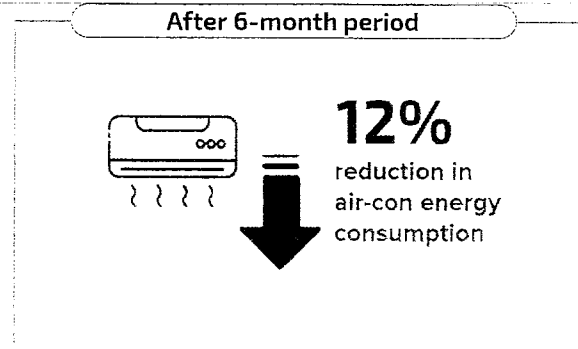
Live data was fed into a smart machine learning model, trained to derive the optimal balance between thermal comfort, air quality and energy consumption. As time progressed, this model was able to learn from a growing base of sensor data. This further refined its understanding of factors affecting indoor air quality trends, improving the model's performance.



## Outcomes

After a six-month period, the deployed solution was able to achieve a 12% reduction in air-con energy consumption. The system was also able to improve thermal comfort and indoor air quality, creating a more conducive work environment for occupants.

Before Improvement	After Improvement	Achieved Savings
38.46 RTh	33.87 RTh (Jul - Dec 2019)	12%



# Smart Lighting System

## Technology Introduction

This lighting system is a fully autonomous solution that utilises occupancy sensors to allow seamless transition (dimming) in lighting levels according to building occupants' activities level. The system uses the Passive InfraRed (PIR) motion sensors as the counter of activities rather than a relay switch similar to lighting systems in a typical office building set-up. Lighting controllers collect the activities and then send the data to the cloud to decide the mode to operate the light:

### Busy Mode:

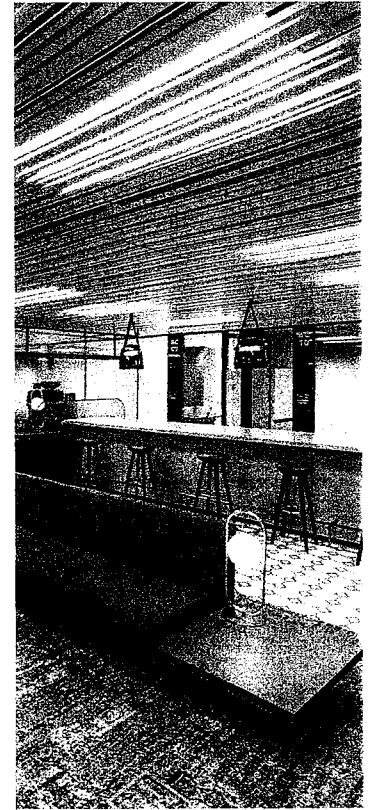
Switches to the upper dimming level when high activity level is detected

### Sensor Mode:

The dimming level fluctuates between upper and lower levels in response to the triggers of the PIR sensors

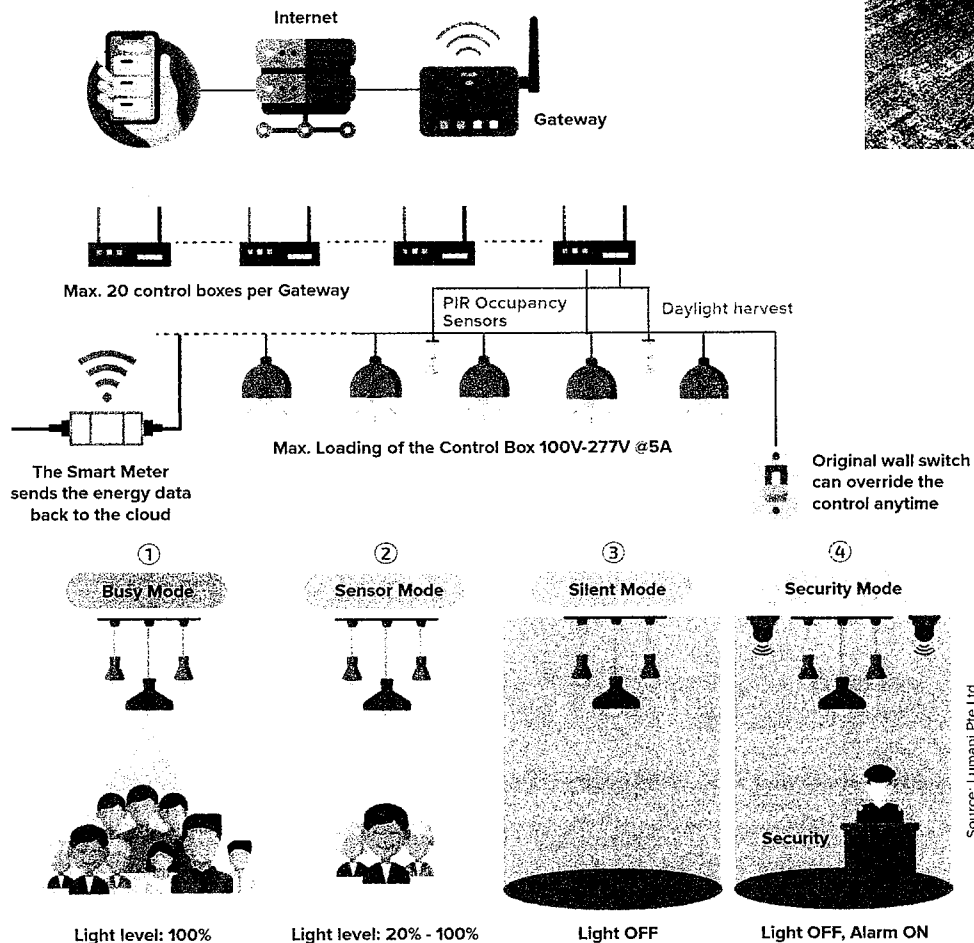
### Silent Mode:

When there is no activity detected for a while, the lights are switched off



## Project Implementation

The lighting system was installed across 270 localised zones in seven floors of KBT.

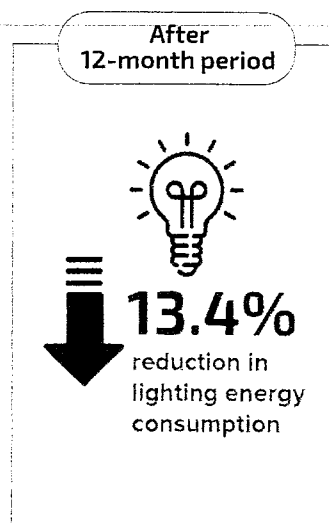


## Outcomes

The system was implemented from December 2018 and after a 12-month period, the system significantly achieved a 13.4% energy reduction, from best-in-class (LED) levels.

To define lighting parameters across such a large number of zones, innovations in software allowed for the creation of lighting 'templates' to be set for each zone, greatly speeding up current deployment and future expansions of the system. Further optimisations relating to the day of the week - weekday, weekend and holiday modes - were also deployed to further reduce energy use.

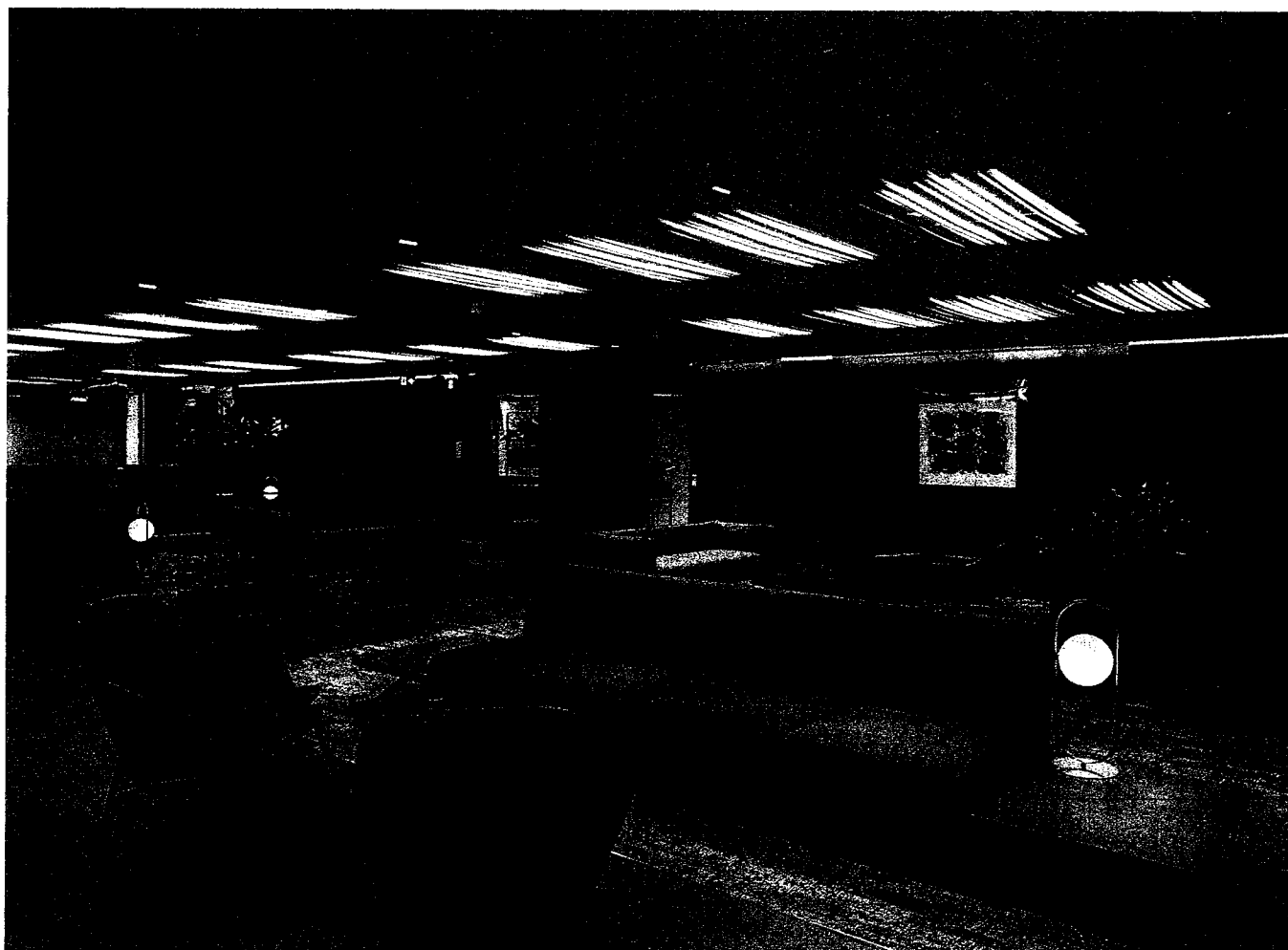
The system also holds much potential for the future expansion of its capabilities. With the addition of new sensors, such as CO<sub>2</sub> monitoring, the system can also potentially be used to warn occupants in the event that hazardous working conditions arise. Various ambient inputs can be used to further improve and dynamically alter system behaviour, to keep lighting energy consumption to an absolute minimum, and possibly add new features into the system.



