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Integrating Innovation: Engineering Singapore's Large-Scale Systems for a Sustainable Future

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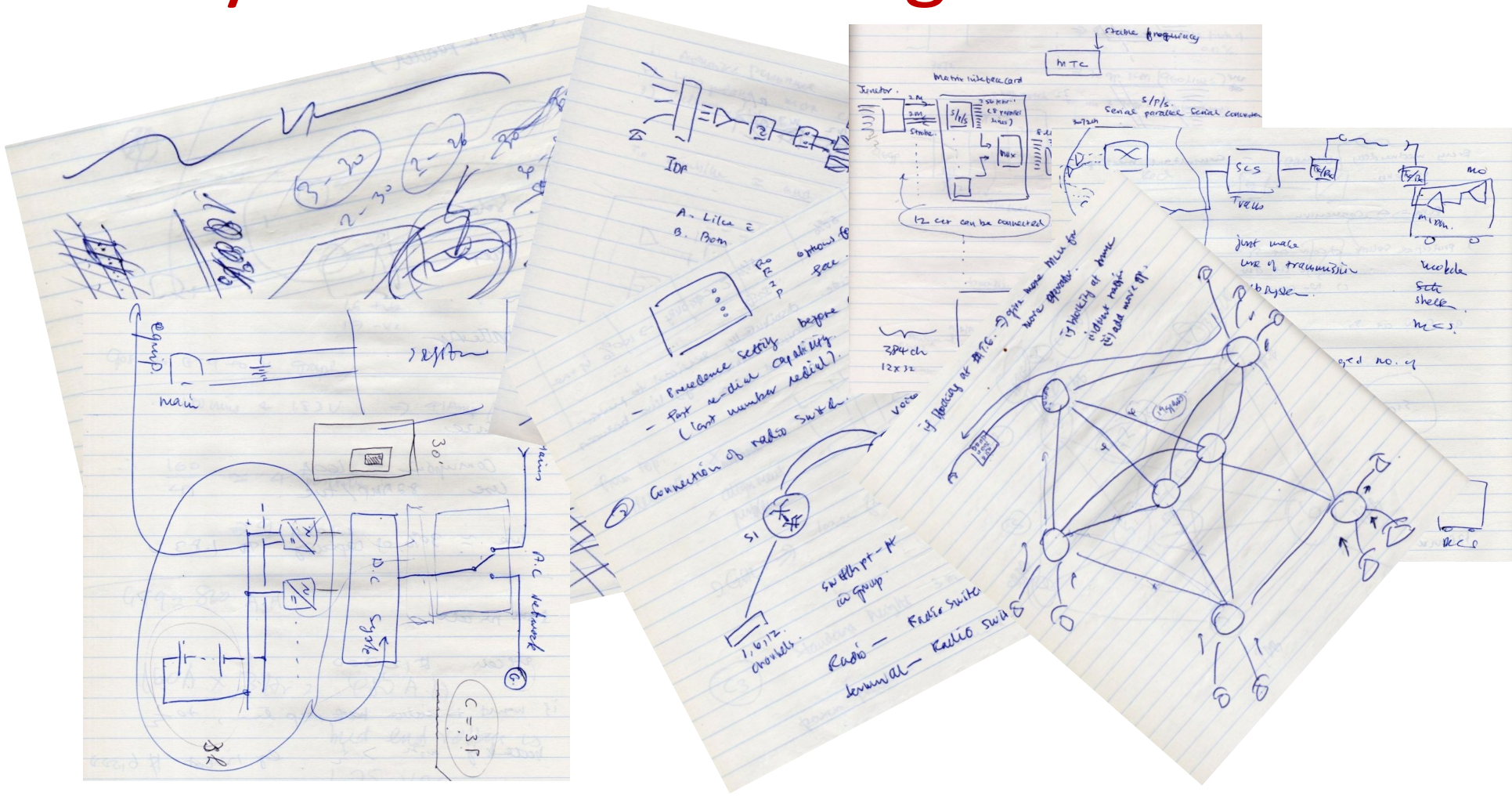
Systems Law

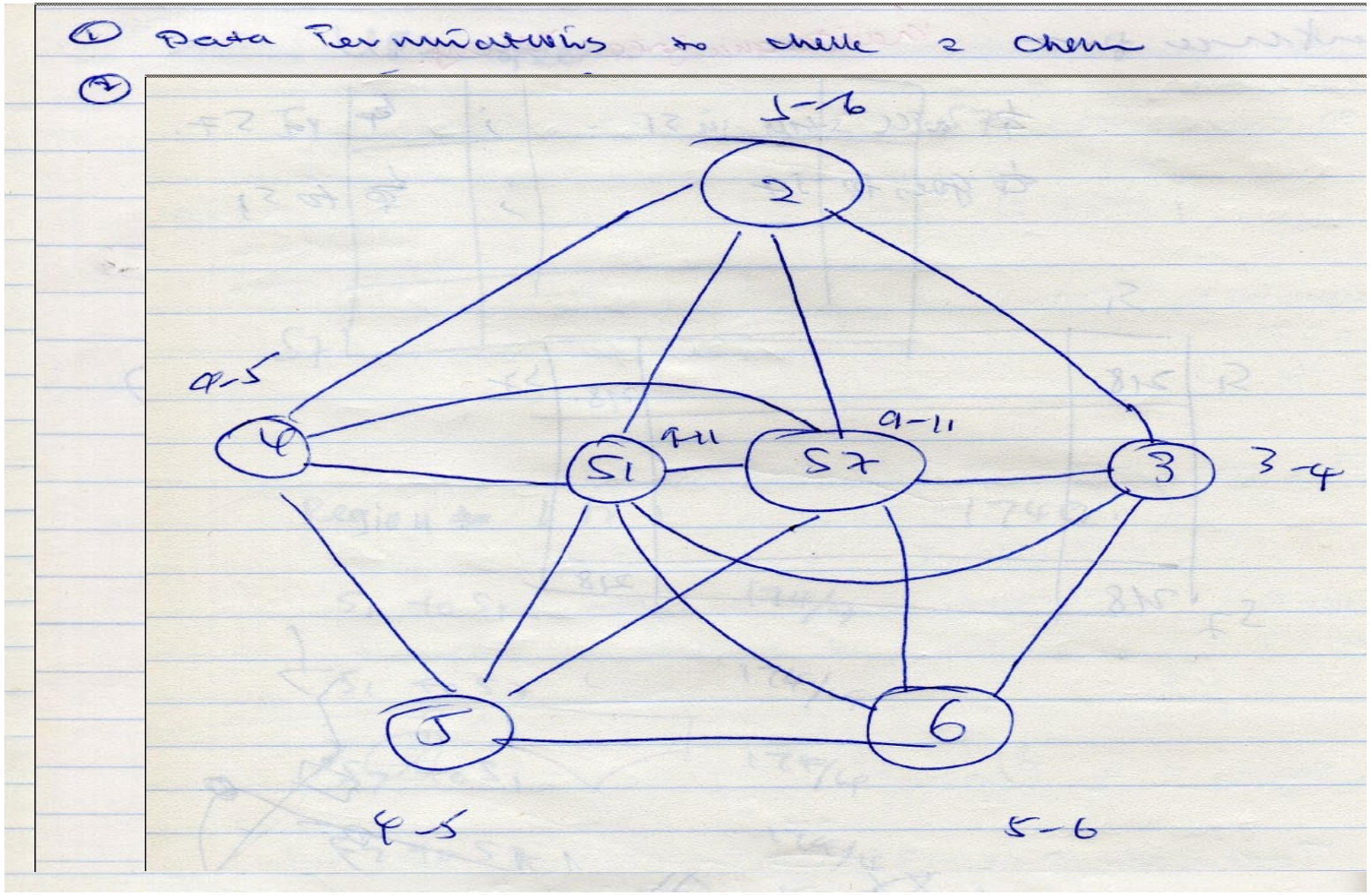
- **"An optimal solution for a sub-system is usually a sub-optimal solution for the whole system"**
  - Dividing a system into parts is necessary for analysis -- reductionist scientific approach. Interaction between parts will however be lost
  - Systems Engineers try to deal with this challenge by examining the interaction between the parts and to keep tightly coupled parts within the boundaries of a sub-system

