MEBS6020 Sustainable Building Design

http://ibse.hk/MEBS6020/

Analysis Methods and Tools (II)

Ir Dr. Sam C. M. Hui
Department of Mechanical Engineering
The University of Hong Kong
E-mail: cmhui@hku.hk

Jun 2021

Contents

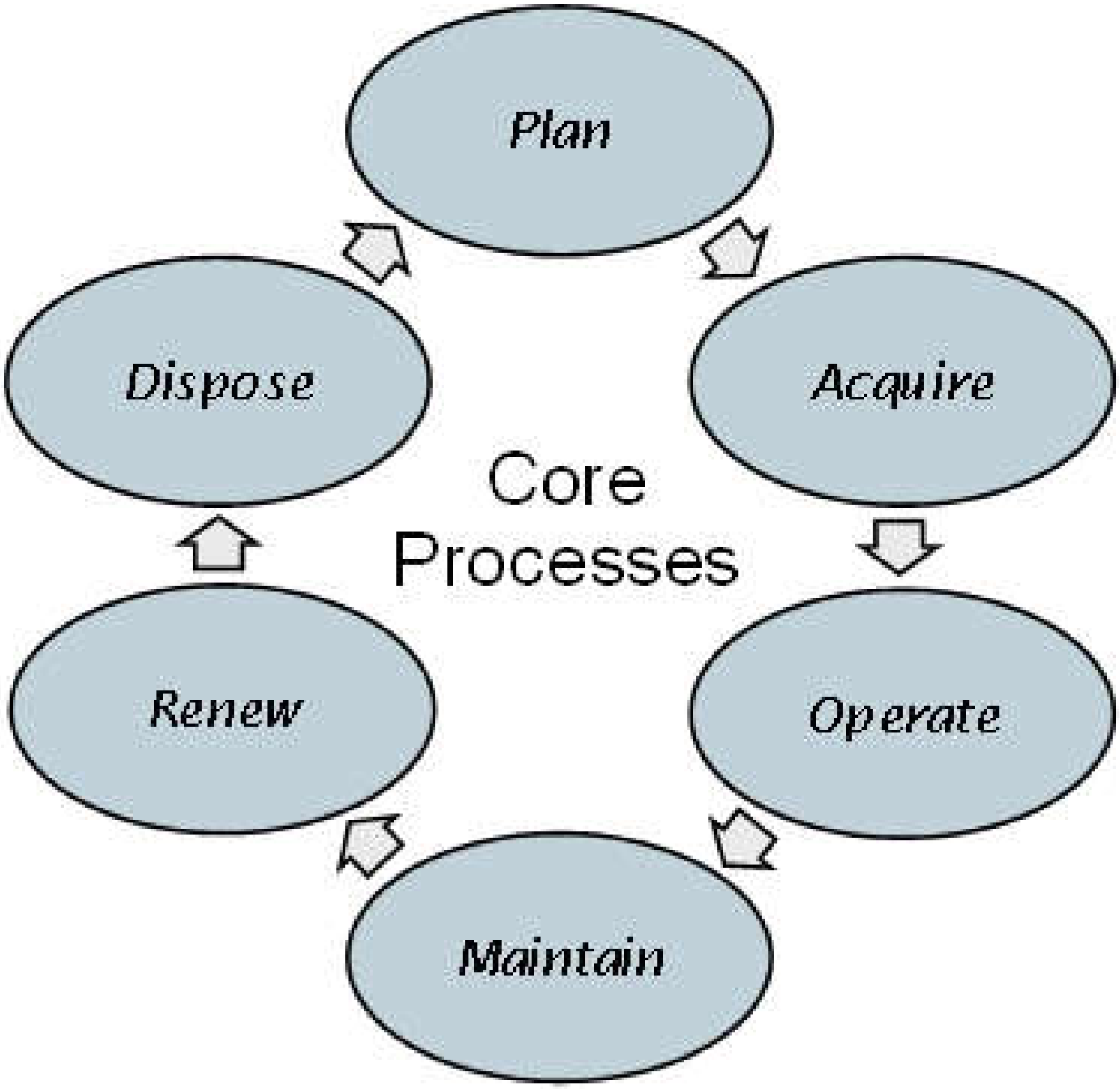
- Life cycle costing
- Carbon audit
- Zero carbon building
- Assess carbon footprints

Life cycle costing

- *Life cycle cost* is ‘cost of an asset, or its parts throughout its life cycle, while fulfilling the performance requirements’ (ISO 15686-5)
- *Life cycle costing* is ‘methodology for the systematic economic evaluation of life cycle costs over a period of analysis, as defined in the agreed scope’ (ISO 15686-5)
  - It can address a period of analysis which covers the entire life cycle, or selected stage(s) or periods of interest therein

生命周期成本法

Life cycle of an asset
(ISO 15686 Buildings and constructed assets - Service life planning)

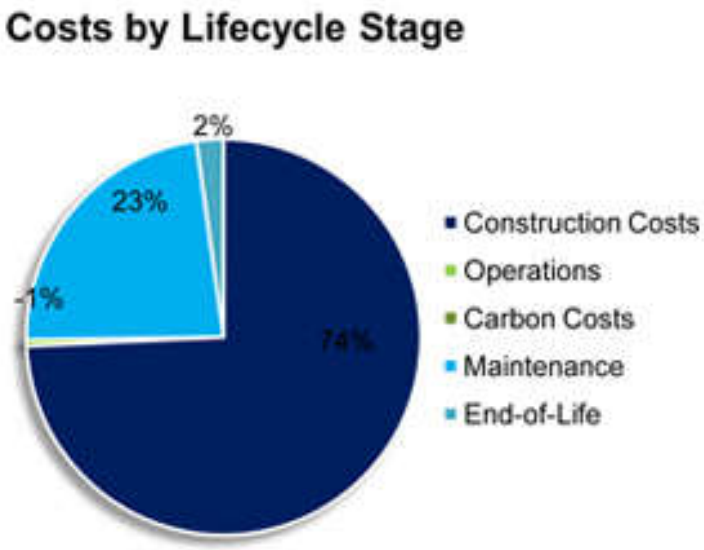


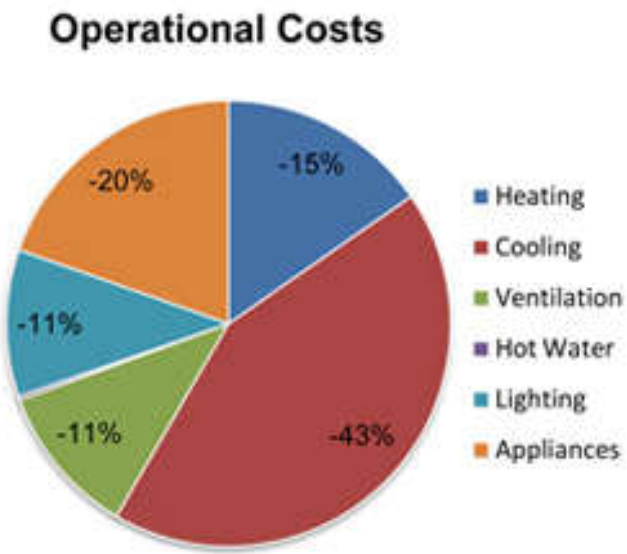
(Source: http://simple.werf.org/simple/media/LCCT/index.html)

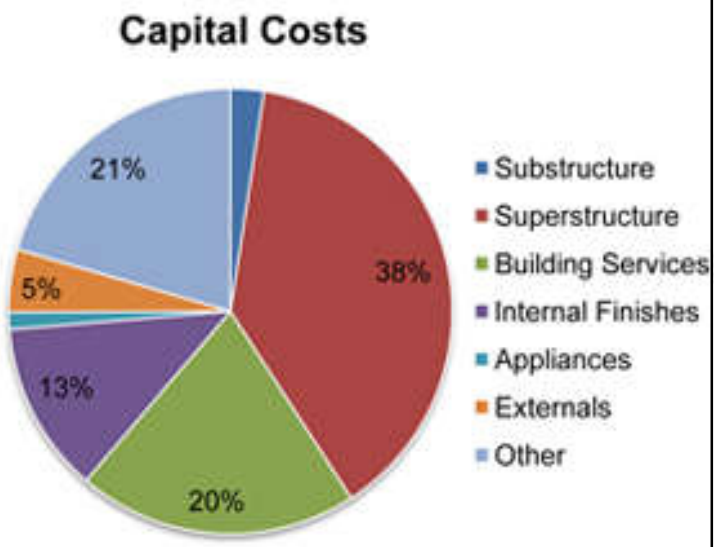
Life cycle costing

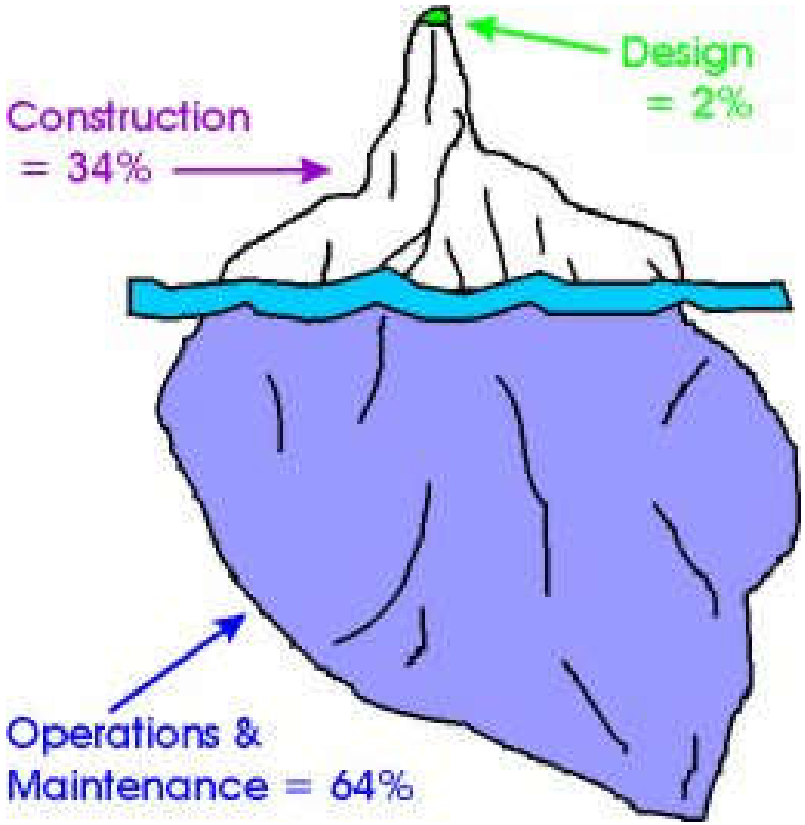
- Life-cycle costing (LCC) for buildings
  - Also known as whole life costing (WLC)
  - Analyses the design of building or building systems including initial costs, maintenance costs, repair costs, energy & water costs, and other significant costs over the assumed life of the facility or system (*total cost of ownership*)
  - Combines all costs into net annual amounts, discounts them to present value, and sums them to arrive at total LCC

Why consider life cycle cost?