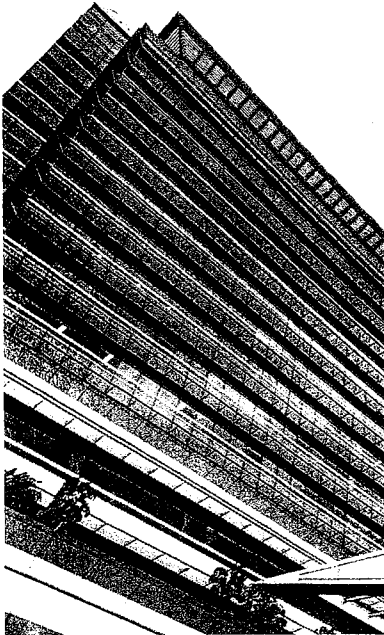
### Website:

<http://www.lumazones.com/index.html/#msg-box>

Before Improvement	After Improvement	Achieved Savings
11.15 W/m <sup>2</sup> (T8)	3.31 W/m <sup>2</sup> (Jul - Dec 2019)	70%
3.89 W/m <sup>2</sup> (LED)	Ave 3.37 W/m <sup>2</sup> (Jan-Dec 2019)	13.4%



# Intelligent Building Control System



## Technology Introduction

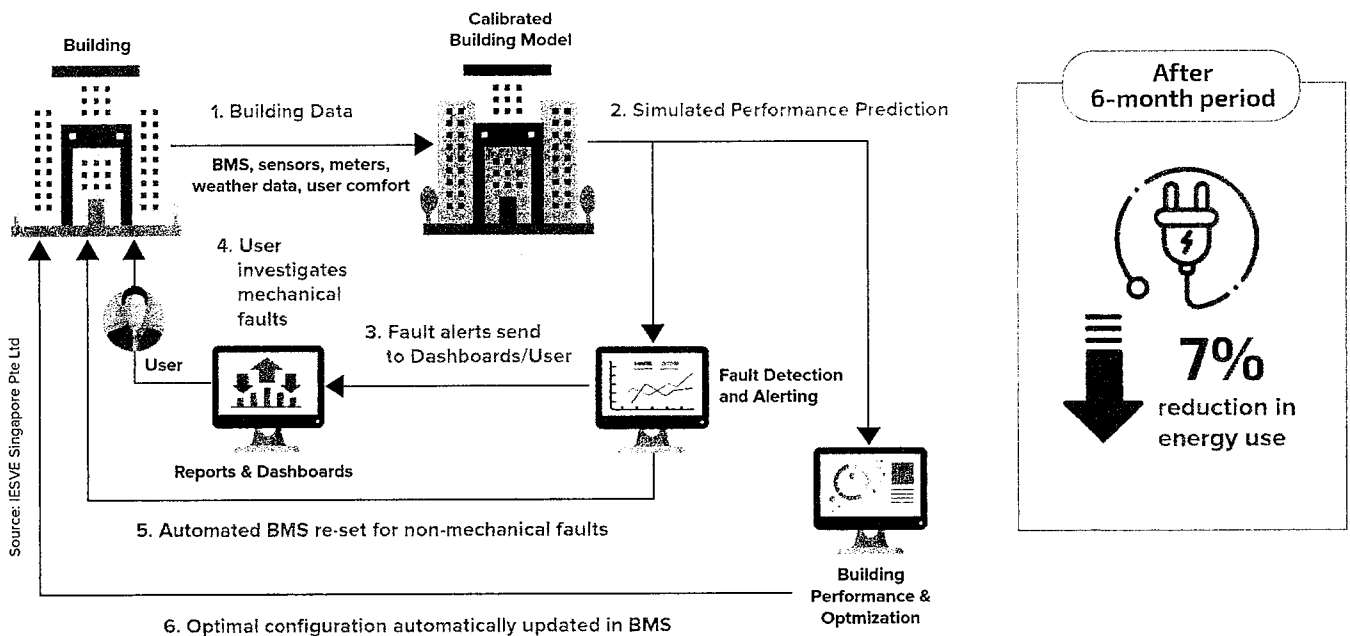
The Intelligent Building Control (IBC) system developed for this project uses a combination of building simulation modelling and real-time building data (digital twin approach) to provide cloud-based advanced building performance prediction, optimisation and diagnosis. This IBC prototype integrates proprietary software tools (The IES Virtual Environment, IES SCAN and the IES model calibration toolset) along with intelligent control algorithms, to create a flexible and robust web-based operational building analysis and optimisation tool.

## Project Implementation

The IBC system was implemented in September 2019 and different energy conservation measures (ECMs) were carried out. Comparisons were made between simulation results and actual energy data to verify the achievable savings.

In addition, the IBC system can provide performance prediction and suggestions for further optimisation. It also uses novel data analysis techniques, 'virtual sensors' built upon live data and complex calculations, and the ability to consider real-time weather data to simulate key parameters. Running in the cloud, the IBC system can be accessed remotely with minimal downtime, providing a robust total control solution to KBT.

### IES Intelligent Building Control (IBC) cloud-based solution



## Outcomes

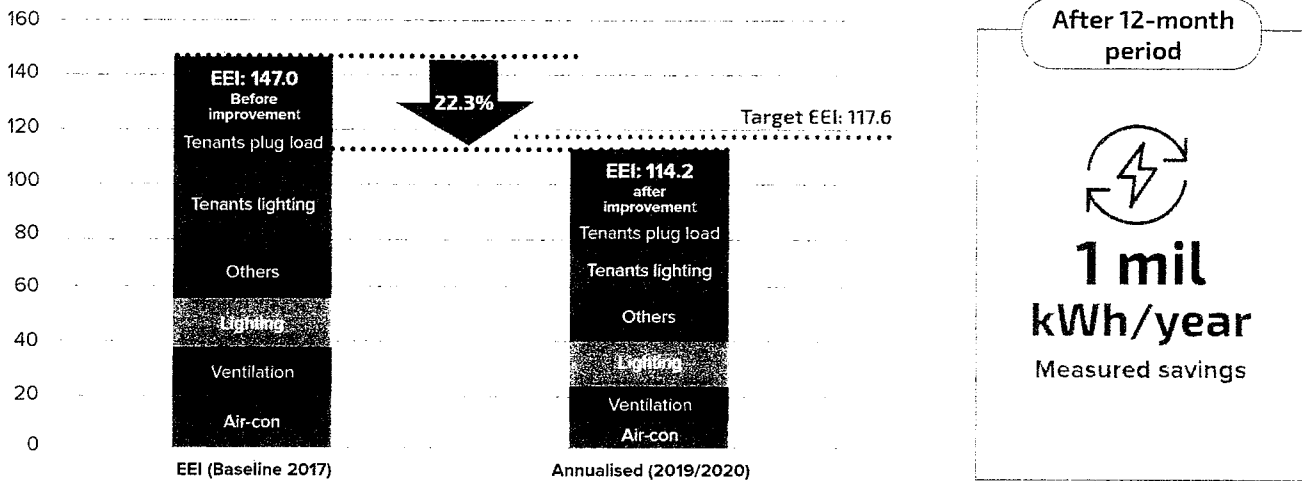
Based on KBT's 'digital twin', an energy saving of about 10% over a six-month period was predicted. When the ECMs were implemented, the IBC system achieved a 7% measured reduction in energy use, a hugely convincing performance for a new, experimental technology.

Before Improvement	After Improvement	Achieved Savings
EEl = 122.8 (Jan - Aug 2019)	EEl = 114.2 (Sep 19 - Feb 20)	7%

## Overall Building Performance Outcomes

The overall project was successfully completed in November 2019. Based on annualised measured electricity consumption, the total building EEl is at 114.2 kWh/m<sup>2</sup>/yr. Comparing with baseline EEl of 147 kWh/m<sup>2</sup>/yr, KBT's annual energy usage has been reduced by 22.3%. At level 12, where all the five emerging energy efficient technologies have been implemented, the resultant EEl is 72.5 kWh/m<sup>2</sup>/yr which is an energy improvement of about 50% as compared to a pre-retrofit baseline. When comparing with the 2005 baseline, KBT's level 12 is about 70.3% more energy efficient, making it effectively a super low energy floor.