Ref: Prof Lui

Systems Architecting in the 80s

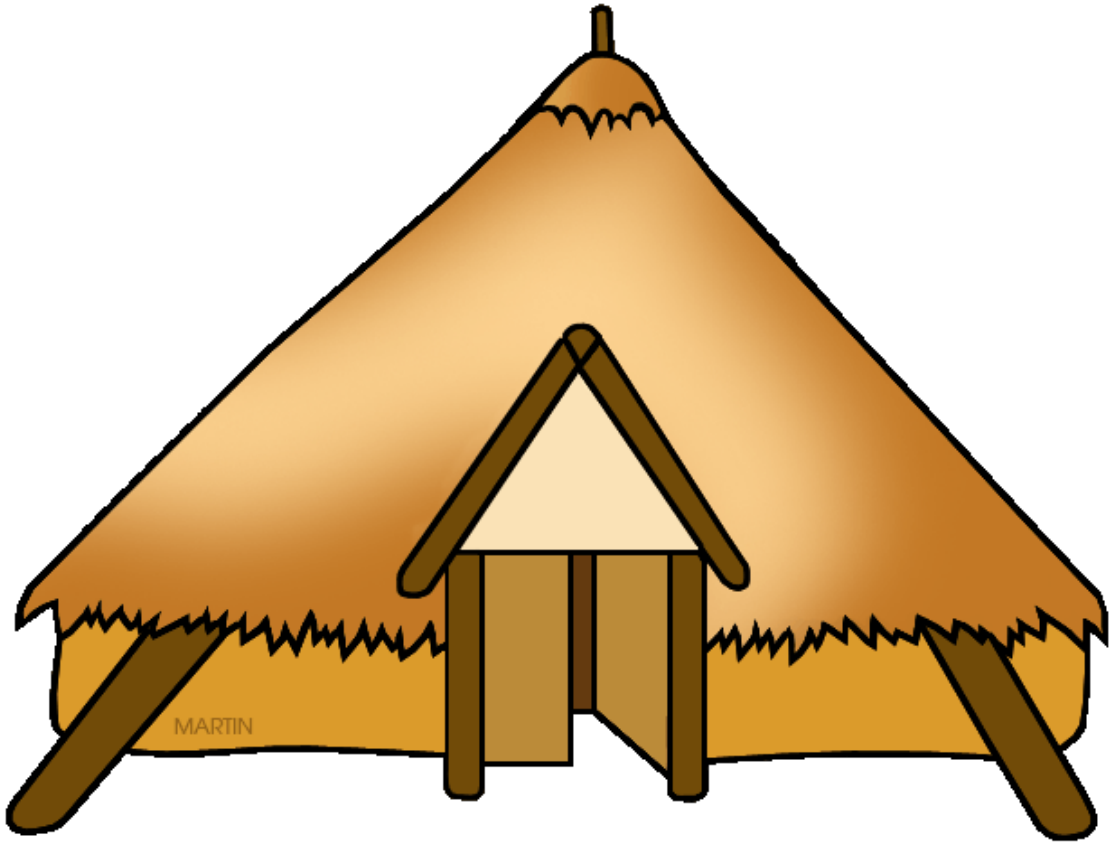


Systems Architecting in the ’80s…



Large-scale systems engineering initiatives

From Housing to Smart Living



Frame the issue

Ref: Prof Lui

Singapore's Version of Henry Ford's Mass Production

1 Room

2 Room

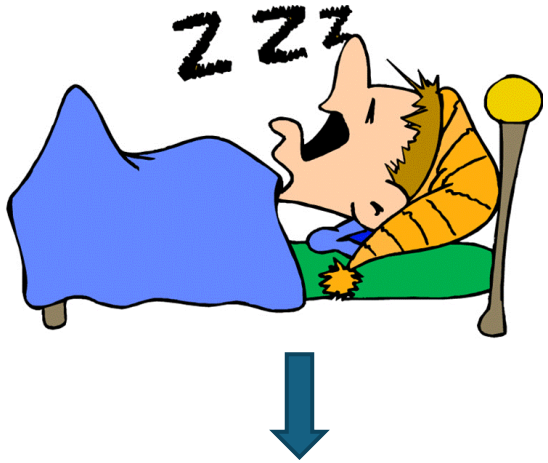
3 Room

Ref: Prof Lui

Beyond Public Housing

Self-contained satellite towns

- Not building houses alone but building communities
- Proximity to places of worship, schools, supermarkets, clinics, hawker centres, sports and recreational facilities, places of work, and transportation



Beyond Public Housing

Racial Harmony

Foster social cohesion in multi-racial Singapore.

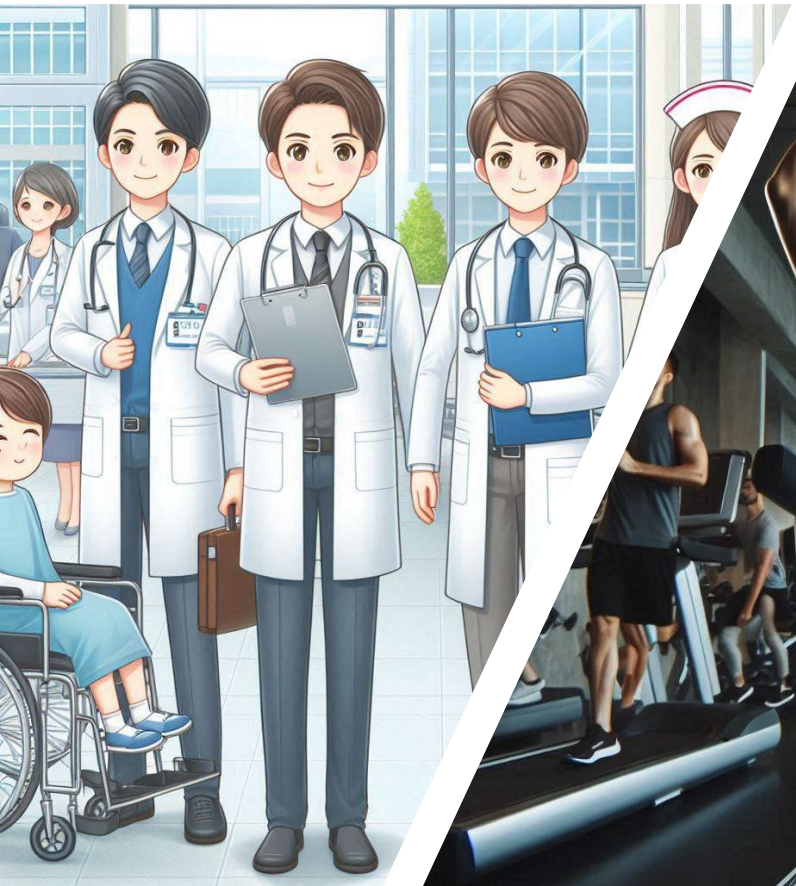
- A policy of ensuring a mix of races within each housing district to promote racial integration
- In the 60s, Singapore was a very racially segregated city. Different racial groups and even different dialect groups in each race lived in different parts of Singapore.

Beyond Public Housing

- Housing financing to make home ownership affordable
- Important for a largely immigrant community
- Gave a great sense of ownership and stability
- Mortgage payments could be drawn from the compulsory savings scheme, Central Provident Fund.
- High rate of home ownership, today, nine out of 10 Singaporeans own homes








Integrated Solutions for the community

Towards Liveability and Smart Living

- Exploitation of technologies to make the lives of people better

Urban Challenges – complex and interlinked

CO_2 impacts Climate Change,

Including rate of rise in sea level, and increase in average temperature

1.2 to 1.7 mm/year

Mean rate of rise in sea level from 1975 to 2009

26.9 to 28.0°C

Average temperature between 1980 to 2020

Video source: Pexels

Extreme Heat

Disease

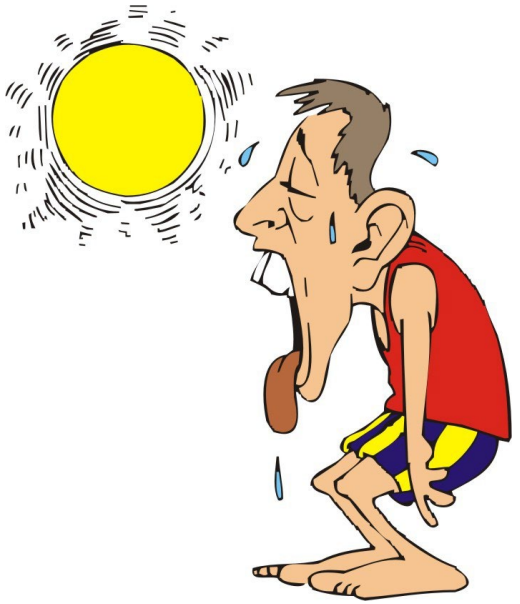
Impact of Climate Change
It is happening now!

