



CLC Lecture Series

# Uncovering the Underground

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# Uncovering the Underground

- Why Underground?— the next frontier for Singapore
- Examples of Underground Projects
- Underground Space Planning
- Tunnel Talking Points
- What's next for Singapore? – envisioning Singapore 50 years from now



# Uncovering the Underground



ASSOCIATION  
INTERNATIONALE DES TUNNELS  
ET DE L'ESPACE SOUTERRAIN

ITA  
AITES

INTERNATIONAL TUNNELLING  
AND UNDERGROUND SPACE  
ASSOCIATION



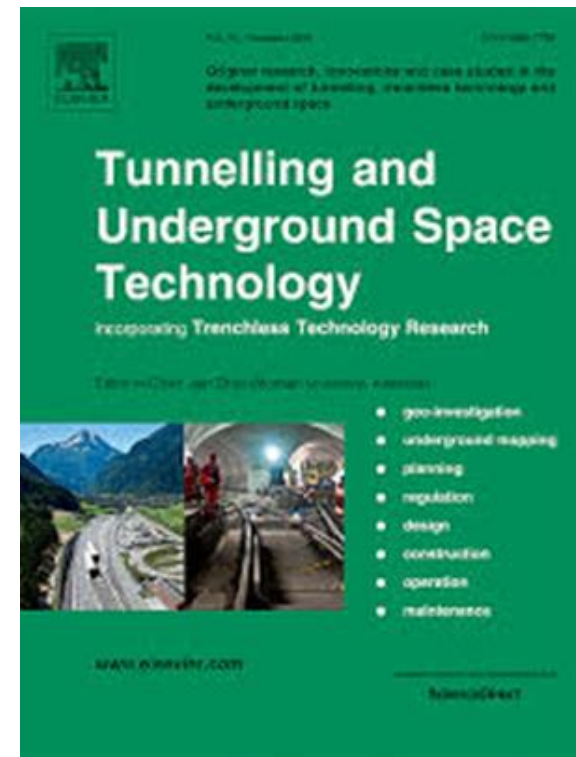
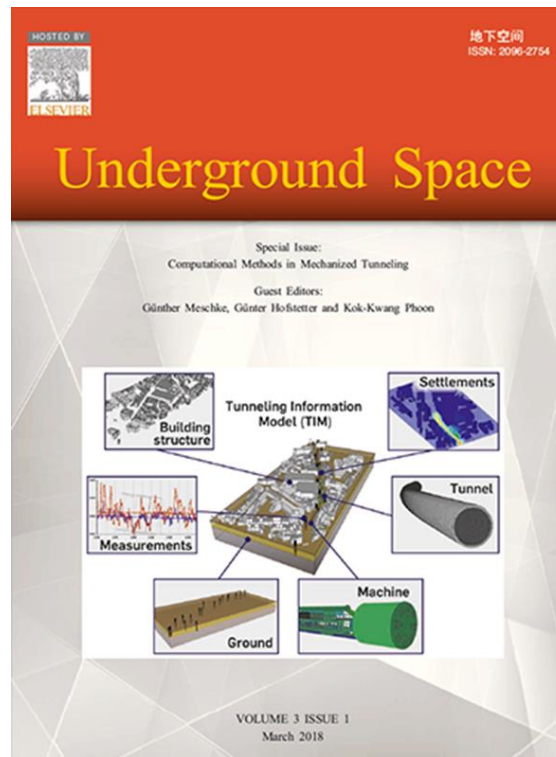
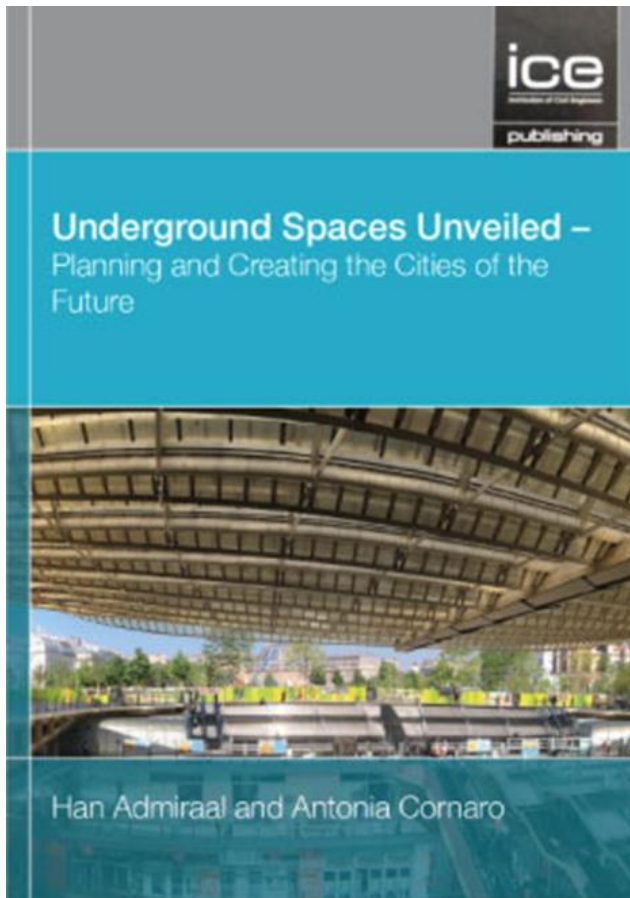
Tunnelling and Underground Construction  
Society (Singapore) - TUCSS



Geotechnical  
Society of  
Singapore



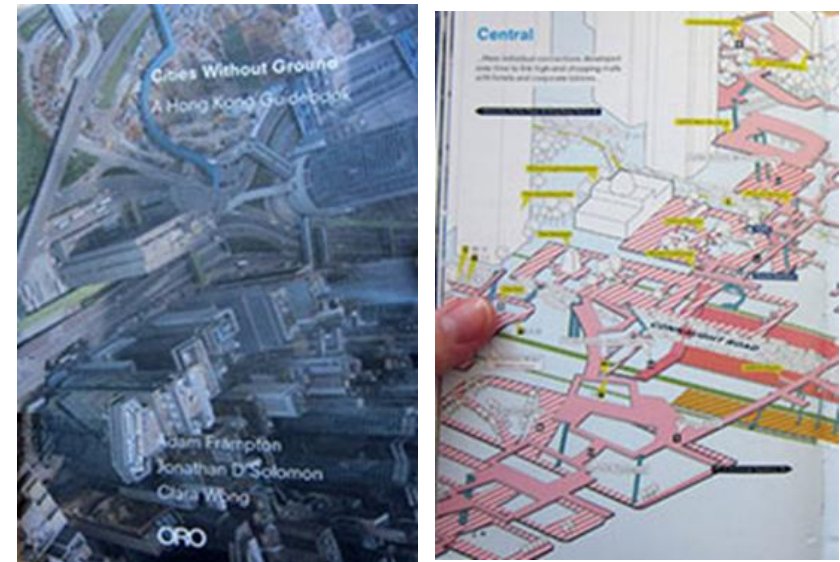
Spore Rock Mechanics  
& Engineering Geology



# Uncovering the Underground



Benchmarking Study and Establishment of Guidelines for Underground Space Planning, Singapore - Optimising underground space in land-scarce Singapore (2014)