### Achieved EEl - Annual Energy Consumption (kWh/m<sup>2</sup>/year)

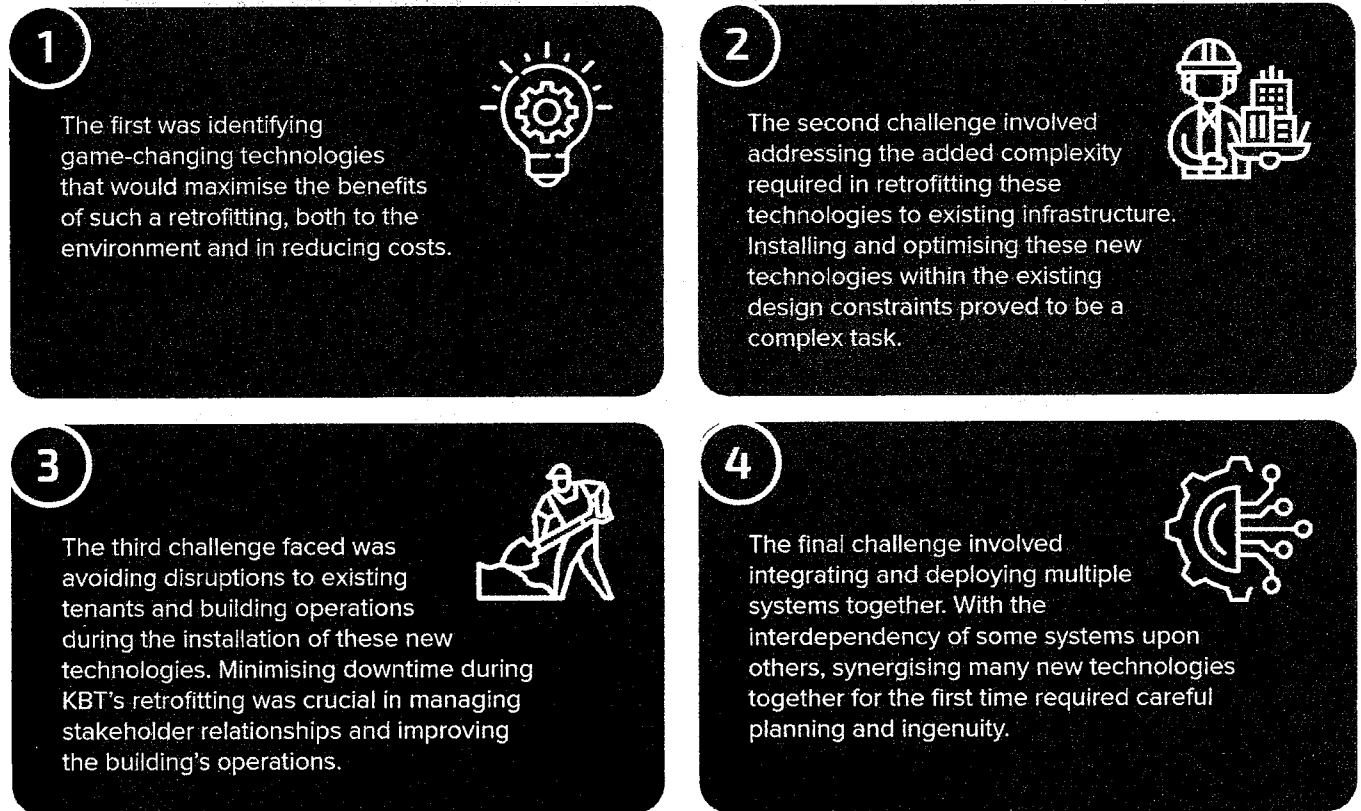




## Challenges Faced by KBT

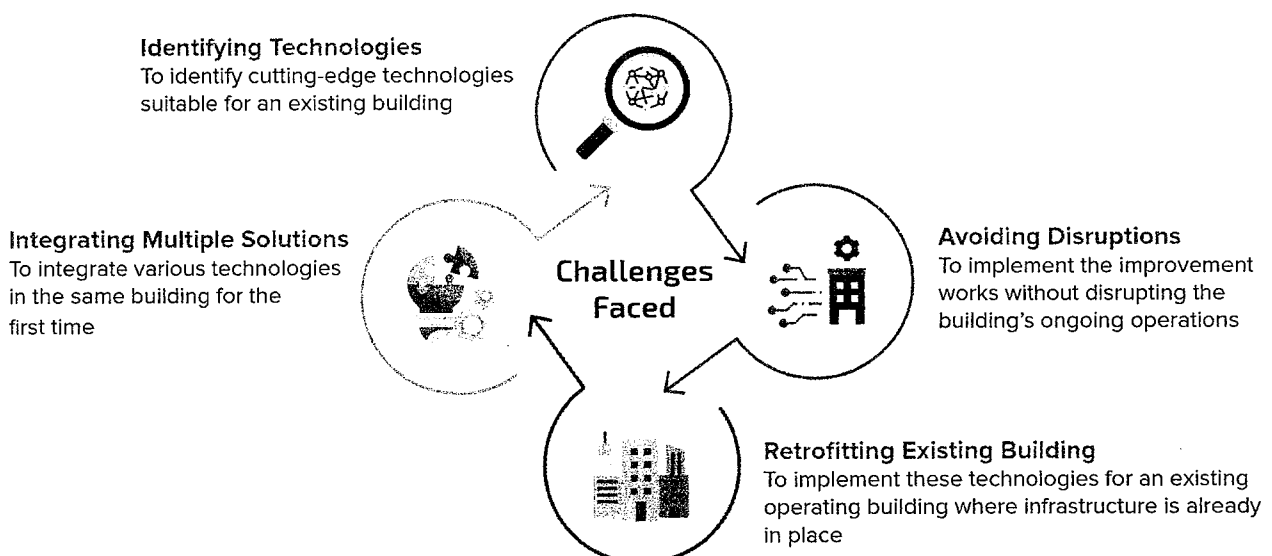
All test-bedding of technologies must be carried out without affecting the ongoing operations of the tenants. This is challenging especially when establishing baseline measurements and quantifying energy savings.

During the retrofitting of KBT, several challenges were faced.



For the KBT project, Keppel Land was able to overcome the challenges with the management's strong commitment and support, and by having an experienced team that was focused on achieving the goals.

The team adopted a comprehensive project management and planning process to ensure that the deployment was carried out in phases so that energy savings for each technology and overall building could be properly measured and verified.

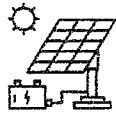




# Taking the Next Steps

## Powering KBT Through Renewables

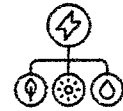
In January 2020, Keppel Bay Tower became Singapore's first commercial development to be completely powered by renewable energy. This was achieved through the installation of over 400 square meters of solar panels on KBT's roof and its adjacent podium block, and offsetting all its remaining energy use through the purchase of renewable energy certificates from Keppel Electric.



**103.4 mWh/year**  
onsite renewable energy generated  
Offset energy consumption of  
about 22 4-room HDB flats per year



**4,834.5 mWh/year**  
offsite renewable energy  
certificates (REC)

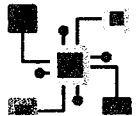


**97 kWp**  
installed capacity



## Envision Energy Management

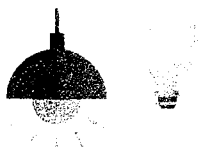
To further minimise energy consumption from air-conditioning, KBT partnered with Envision Digital International Pte Ltd, a global leader in energy management, to introduce additional smart building control systems. These systems helped to further decrease KBT's energy consumption.



The energy management system is powered by EnOS, Envision's leading AIoT operating system that comes with a complete suite of connectivity and device management tools, along with pre-built applications for decarbonisation and digitalisation.



**Reduced air-con energy  
consumption by 10%**



## LED light installation

KBT also partnered Signify Singapore to enable tenants to replace fluorescent lights with energy-efficient LED lights without any upfront capital investment. This helped to reduce tenants' electricity bills by 30% and reduced KBT's total energy consumption by 5%.



**Philips LED lights**  
at 14.5W/tube  
compared with existing  
T8 lights at 44W/tube

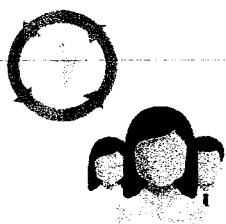
About  
**344,000 kWh/year**  
energy savings



Improves lighting power  
density of average  
**12 W/m<sup>2</sup> to 4 W/m<sup>2</sup>**



## Green Leases



Reducing energy consumption and maintaining a healthy working environment are shared goals of both Keppel Land and its tenants in KBT. In 2019, Keppel Land began offering green leases to its tenants, incorporating requirements such as a minimum Green Mark certification standard for the building and set energy reduction targets for tenants. These green leases reflect Keppel Land's commitment to both environmental sustainability and tenant well-being. Keppel Land was able to achieve a 100% participation from tenants in signing green leases in the same year, an encouraging move towards synergising tenant needs with a sustainable future.

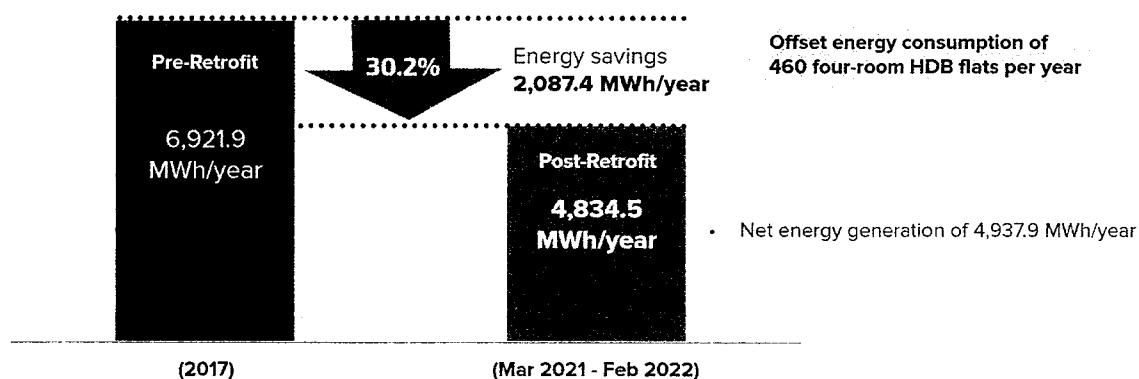


Through the green leases, all tenants have committed to allocate necessary resources to manage operations effectively to maintain high standards of environmental protection as well as to enhance the health and wellness of employees, including to reduce energy use by 5%.