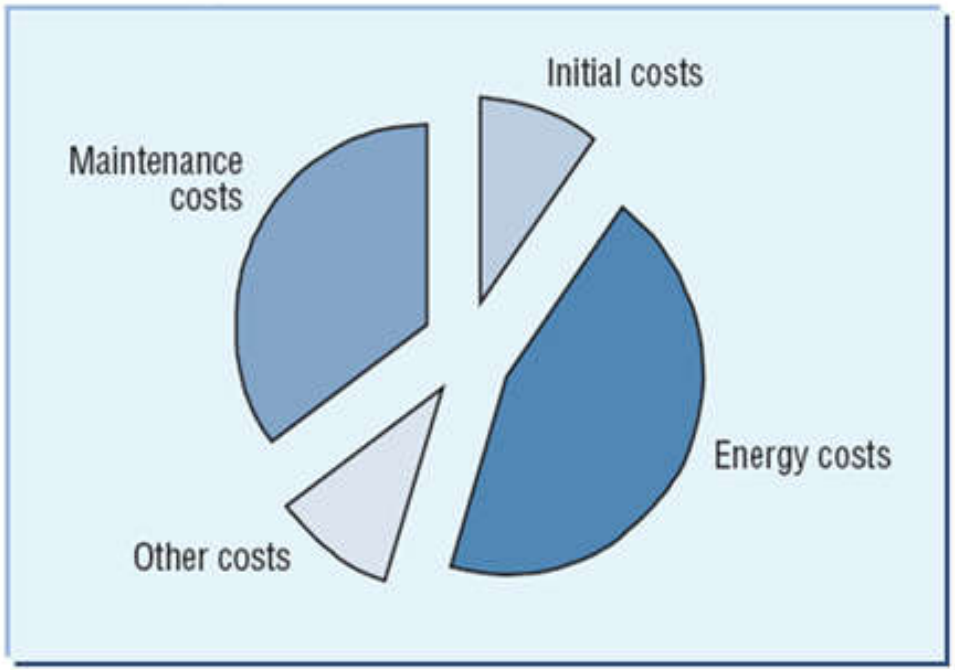








Life cycle cost of electric motor

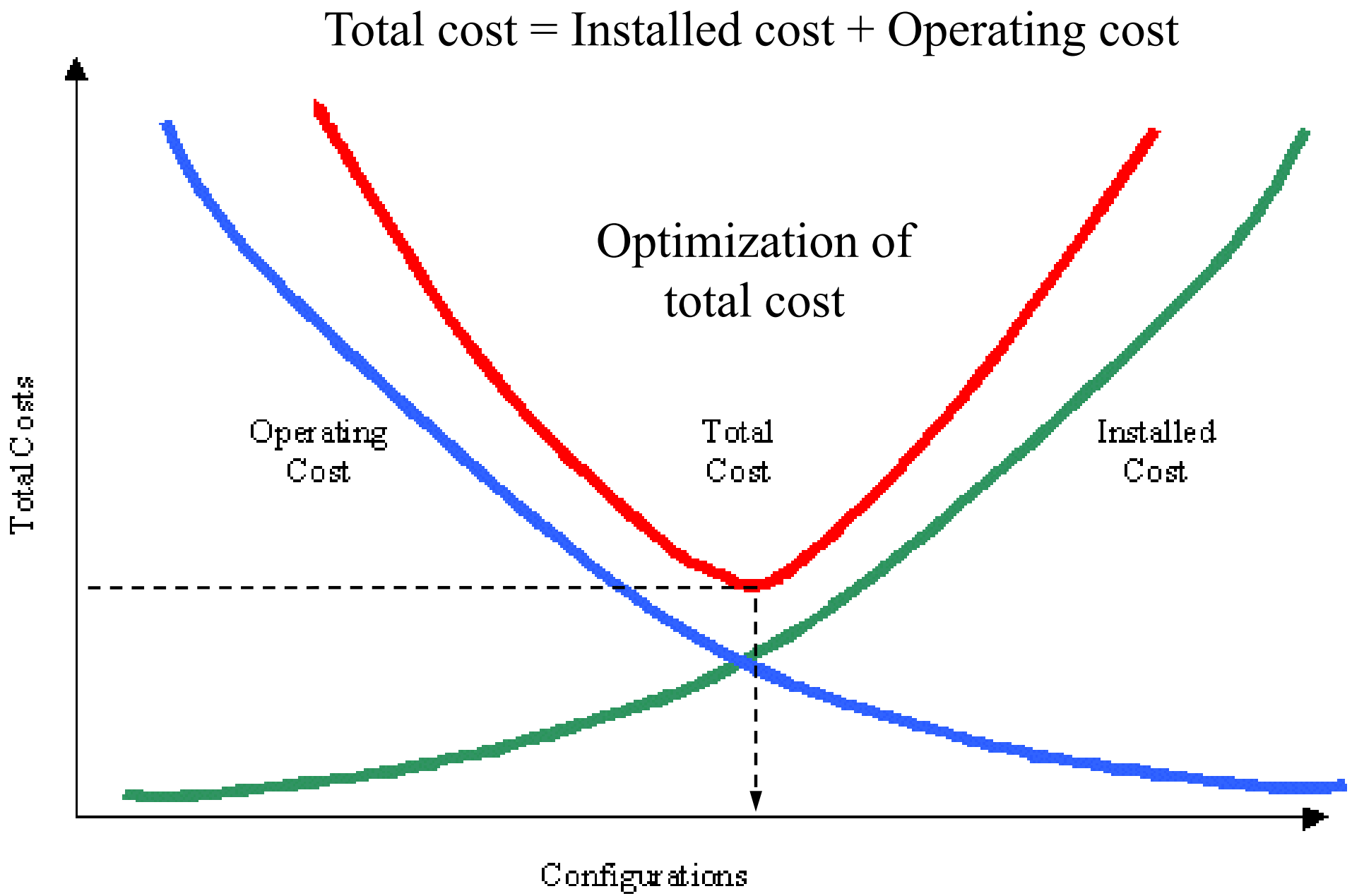


(Video: Life Cycle Costing (4:19) https://youtu.be/24By2bglwys)

Life cycle costing

- LCC is that it is not the same as life cycle assessment (LCA)
  - The two methodologies are complementary, but LCC focuses on the *dollar $$ costs* of building and maintaining a structure over its life cycle, while LCA focuses on *environmental performance*
  - Performance is measured in the units appropriate to each emission type or effect category

Concept of total cost or life cycle cost



Life cycle costing

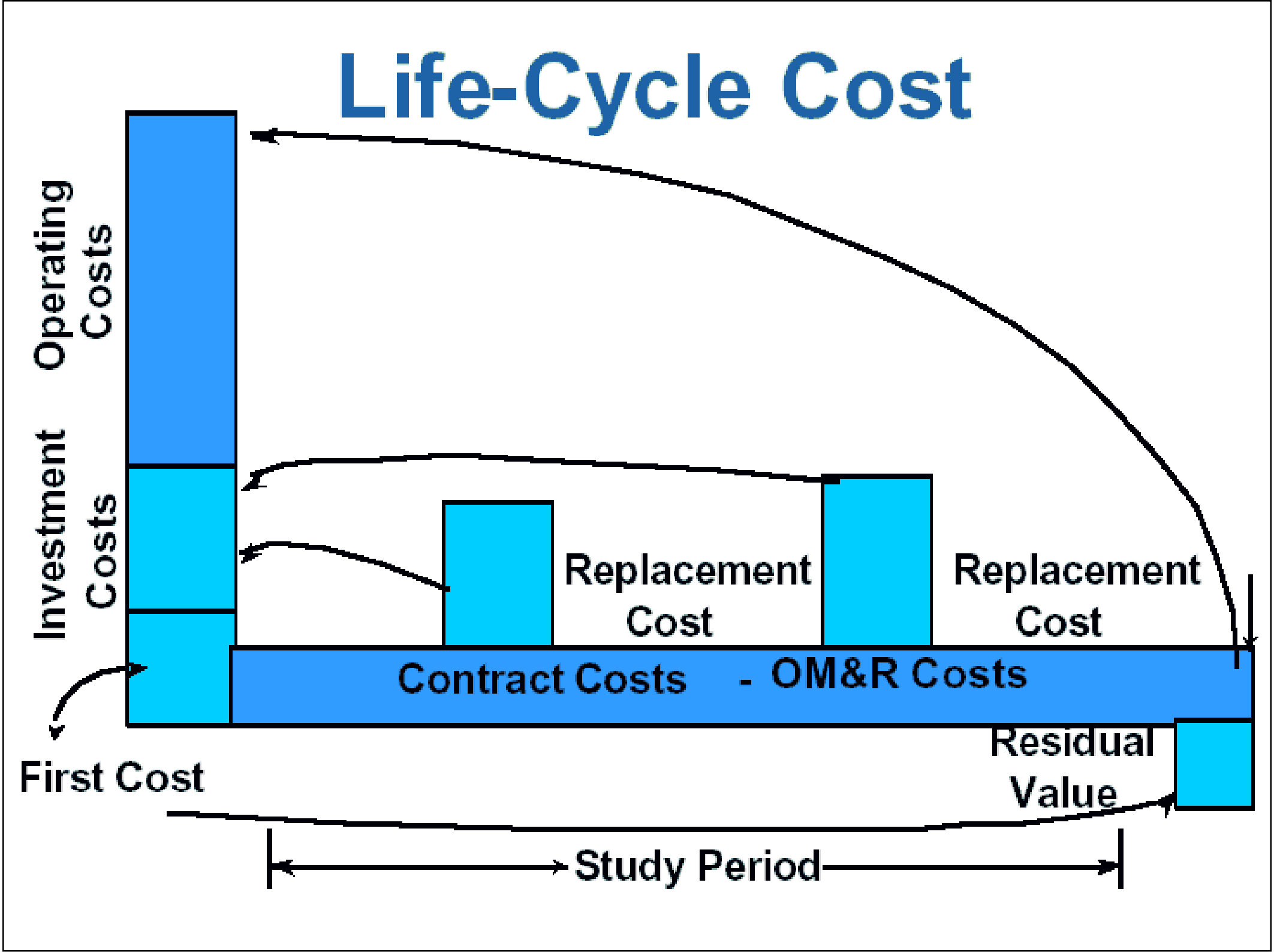
- Basic steps of LCC analysis
  - 1. Gather basic financial data
  - 2. Estimate annual energy costs
  - 3. Estimate first costs
  - 4. Estimate ongoing costs
  - 5. Calculate life-cycle costs
  - 6. Compare life-cycle costs

Life cycle costing

- General life cycle cost (LCC) equations

$$LCC = \sum_{t=0}^{N} \frac{C_t}{(1+d)^t} \qquad PWF = \frac{\left[\, 1 - \frac{1}{(1+d)^N} \,\right]}{d}$$

  - C_t = sum of all relevant costs occurring in year t
  - N = number of years in the study period
  - d = discount rate used to adjust cash flow to present value
  - PWF = present worth factor


Life-Cycle Cost
Operating Costs
Investment Costs
Replacement Cost
Replacement Cost
Contract Costs - OM&R Costs
First Cost
Residual Value
Study Period

Life cycle costing

- LCC calculation
  - LCC = I + Repl - Res + E + W + OM&R + O
    - LCC = Total LCC in present-value (PV) dollars
    - I = PV investment costs
    - Repl = PV capital replacement costs
    - Res = PV residual value less disposal costs
    - E = PV of energy costs
    - W = PV of water costs
    - OM&R = PV of non-fuel operating, maintenance and repair costs
    - O = PV of other costs (e.g. contract costs)

An example of life cycle cost calculation

	Building A	Building B
Construction Year	1950	2010
Useful Life (years)	20	20
Purchase Price (P)	$35,000,000.00	$45,000,000.00
Interest (I)	$49,409,990.87	$63,527,131.12
Replacement Cost (re)	$20,500,000.00	$20,500,000.00
Resale/Salvage Value (Rs)	$20,000,000.00	$40,000,000.00
Disposal Cost (D)	$5,000,000.00	$0.00
Energy Costs (E)	$2,450,000.00	$400,000.00
Water Costs (W)	$60,000.00	$32,000.00
Maintenance (M)	$2,200,000.00	$750,000.00
Other (O)	$100,000.00	$100,000.00
Life Cycle Cost	**$59,720,010.87**	**$45,309,151.12**

Cost Considerations for Design

Direct and indirect: initial, life cycle, and environmental

Initial:
Construction: supply and installation
Design

Life cycle:
Daily, weekly and annual maintenance including cleaning, repair, redecoration
Replacement, including removal, waste disposal, replacement
Running cost for energy consuming components

Environmental:
Resource depletion and environmental pollution
Extraction, manufacture, transport, use and disposal: to air, ground and water
Indoor environmental quality