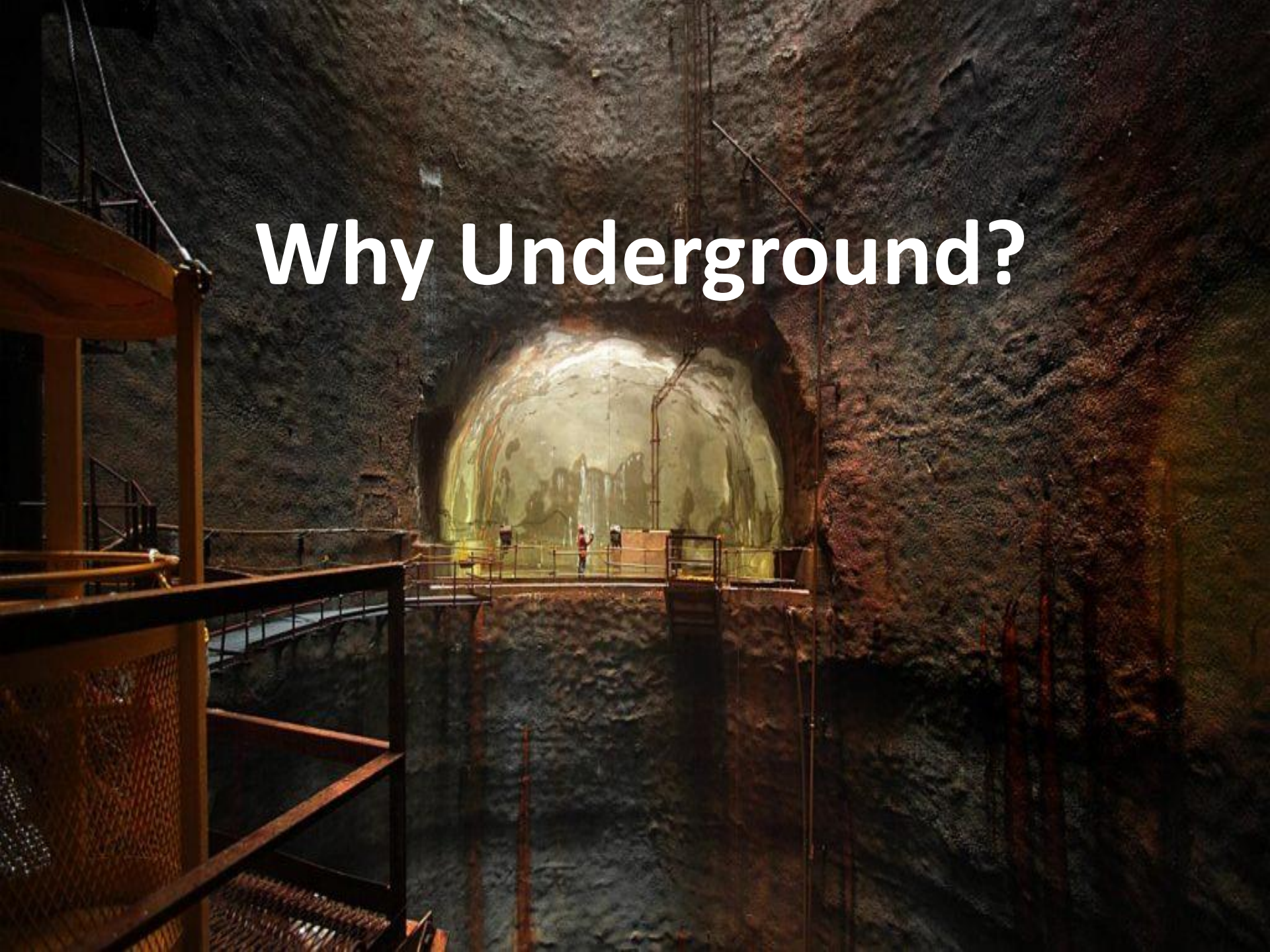


Cities without Ground:  
A Hong Kong Guidebook

**Underground – Singapore Next Frontier  
Exhibition in May 2018 at URA Centre**



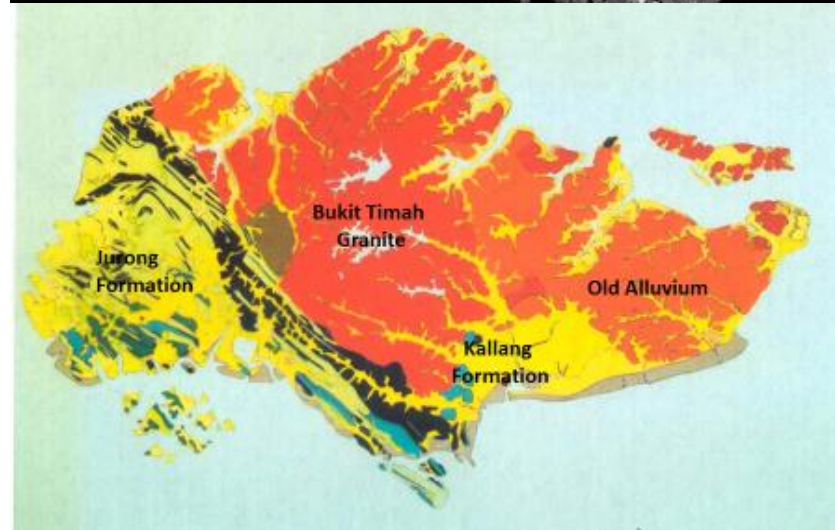
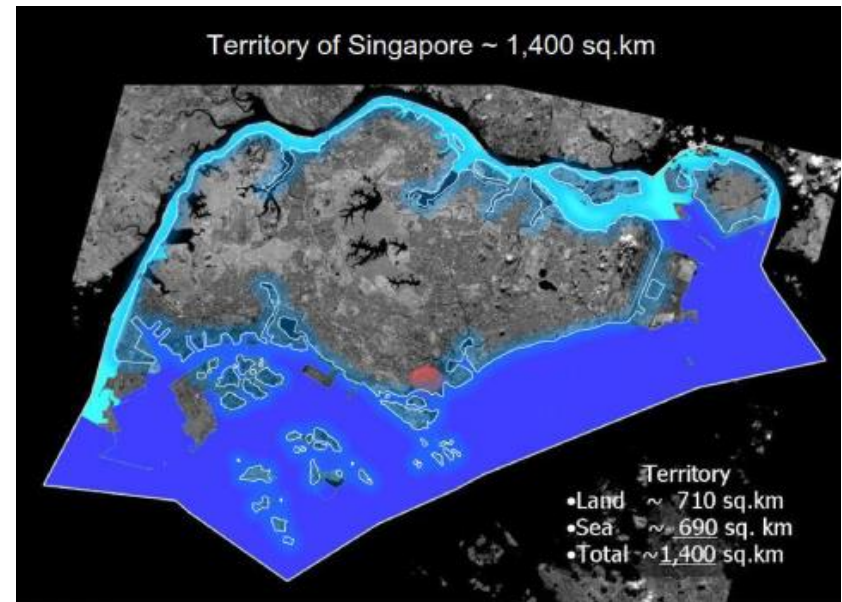
# Why Underground?





# Perspective of Singapore

- Finite land (718 km<sup>2</sup>) and sea (700 km<sup>2</sup>) space
- Challenging geology – soft clay and rocks
- No typhoon but strong winds (“sumatras”)
- No earthquakes but far-field seismic response
- No tsunamis but 40% low land
- Plenty of rain - extreme rainfall events (high intensity, short duration)
- Getting hotter - drought events
- Natural resources – sand, aggregates, water, sun



Geology of Singapore

small island  
**BIG  
NEEDS**



Singapore has to cater for more than other cities

# **Report of the Inter-Ministerial Committee on Sustainable Development (IMCSD)**

**Launched in April 2009**

## **A LIVELY AND LIVEABLE SINGAPORE: STRATEGIES FOR SUSTAINABLE GROWTH**

One of key strategies – expand land resource:

- Go higher - build taller buildings
- Go wider - more land reclamation
- Go deeper - develop underground spaces





# Go Higher!



7 x 48-storey Public Housing project

# Go Wider – more Land Reclamation

Since first reclamation works began in 1822, **Singapore's land area has expanded by almost 25%** from 580sqkm to 720sqkm [sea space about 700 sqkm]

## Depth of water

- Early phases – less than 5m
- Recent phases – up to 30m
- Future phases – up to 45m

## Fill materials

- Hill cut from old alluvium
- Hydraulic fill dredged from sea shoals
- Barge transported sand from overseas
- Challenges of fill availability



- Areas shaded in pink indicate land reclaimed as of end 2015
- Areas in red show possible plans for future reclamation



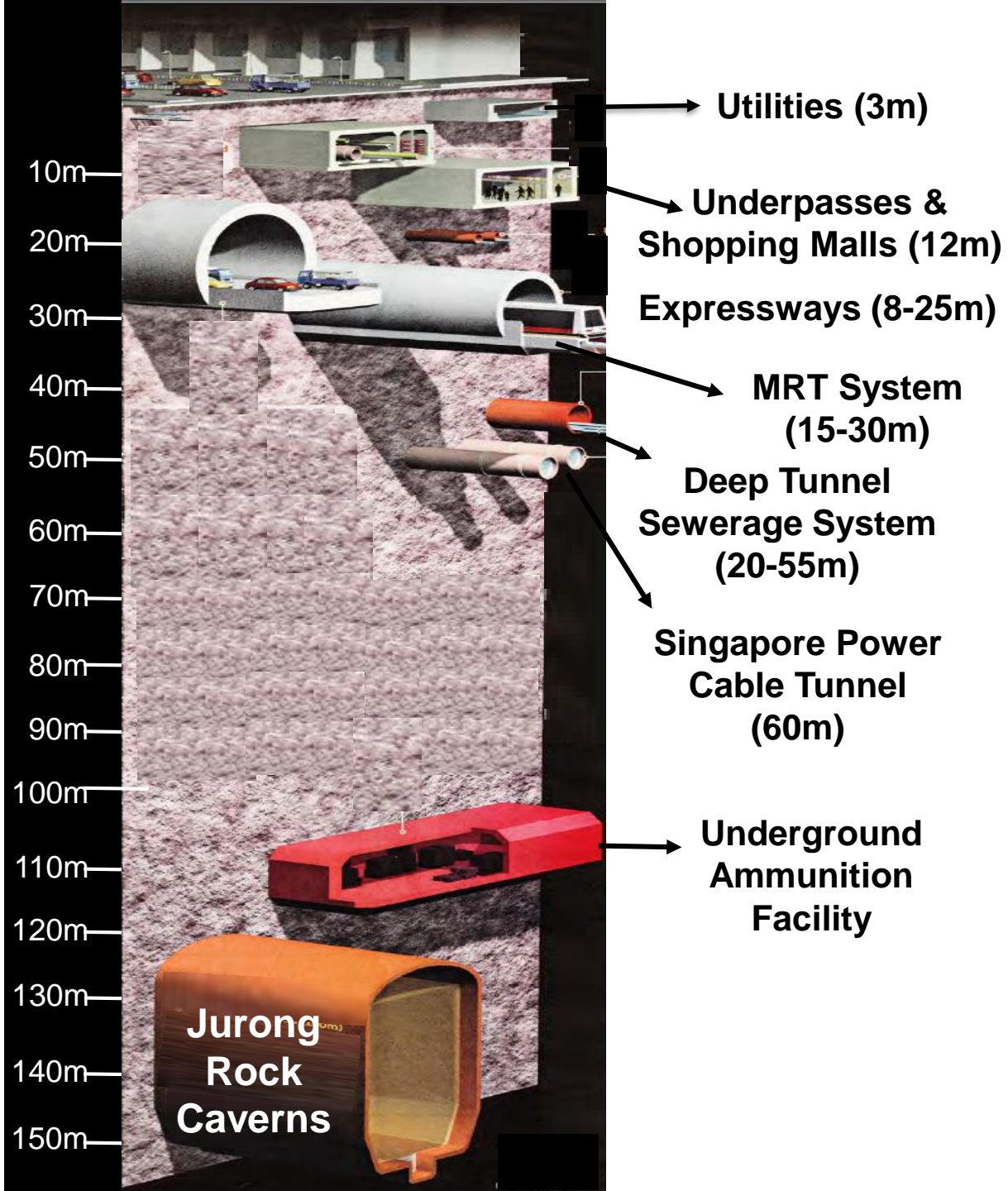
# Go deeper ... unlimited underground space