Flooding

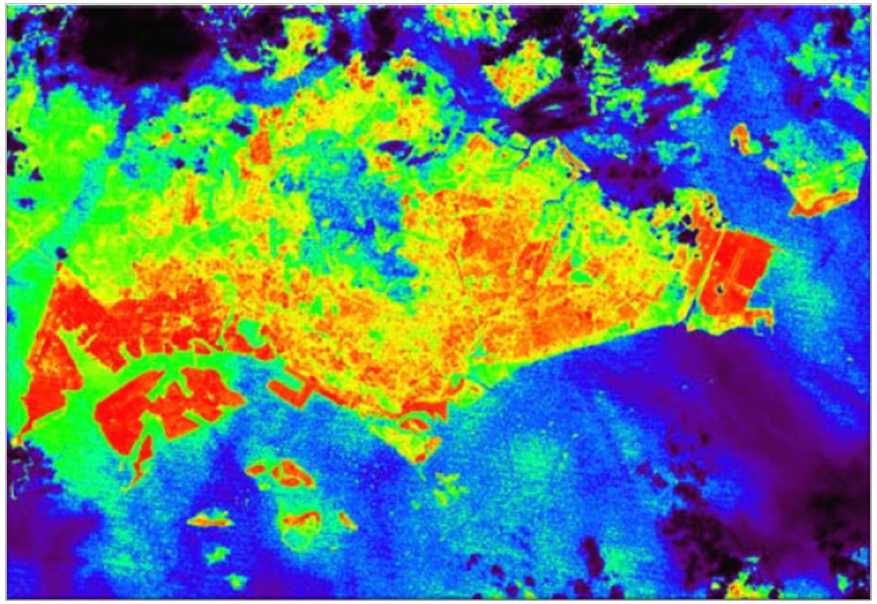
Drought

Video source: Pexels and Google

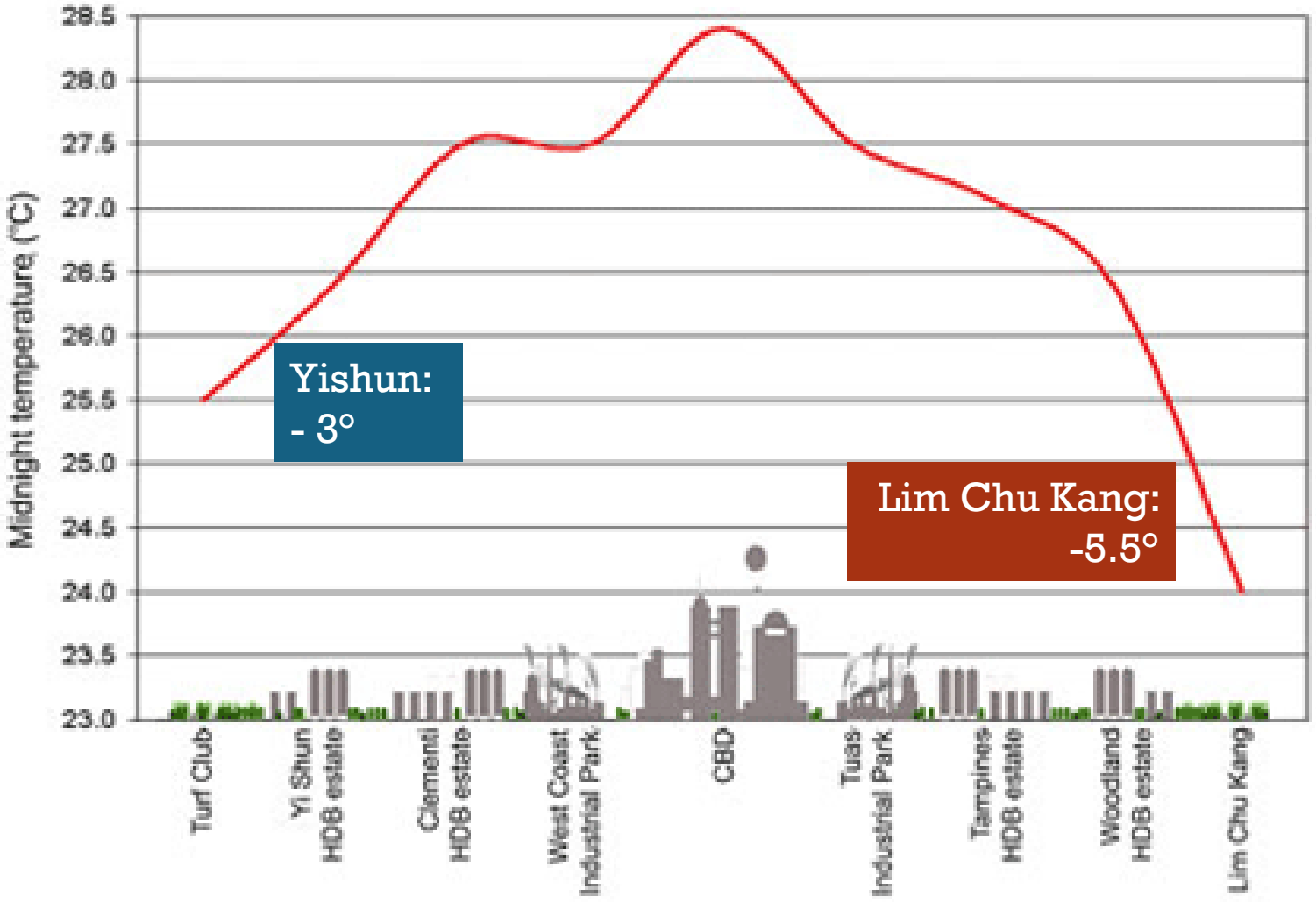
Urban Heat Island (UHI) Effect



Characterised by rise in temperature of any man-made area, resulting in a well-defined, distinct "warm island" among the "cool sea" represented by the lower temperature of the area's nearby natural landscape