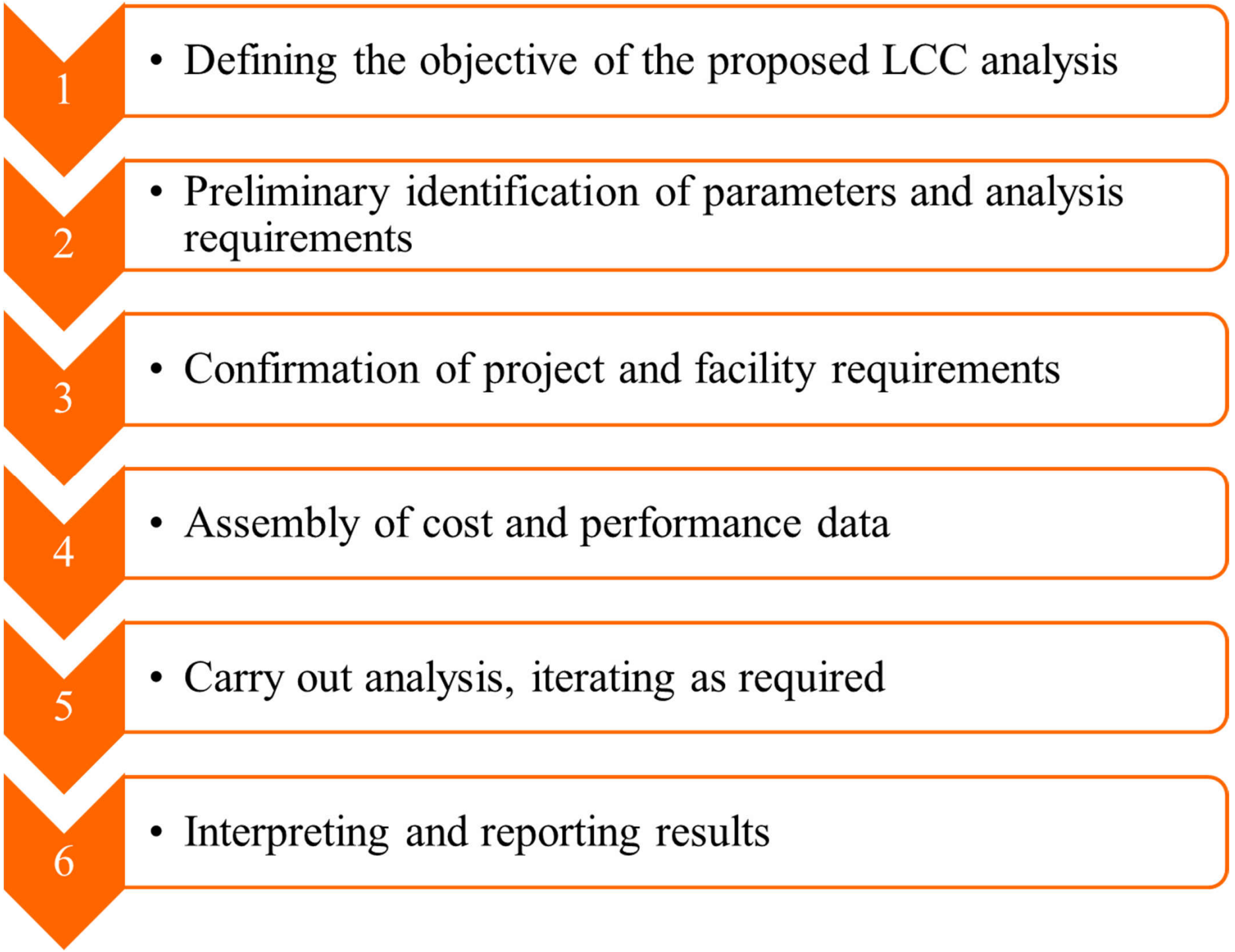
(Source: *A Green Vitruvius: Principles and Practice of Sustainable Architectural Design*)

Life cycle costing

- Typical life-cycle cost analysis include:
  - Acquisition costs (or design & development costs)
  - Financing costs (e.g. interest rate on a loan)
  - Energy savings
  - Equipment replacement costs
  - Operations, maintenance and repair costs
  - Tax implications
  - Impacts of inflation

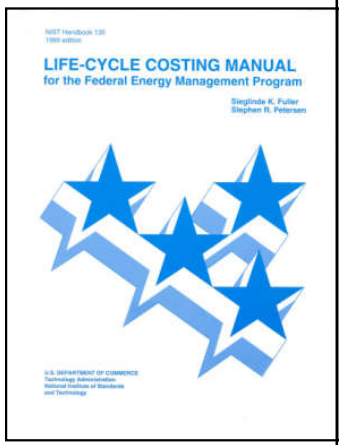
(Example: Video: Life Cycle Cost Analysis of PV Systems (5:58) https://youtu.be/7rDpYZi6Lk8)

Core process of life cycle costing (LCC)



Life cycle costing

- Useful references and tools:
  - ISO 15686-5:2008 Buildings and Constructed Assets. Service Life Planning. Life Cycle Costing https://en.wikipedia.org/wiki/ISO_15686
  - NIST Handbook 135 Life-Cycle Costing Manual, https://www.wbdg.org/FFC/NIST/hdbk_135.pdf
  - Building Life-Cycle Cost (BLCC) software, http://www.wbdg.org/tools/blcc.php

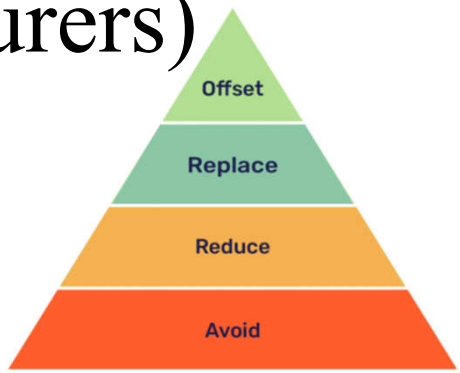


Carbon audit

- What is a **carbon audit**? 碳審計
  - It is a means of measuring and recording the green house gas (GHG) emissions of an organization or building within a defined system boundary
  - Sometimes called a ‘carbon footprint’
  - Includes:
    - Direct power usage (from fuel-powered sources)
    - Fuel-powered transport (haulage & travel)
  - The wider footprint may include:
    - Waste and recycling, carbon saving arrangements

Carbon audit

- Carbon audit is the first step in developing a carbon strategy
- Carbon strategy: A long term action plan to manage and reduce the carbon emissions of the organisation and its clients
- Carbon strategy is compulsory in certain industries (e.g. steel and car manufacturers)

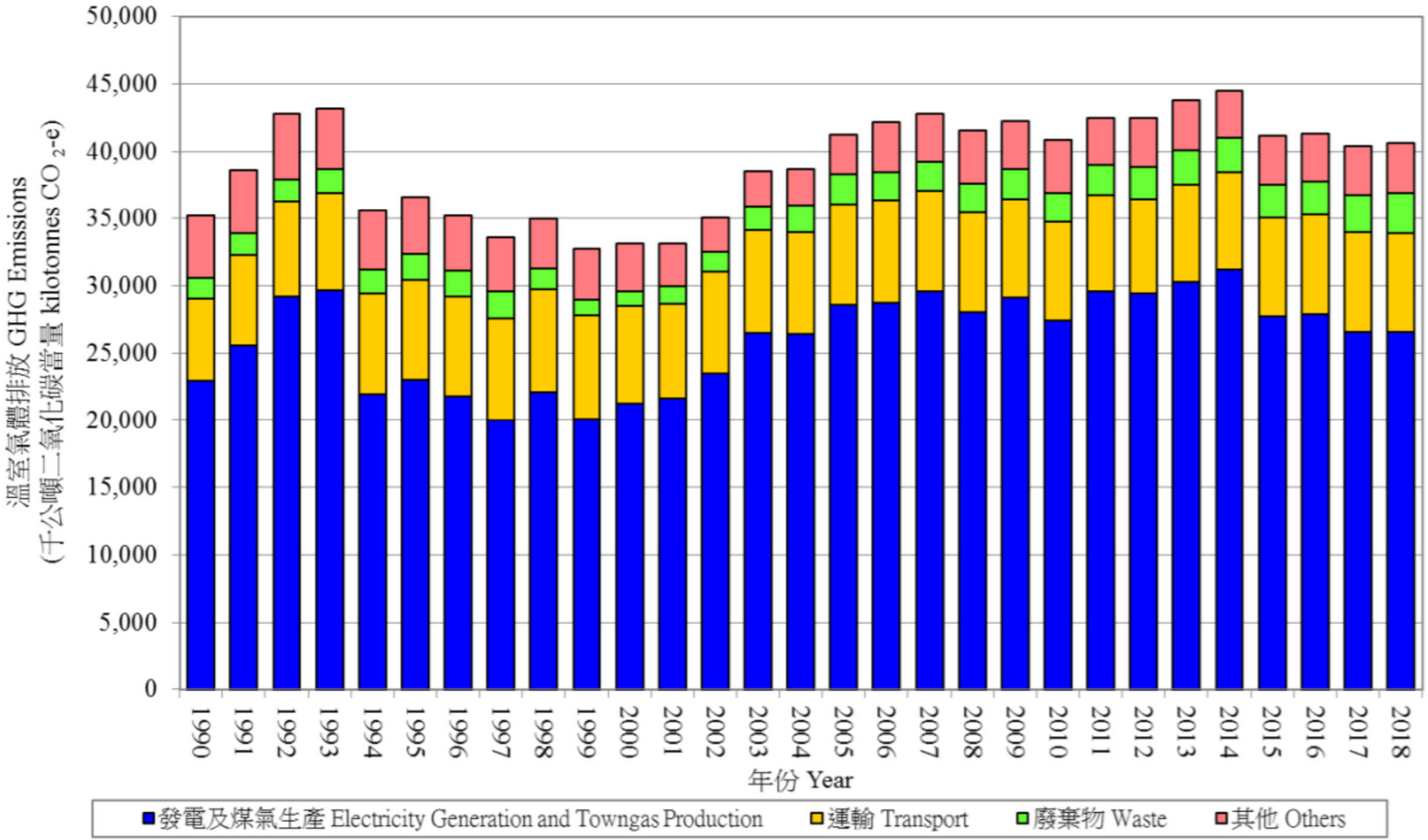


Carbon audit

- Why should we do a carbon audit?
  - Some countries has set targets to cut carbon emissions under the Kyoto Protocol
  - Related local legislation
  - Corporate social responsibility policies
  - Employee & customer expectations
  - Brand value & corporate image
  - Carbon reporting provides good management data
  - Savings in energy consumption

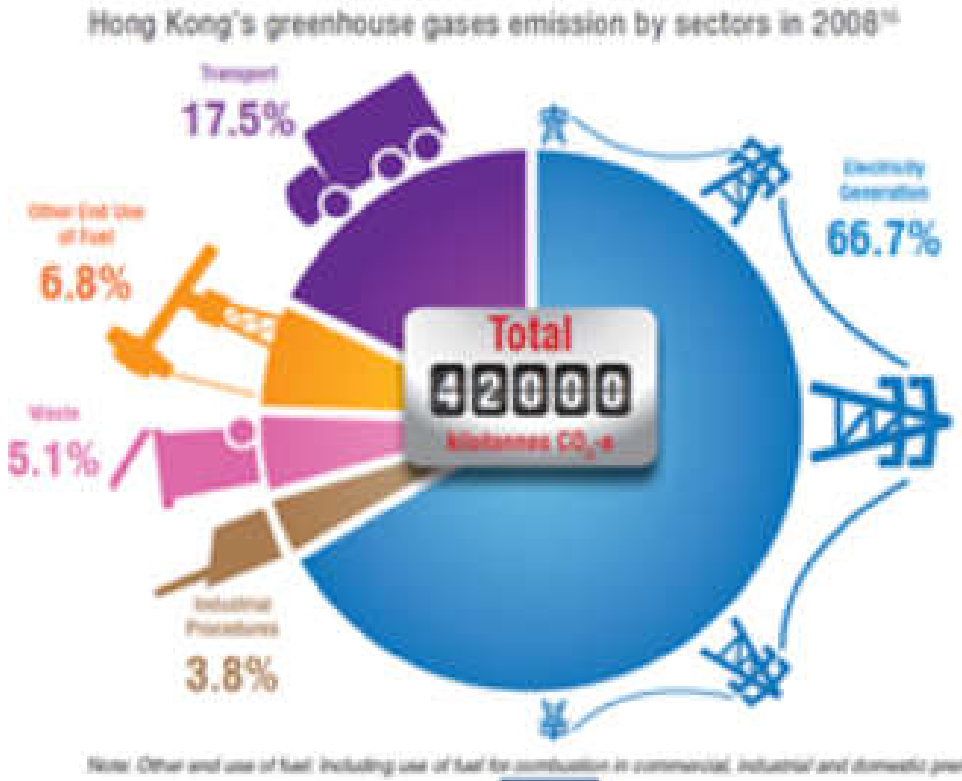
Carbon Audit碳審計
綠色機構 Green Partner

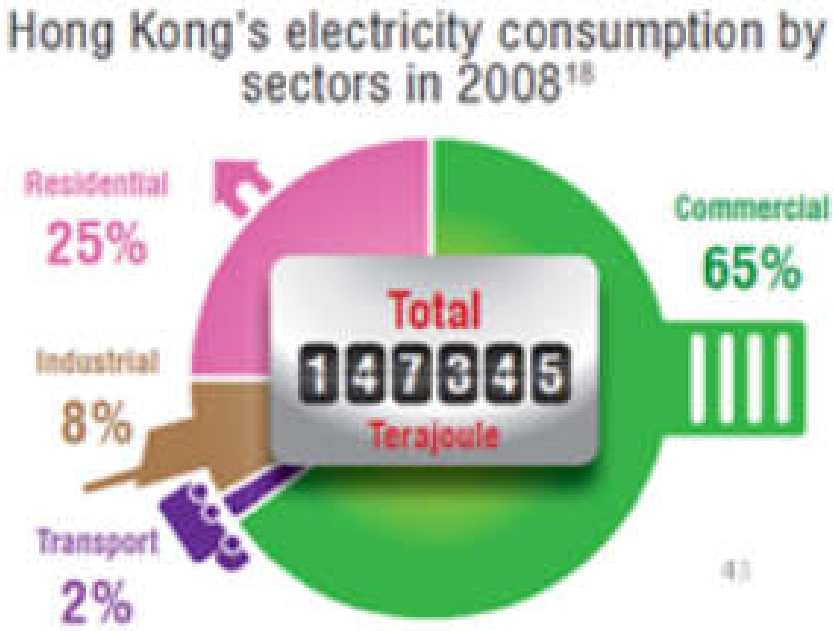
Greenhouse gas (GHG) emission trends of Hong Kong 1990-2018