- Southeast Asia's first underground facility for storing liquid hydrocarbons
- By going deep under seabed, freed up 60 ha of surface land, enough for six petrochemical plants
- 130m beneath the seabed and cavern is as tall as 9-storey building!



Jurong Rock Cavern (JRC)

# Definition of Underground Space – beneath the ground surface





# Examples of Underground Projects

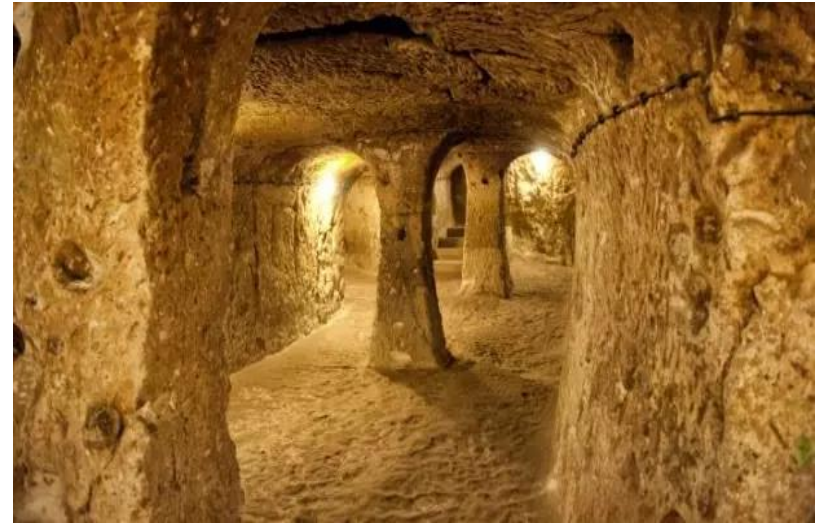
How ahead of the curve is Singapore in terms of Global Underground Space usage?



# History of underground cities as refuge from war

## 8<sup>th</sup> century BC Derinkuyu Underground City

- Turkey home to >36 underground cities
- Some as deep as 85m
- Derinkuyu deepest; 20,000 population
- Turkey's Cappadocia region.
- Labyrinthine complex carved in volcanic rocks
- Built to serve as a refuge during wars



## 14<sup>th</sup> century Pilsen Historical Underground, Czech Rep

- A 12.5 mile long labyrinth of passageways, cellars and wells built below the city streets
- Cellars once served as storage space for food and barrels of beer (renowned Pilsner Urquell)
- Serve as escape route in case of an attack



[source: History Channel]



# Underground Bunkers during Cold War

## Burlington Bunker, Village of Corsham, UK

- 35-acre underground complex, **30m deep**
- built in 1950s for **4000 key govt.** personnel in event of a Cold War-era nuclear strike
- series of existing tunnels and stone quarries
- office spaces, cafeterias, medical facilities, telephone exchange, sleeping quarters
- Burlington facility operational until 2004, it was decommissioned and declassified.



## Beijing Underground City (Dixia Cheng)

- Built in 1960s/70s - threat of nuclear war
- Chinese govt built mammoth fallout shelter beneath Beijing covering **85 sqkm**
- Hand-dug site can safeguard **300,000 people**
- Consisted of rooms, schools, hospitals, granaries, restaurants, skating rink, 1,000-seat movie theatre and tunnels
- Certain passageways large enough for tanks
- Bunker never put to use, now sealed off



# Modern day underground cities

## RESO in Montreal

Montreal's Underground City is an elaborate set of over 60 underground complexes that house a number of residential apartments, banks and offices, shops, hotels, and other establishments.

500,000  
people access the  
RESO each day

spread over  
3.6 sq km

It is a complete city unto itself with **universities, museums, entertainment centers, Metro stations, and bus terminals**. The RESO is home to about 1600 housing units and is very well lit and ventilated. The RESO is also referred to as the La Ville Souterraine.

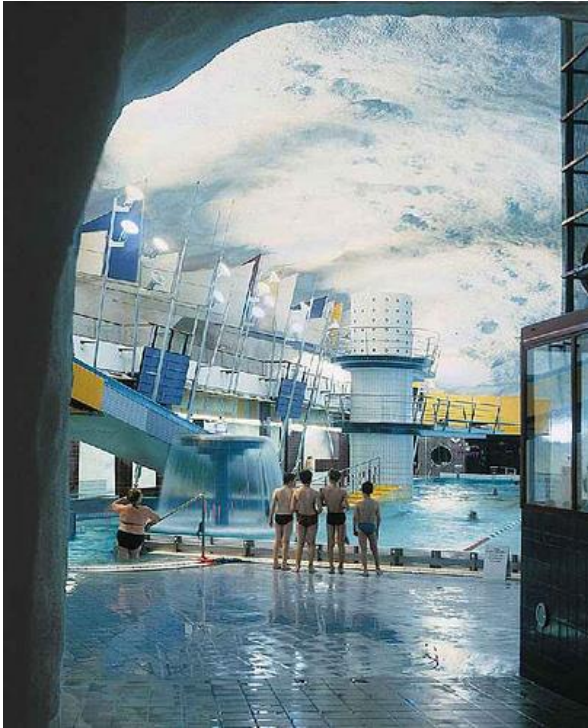


Escape the winter cold at RÉSO,  
Montreal's complex network of  
underground passageways  
32 km tunnels, 120 access points





# Helsinki Underground Plan, Finland

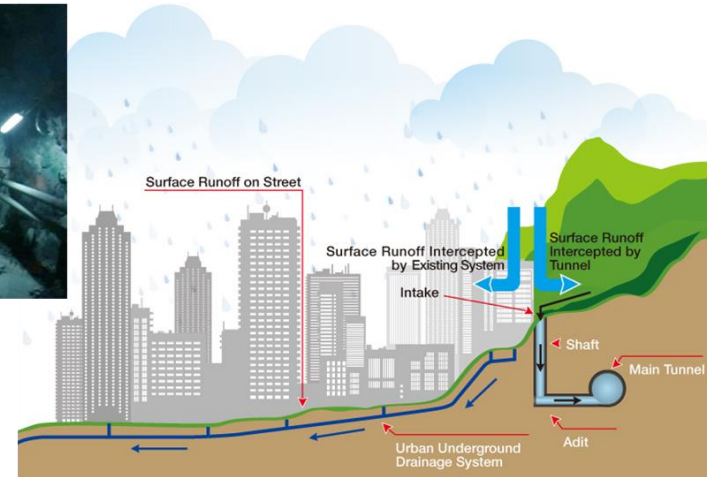


Helsinki, Finland protect its prime near-surface rock resources and developed deep common utility tunnels that limit interference with shallower, people-oriented underground infrastructure