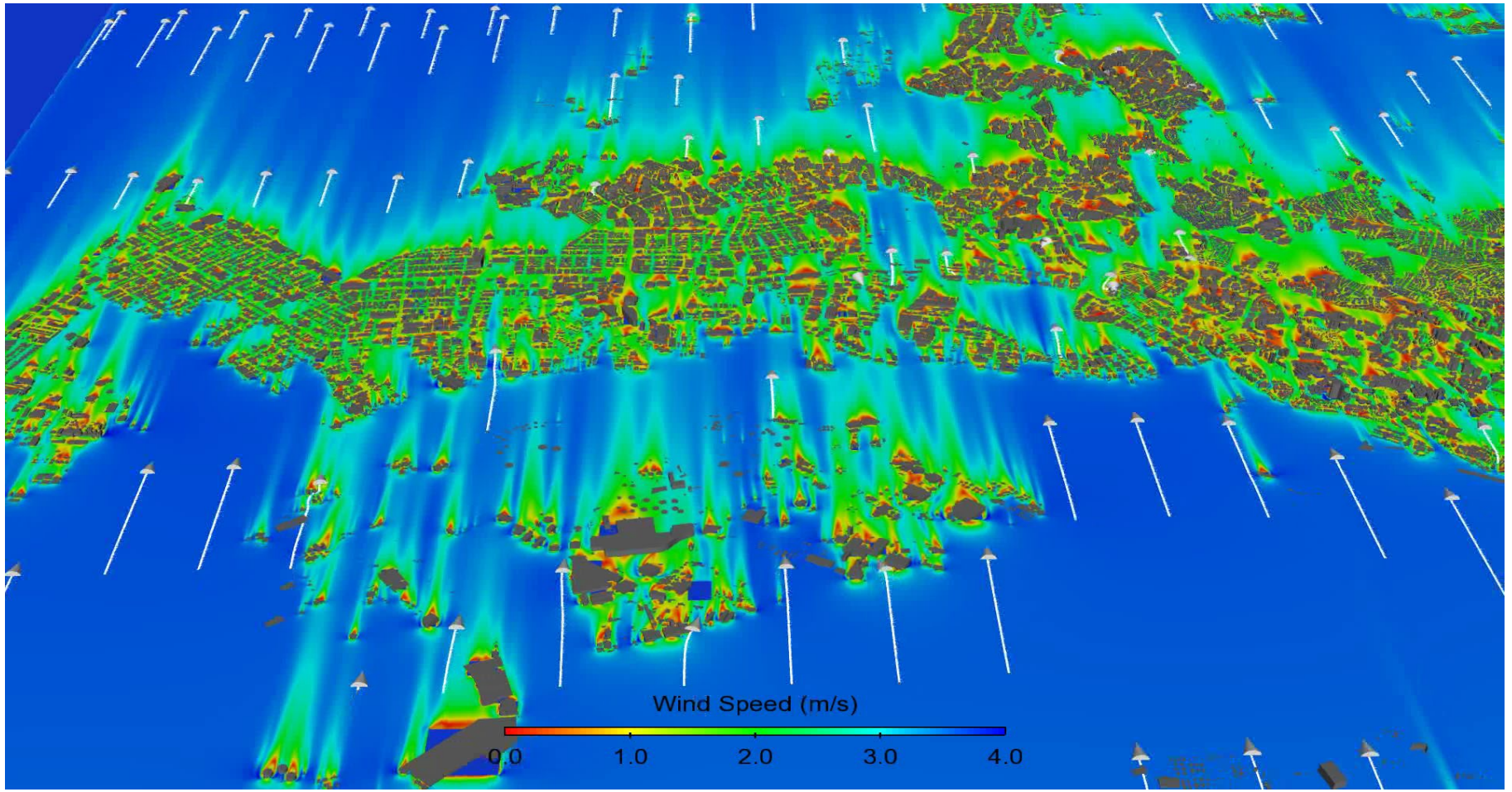
Urban Heat Island Effect - Singapore

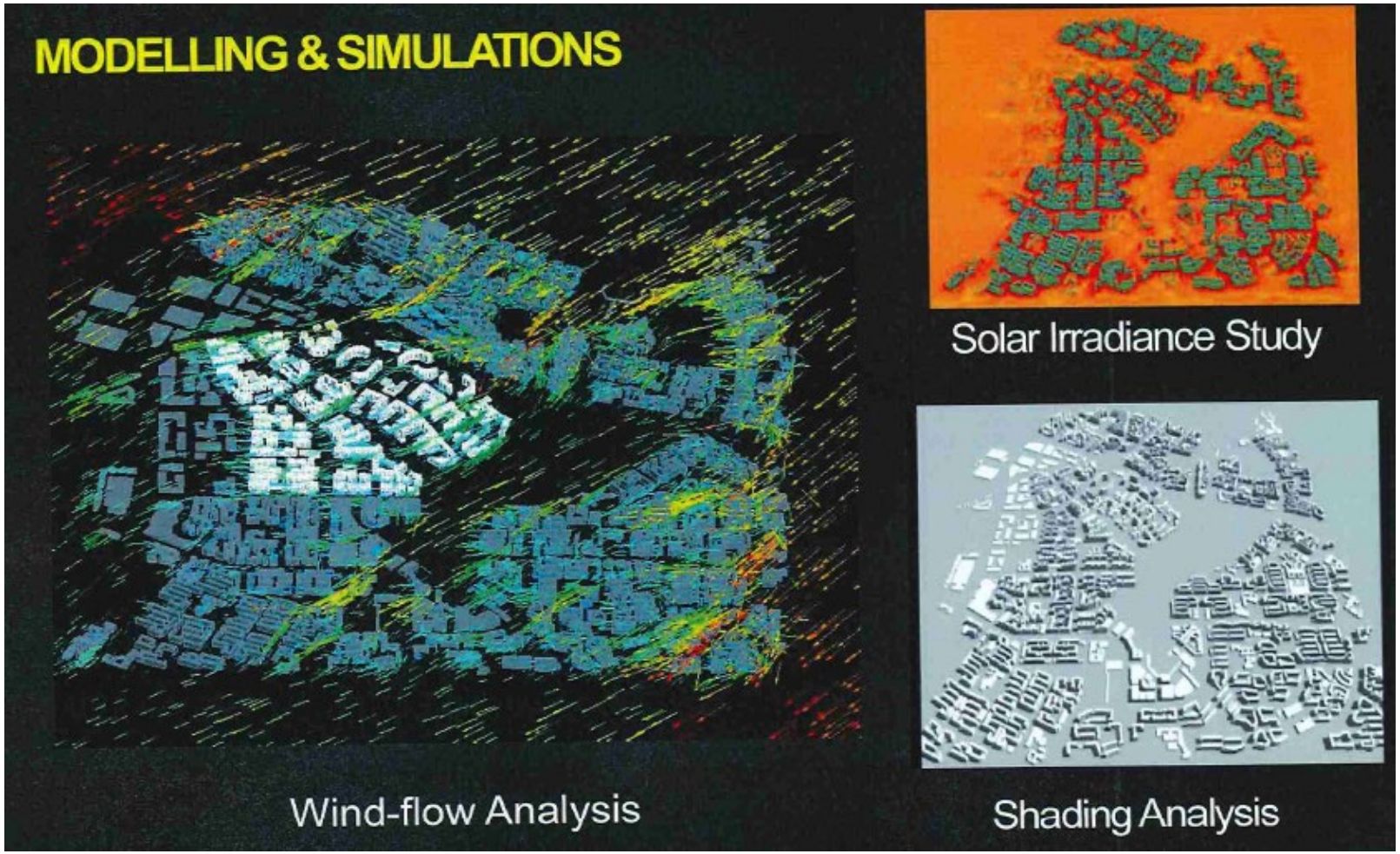


http://www.sde.nus.edu.sg/common/images/research_HighlightsB01b.gif

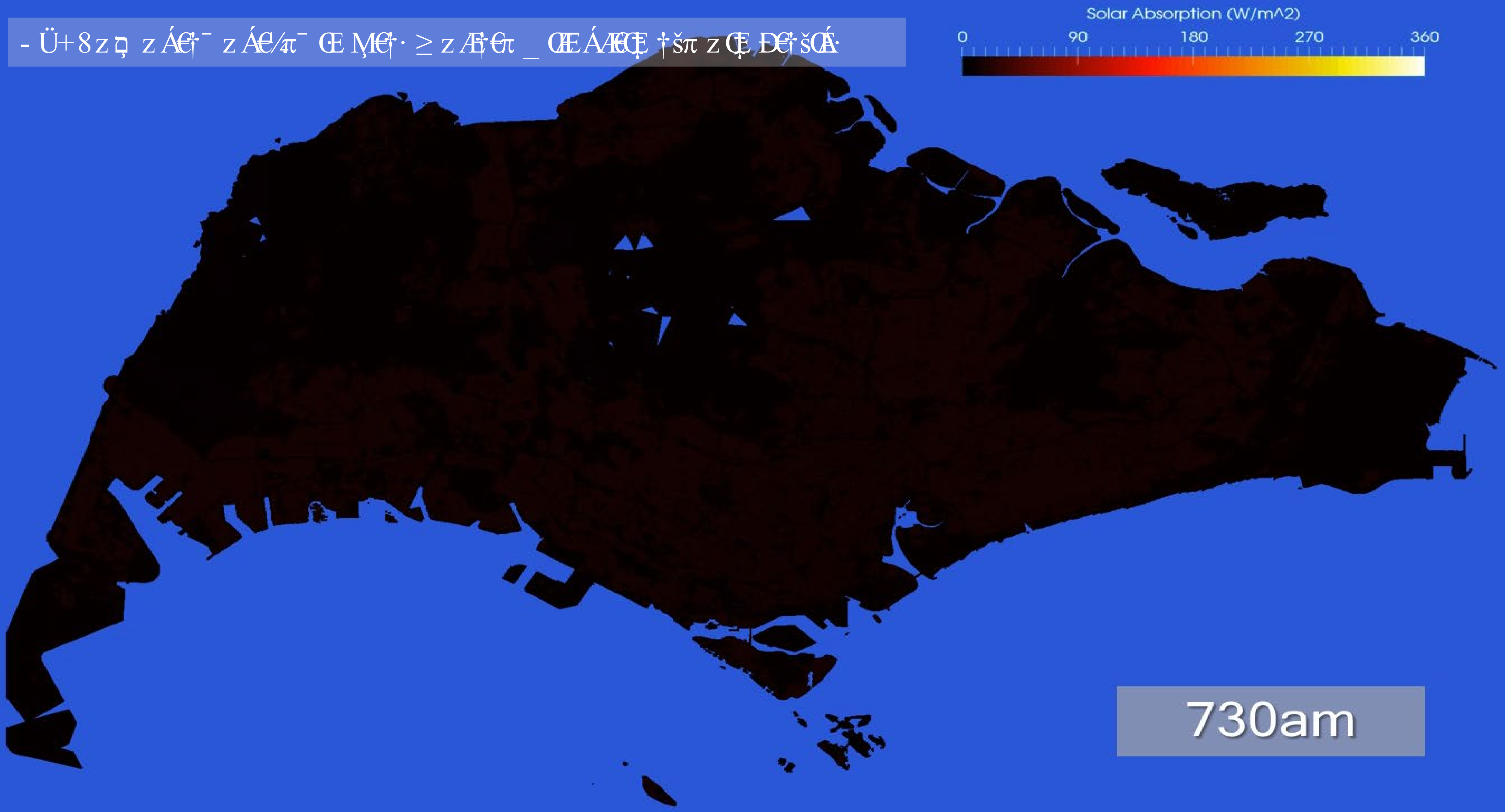
Leverage Modelling and Simulations

- Wind Flow Analysis

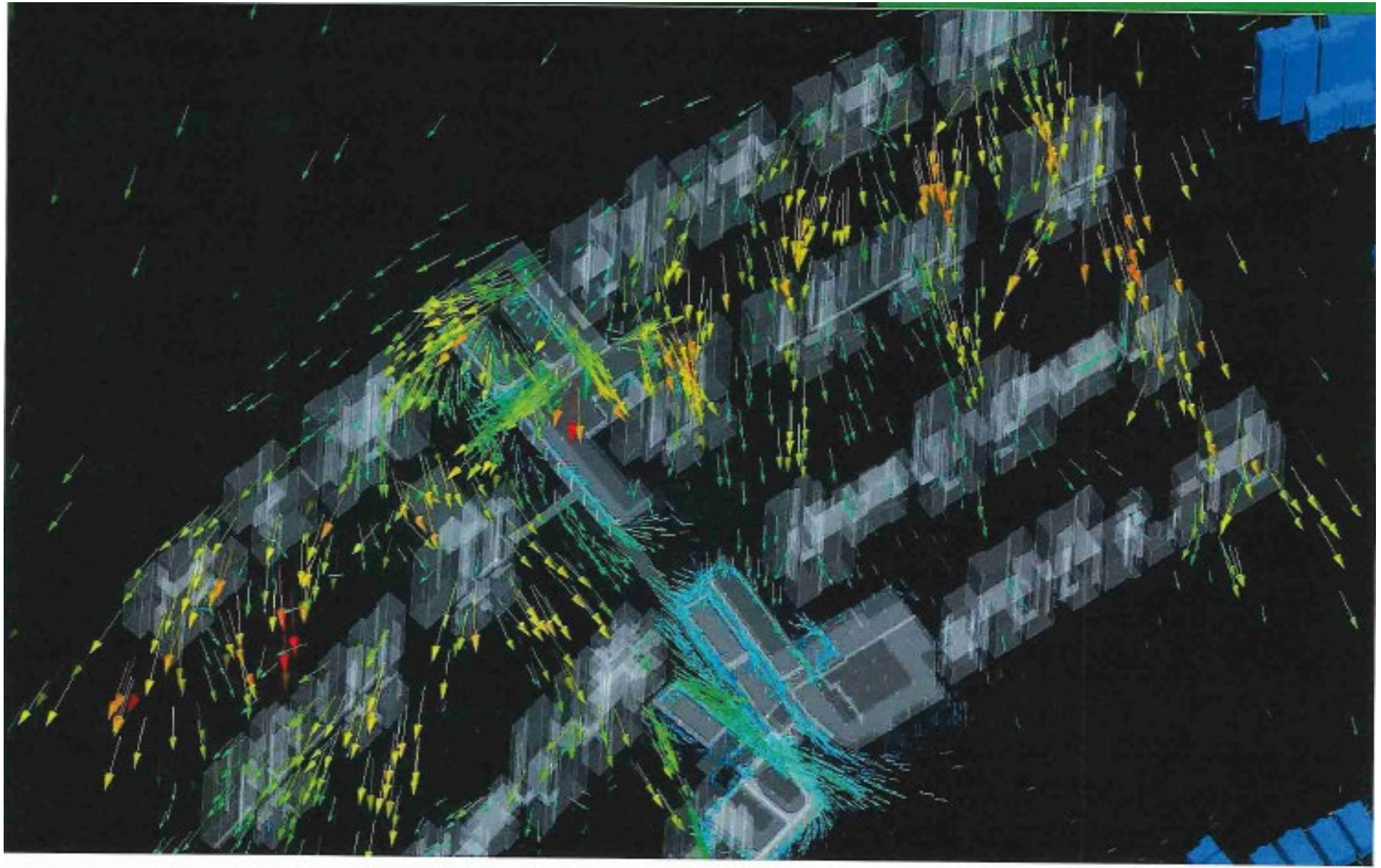



MODELLING & SIMULATIONS
Solar Irradiance Study
Wind-flow Analysis
Shading Analysis