(Source: https://www.climateready.gov.hk/files/pdf/greenhouse_gas_emissions_trends.pdf)

Greenhouse gas (GHG) emission of Hong Kong 2008





(Source: www.epd.gov.hk)

Carbon audit

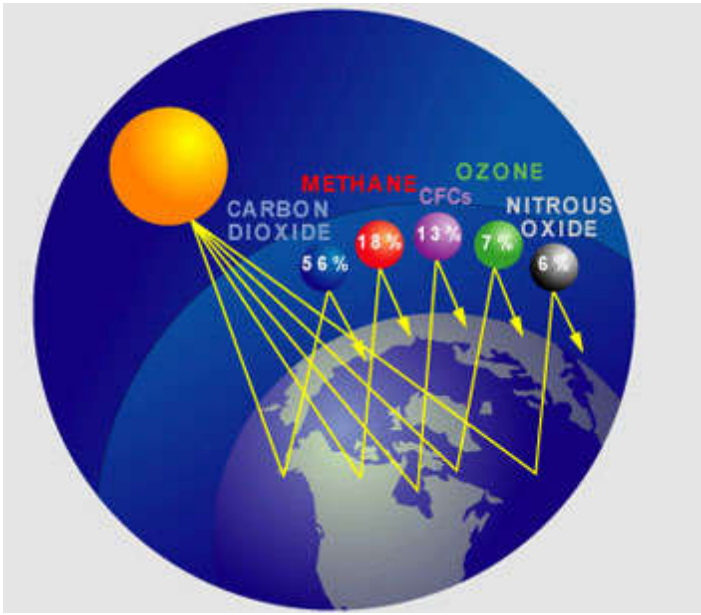
- EPD and EMSD, 2010. *Guidelines to Account for and Report on Greenhouse Gas Emissions and Removals for Buildings (Commercial, Residential or Institutional Purposes) in Hong Kong*, 2010 Edition, Environmental Protection Department (EPD) and Electrical and Mechanical Services Department (EMSD), Hong Kong
  - https://www.epd.gov.hk/epd/sites/default/files/epd/english/climate_change/files/Guidelines_English_2010.pdf

Carbon audit

- Purpose of the guidelines: Assist the building user and managers to:
  - Measure their greenhouse gas (GHG) performance
  - Identify areas of improvement
  - Conduct voluntary programmes to reduce and/or offset emissions
- Voluntary participation and self-reporting
- Compile the GHG inventory

Carbon audit

- Principles to ensure true and fair reporting
  - Relevance
  - Completeness
  - Consistency
  - Accuracy
  - Transparency



- Include 6 types of GHG: CO_2, CH_4, N_2O, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6)

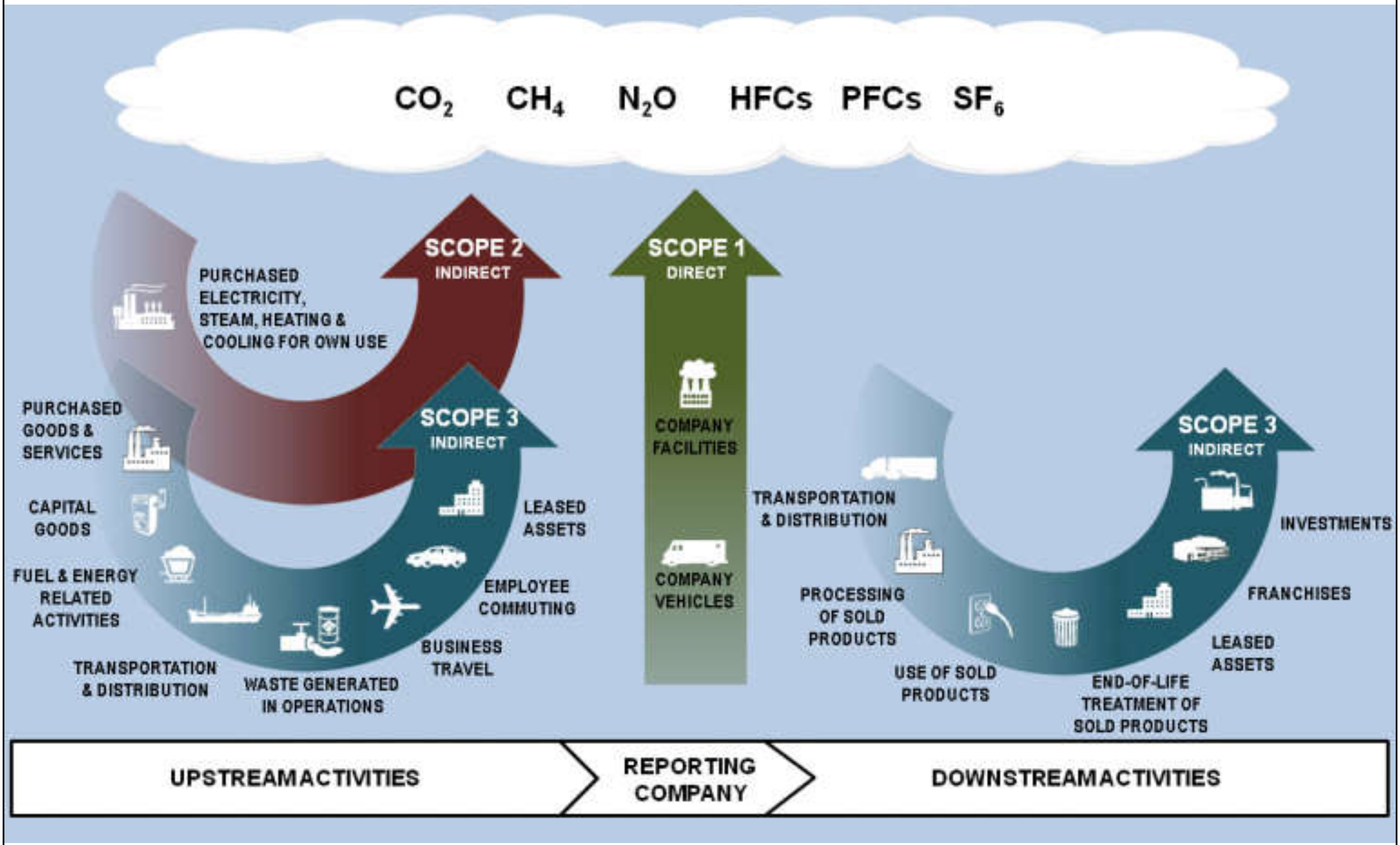
Carbon audit

- Typical steps:
  - 1. Determine the physical boundaries (e.g. site boundaries of building)
  - 2. Determine the operational boundaries (identify and classify the activities to determine the scope)
  - 3. Determine the reporting period (e.g. one year)
  - 4. Collect necessary data and information and to quantify the GHG performance
  - 5. Prepare the report

Carbon audit

- *Physical boundaries* (e.g. site boundaries)
- *Operational boundaries*
  - Operational activities which will result in GHG emissions or removals
  - Scope 1 – direct emissions and removals
  - Scope 2 – energy indirect emissions
  - Scope 3 – other indirect emissions (optional)

Carbon audit and scope of greenhouse gas (GHG) emissions



(Source: UNEP Sustainable Buildings and Climate Initiative, https://energies2050.org/sustainable-buildings-and-climate-initiative-unep-sbci/?lang=en)

Carbon audit

- Scope 1 – direct emissions and removals
  - Combustion of fuels in stationary sources to generate electricity, heat, or steam, e.g. electricity generators, boilers, gas cooking stoves, etc.
  - Combustion of fuels in mobile sources (e.g. motor vehicles and ships), for example, shuttle bus
  - Intentional or unintentional GHG releases from equipment and systems, e.g. HFCs and PFCs from HVAC&R equipment

Carbon audit

- Scope 1 – direct emissions and removals
  - Assimilation of CO_2 into biomass through e.g. planting of trees
  - Any other physical and chemical processing in the physical boundary which will emit or remove GHG. For example, on-site waste or sewage processing facilities

Emission (CO_2) = Σ Amount of Fuel Consumed x Emission Factor of CO_2

Emission (CH_4 / N_2O) = Σ Amount of Fuel Consumed x Emission Factor of (CH_4 / N_2O) x Relative Global Warming Potential

Carbon audit

- Scope 2 – energy indirect emissions
  - Electricity purchased from power companies
  - Towngas purchased from the Hong Kong and China Gas Company
- Scope 3 – other indirect emissions (optional)
  - Methane gas generation at landfill in Hong Kong due to disposal of paper waste
  - GHG emissions due to electricity used for fresh water processing by Water Services Department