## Conclusion

Upon completion of the pilot projects and additional measures, Keppel Bay Tower received the Green Mark Platinum (Zero Energy) accolade in December 2020, the first commercial building in Singapore ever to do so. This accolade recognises Keppel Bay Tower for pioneering all five pilot technologies highlighted above, as well as for having its energy consumption completely supplied from renewable sources.

In the 12 months of March 2021 to February 2022, a 30.2% improvement in energy savings was achieved as compared to pre-retrofit conditions.



## Highlights



### Keppel Bay Tower

Singapore's first Green Mark Platinum (Zero Energy) commercial building



### 50% reduction in Energy Use Index: <115 kWh per square meter per year

KBT consumes 50% less energy per square meter than most office buildings in Singapore



### 30% reduction in energy consumption: Over 2 million kWh per year

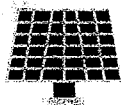





KBT's energy reduction from its new technologies offsets the energy consumption of 400 five-room HDB flats every year



### CO<sub>2</sub> emissions reduction: 2,400 tonnes per year

KBT's use of solar panels, together with its purchase of renewable energy certificates from Keppel Electric, reduces 2,400 tonnes of CO<sub>2</sub> emissions every year

## Sustainable Technologies Powering Keppel Bay Tower

 <p><b>Solar Panel Arrays</b> Generate 100,000 kWh of clean energy from the sun every year</p>	 <p><b>Danfoss-Novenco Air Distribution System</b> Implements cutting-edge air distribution system, consuming 45% less energy than existing units</p>	 <p><b>Demand-Control Fresh Air Intake System</b> Uses smart sensor arrays to optimise energy consumption, while preserving indoor air quality and thermal comfort</p>
 <p><b>Smart Building Control System</b> Deploys a precise physics simulation model of KBT to predict, monitor and minimise energy use</p>	 <p><b>Cooling Tower Water Management System</b> Leverages breakthrough innovations to greatly reduce water use and avoid chemical treatment</p>	 <p><b>Smart Lighting System</b> Seamlessly varies lighting conditions in response to live occupancy levels, reducing energy use</p>



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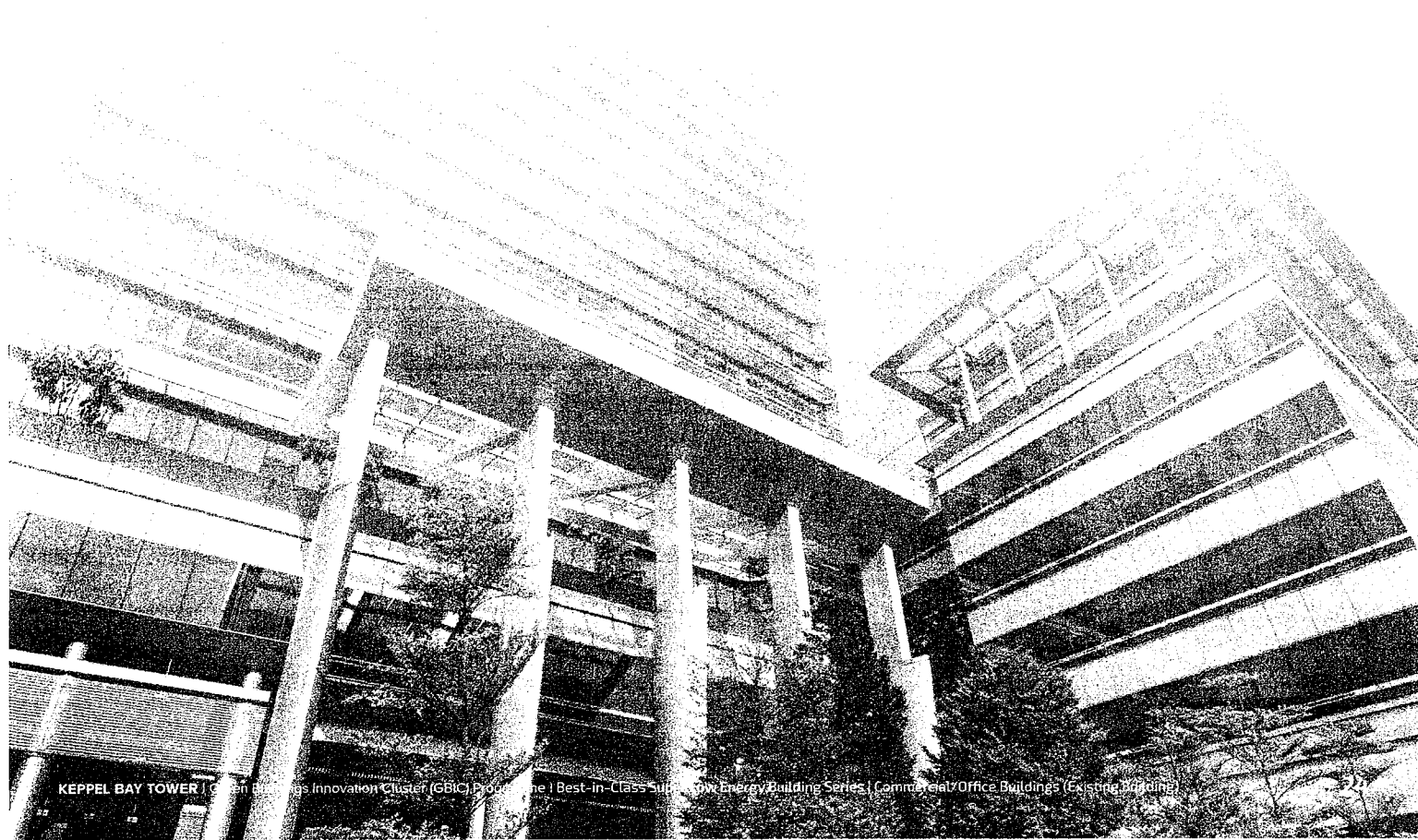
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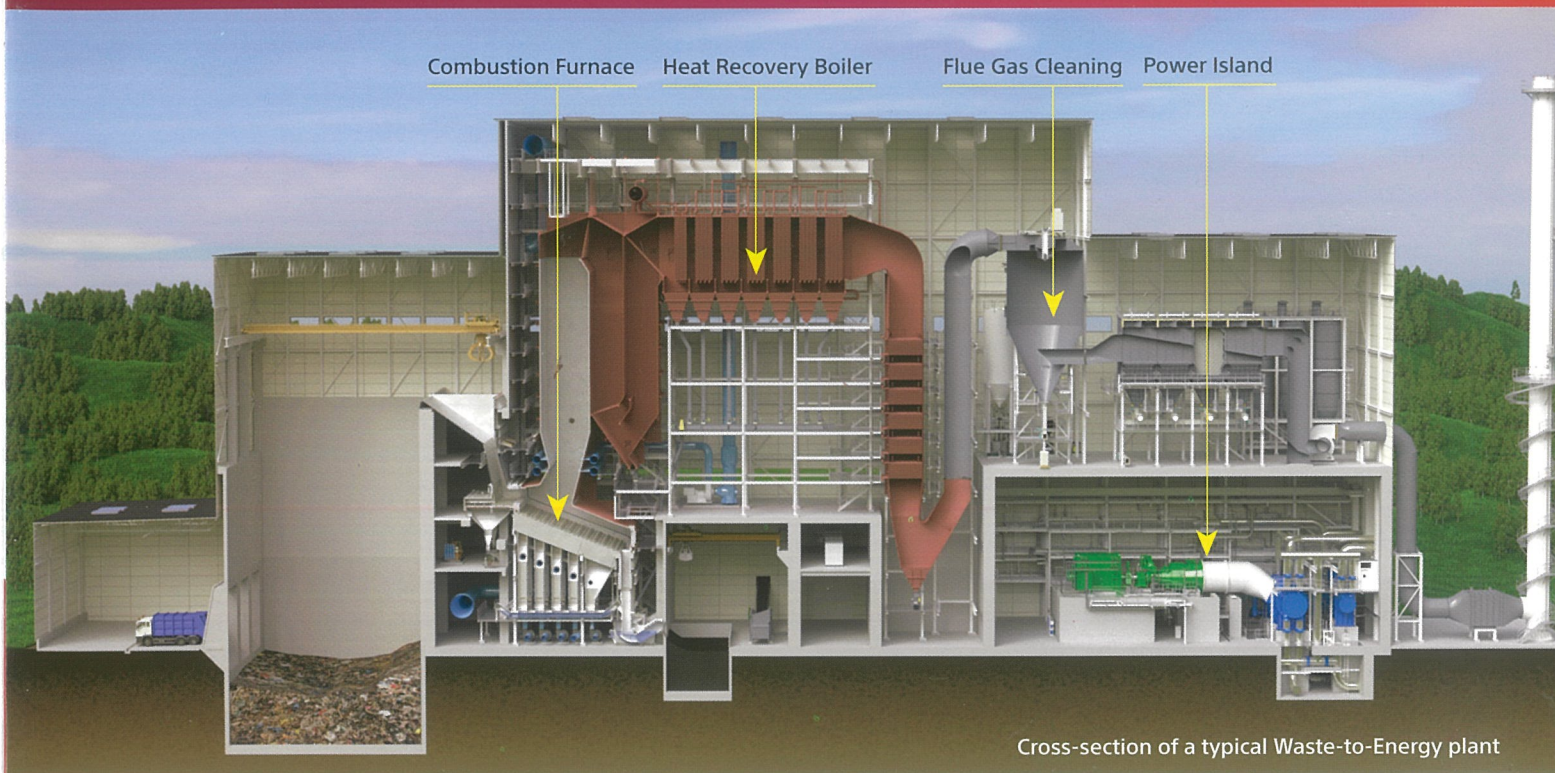