Ref: HDB


Solar Absorption (W/m^2)
0
90
180
270
360
730am

Wind Driven Rain Analysis



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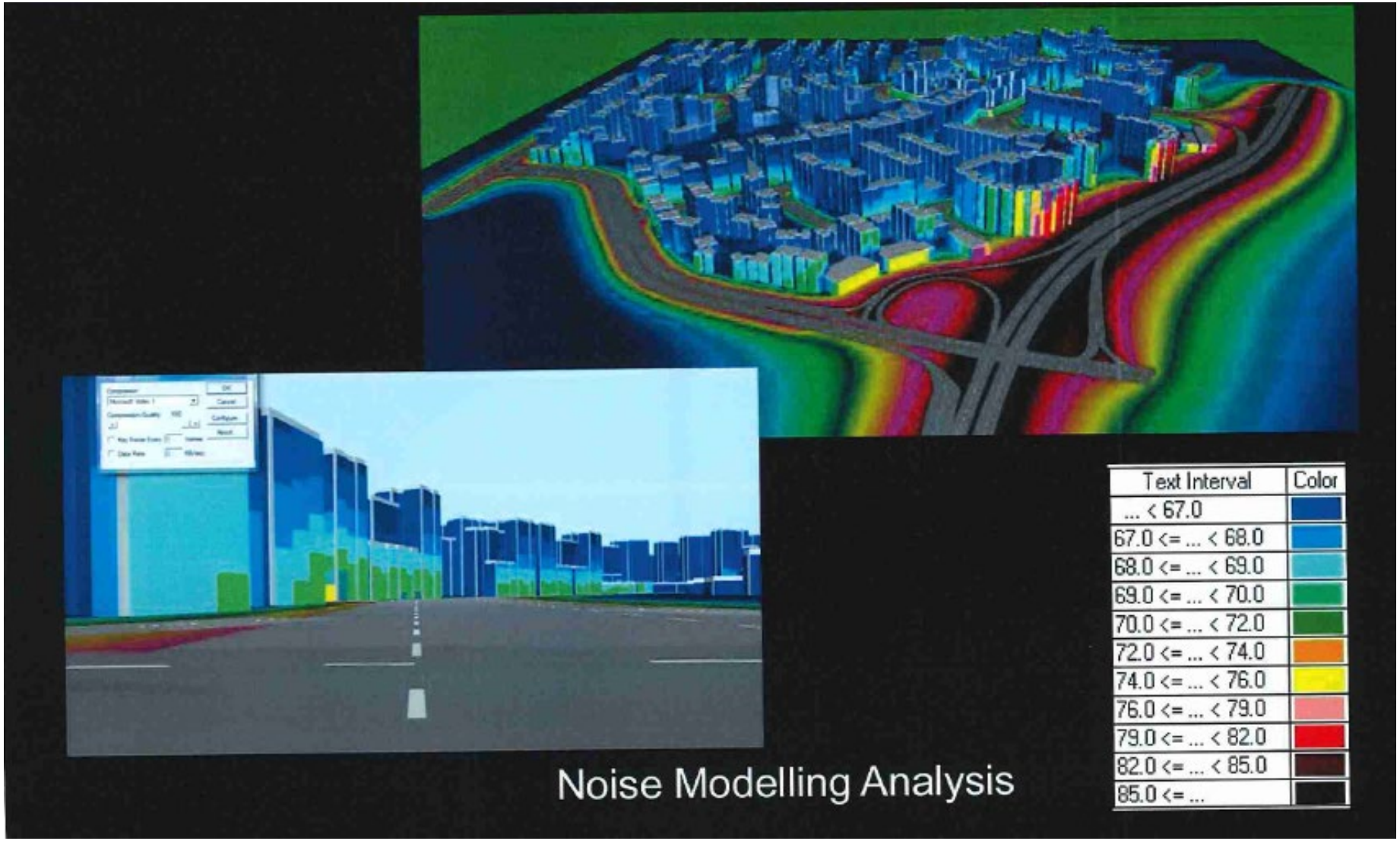
Noise Modeling Analysis



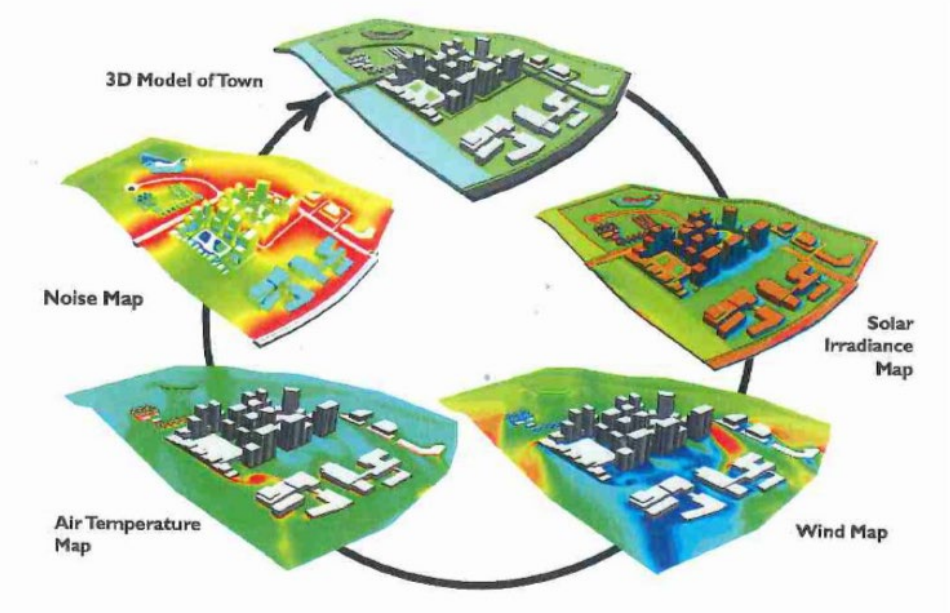
Ref: HDB

Flooding Analysis

Integrated M&S

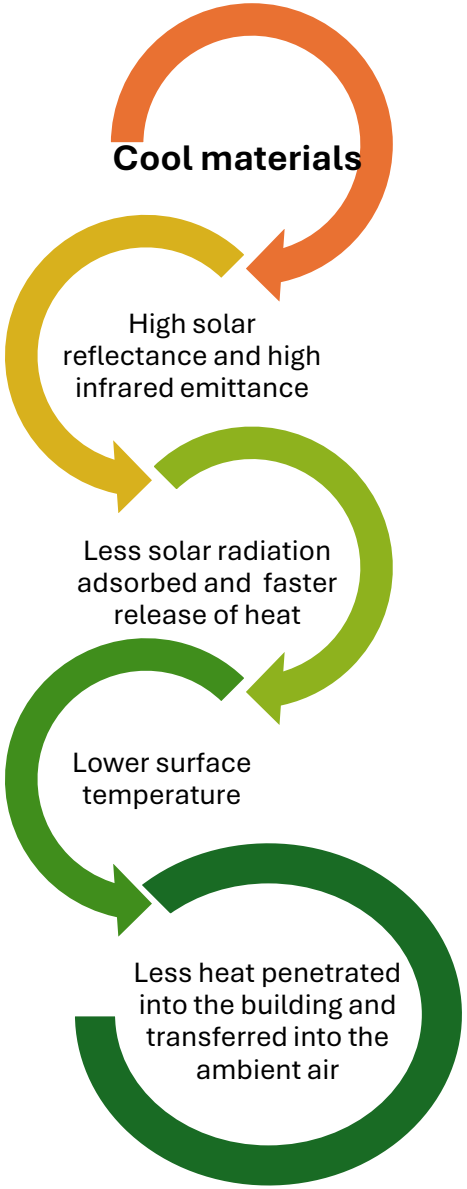
trade-offs and mutually reinforcing

- Wind flow
- Shading
- Rain
- Noise
- Flooding
- Irradiance Profile
- Irradiance Forecasting



Ref:HDB

E.g. ‘Cool’ materials



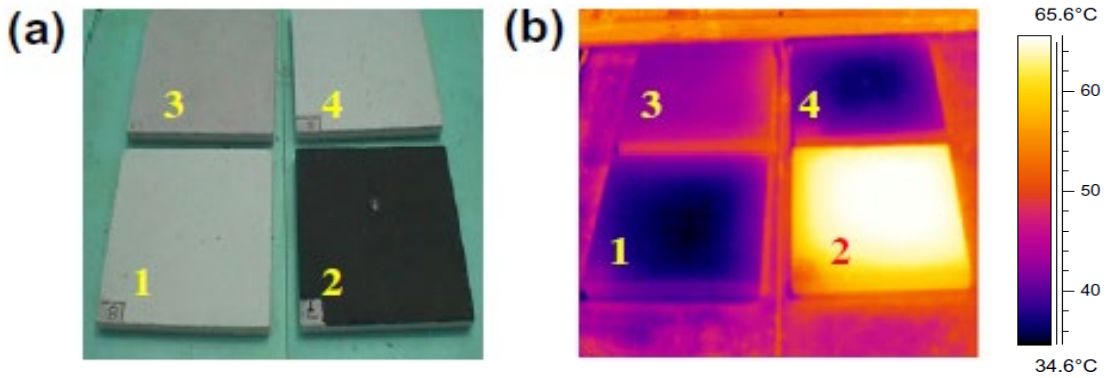
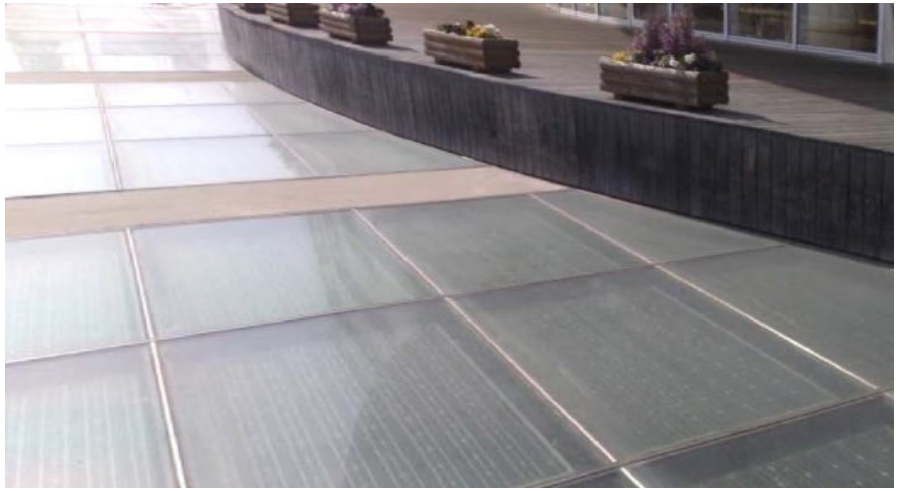
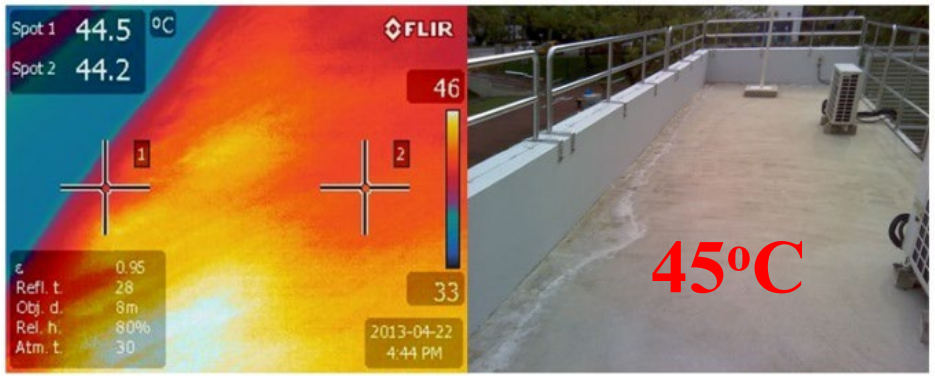


Fig. 2. Visible (a) and infrared (b) images of four concrete tiles painted with cool white coatings (1 and 4), a black coating (2) and an unpainted off-white (3) one. The difference in solar reflectance translates into a significant difference in surface temperatures. *Source*: Synnefa et al. (2006).