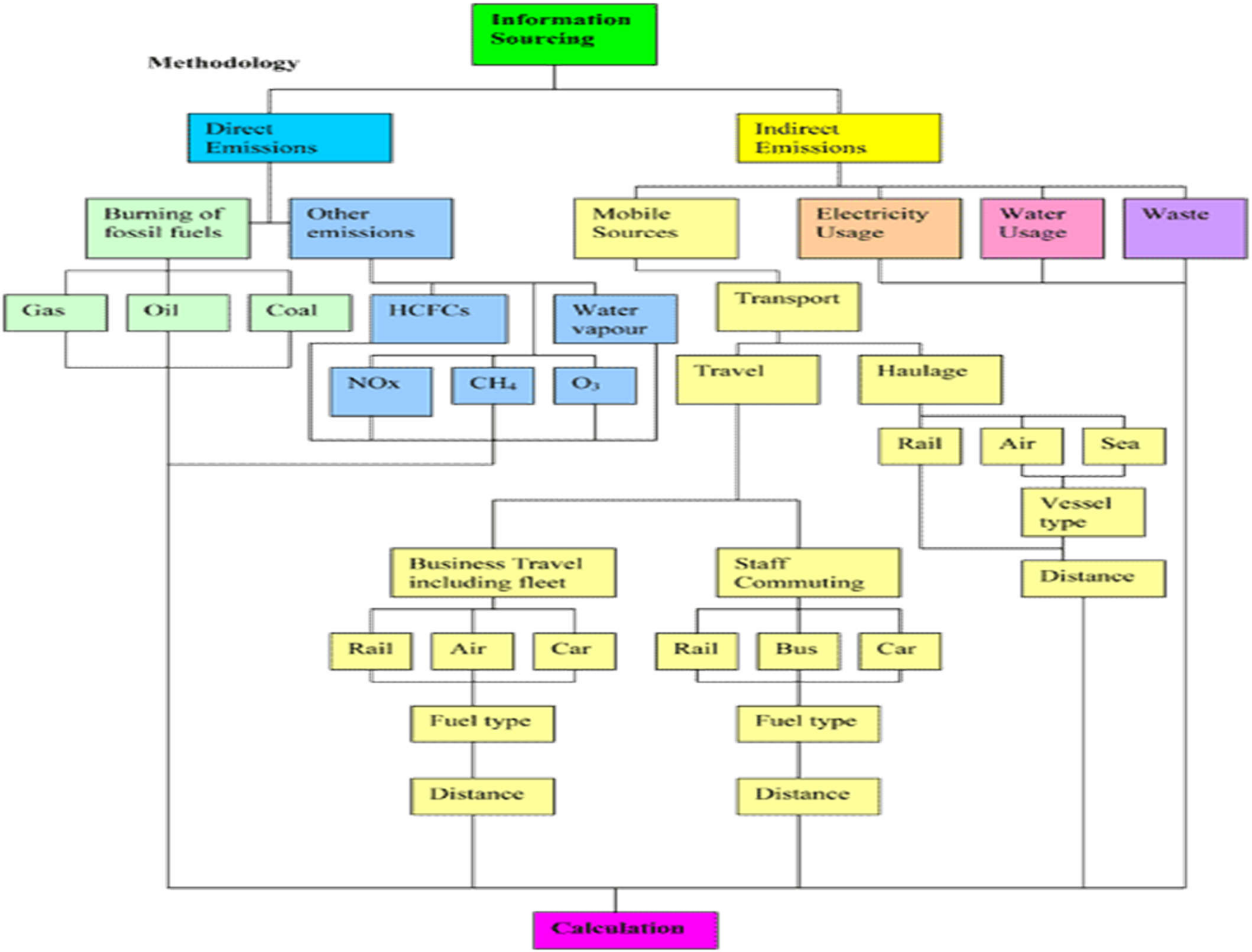
Carbon audit

- Scope 3 – other indirect emissions (optional)
  - GHG emissions due to electricity used for sewage processing by Drainage Services Department
  - Other examples of GHG emissions
    - Extraction & production of purchased materials & fuels
    - Transportation of purchased materials or goods, fuels, products, waste, employees, occupants and guests, to and from the concerned buildings
    - Business travel by employees

Carbon audit

- Scope 3 – other indirect emissions (optional)
  - Other examples of GHG emissions (cont'd)
    - Emissions from outsourced activities or other contractual arrangements
    - Use of sold products and services
    - Waste disposal other than those covered in the above list
- Links with international emissions reporting framework, e.g. ISO14064-1

The carbon audit methodology



(Source: http://www.carbonmanagers.com/carbon-audit-methodology%20.aspx)

Carbon audit

- Implications to sustainable building design
  - Future green building assessment might include the GHG indicators
  - Building projects that aim at “zero energy”, “zero carbon” or “zero emission” must demonstrate their compliance by carbon audit
  - Possibility of trading off GHG emission and allow carbon trading

Zero carbon building

"0"

- Zero carbon building (ZCB) 零炭建築
- Zero energy building (ZEB) 零能耗建築
  - A building that produces as much energy on-site as it consumes on an annual basis
  - "Net" zero energy building 淨零能耗建築

- In recent years, many researchers and governments investigated the definitions of ZEB and ZCB to develop an internationally agreed and consistent definition

Terms and definitions of ZEB and ZCB

Terms	Definitions/Meanings
Zero energy building (ZEB) or net zero energy building (NZEB)	A building that produces as much energy on-site as it consumes on an annual basis
Net zero site energy building (site ZEB)	Amount of energy provided by on-site renewable energy sources is equal to the amount of energy used by the building
Net off-site zero energy building (off-site ZEB)	Similar to previous one, but consider purchasing of energy off-site from 100% renewable energy sources
Net zero source/primary energy building (source ZEB)	It produces as much energy as it uses in a year, when accounted for the source. For electricity, only around 35% of the energy used in a fossil fuel power plant is converted to useful electricity and delivered. Site-to-source conversion multipliers are used to calculate a building's total source energy
Net zero energy cost building (cost ZEB)	The cost of purchasing energy is balanced by income from sales of electricity to the grid of electricity generated on-site
Net zero energy emissions building, zero carbon building (ZCB), zero emission building	The carbon emissions generated from the on-site or off-site fossil fuel use are balanced by the amount of on-site renewable energy production

Zero carbon building

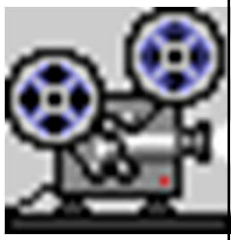
"0"

- Zero energy building (ZEB)
  - A building that produces as much energy on-site as it consumes on an annual basis
  - "Net" zero energy building
- Advantages of ZEB:
  - Reduce energy consumption and costs
  - Reduce carbon emissions
  - Reduce dependence on fossil fuels

Zero carbon building

"0"

- Video: Achieving Net-Zero-Energy Buildings - ASHRAE (2:05)
  - http://youtu.be/pQFJr5E7_R0
  - By American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE)
  - 1. Building envelope measures
  - 2. HVAC, service water heating and lighting measures
  - 3. Renewable energy measures

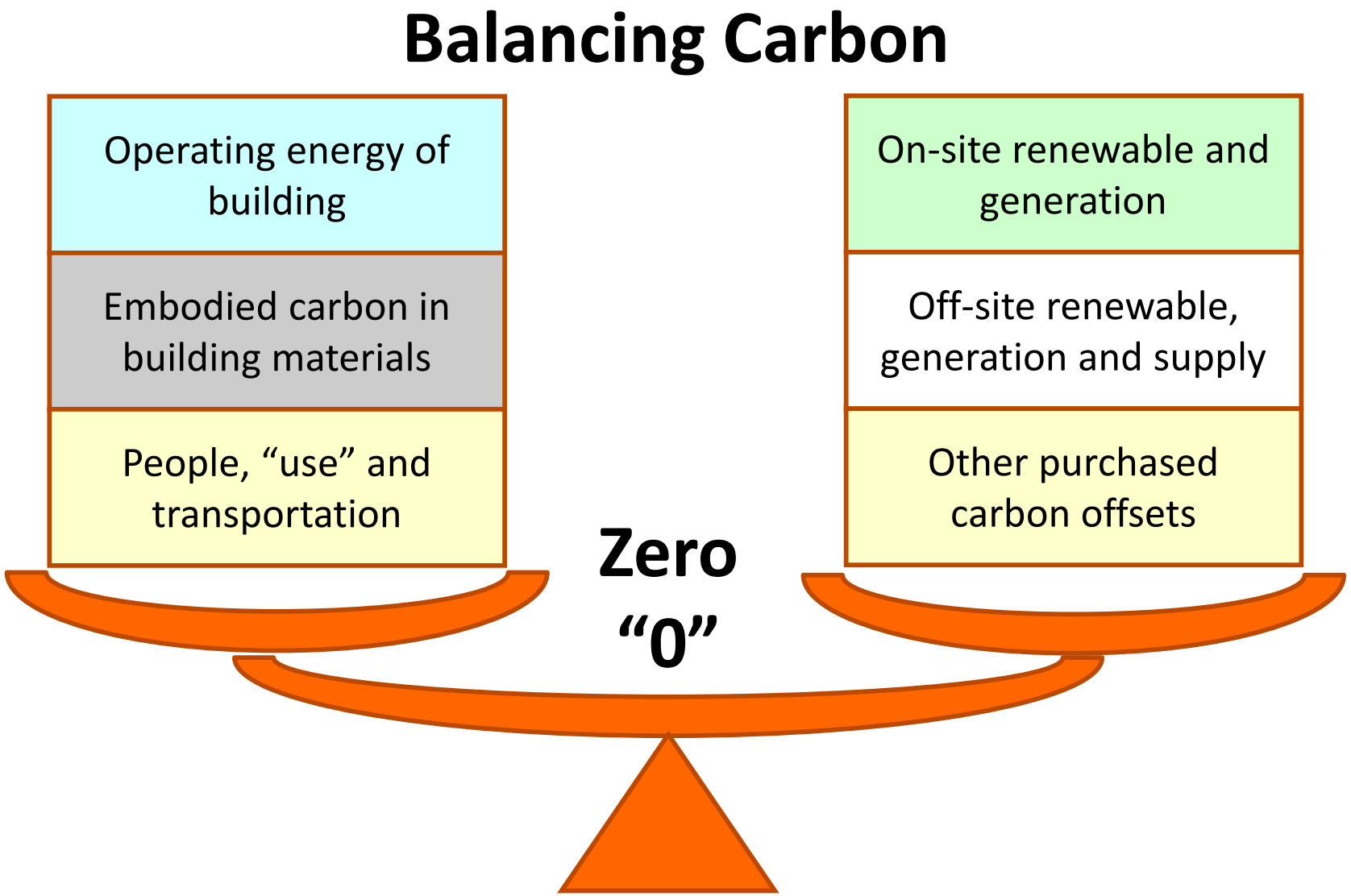


Zero carbon building

"0"

- ZEB is often used in conjunction with ZCB
  - ZEB: reduce the operating energy requirements → zero fossil energy
  - ZCB: use renewable and low-carbon energy sources to offset or balance carbon emissions
- ***Balancing*** carbon concept for ZCB
  - Two major types of balance:
    - Import/export balance (e.g. for ZCB)
    - Load/generation balance (e.g. for ZEB)

Balancing carbon emissions for zero carbon buildings (ZCB)



Sources of difference between definitions of ZCB

a. The metric of the balance (e.g. primary energy, final energy, carbon emission)
b. The balancing period (monthly, seasonal, operation year, life cycle)
c. The type of energy use included in the balance (e.g. HVAC, lighting, appliances)
d. The type of energy balance (import/export and load/generation)
e. The accepted renewable energy supply options
f. The connection to the energy infrastructure (grid connected or standalone)
g. Other requirements relating to energy efficiency, the indoor climate and building-grid interaction

(Source: Marszal, *et al*., 2011. Zero energy building – a review of definitions and calculation methodologies, *Energy and Buildings*, 43 (4): 971-979. https://doi.org/10.1016/j.enbuild.2010.12.022)

Zero carbon building

"0"

- Australia has developed a definition for ZCB
  - "A zero carbon building is one that has no net annual Scope 1 and 2 emissions from operation of building incorporated services.

    - Include building envelope, water heater, built-in cooking appliances, fixed lighting, shared infrastructure and installed renewable energy generation
    - ZCB must meet specified standards for energy efficiency and on-site generation
    - Compliance is based on modelling or monitoring of greenhouse gas emissions in kg CO2-e/m^2/yr."

Variations of ZCB [adapted from ASBEC (2011)]

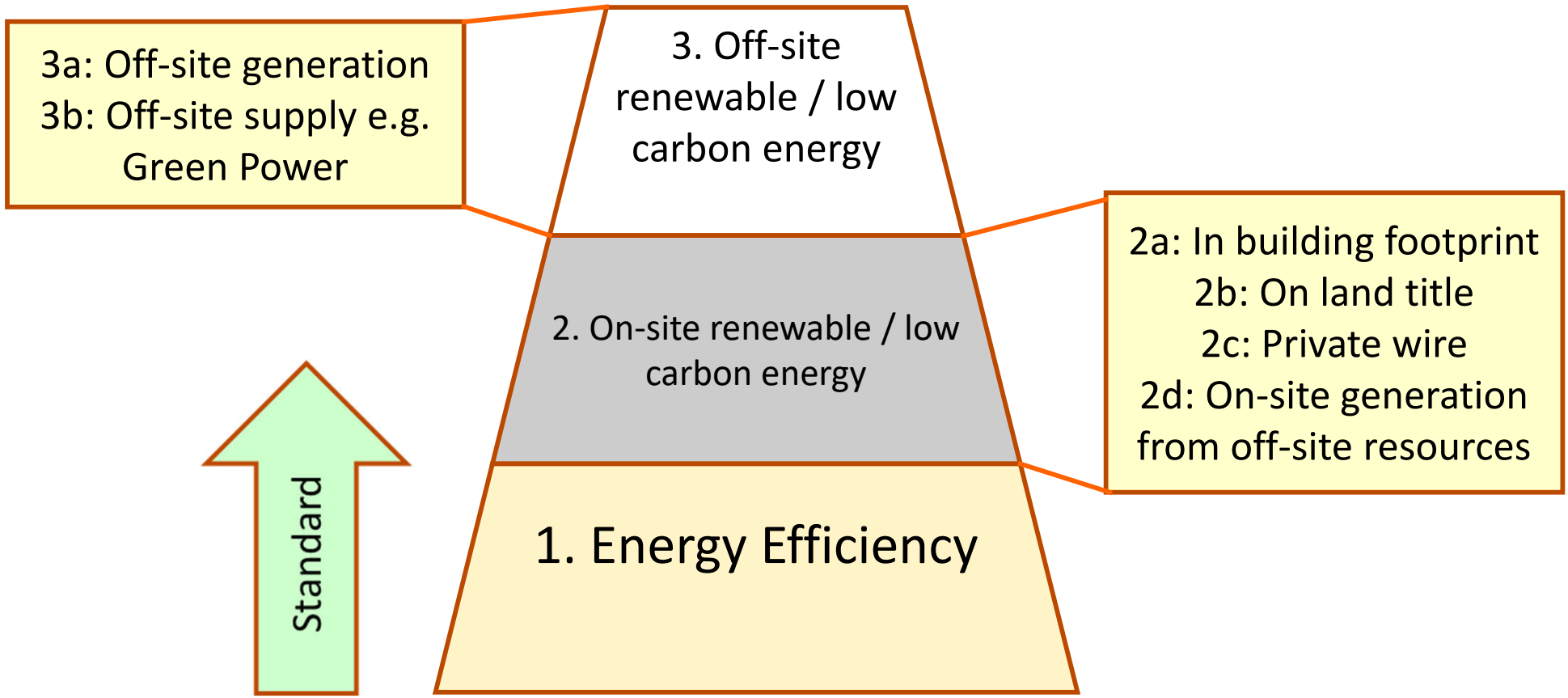
Zero carbon occupied building	Include occupant emissions
Zero carbon embodied building	Include embodied emissions
Zero carbon life-cycle building	Include all emission sources in the building life cycle
Autonomous zero carbon building	No grid connection
Carbon positive building	Achieves less than zero emissions