Leading provider  
of environmental solutions and services

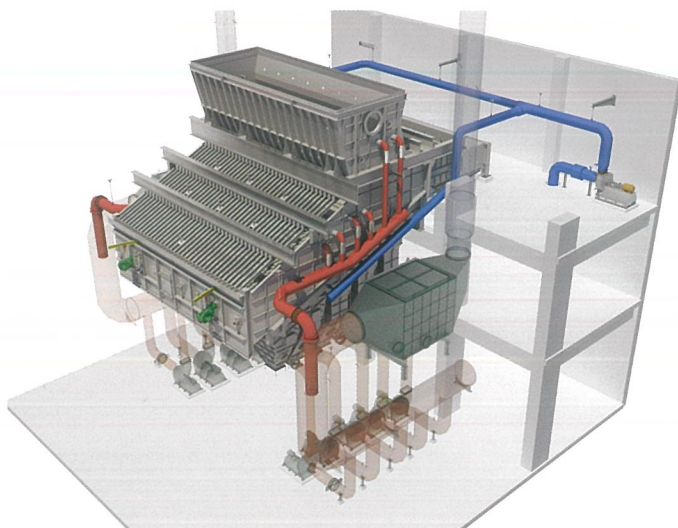




Cross-section of a typical Waste-to-Energy plant

## Recovering energy from waste

Keppel Seghers' proven advanced thermal treatment technology is equipped to deal robustly with varied waste types, from highly heterogeneous municipal solid waste (MSW) with lower calorific value and higher moisture content, to refuse derived fuel (RDF) with higher calorific value.



### Unrivalled flexibility and intelligence

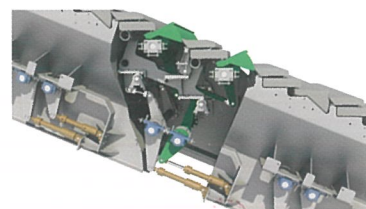
Rigorously developed with extensive R&D and knowledge gained from close to half a century of designing, delivering and operating waste-to-energy (WTE) plants globally, Keppel Seghers' unsurpassed grate design brings you the advantage of a system that is intuitive, durable, robust and cost-effective.

### Modular and scalable – Above 1,000 TPD

Evolving from the classic grate design, Keppel Seghers' lane-type grate design features standard grates of various sizes and a modular construct for optimal sizing. Being modular and scalable, a single thermal processing unit can process high throughputs exceeding 1,000 tonnes per day (TPD).

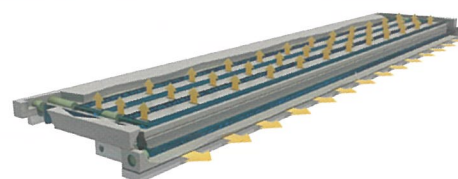
## State-of-the-art grate technology and combustion control system

**Keppel Seghers Air-Cooled Grates:** It is the only combustion grate which incorporates separate and independently-controlled grate elements which allow better control of horizontal movement and vertical aeration. Intelligently controlled by the Keppel Seghers' SIGMA advanced combustion control system, our unique design allows our multi-stage MATRIX grate technology to adapt effortlessly to short and long-term fluctuations in waste composition to reduce waste volume by more than 90%.



Air-cooled combustion grates are uniquely designed to handle fluctuations in waste composition.

**Keppel Seghers Water-Cooled Grates:** This grate is designed to handle variation in waste composition and combustion of higher calorific wastes, where grate tiles are protected from very high combustion temperatures by the water-cooling system that greatly reduces the risk of thermal corrosion.



Water-cooled combustion grate tile featuring effective cooling and optimal distribution of primary air to combust high calorific value waste.



# About Us

**Keppel Seghers, a member of the Keppel Infrastructure group, is the environmental technology arm of Keppel Corporation, a multi-business company providing robust solutions for sustainable urbanisation.**

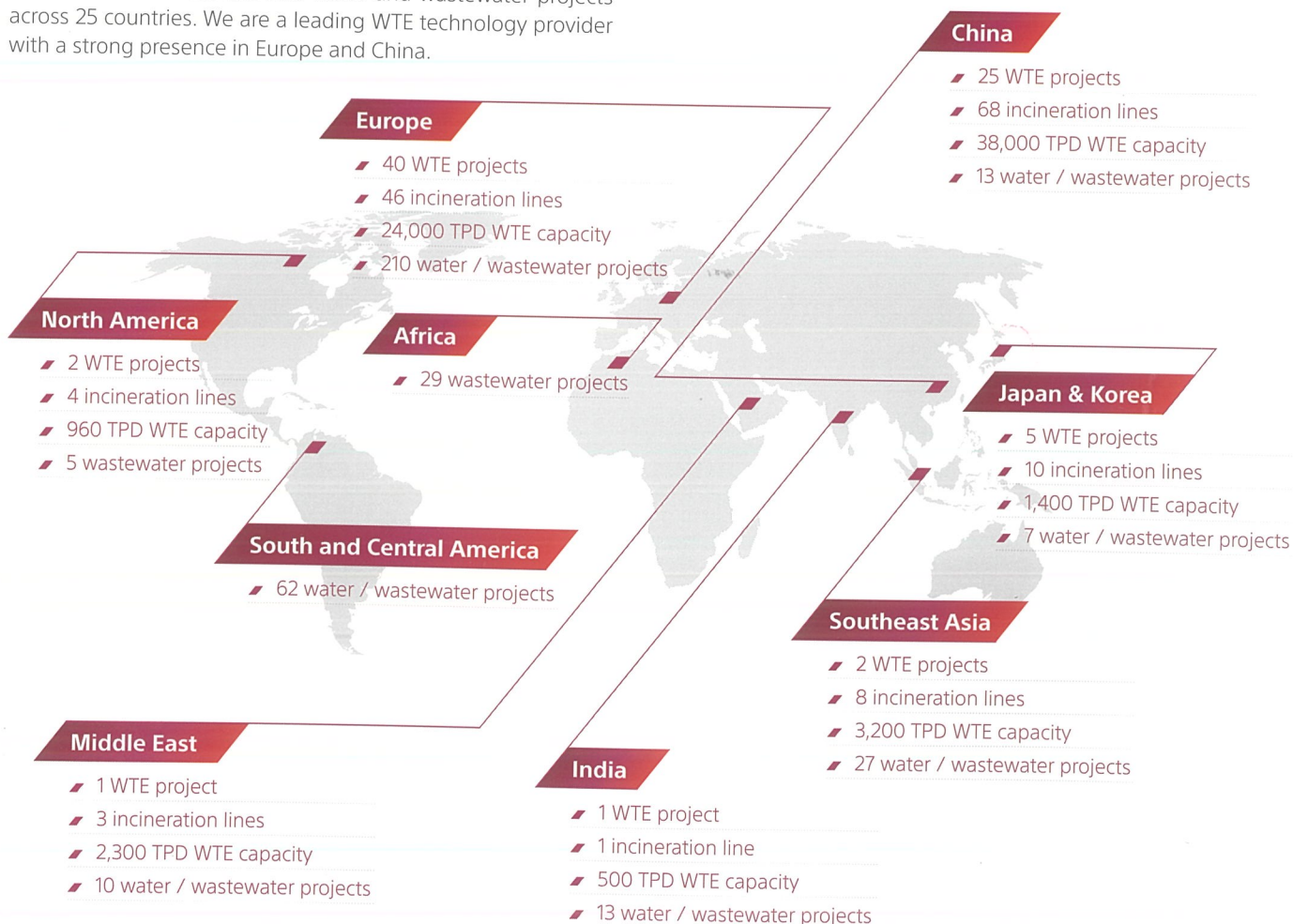
As a leading provider of environmental solutions, Keppel Seghers solves some of the worlds' most pressing waste and water issues. We provide expertise in design and engineering, technology development, construction, as well as operations and maintenance of plants and facilities. We also invest in large-scale environmental projects, focusing on waste-to-energy (WTE), water reuse, desalination and wastewater treatment.

Leveraging our extensive engineering experience and global network, we aim to deliver and operate environmental projects in a profitable, safe and sustainable manner.



## Global Presence

As a global environmental player, Keppel Seghers has delivered more than 100 waste and 360 water and wastewater projects across 25 countries. We are a leading WTE technology provider with a strong presence in Europe and China.





# Feature Projects - Solid Waste

## Hong Kong Integrated Waste Management Facilities Phase 1

### First of its kind in Hong Kong

Keppel Seghers will provide its proprietary waste-to-energy technology to the Hong Kong Integrated Waste Management Facilities Phase 1, and undertake the 15-year operations and maintenance period for the 3,200 TPD facility upon completion. The Design-Build-Own (DBO) contract worth HKD 31 billion was awarded to the Keppel Seghers-Zhen Hua Joint Venture, via a competitive international tender called by the Hong Kong Environmental Protection Department.

### Features

- Zero wastewater discharge
- State-of-the-art double-dry flue gas cleaning system to meet strict international emission standards
- High thermal energy recovery efficiency producing more than 100MW of green power
- Mechanical treatment facility of 200 TPD to recover plastics, ferrous and non-ferrous metals, glass for further recycling

### ► Hong Kong Integrated Waste Management Facilities Phase 1, Hong Kong SAR

The first waste-to-energy facility built on a reclaimed island off the coast of Shek Kwu Chau will blend seamlessly with its natural surroundings



Innovative application of proven off-site prefabrication construction methodology will ensure high quality and scheduled optimisation with reclamation activities



Artist's Impression

### ◀ Baoan WTE Facility, Shenzhen, China

*"Since the first WTE plant that was delivered to the Chinese WTE market in early 2000, Keppel Seghers has emerged to be a technology provider of choice, having consistently delivered highly reliable and efficient WTE solutions evident in the various WTE plants which we are successfully operating in China."*

– Shenzhen Energy Environment

## Bialystok Energy-from-Waste Plant

### One of the first dual-mode waste-to-energy facilities in Poland

Keppel Seghers undertook the EPC of the 372 TPD Bialystok Energy-from-Waste plant via a consortium arrangement with Budimex S.A. (one of Poland's largest construction companies) and Spanish waste management company CESPA.