# Underground Storm Water Drainage

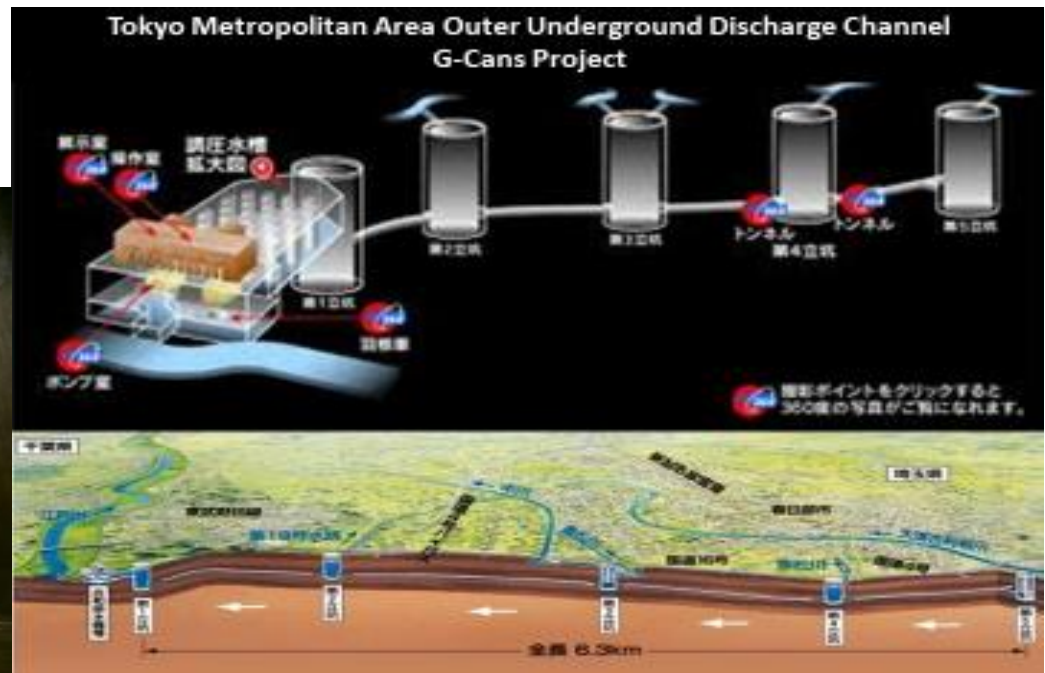
## Hong Kong West Drainage Tunnel

- intercept storm-water from upper catchment at Mid-Levels and discharge to sea directly.
- Alleviate flooding on Northern Hong Kong Island



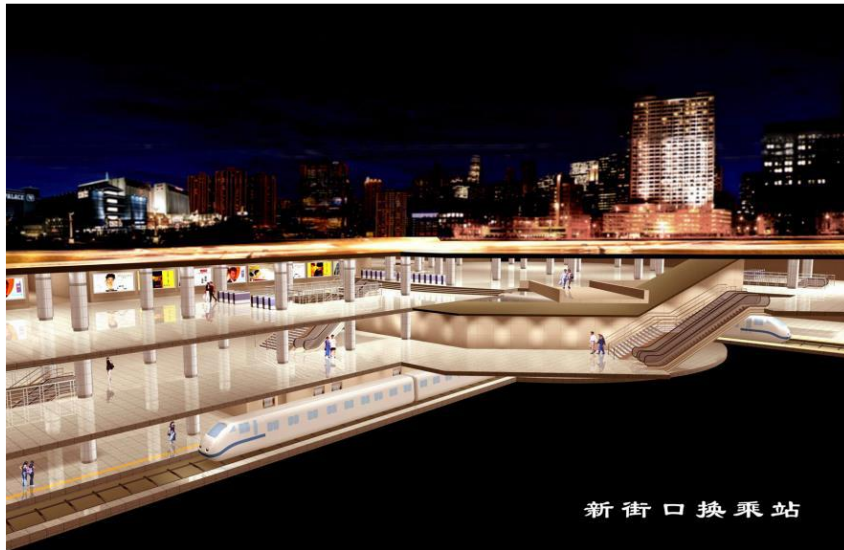
## Tokyo G-Cans Project

- 6.4 km tunnels, 50m deep connect 5 silos to one massive tank – the Temple





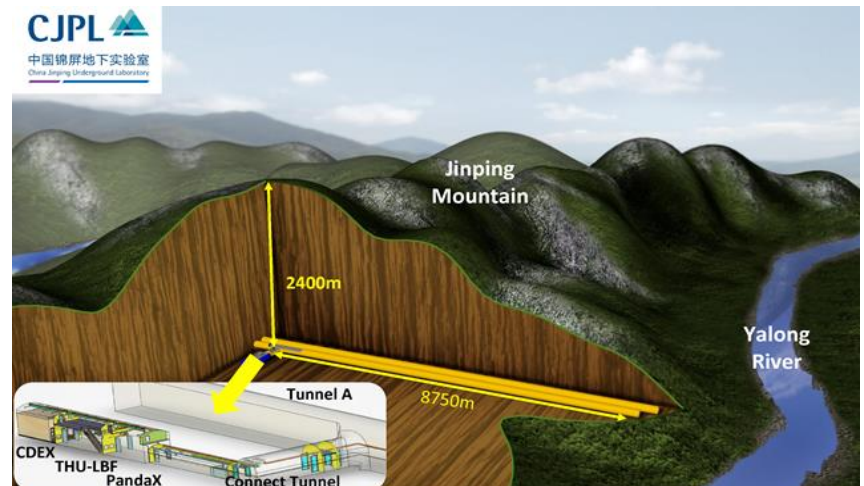
# China leading the way in underground rail and urban underground developments



**Xiongnan, Hebei mega city** - above and underground (26m and 40m bgl)

- **1400 sq km area**
- Shallow – storage, shopping, parking, entertainment, civil defence
- Deeper – water storage and key infrastructure and defence facility

President Xi Jinping  
South China Post June 2017



Deepest underground facility -  
research lab for astro-particle research

# UNDERGROUND DEVELOPMENTS IN SINGAPORE

Over the years, underground spaces in Singapore have been developed to house shopping malls, car parks, transport infrastructure, pedestrian links and utility infrastructure. This benchmarking study provides a platform to learn from global best practices so that we can better utilise Singapore's underground space.

## UNDERGROUND INFRASTRUCTURE AND KEY MILESTONES



### Rail

Singapore has one of the world's densest rail networks, coming behind Tokyo. Out of 180km of urban rail, 82km are located below ground. Singapore continues to invest heavily to extend its rail network across the island.

—

**1987**  
North-South Line and East-West Line  
Singapore's first MRT tunnels

**2003**  
North East Line  
Singapore's first fully underground MRT line

**2010**  
Circle Line  
Bras Basah Station features the longest escalator in the whole MRT system

Kim Chuan Depot  
World's first underground train depot



### Roads

Nearly 10% of Singapore's expressway network is located below ground, including the KPE, CTE, MCE and the future North-South Corridor.

—

**1989**  
Central Expressway  
Chin Swee Tunnel and Kampong Java Tunnel are Singapore's first road tunnels

**1996**  
Woodlands Bus Interchange  
Singapore's first underground bus interchange

**2008**  
Kallang-Paya Lebar Expressway  
Southeast Asia's longest underground road tunnel

**2013**  
Marina Coastal Expressway  
Singapore's widest road tunnel



### Caverns

Singapore has two major cavern developments, the Underground Ammunition Facility and the Jurong Rock Caverns which can hold about 1.47 million cubic metres of crude oil and petroleum. There is currently no comprehensive plan to identify potential cavern sites.

**2008**  
Underground Ammunition Facility  
Singapore's first cavern development

**2014**  
Jurong Rock Caverns Phase 1  
Singapore's deepest underground development



### Underground Pedestrian Networks (UPN)

Singapore's UPN are mostly concentrated in the Central Business District and Orchard Road shopping district. Further plans to extend the networks within the core city areas have already been drawn up.

**2000**  
CityLink Mall  
Singapore's first underground shopping mall

**2013**  
Marina Bay Link Mall  
Expanding Singapore's underground pedestrian network in the Marina Bay area



### Utility tunnels

Singapore has developed the Common Services Tunnel in the Marina Bay area and will study the use of such tunnels for other green field development areas.

### Utility plants

Around the world, utility plants have been located underground. Singapore has successfully implemented underground district cooling plants in Marina Bay, with scope to locate more plants underground.

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**2008**  
Labrador-Harbour Cable Tunnel