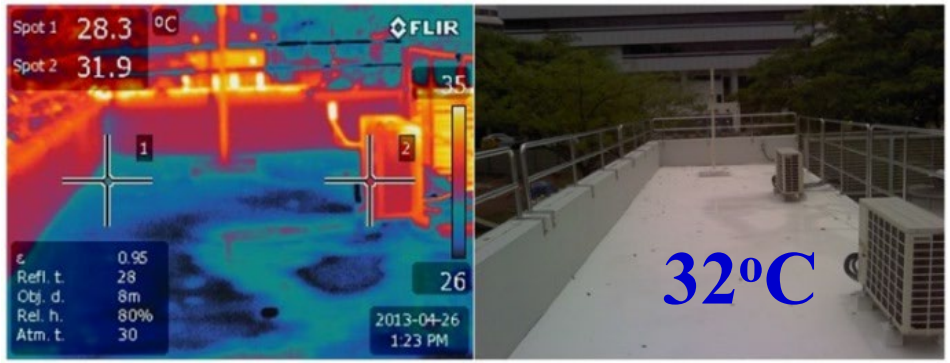


Source: Santamouris et al. 2011

Cool Roof



Uncoated roof



Cool roof

Ref:ERI@N

Leveraging the emerging capability of
System of Systems

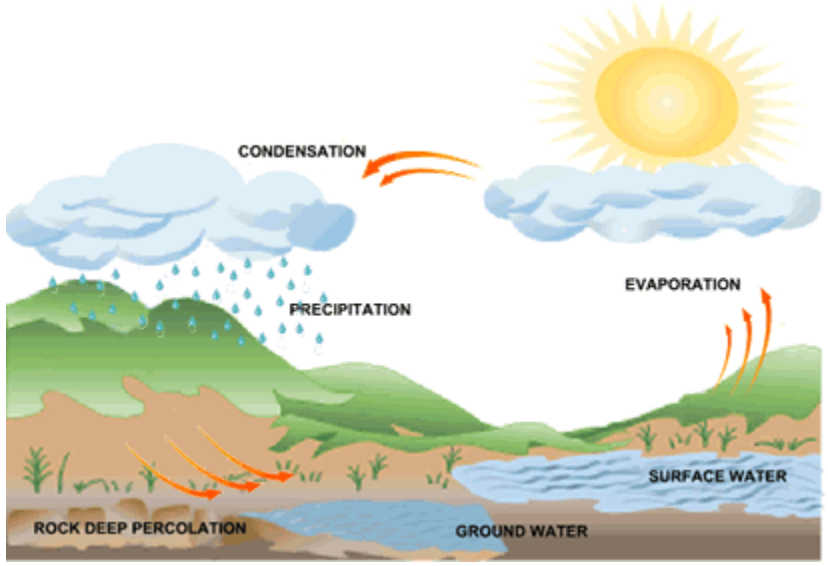
Beyond Urban Systems…

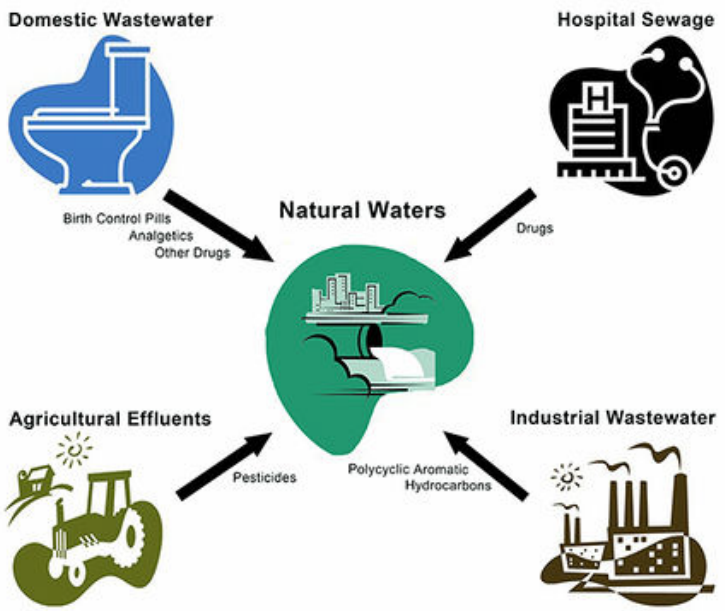
Water Management… challenges

(Frame the issue)

- An island state without ground water
- Collect as much rain water as possible
- Requires a wide spanning network of drains and canals to channel rain water into reservoirs
- Stringent environmental control to ensure water remains clean and unadulterated by pollutants on the way to our reservoirs.

Water management

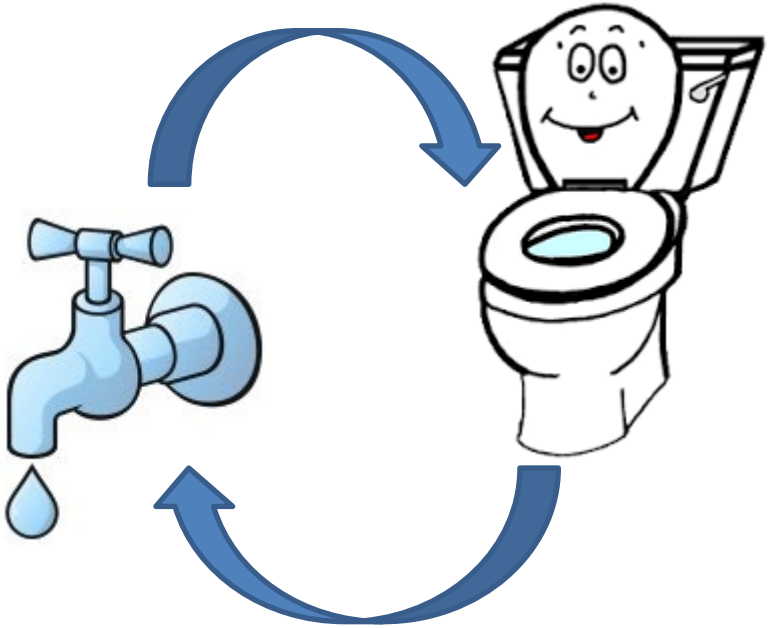




- Segregate our storm water system from our used water system
  - Used water is directed to sewage plants for treatment to high standards for re-use
  - Storm water, unpolluted by used water, is channelled to our reservoirs

Water Management

- Over the last 40 years, we have built a reliable, diversified and sustainable supply of water
- About 40%, despite a very high urbanization, is water catchment areas.
- Drainage, water catchment, purification and sewage treatment managed as part of a single system.



Closing the water loop

- Water supply management system
  - whole system of reservoirs, drains, water treatment plants, smaller pipes to every household, distributed to several rooms in each household.
- Waste water treatment system
  - a collection of pipes, drains, pumping stations, treatment plants
- Two systems are complete mirror image of each other
- Managed by ONE agency – PUB, MSE

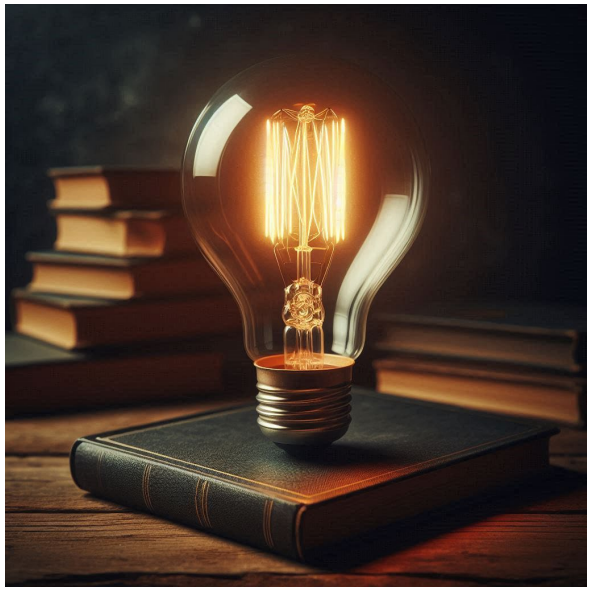
Active, Beautiful Clean (ABC) Water's Programme

- Creating a sense of ownership of Singapore's water resources.
- Network of drains, canals and reservoirs transformed into vibrant and beautiful streams, integrated with the urban landscape.
- From waterways to active, beautiful and clean community spaces.