The facility's dual-mode operations generate electricity in summer (8.6MWe), and combined heat and power in winter (17.5MWth and 6MWe).

The facility also features a mechanical treatment facility for the recovery of ferrous and non-ferrous metals from incineration bottom ash, zero wastewater discharge, and an ash residue solidification system.

## Baoan Waste-to-Energy Facility

### Largest waste-to-energy facility in the world

Together with Phase 3, the Baoan WTE facility in Shenzhen, China, is the largest WTE facility in the world, with an incineration treatment capacity of 8,875 TPD. Testament to Keppel Seghers' capabilities in designing and delivering world-class WTE technological solutions, Keppel Seghers has secured contracts to supply its proprietary technology and technical services to all three phases of the Baoan WTE facility development from repeat client Shenzhen Energy Environment.

The Baoan WTE facility was also the first WTE plant to be awarded the Gold Medal for the "National Outstanding Engineering Award" in 2014.

### ► Bialystok EfW Plant, Poland

One of Poland's first operating EfW plants, featuring a unique dual-mode to suit winter and summer energy needs.





# Feature Projects - Water & Water Reuse

## Keppel Marina East Desalination Plant

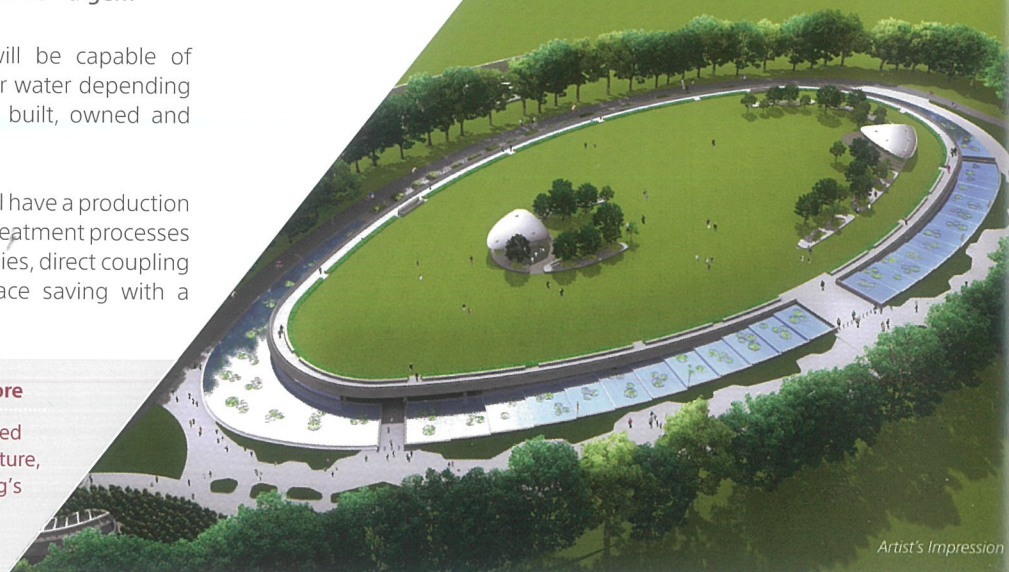
Singapore's first dual-mode desalination plant – a gem within the city center

This first dual-mode desalination plant will be capable of treating either seawater or brackish reservoir water depending on rainfall seasonality. It will be designed, built, owned and operated (DBOO) by Keppel Seghers.

The Keppel Marina East Desalination Plant will have a production capacity of 137,000 m<sup>3</sup> per day, and features treatment processes which utilise advanced membrane technologies, direct coupling and ultraviolet primary disinfection for space saving with a compact footprint of only 2.5 hectares.

### ▶ Keppel Marina East Desalination Plant, Singapore

Water treatment facilities and equipment are located underground, which protects the critical infrastructure, and frees up 20,000 square metres of the building's rooftop to become green space for community recreation.



Artist's Impression

### ▶ Doha North Sewage Treatment, Qatar

*"The DNSTW, designed and built by Keppel Seghers, is an exemplary showcase of how the innovation and technical expertise of a private enterprise is combined with the vision of the public service to create an infrastructure masterpiece."*

*"Thanks to the cooperation between Ashgal and Keppel Seghers, the DNSTW is steadily transforming a significant portion of Qatar into an oasis in the desert, with thoughtfully designed eco-habitats which now house migratory birds and reuse water for irrigation. These efforts bolster Qatar's ambitions for a liveable and green environment."*

– Ashgal, Public Works Authority of Qatar



## Doha North Sewage Treatment Works

First of its kind and largest greenfield wastewater, water reuse and sludge treatment plant in the Middle East

Situated at Umm Salal Mohammed in Qatar, the Doha North Sewage Treatment Works (DNSTW) was designed, built and has been operated (DBO) by Keppel Seghers for 10 years. With a peak design capacity of 439,000 m<sup>3</sup> per day of high-quality reclaimed water for reuse, the DNSTW is able to serve a population of around 900,000.

The facility has marked several "firsts", being the first wastewater treatment facility in Qatar to use advanced membrane and ultraviolet treatment to reclaim high-quality water for non-potable use. It is also the first facility in the

Middle East with a comprehensive odour control system to minimise the impact on the surrounding environment. The DNSTW is also the first to be equipped with a modern sludge treatment process to deal with a large amount of sludge from all sewage treatment works in Qatar.

## Sino-Singapore Tianjin Eco-City (SSTEC) Water Reclamation Centre

This project utilises a unique patent developed by Keppel Seghers, through its joint venture company, which recovers excess pressure in the reverse osmosis stream for recycling effluent (Patent No. 201420381047.2) to achieve energy savings.

The project is developed under a 25-year concession Build-Own-Operate-Transfer (BOOT) arrangement by 40-60 joint venture between Keppel Infrastructure and Tianjin Eco-City Investment and Development Co.

### ▶ Sino-Singapore Tianjin Eco-City Water Reclamation Centre, Tianjin, China

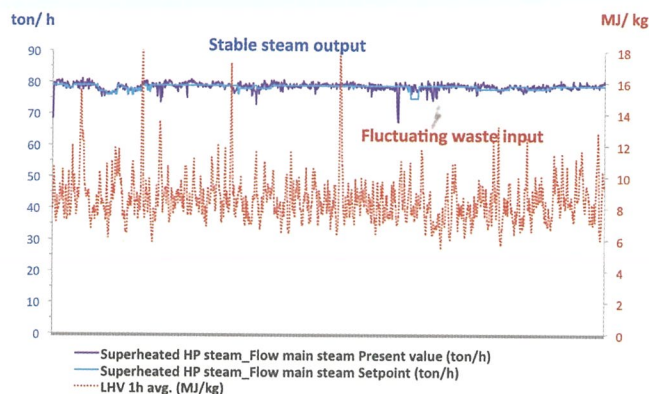
The SSTEC project serves all of the Eco-City's landscaping and non-potable water needs, comprising wastewater treatment (Class 1A WWTP: 100,000m<sup>3</sup>/day, future expansion of 50,000m<sup>3</sup>/day) and water reuse (21,000m<sup>3</sup>/day, future expansion of 21,000m<sup>3</sup>/day).





## Waste as a valuable fuel - Stable baseload power

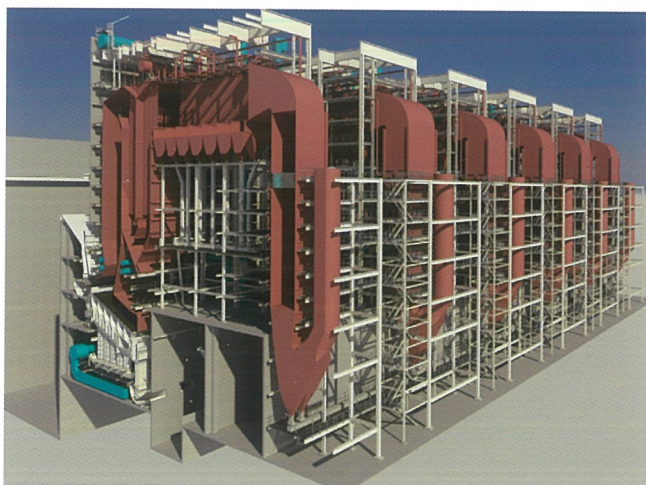
With better control of each individual reaction zone, combustion air control zone and better mixing and transport by the SIGMA combustion control system, Keppel Seghers' grates achieve high levels of complete combustion. This maximises energy recovery and guarantees stable steam production to reliably meet your energy needs.



## Boiler design - An in-house strength

Our WTE design philosophy has evolved from incineration and treating waste for volume reduction, to recovering energy from waste and valuables from ash, while addressing long-term issues like corrosion, fouling, thermal stress, slagging and other system dynamics.

In view of these complexities, Keppel Seghers' key capability in boiler design is critical in determining plant efficiency and availability throughout its lifespan. We optimise the geometry of the furnace and boiler with respect to flue gas flow pattern, looking into the details of combustion air distribution, fouling control, dust removal and heat transfer and optimisation of steam parameters.

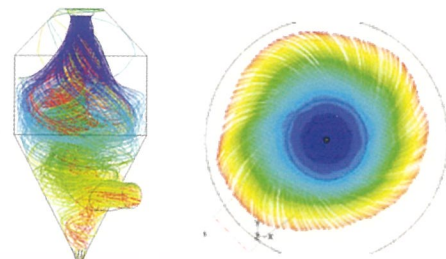


Keppel Seghers' proprietary grate technology and expertise in boiler design also prevents dioxin formation by achieving lower oxygen concentration at the boiler outlet, shorter residence time in the dioxin reformation temperature zone, and lower dust formation and entrainment. The result is cleaner air, for a cleaner future.