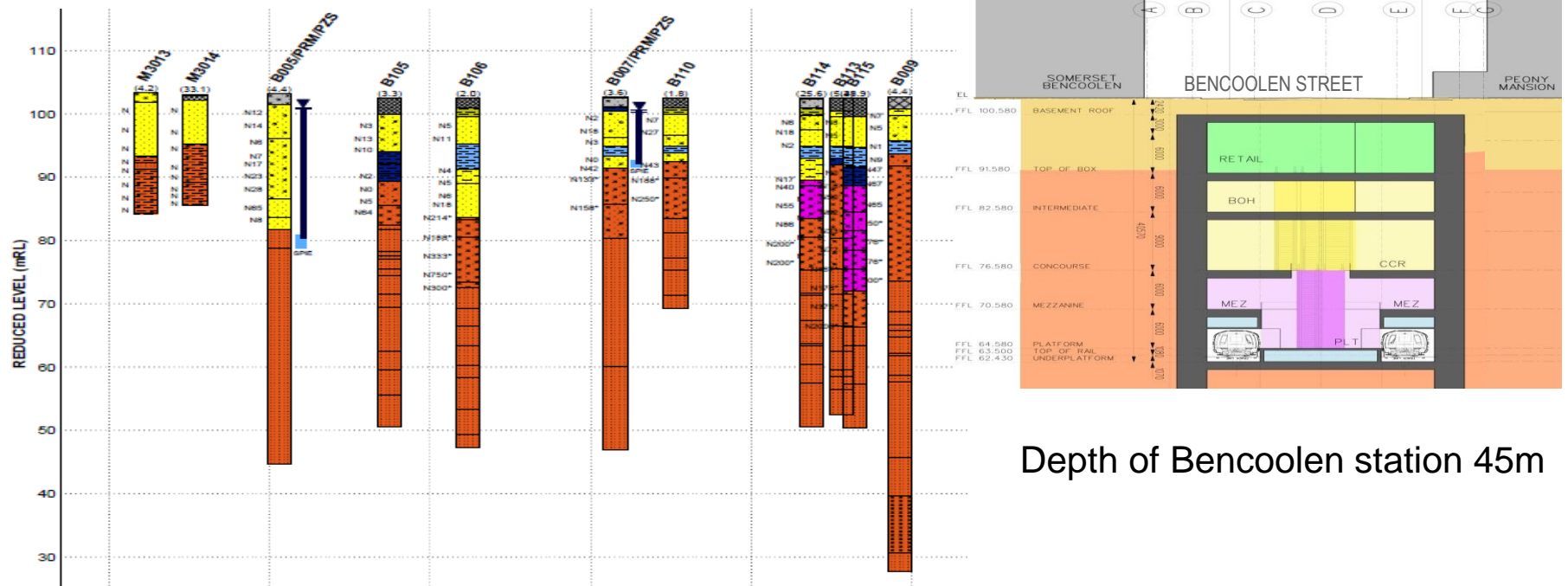
Deep Tunnel Sewerage System Phase 1

**2008 - 2014**  
Marina Bay Common Services Tunnel  
Southeast Asia's first multi-utility tunnel





# Underground rail development

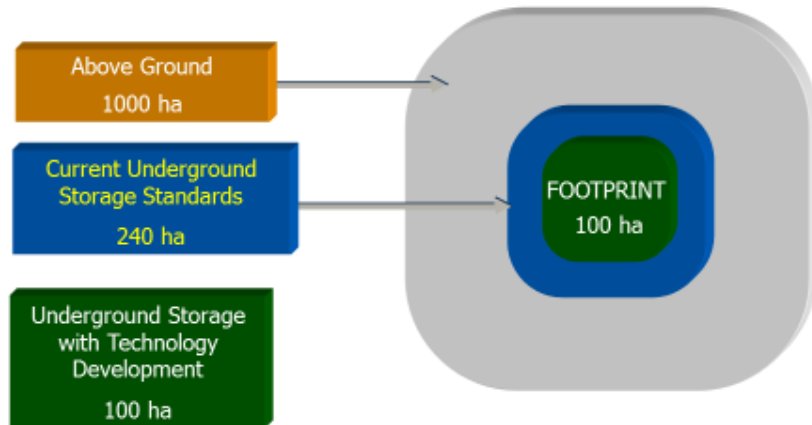


Depth of Bencoolen station 45m

# Land Optimization 1 Underground Storage

## Underground Ammunition Storage

Results of Technology Development on  
Underground Storage of Ammunition



DSTA Engineers & their R + D Partners Spent \$12m & Saved 140 ha of Land

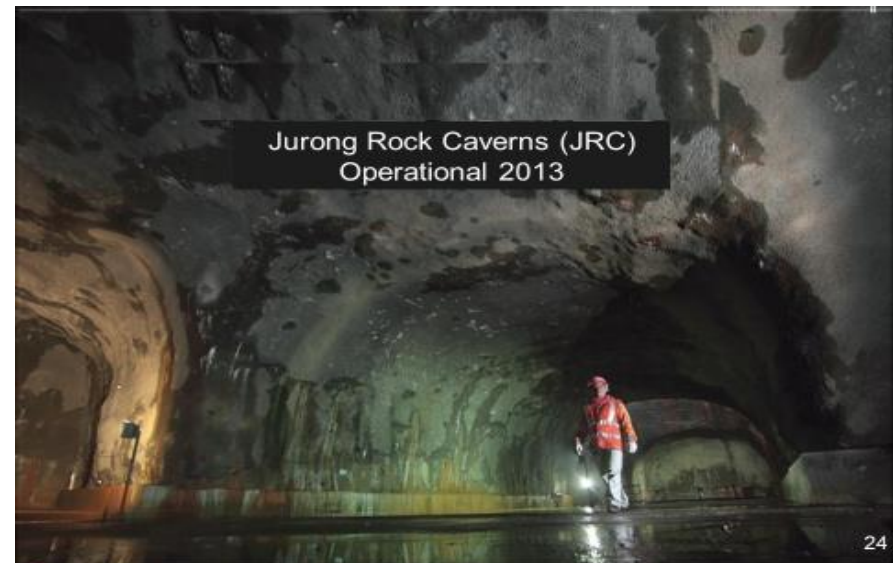
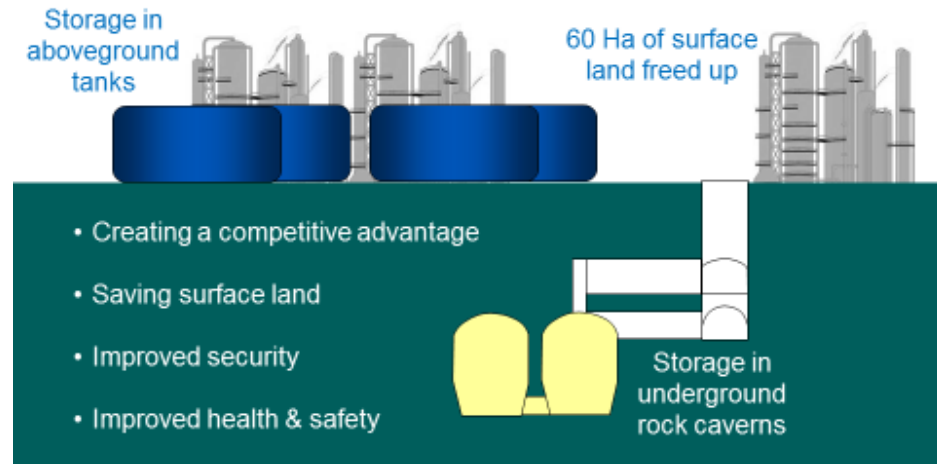


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[source: Prof PC Lui]

## Underground Oil Storage

Aboveground land used for production; underground land used for storage

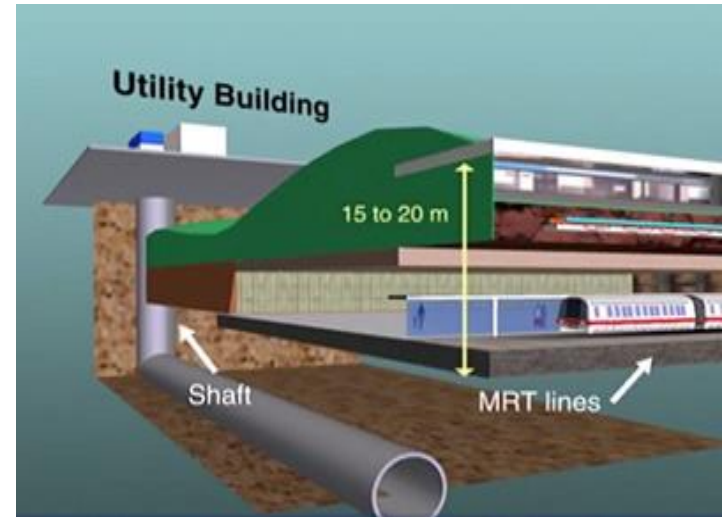


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[source: JTC -  SINTEF  TriTech Multiconsult]



# Land Optimization 2 - High voltage power transmissions cable tunnels



6m dia. cable tunnel 60m below GL

- 35km cable tunnels (50m - 60m deep) - completed tunnelling in April 2017
- No competition for shallow underground space and minimal utilities diversion in future
- 10 hard rock TBMs and EPBMs in 6 contract packages



# Land Optimization 3 - The Deep Tunnel Sewerage System (DTSS) saves large areas of land sterilized by Sewage Treatment Plants



- **Link Sewers** convey used water from existing sewerage network to the **Deep Tunnels**
- Used water flows by gravity through the deep sewer tunnels to **centralised Water Reclamation Plants**
- Treated used water will be channelled to the **NEWater plant** for further purification or discharged through the **outfall**

- DTSS – a used water underground gravity superhighway to meet long term needs for used water collection, treatment, reclamation and disposal – deep sewers typically 30m – 50m depth and run under roads
- DTSS Phase 1 (2000-2008) – 48km long deep sewer tunnel by TBMs + 60km link sewer by micro-tunnelling/pipe jacking
- DTSS Phase 2 (2013- 2025) – 40km long deep sewer tunnel + 60km link sewer

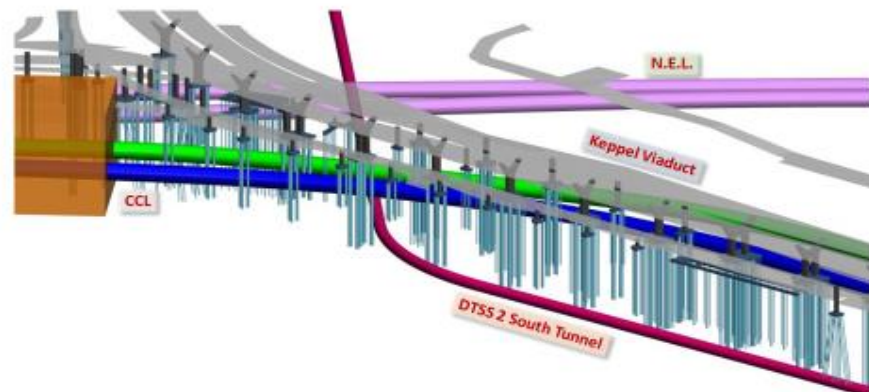


# Expanding the Metro (MRT) rail network under LTMP2013

- On-going construction of Thomson-East Coast Line
- New Lines include:
  - 50 km Cross Island Line
  - 20 km Jurong Regional Line
  - Extensions to Circle Line, Downtown Line and North-East Line
- Two cross borders lines:
  - Singapore-Johor Rapid Transit System Link to enhance connectivity between Iskandar Malaysia and Singapore
  - High Speed Rail (HSR) connecting Kuala Lumpur and Singapore (suspended).