Picture source: Ramboll Studio Dreiseitl

We solved our water problem

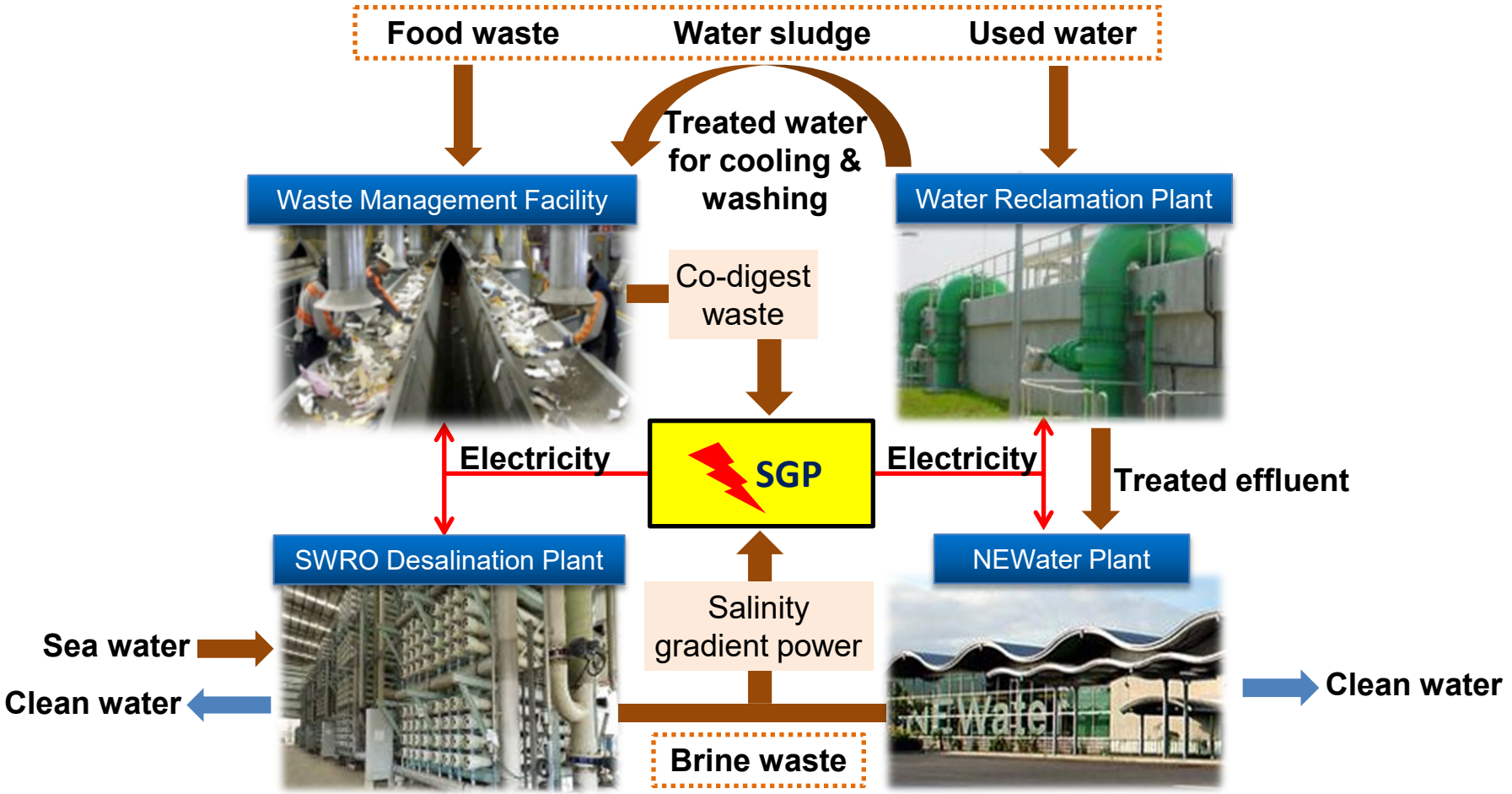
Created an energy problem



Reducing Energy Dependency of Water Sector

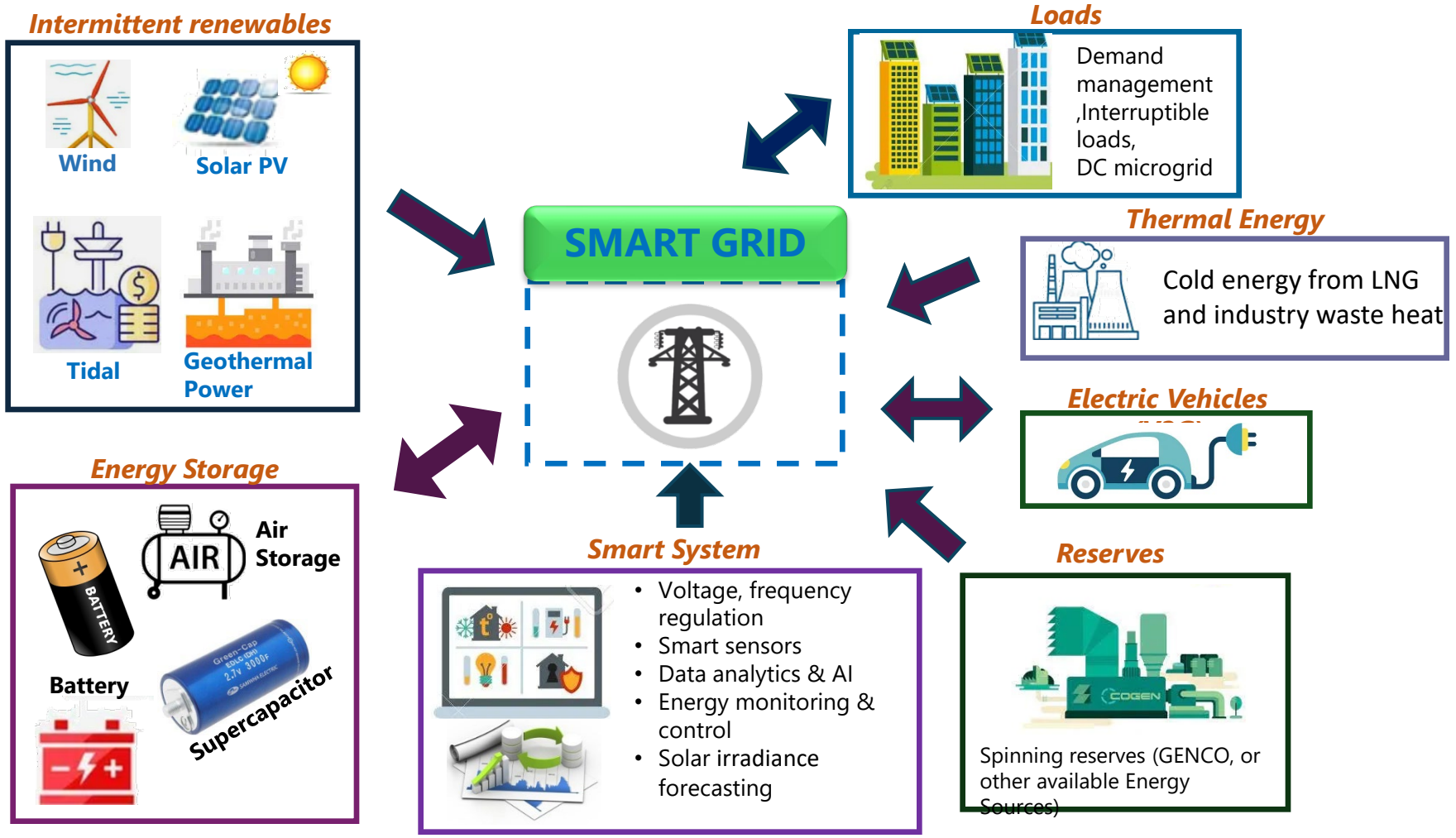
- Motivation: Energy-Water nexus – water and energy are key national priorities, and water security should not be at the expense of energy efficiency.
- RD&D opportunities:
  - Reducing energy usage for desalination at the system level, through technologies like reverse osmosis, pressure retarded osmosis, biomimetic aquaporin membranes and waste heat recovery
  - Technologies to achieve energy self-sufficiency for used water treatment (e.g. microbial biofilm, upflow anaerobic sludge blanket)
  - Facility integration to generate energy for used water treatment or seawater desalination (e.g. co-digesting sludge and food waste, salinity gradient of NEWater and desalination brine)
  - Real-time analysis of water quality (e.g. long term sensors and instrumentation development, sensor networks)

‘Nexus’ Approach



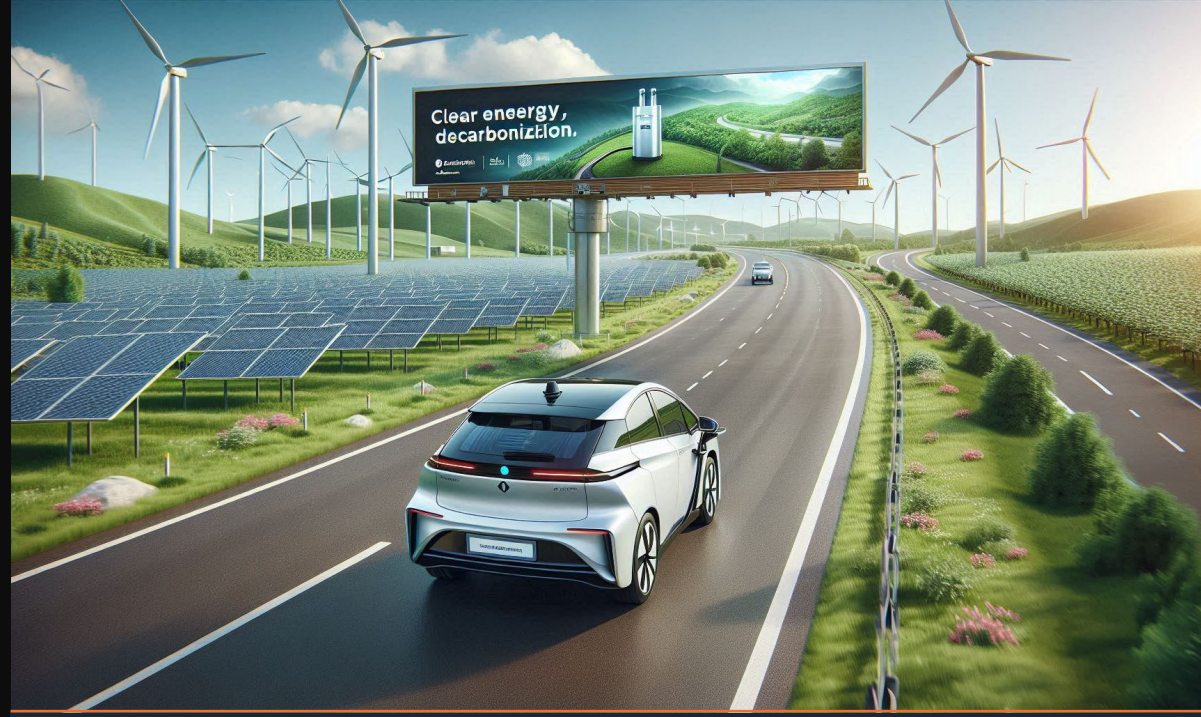
Optimise land use . Reduce energy demand . Increase resource