(Source: ASBEC, 2011. *Defining Zero Emission Buildings*, Australian Sustainable Built Environment Council (ASBEC), Sydney, Australia. https://www.asbec.asn.au/research-items/zero-emissions-residential-defining-zero-emission-buildings-review-and-recommendations-report/)

Zero carbon
Zero energy
Zero waste
Zero-carbon transport
Zero-carbon energy
Zero-carbon home
Zero-carbon city

我完全自給自足

Allowable emission reduction options for zero carbon buildings



- '**Zero carbon**' demands a numerical assessment and validation of the building design

- ZCB compliance requires designers to numerically validate the effectiveness of their approaches

Comparison of low energy, zero energy/carbon and green buildings [adapted from ECEEE (2009)]

	Pros	**Cons**
Low energy building (LEB) (e.g. passive house)	Cost optimal; well established principles with thousands of buildings constructed	Does not achieve greatest energy/carbon saving potential
Zero energy building (ZEB)/ Zero carbon building (ZCB)	Greatest energy/carbon saving	More expensive; limited practical experience
Green Building (GB)	Takes account of wider sustainability and resource use issues	May not be realistic across all new buildings

(Source: ECEEE, 2009. *Net Zero Energy Buildings: Definitions, Issues and Experience*, European Council for an Energy Efficient Economy (ECEEE), Stockholm, Sweden. https://ec.europa.eu/energy/sites/ener/files/documents/nzeb_full_report.pdf)

Examples of zero energy/carbon building projects in the world

Pearl River Tower, Guangdong, China [2010]

Self-sufficient solar house, Freiburg, Germany [1992]

Pusat Tenaga Malaysia's ZEO Building, Malaysia [2007]

BCA Academy, Singapore [2009]

Beddington Zero Energy Development (BedZED), London [2002]

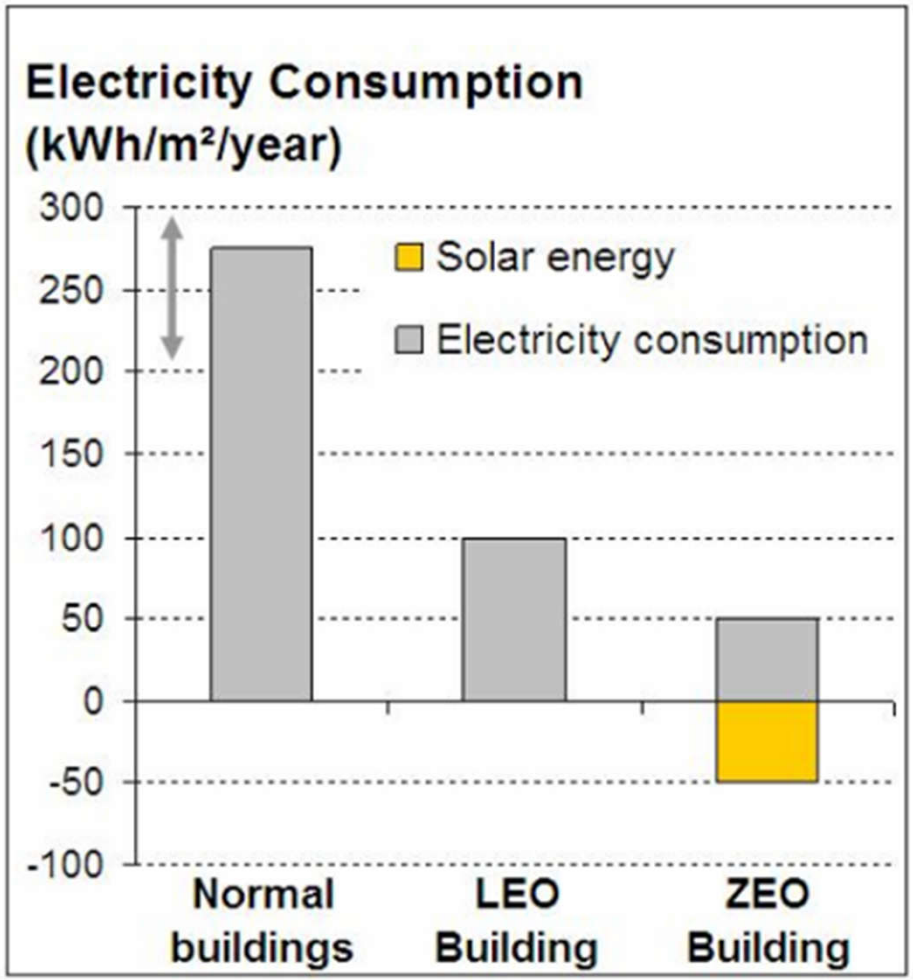
The Barratt Green House in Watford, UK [2008]

Beddington Zero Energy Development (BedZED), UK

Energy design features:
- Triple glazed
- High thermal insulation
- 777 m² of solar panels
- Co-generation
- District heating & electricity

Wind catcher

Malaysia low energy building and zero energy building



0-energy
(Zero Energy Office)

(Source: www.ptm.org.my/PTM_Building)

Zero energy office building in Guangdong, China (Pearl River Tower, for Guangdong Tobacco Company)

(completed in 2011)

Main features:

- Orientation of the building
- Low-E-glass
- Double-layer curtain-wall
- Chilled slab concrete ceilings
- Lighting efficiency
- Geothermal heat sink
- Energy storage
- Wind
- Integrated photovoltaics
- Microturbines

(Further info: http://www.som.com/projects/pearl_river_tower__sustainable_design)

(Source: www.sustainabledesignupdate.com)

Zero Carbon Park (ZCP) https://zcp.cic.hk/eng/story-of-zcb

ZCP 建造業零碳天地

ZCB 零碳天地

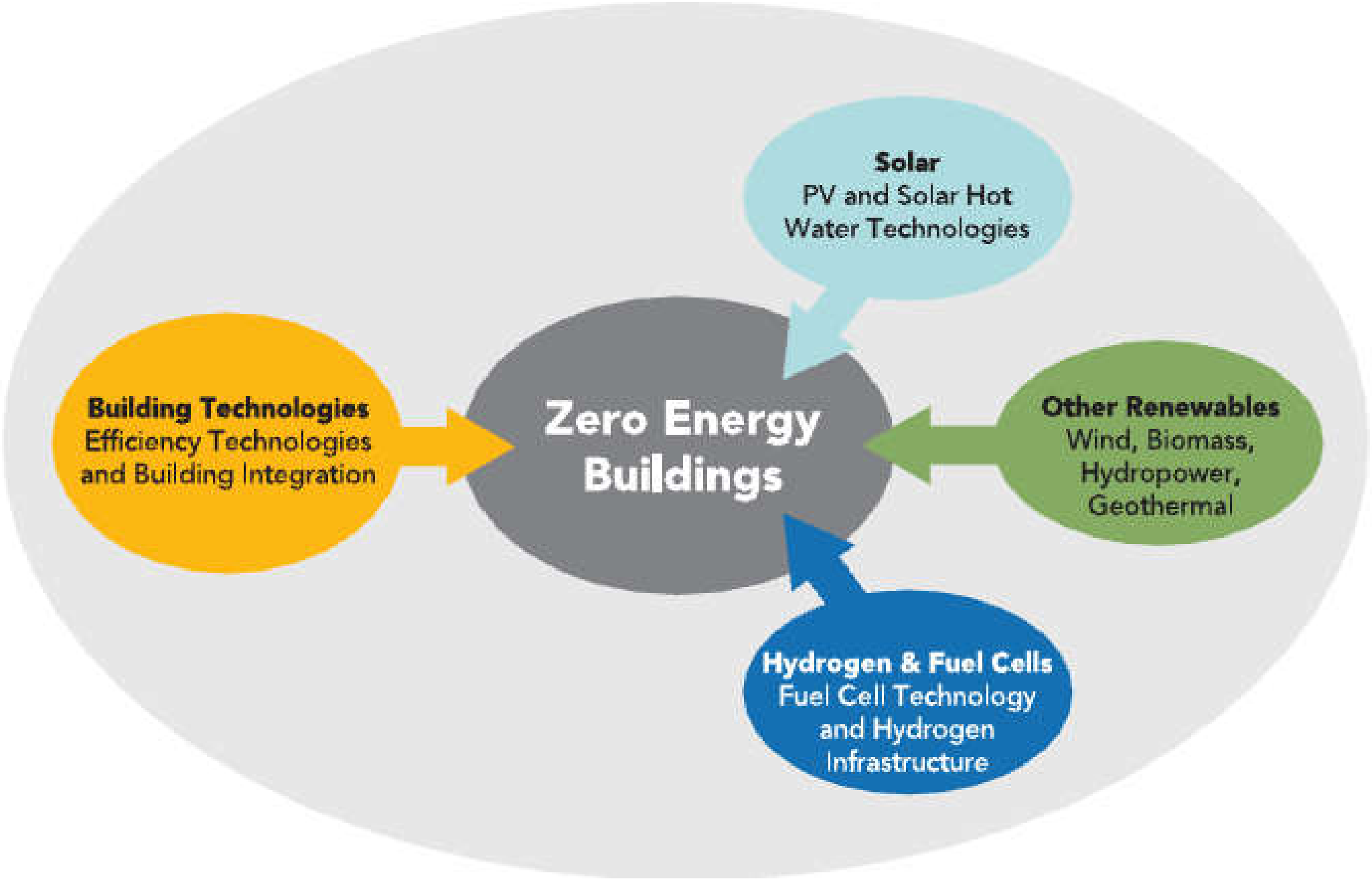
- Hong Kong's first zero carbon building (2013) (3:45) https://youtu.be/pFRx-8xmvbE
- Zeroing in on Green-Building (3:20) https://youtu.be/oiUkoJMhdvw
- 環保基金 綠色建築教育短片系列 - 綠色建築網上導賞團 (7:23) https://youtu.be/8JkTfb0H9u0