## Flue gas cleaning

Modern flue gas cleaning systems are designed to meet strict emission standards, achieving stack emissions that may even be cleaner than surrounding air used for combustion.

Keppel Seghers offers integrated solutions, combining various flue gas cleaning technologies to suit to waste characteristics, required emission standards, and customers' requirements. We seamlessly integrate flue gas treatment systems with our combustion control technology to effectively and consistently achieve high quality emissions, while optimising heat recovery to maximise overall plant efficiency.



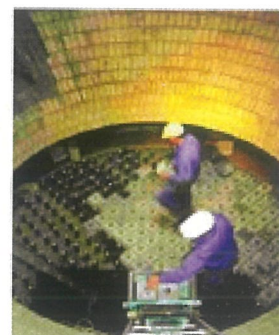
Keppel Seghers' Rotary Atomiser is used in semi dry flue gas treatment systems. Lime milk is injected at high pressure in a spray dryer absorption tower, and finely dispersed for complete reaction and highly effective removal of acidic pollutants, while cooling the flue gas.

## Water treatment

Leveraging Keppel Seghers' multi-faceted experiences in NEWater, wastewater treatment and desalination water projects, we possess capabilities and expertise to design, build and undertake the Operations & Maintenance (O&M) to deliver innovative and holistic solutions to address customers' requirements.

## Sludge combustion - Fluidised bed technology

Keppel Seghers offers a suite of thermal treatment technologies, including the ZERO FUEL fluidised bed incinerator featured in many of Keppel Seghers' projects. It robustly handles various types of sludge - from primary or secondary municipal sewage sludge (digested or non-digested), to oily industrial sludge, and even de-inking sludge mixed with wood chips. It features a shallow bed allowing lower energy consumption, more homogeneous mixing and fluidisation, and even autothermal combustion of sludge with low calorific value and a low dry solid content (<20%), while having a low residence time for complete combustion.



### Unique features

- High-temperature alloy and unique nozzle system allow high durability and long lifespan (>25 years) with no maintenance
- Highly flexible with lower turndown ratio and lower air stoichiometry requirements
- Low NOx, low CO
- Highly scalable (> 450 TPD)

Keppel Seghers' proprietary grate design also offers the potential for co-incineration of sludge with municipal solid waste or refuse derived fuel using thermal treatment.



# Services

## Specialist technical support

We deliver customised solutions designed to improve operating plant availability, ensure safer production, prolong lifetime of equipment and optimise life cycle cost. Our team of specialists are passionate, continuously improving our WTE technology.

We have a full spectrum of on-site and off-site specialist technical support through remote monitoring and control, data analysis and advice on plant performance, upgrading potential and advice, and guidance on process optimisation of availability, throughput, efficiency and lifetime.

### ► Runcorn, Greater Manchester, United Kingdom

Runcorn EfW is one of the largest and most efficient facilities in Europe. Keppel Seghers' specialist technical support for Runcorn TPS Phase 2 runs for a further 5 years, covering a broad scope including plant performance enhancement analytics and reports, assistance with major overhauls and personnel training.

## Operations and maintenance (O&M)

Our highly-skilled teams run WTE, water, wastewater and water reuse plants safely, efficiently and in compliance with industry regulations, emission and discharge standards and safety norms.

Our global team of more than 400 operating staff is ready to support your plant operations and maintenance, maximising the potential of your assets.

Customised medium-term or short-term O&M support contracts are also available for customers who have aspirations of taking over O&M responsibilities of their assets in the longer term.

### ▲ Domestic Solid Waste Management Centre, Qatar

- 2,300 TPD integrated waste management facility in the Middle East
- First of its kind in Qatar
- 20-year O&M contract

### ▲ Senoko WTE Plant (left) & Keppel Seghers Tuas WTE Plant (right), Singapore

- 3,110 TPD of treatment capacity across two plants in Singapore
- Keppel Seghers is largest private WTE operator in Singapore
- 25-year O&M contract for Keppel Seghers Tuas WTE Plant
- 15-year O&M contract for Senoko WTE Plant
- Together, they treat 40% of Singapore's MSW

### ▲ Ulu Pandan NEWater Plant, Singapore

- Production capacity of 162,800m<sup>3</sup> per day (post-expansion)
- First commercial plant in Singapore utilising third stage reverse osmosis for 90% main plant recovery
- 20-year O&M contract

## Spares management service

Together with technical support in plant performance diagnostic and analysis, we offer customers the value-added service of spares parts management. Keppel Seghers will deliver original spare parts within short notice, benefiting customers as it reduces the need for on-site storage of spare parts which is costly, complex and space-consuming.



*"The Chengdu Xiang Fu WTE plant designed and delivered by Keppel Seghers has exceeded our expectations in all aspects of WTE plant performance.*

*With a sizeable capacity of 1,800 tonnes per day, the Xiang Fu WTE plant has consistently met strict emission standards since beginning commercial operation in 2012, while still being highly efficient in achieving considerable power generation from the waste throughput.*

*This robust operating performance track record makes the Xiang Fu WTE plant the showcase that we proudly present to all our business partners who are keen to understand WTE operations.*

*With the successful delivery of the Xiang Fu WTE plant, Keppel Seghers has clearly demonstrated its capabilities as one of the leading players in the WTE industry with reliable WTE technology."*

**– General Manager, Chengdu, China National Environment Protection Group (CNEPG)**

Find out more at <http://www.keppelseghers.com>

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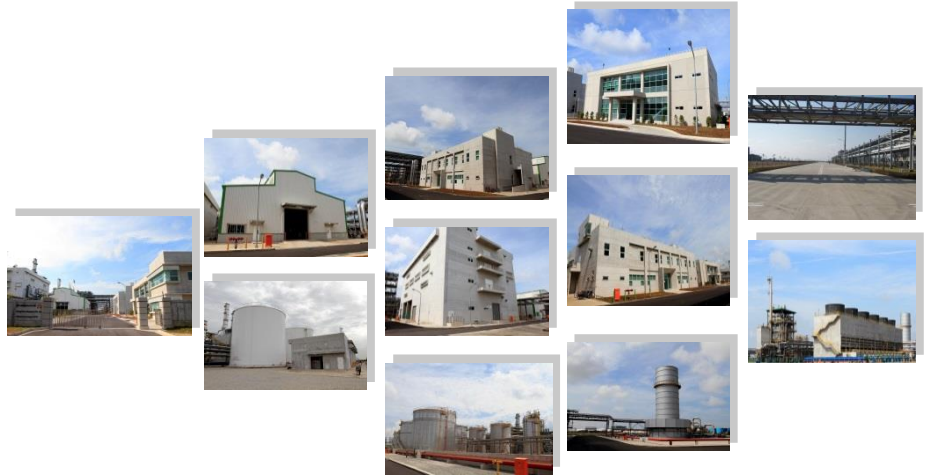
*Keppel Seghers is a member of Keppel Infrastructure*



CHANG CHUN GROUP  
長春集團

# AIR EMISSION MONITORING AND WORKPLACE NOISE BOUNDARY MONITORING

4 DEC 2024





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# Agenda

1. Introduction of NEA
2. Air Emission Monitoring
3. Workplace noise boundary monitoring
4. Summary of Air Emission monitoring work process
5. Summary of Workplace noise boundary monitoring work process





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## 1. Introduction of NEA

**National Environment Agency (NEA)** is the leading public agency responsible for the country's environmental management and sustainability efforts.

NEA is divided into several key divisions and departments, each focusing on a specific aspect of environmental management.

- ❖ Environmental protection: Groups and Divisions
  - a) Clean Environmental Group: The Clean Environment Group (CEG) is responsible for pollution control, from front-end development control & licensing work to downstream environmental monitoring and hazardous substance control.
    - i. Development Control and Licensing Division (DCLD)
    - ii. Environmental Monitoring and Modelling Division (EMMD)
    - iii. Pollution Control Division (PCD) (Air Emission and Noise boundary)

**For further detail information :**

<https://www.nea.gov.sg/corporate-functions/who-we-are/groups-and-divisions>



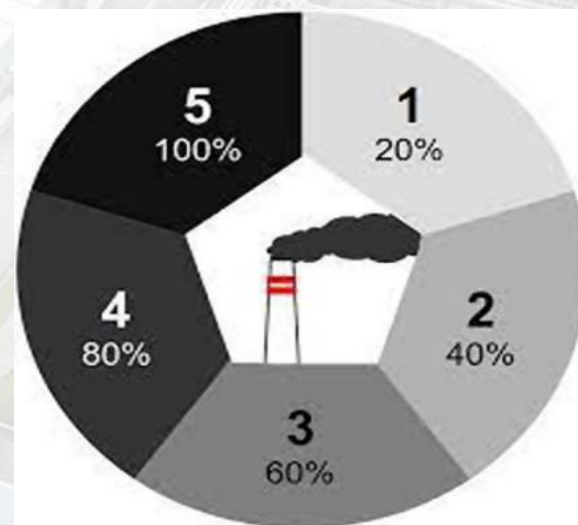
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## 2. Air Emission Monitoring

Air Emission: collecting and measuring samples of ambient air to evaluate the status of the air pollutants in the atmosphere as compared to clean air standards and historical information

Under Environmental Protection and Management (Air Impurities ) Regulations stated:

- Dark smoke includes smoke of any colour which appears to be darker than shade No. 1 on the Ringelmann Chart







## 2. Air Emission Monitoring

Under Environmental Protection and Management (Air Impurities ) Regulations stated:

- Prohibition of dark smoke from chimney shall not apply where —
  1. The emission of dark smoke is for a duration of **less than 5minutes** in any period of one hour in a day; and
  2. The total number of emissions of dark smoke from that chimney does not exceed **3 times** a day.
- Standards of concentration of air impurities







## 2. Air Emission Monitoring

Under The Environmental Protection and Management (Air Impurities) Regulation, air emission testing is require yearly.