## Tunnel Modelling – Avoiding Existing Infrastructures



# Underground Space Planning





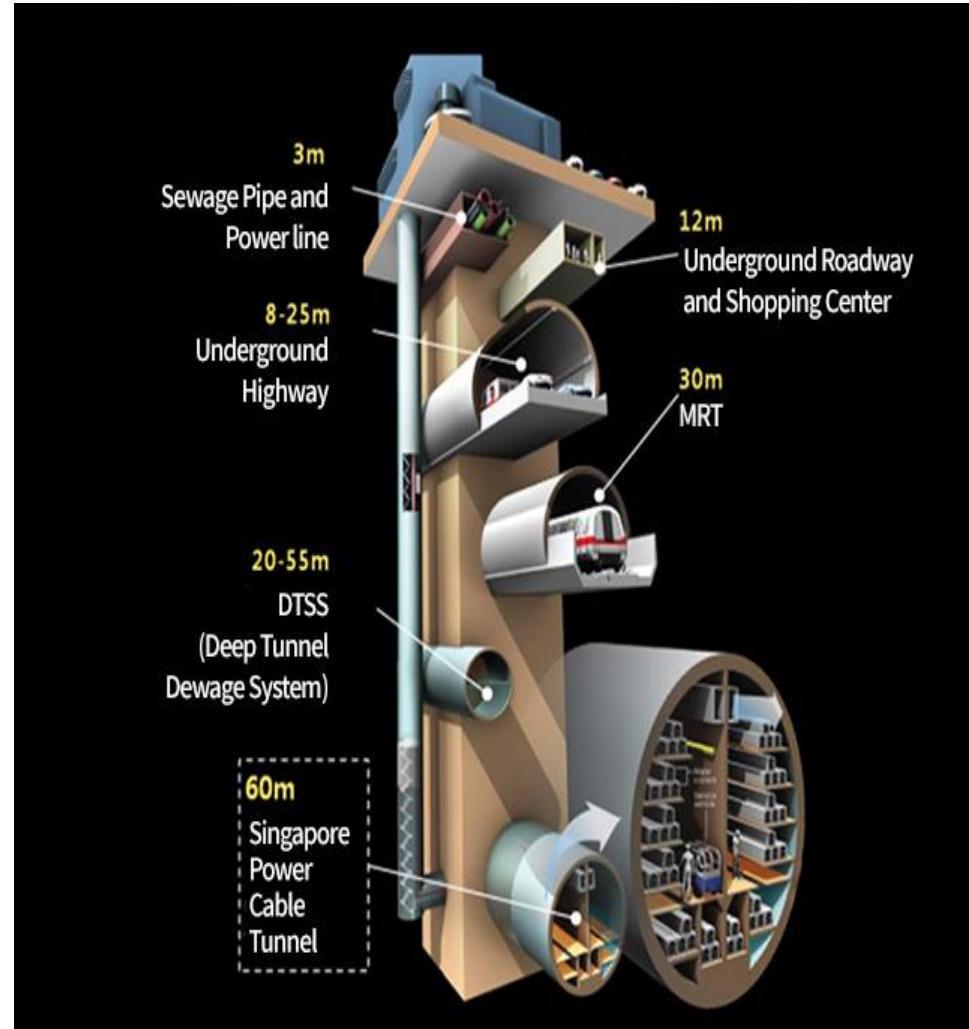
# Planning and Governance for Sustainable Development

## At grade (surface)

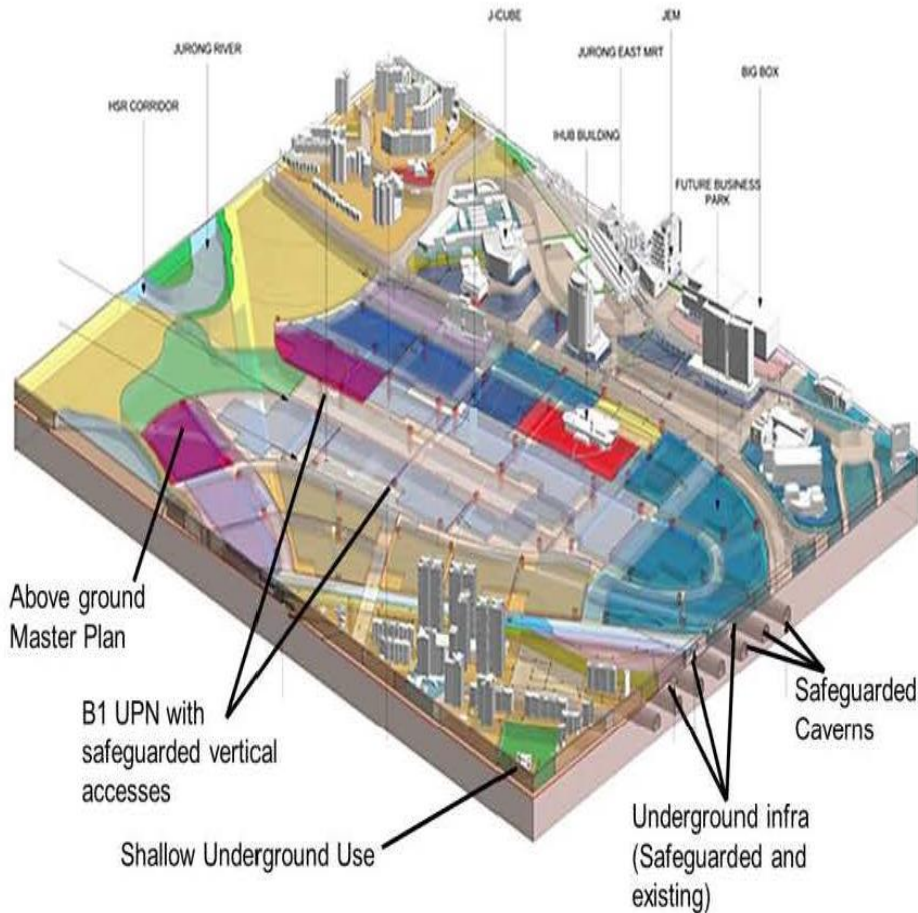
- URA Concept Plan (40- 50 years)
- Master Plan Committee (MPC) - 5-year review
- Communities Facilities Co-ordination Committee (CFCC)

## Underground

- Underground Master Plan Task Force (UMPTF) led by Ministry of National Development
- Advanced planning and inter-agency coordination of future underground plans



# Developing Singapore's 3D Underground Masterplan



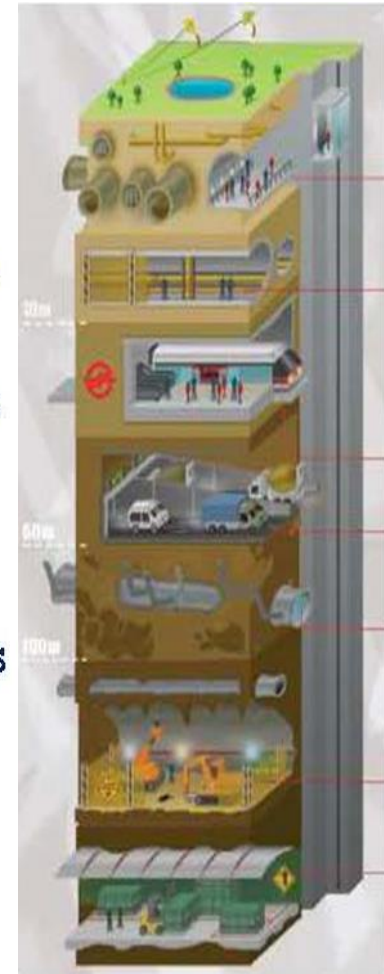
*\*For illustrative purposes only*

Ensure efficient use of UG space

Synergy with above ground uses

Safeguard vertical accesses

Coordinate efforts from agencies



[source: URA]