Zero carbon building

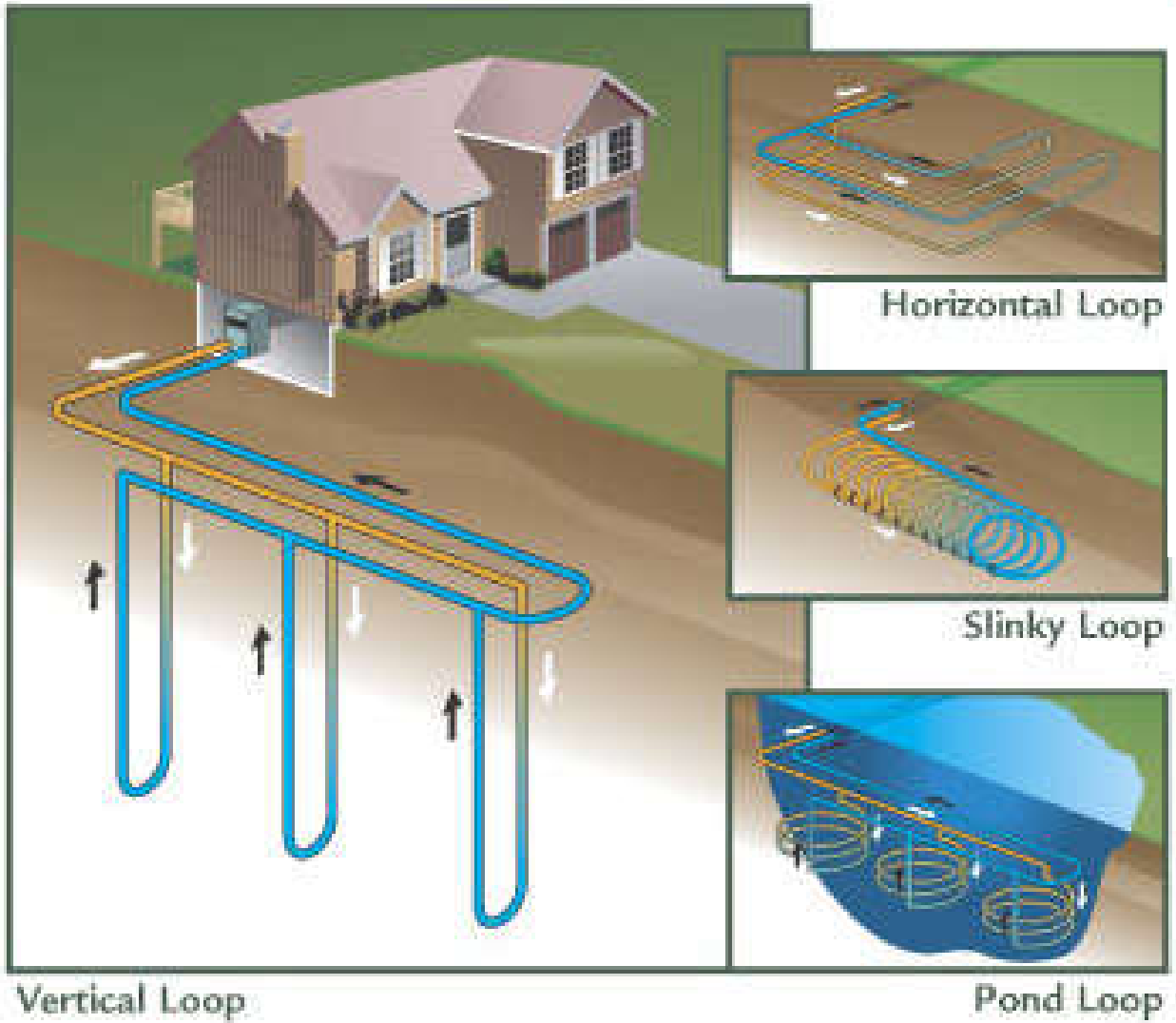
"0"

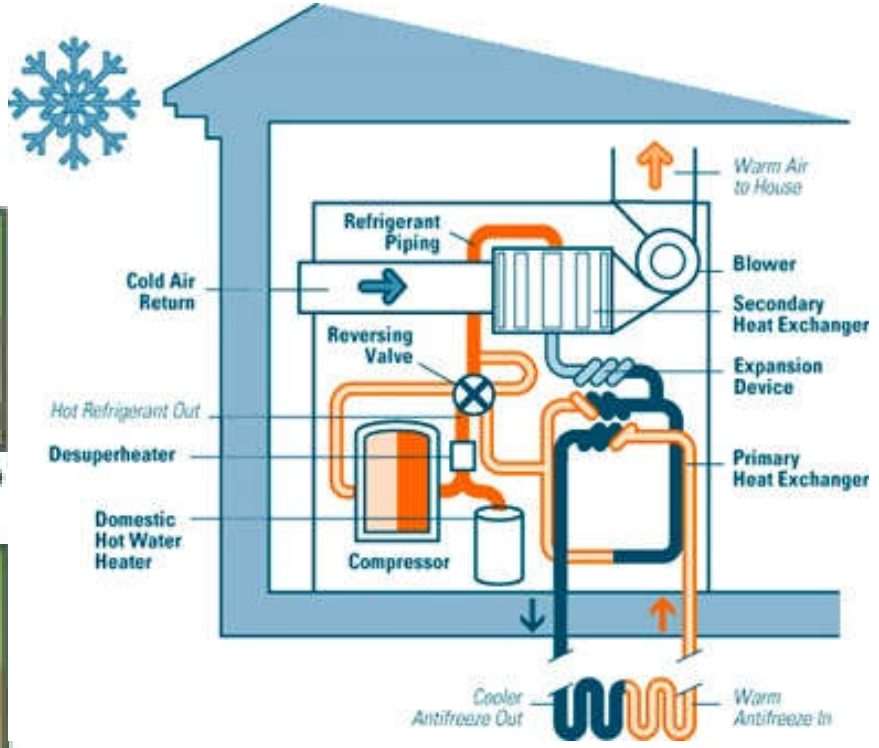
- How to achieve zero energy/carbon building?
  - High energy efficiency
  - On-site carbon reduction measures
    - Such as renewable energy systems, water efficiency
  - Methods to offset the remaining emissions, e.g.
    - Large scale off-site renewable energy facilities (unconnected)
    - Investment in local energy efficiency measures
    - Energy efficient appliances

Strategies for net zero energy building [Source: NSTC (2008)]

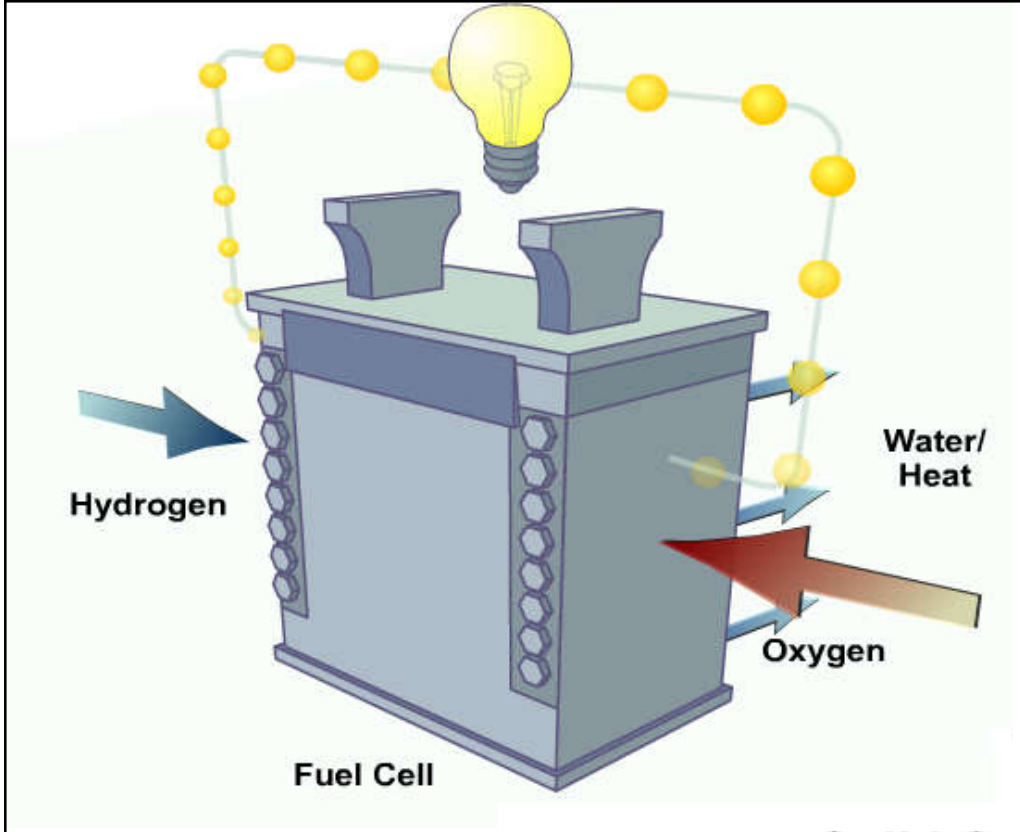


(Source: NSTC, 2008. *Federal Research and Development Agenda for Net-Zero Energy, High-Performance Green Buildings*, Subcommittee on Buildings Technology Research and Development, Committee on Technology, National Science and Technology Council (NSTC), Washington, DC. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/nstc-netzero-2008.pdf)