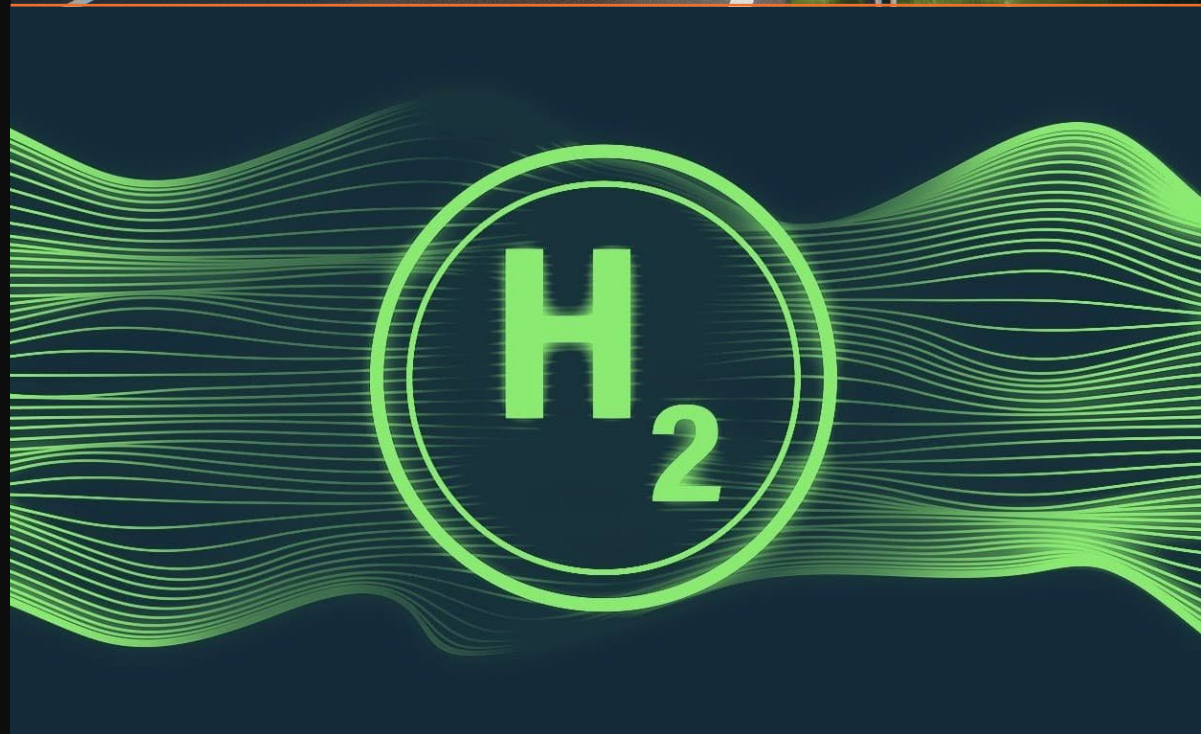
The Energy Grid as a System of Systems



Beyond the distributed grid…

Decarbonisation - Hydrogen as a clean energy vector





Beyond the distributed grid –

Carbon Capture, Utilisation and Storage (CCUS)

Closing the carbon loop

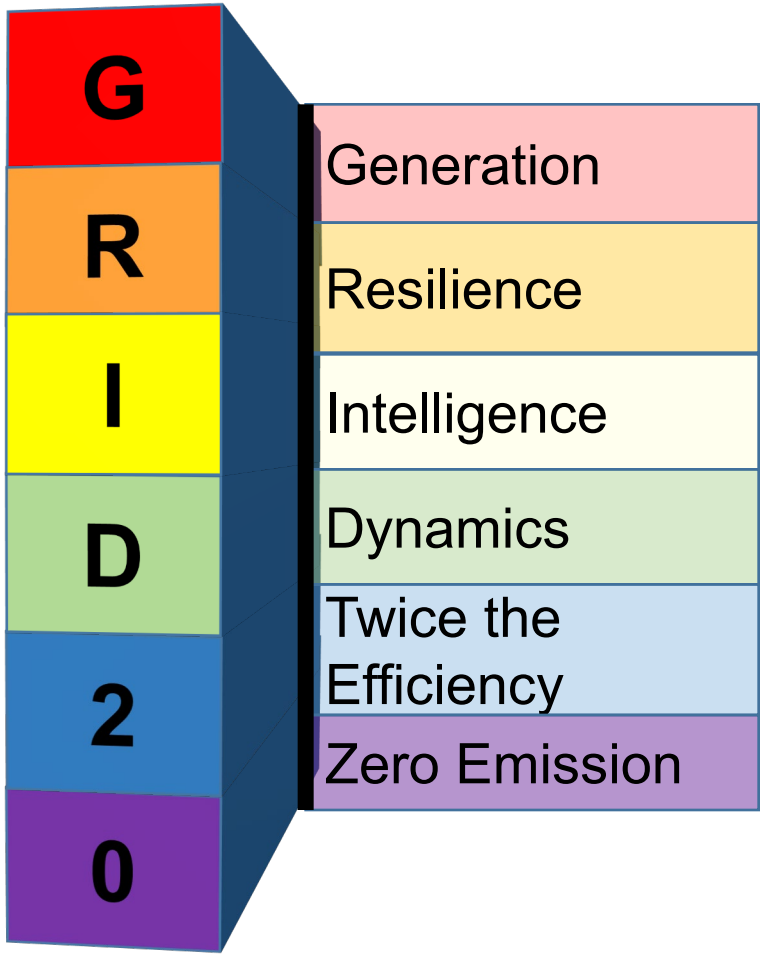
CO2

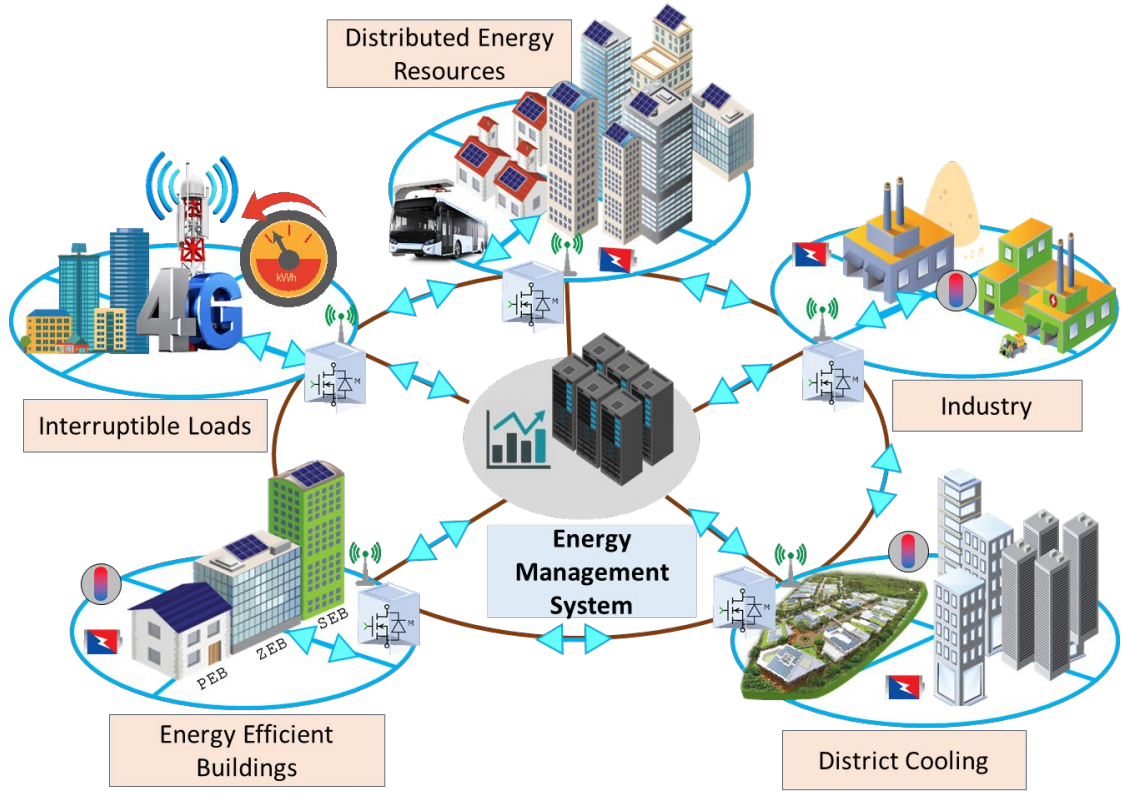
e-fuel

e-fuel to produce electricity

Grid of the future – distributed generation of green energy

Energy Grid 2.0





Vision of Integrated Urban Solutions…