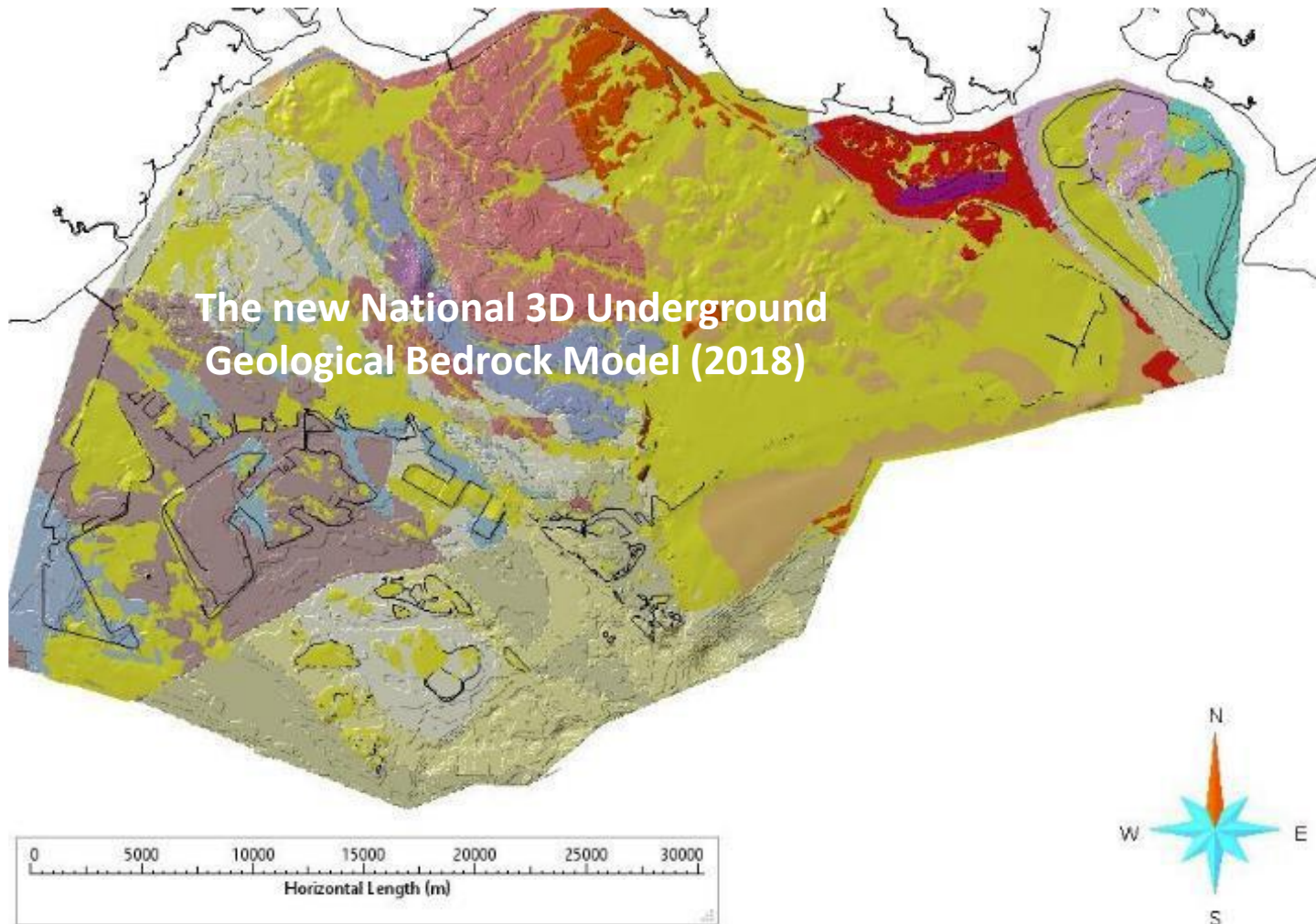




Geology of Singapore (PWD) 1976

Geology of Singapore updated (DSTA) 2009

Singapore Geology Office (BCA) set up in April 2010

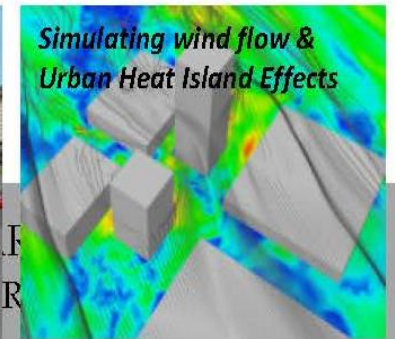
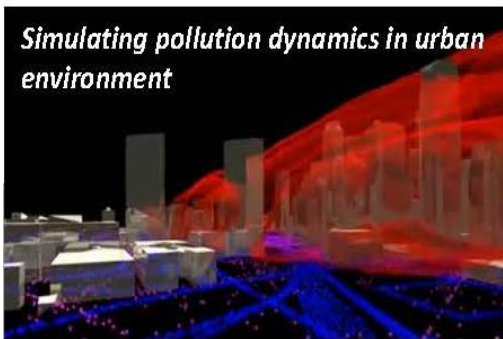


[source: Keifer Chiam, BCA]

# Virtual Singapore concept – 3D digital model of the physical city state

- Planning and decision making
- Predictive environmental modelling
- Resource Management
- Disaster Management
- Management of diseases
- Rich data environment for R&D and innovation

## Government Agencies Working on Urban Challenges



Source: National Research Foundation, Prime Minister's Office Singapore



A photograph of a large tunnel under construction or maintenance. A group of about 15 workers wearing hard hats and safety gear are standing in a line on the left side of the tunnel. They are positioned behind a series of yellow and red safety barriers that run along the length of the tunnel. The tunnel walls are rough and rocky, and the floor is wet and reflective. Several bright lights are mounted on the walls, illuminating the scene. In the background, a small white vehicle is visible on the right side of the tunnel. The text "Tunnel Talking Points" is overlaid in the center of the image.

# Tunnel Talking Points

# Talking Point 1 - New Legal and Planning Frameworks

- March 2015, Singapore's Parliament amended two laws to facilitate underground development
- **State Lands Act** amended – surface landowners own underground space up to 30m under the Singapore Height Datum
- **Land Acquisition Act** amended to give state the right to buy out plots of surface land or a specific stratum of subsurface so that the ground underneath it can be accessed



Note: Japan's Special Measures Act for Public Use of Deep Underground (Act no. 87 of 2000)



## Talking Point 2 - Social Dimension

- Quality of life and taboo on living underground
- Behavioural and psychological impact on humans living or working long hours underground
- No different from a person working in basement or in rooms without windows!
- Lund University study – difference in decision-making between people working above ground with daylight against people working in rooms without windows
- Journal of Clinical Sleep Medicine - workers in windowless rooms, or with little daylight exposure, may lose up to 46 minutes of sleep a night)



Cave dwelling complex in Sanmenxia  
– 3000 ppl live in subterranean city

## Talking Point 3 - Technical challenges

- **Urban** Underground Space
- Technical constraints and challenges in underground construction, whether in rock or in soils are not insurmountable.
- Once built difficult to re-develop – design for permanency or high degree of flexibility
- From engineering perspective, **no limit** to how much underground space, including those below seabed could be potentially exploited.
- Limit often lies in the economic and commercial viability of the project.



## Talking Point 4 - Construction Cost and Maintenance

- High construction cost (2 - 5 times depending on type of facility, size, depth and geology)
- If land prices rises to an astronomical level as in Tokyo CBD area, it makes commercial sense for land owner to go as deep as 30m below ground (about 8-10 storeys below ground), which is the limit of its ownership.
- Higher cost compensated by savings in façade construction and maintenance, and lower energy consumption (can be 12% or less)
- Must address institutional and economic barriers. For public sector, higher costs offset by value gain in terms of land and better environment. For private sector, issues such as development charge must be addressed.

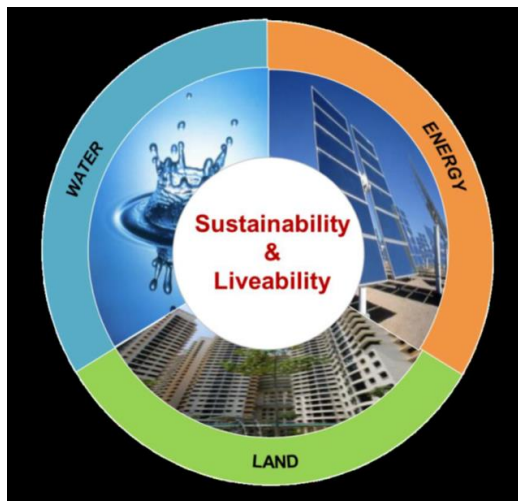
## Talking Point 5 - Risks in Underground Development

- Environmental
  - Seepage of water leading to water drawdown
  - Underground air quality and high humidity
  - Fire risks and evacuation
  - Contamination due to Explosives residues
- Uncertainties due to variable geological and hydro-geological formations.
- Assessing integrity of underground structures
- Insurance and risk assessment