A summary of test results is listed in the table below

Parameters	Results (mg/Nm <sup>3</sup> ) T- 931 Incineration Stack	Allowable Emission Limits (mg/Nm <sup>3</sup> )
Particulates	0.61	50
Carbon Monoxide (CO)	72.07	250
Oxides of Nitrogen (No <sub>x</sub> )	103.16	400
Sulphur Dioxide (SO <sub>2</sub> )	< 1.0	1700
Benzene	< 0.5	5



### 3. Workplace Noise boundary monitoring

Pollution Control Division (PCD) is responsible for monitoring and managing noise levels, ensuring that industrial and construction activities comply with the **Environmental Protection and Management (Boundary Noise Limits for Factory Premises) Regulations**.

#### **Condition to conduct noise boundary test as following:**

##### 1. When setting up or altering a new workplace

If a new industrial or commercial facility is being established, or if major modifications or expansions are planned to an existing layout or machinery, a noise boundary test may be required to assess noise levels at the boundaries of the property.

##### 2. Changing operational hour

If a workplace changes its working hours, particularly night shifts or weekends, a noise boundary test may be required, particularly if the noise could affect nearby neighbouring areas.





### 3. Workplace Noise boundary monitoring

**Condition to conduct noise boundary test as following:**

3. When requested by NEA

NEA may require noise boundary testing as part of its enforcement action or investigation into noise levels in a workplace, particularly if there have been previous breaches or non-compliance.

4. Response to complaints

If a noise complaint is received from a nearby neighbour, the NEA may request a noise boundary test to assess whether the workplace operations are the cause of the disturbance.



### 3. Workplace Noise boundary monitoring

**During a noise boundary test, the following are typically measured:**

- i. Ambient Noise Levels: The total noise level at the property boundary, including background and environmental noise.
- ii. Frequency and Duration: The specific times and duration of noise levels that exceed permissible limits.
- iii. Peak Noise Levels: Assessment of sudden, sharp noise peaks (like machinery operation or alarms).





### 3. Workplace Noise boundary monitoring

#### Maximum permissible noise levels

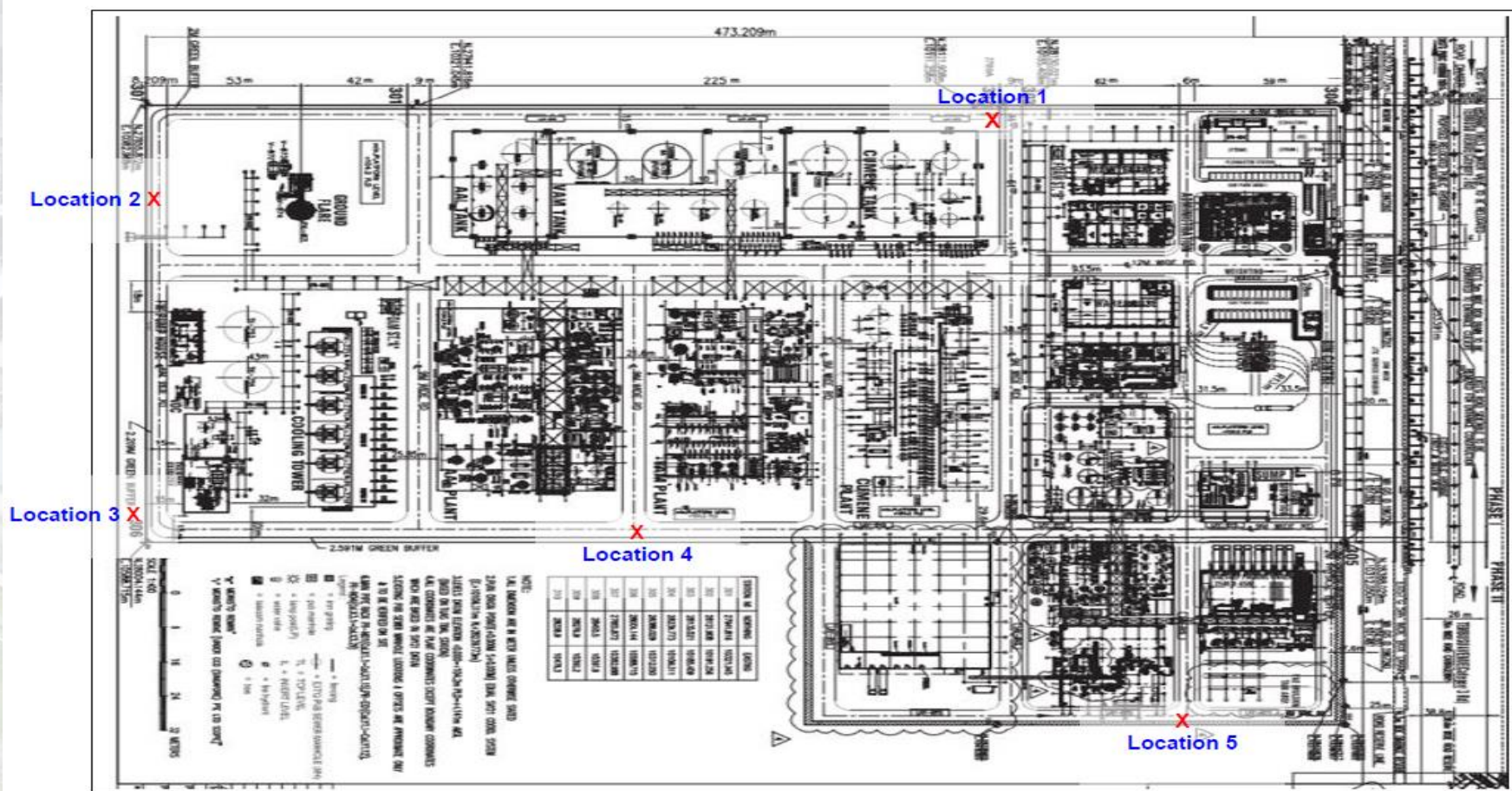
Types of affected premises	Day 7 a.m.-7 p.m.	Evening 7 p.m.-11 p.m.	Night 11 p.m.-7 a.m.
(a) Noise sensitive premises	65	60	55
(b) Residential premises	70	65	60
(c) Commercial premises	75	70	65
(d) Factory premises	75	70	65



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### 3. Workplace Noise boundary monitoring

Example of determine boundary test locations



Location 1: CCD Singapore Pte Ltd, 29 Tembusu Avenue





## 4. Summary of Air Emission monitoring work process

### 1) Determine Requirement for Emission Test

- Is the facility in an industry that produces air emissions (e.g., manufacturing, incineration, power generation)?  
Yes → Proceed to next step.  
No → No test required.

### 2) Prepare for Emission Test

- Review air quality standards and emission limits.
- Identify specific sources to be tested (e.g., stacks, vents, industrial processes).

### 3) Select Accredited Testing Agency

- Choose a certified testing agency.

### 4) Conduct Emission Test

- Collect air samples from the identified emission sources.
- Analyze pollutants (e.g., particulate matter, gases, VOCs) using approved methods



## 4. Summary of Air Emission monitoring work process

### 5) Compare Results to NEA Standards

- Are the emission levels within permissible limits?  
Yes → Compliance met. Issue report.  
No → Proceed to next step (possible corrective actions).

### 6) Corrective Actions (If Exceeds Limits)

- Implement mitigation measures (e.g., improve filtration, modify processes).
- Schedule follow-up test after corrections

### 7) Submit Results to NEA

- Submit final test results and reports to NEA for review and approval.





## 4. Summary of Air Emission monitoring work process

### 8) Receive NEA Feedback

- Is the report approved by NEA?  
Yes → Test results approved. Compliance achieved.  
No → Re-submit with necessary adjustments.

### 9) On going Monitoring & Compliance

- Continue regular emissions monitoring as per NEA requirements.
- Annual or periodic testing may be required based on industry and permit conditions.



## 5. Summary of Workplace noise boundary monitoring work process

### 1) Determine Need for Noise Boundary Test

- Does the workplace have a potential to cause significant noise emissions (e.g., construction, manufacturing, heavy machinery)?  
Yes → Proceed to next step.  
No → No test required (Continue normal operations)

### 2) Is the Workplace Subject to NEA Noise Control Regulations

- Is the workplace in a regulated sector, or does it fall under NEA's noise control framework?  
Yes → Proceed to next step.  
No → Consult NEA for advice on applicability.

### 3) Plan and Prepare for Noise Boundary Test

- Identify the noise emission sources (e.g., machinery, generators, HVAC systems).
- Determine boundary test locations (usually at property boundary or sensitive receptors).





## 5. Summary of Workplace noise boundary monitoring work process

### 4) Analyze the Test Results

- Compare recorded noise levels with NEA's permissible noise limits control framework?
- Are noise levels within acceptable limits?  
Yes → Compliance achieved. Proceed to report.  
No → Proceed to next step (non-compliance).

### 5) Corrective Actions (If Exceeds Limits)

- Implement corrective actions (e.g., modify operations, install noise barriers, adjust equipment).
- Schedule follow-up test after corrections

### 6) Submit Results to NEA

- Submit final test results and reports to NEA for review and approval



## 5. Summary of Workplace noise boundary monitoring work process

### 7) Receive NEA Feedback

- Is the report approved by NEA?  
Yes → Test results approved. No further actions required.  
No → Re-submit with necessary adjustments.

### 8) On going Monitoring & Compliance

- Monitor noise levels periodically as required by NEA (e.g., annual testing, after major changes).
- Maintain records of noise levels, test reports, and corrective actions.





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## 9. Any other matters arising





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