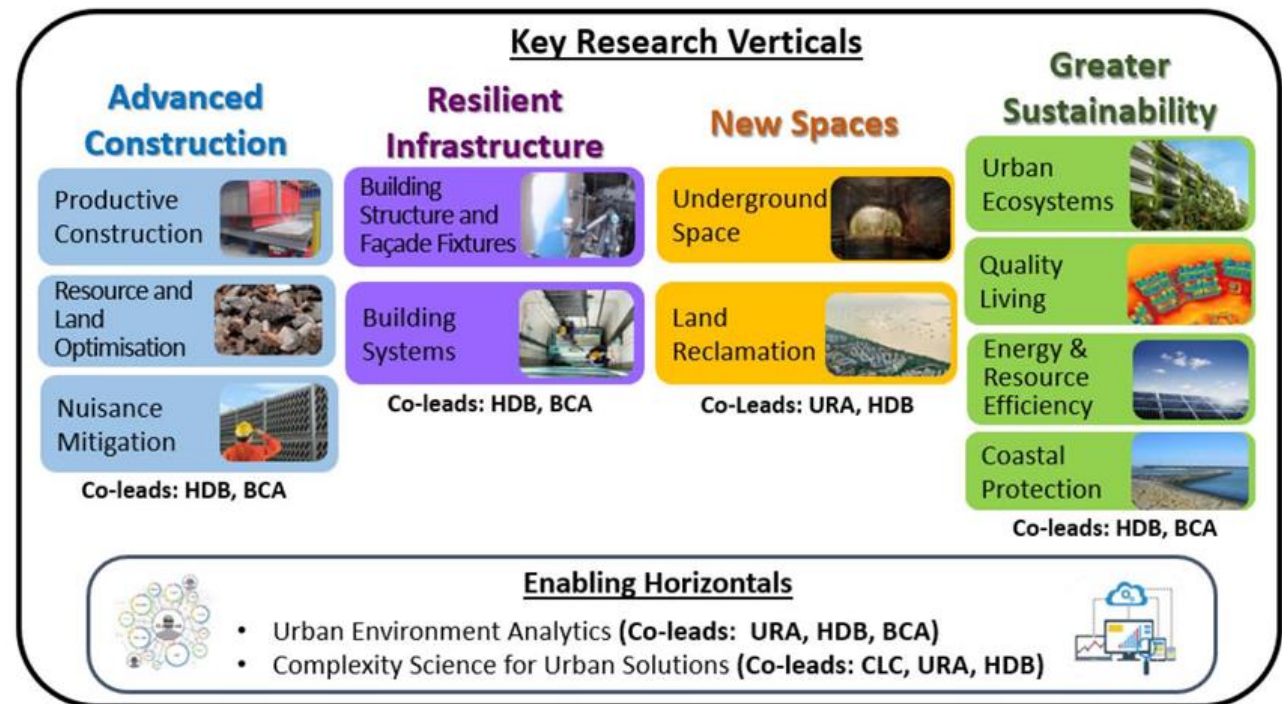


# Talking Point 6 - R & D on underground space

- MND/NRF R&D programme on Land & Liveability and Cities of Tomorrow Programme - research and innovation in underground space
- To reduce cost of underground construction by 50% while maintaining or even reducing recurrent and maintenance costs
- Monitoring and surveillance of underground developments to ensure safety of users.



\$150 m for Cities of Tomorrow R&D programs





Uncovering the Underground

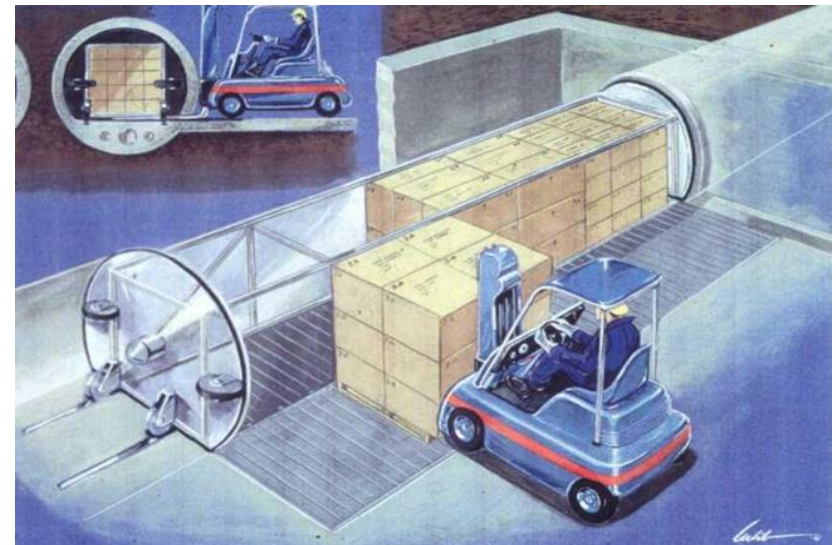
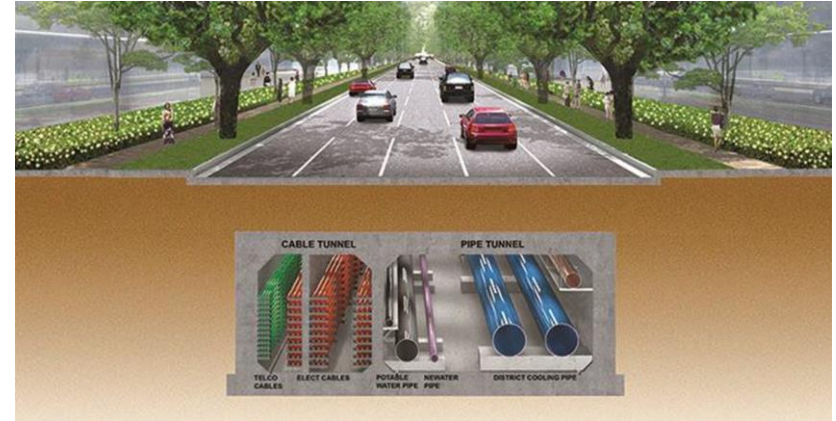
# What's next for Singapore?

*Envisioning Singapore 50 years from now  
wish list for better liveability*



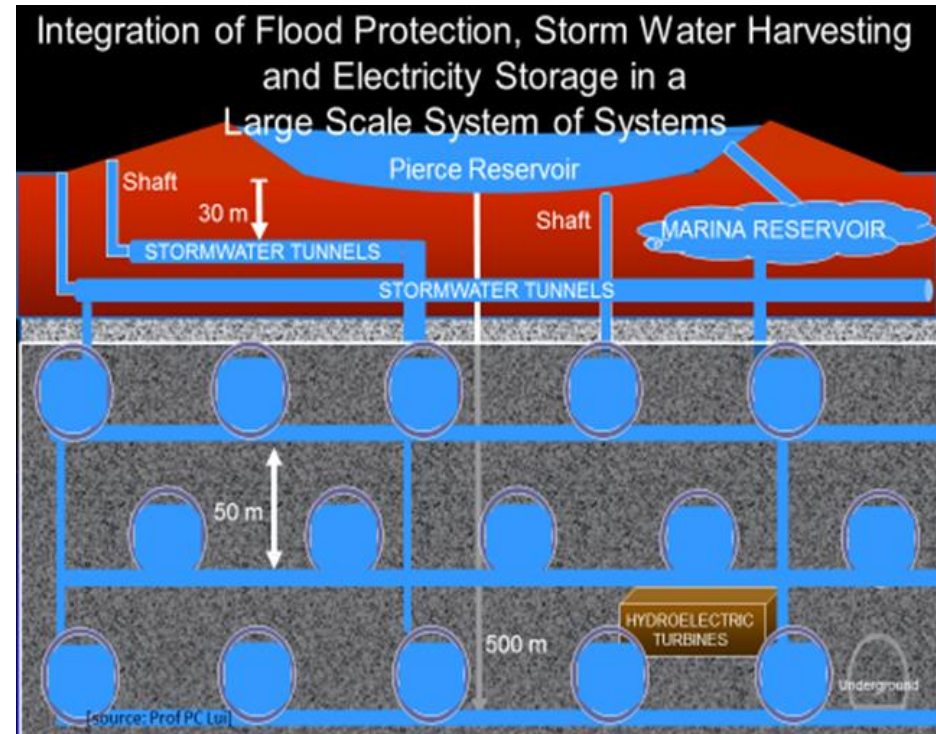
# Envisioning Singapore 50 years from now

- Public mode of transport; car “lite”, shared green AV
- Surface utilities in common services trench
- Road underground connects to major basement carparks
- Underground cities/towns – e.g. from Orchard to Marina Bay to escape heat and rain
- Capsule Transport of Cargo in Pipelines - freight transportation being used Germany, Netherlands and Japan



# Envisioning Singapore 50 years from now

- Collect as much of rain water as possible – now only 10%-20%
- Storm water and canals integrated in and underground system
- Heavy industries, treatment plants and environmentally unfavorable (noise, air, odour pollution) installed underground
- Urban Farming
- Everything underground that don't need light and sky!



[source: Prof PC Lui]

# *Finally, continue to.....*Think Deep

- **Think Deep UK (TDUK)**  
is a group of built environment experts committed to creating resilient, sustainable and liveable cities through smart use of underground space
- **Think Deep SGP (TD.SGP)?**



[source – Think Deep UK]



*Thank you*