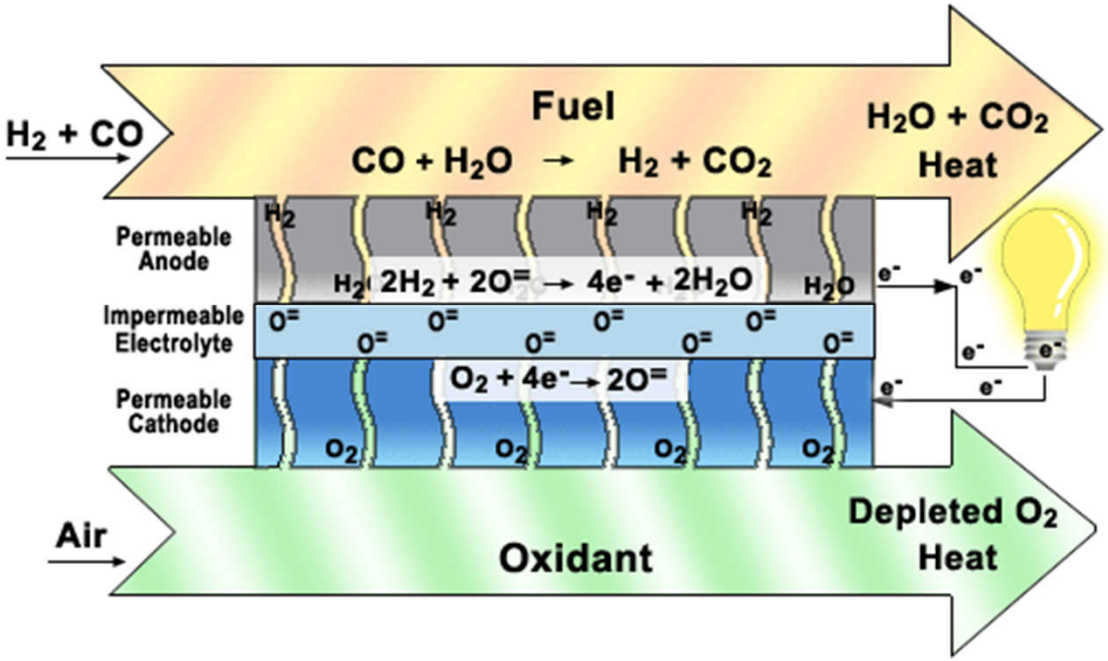


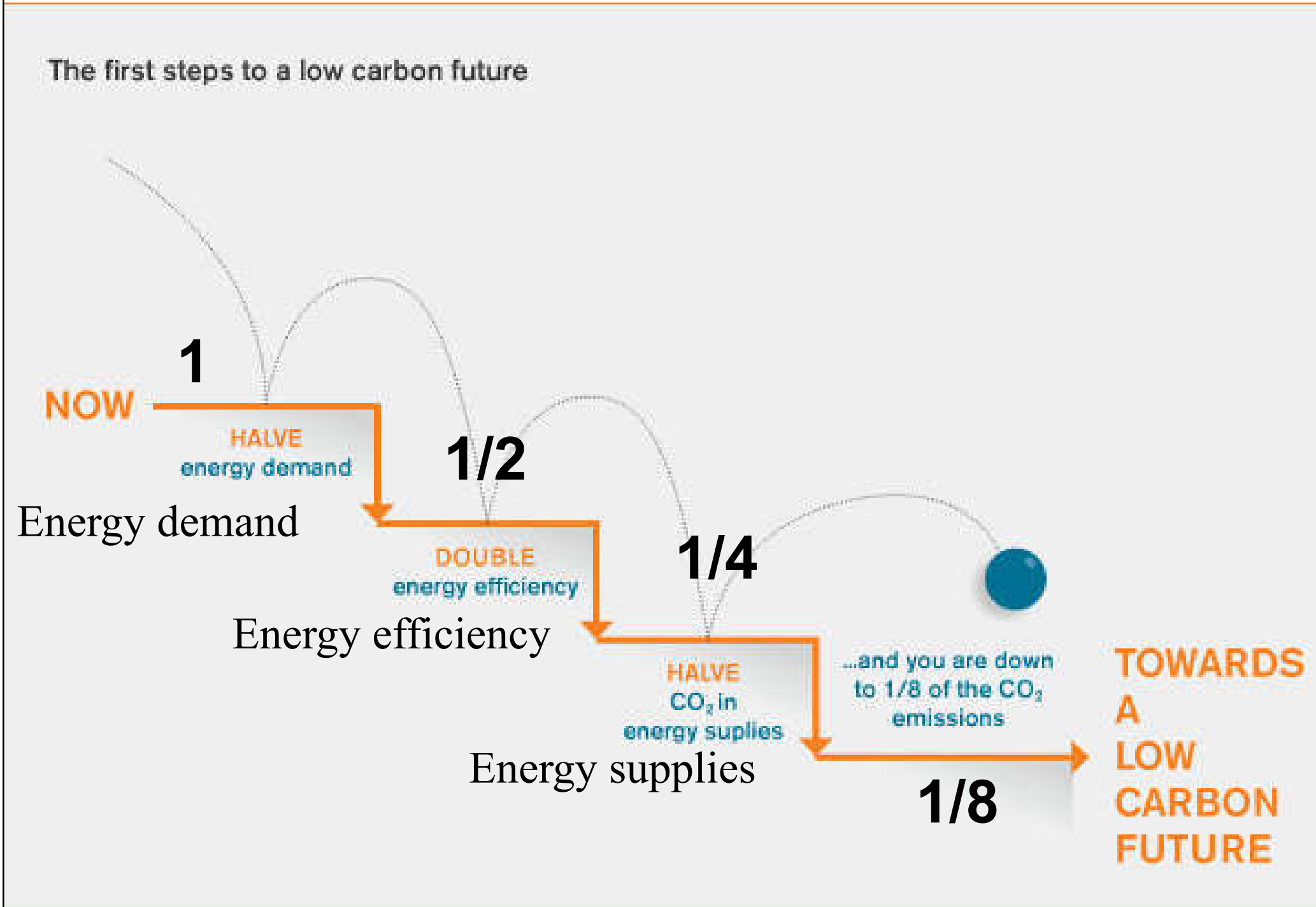


Geothermal heat pumps

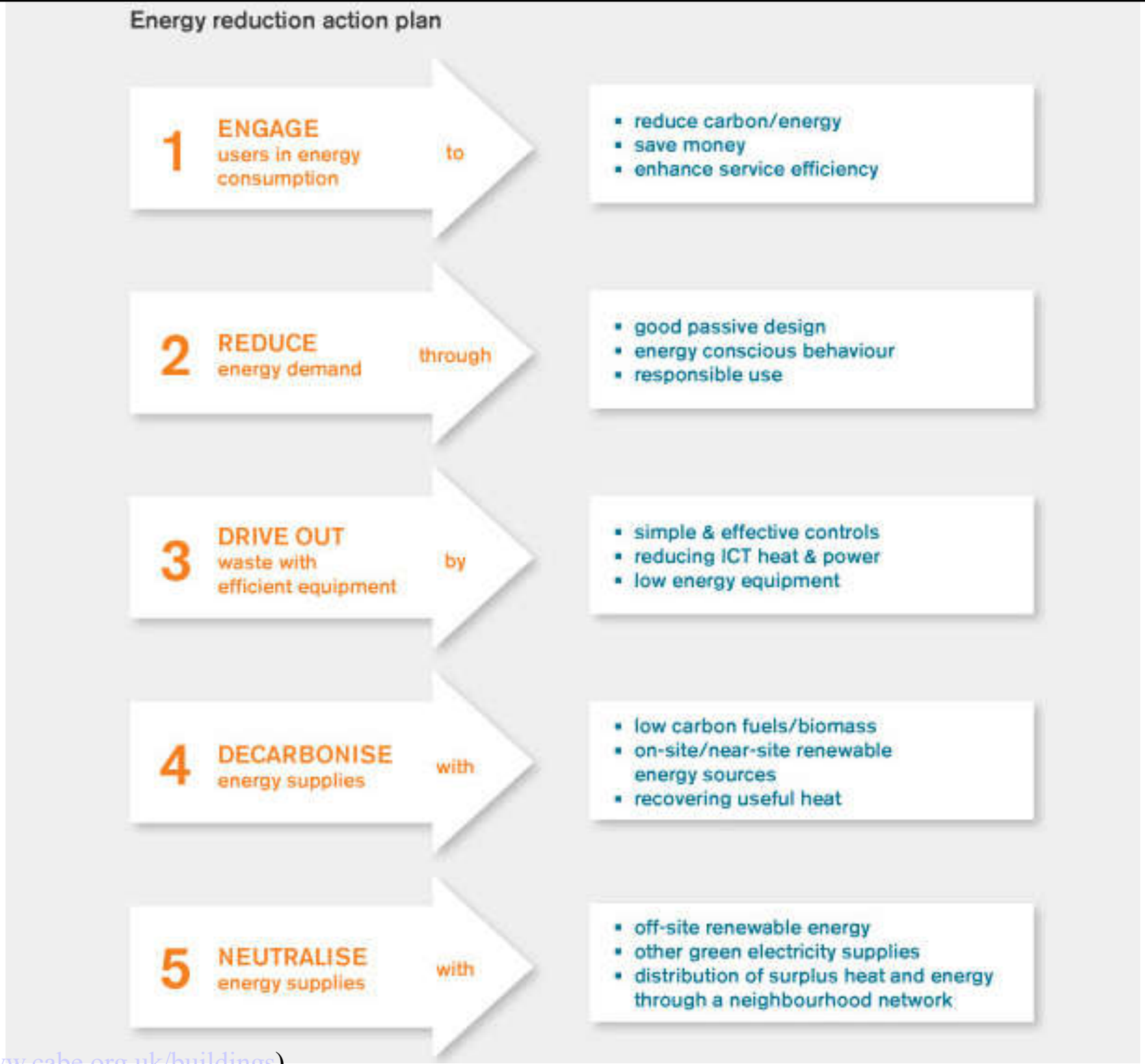


Solid Oxide Fuel Cell





(Source: www.cabe.org.uk/buildings)



(Source: www.cabe.org.uk/buildings)

Assess carbon footprints

- **Carbon** is frequently used as shorthand for either carbon dioxide (CO_2) or carbon dioxide equivalents (CO_2-e) of greenhouse gases
  - Used as an indicator for environmental impact or sustainability level
- **Carbon footprint**
  - Measure the exclusive direct (on-site, internal), and indirect (off-site, external, embodied, upstream, and downstream) CO_2 emissions of an activity, or over the life cycle of a product, measured in kg

Carbon footprint of a building and its components

- Materials manufacturing
- Materials transport
- Demolition wastes transport
- Demolition wastes treatment

- Building construction
- Building operation
- Building renovation
- De-construction

- Electricity consumption
- On-site fuel consumption
- On-site waste water treatment
- On-site solid wastes treatment
- Industrial processes housed in the building

Assess carbon footprints

- International standards for carbon footprint calculation and analysis
  - ISO 14040: Life Cycle Assessment - Principles and Framework
  - BSI: PAS 2050 - Specification for the Assessment of Life-Cycle GHG Emissions of Goods/Services
  - WRI/WBCSD: Greenhouse Gas Protocol
  - IPCC: 2006 Guidelines for National Greenhouse Gas Inventories

Different carbon reduction approaches

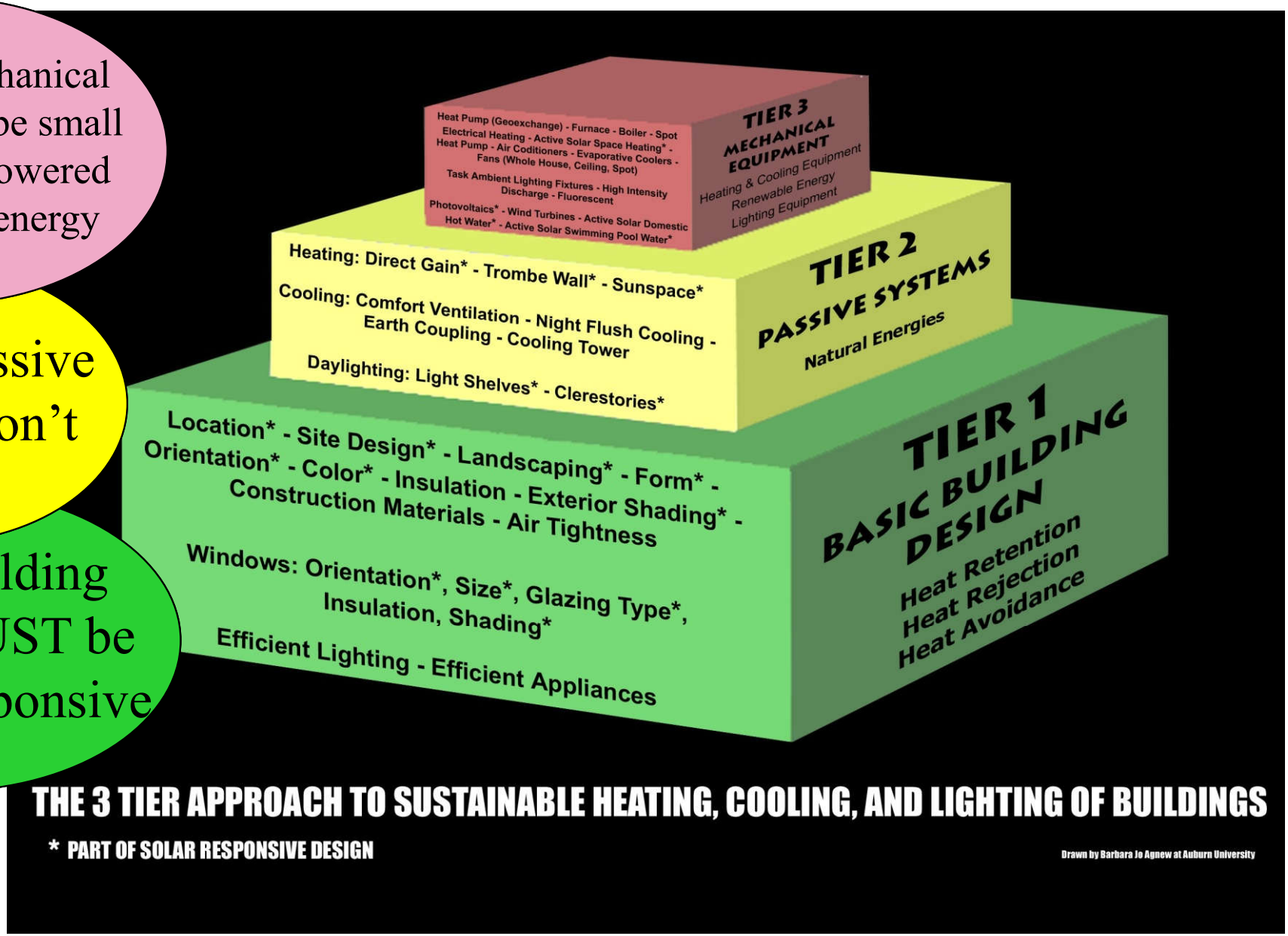
Strictly zero carbon	No carbon is emitted within Scopes 1 and 2; neither balancing nor offsets are allowed.
Net zero carbon	All carbon emissions within emissions Scope 1 are eliminated, and emissions within Scope 2 are balanced through export of low or zero carbon goods, internal or external sequestration, or import substitution of Scope 3 emissions.
Carbon neutral	Any and all emissions for which the building is responsible under Scopes 1 and 2 can be managed through the purchase of offsets from third parties that lie outside the building's boundaries.
Low carbon	Emissions under Scopes 1, 2 and 3 are reduced compared to a baseline. The reduction level is often not clearly specified.

Carbon Reduction: The Tier Approach

…and the Mechanical Systems won't be small enough to be powered by renewable energy

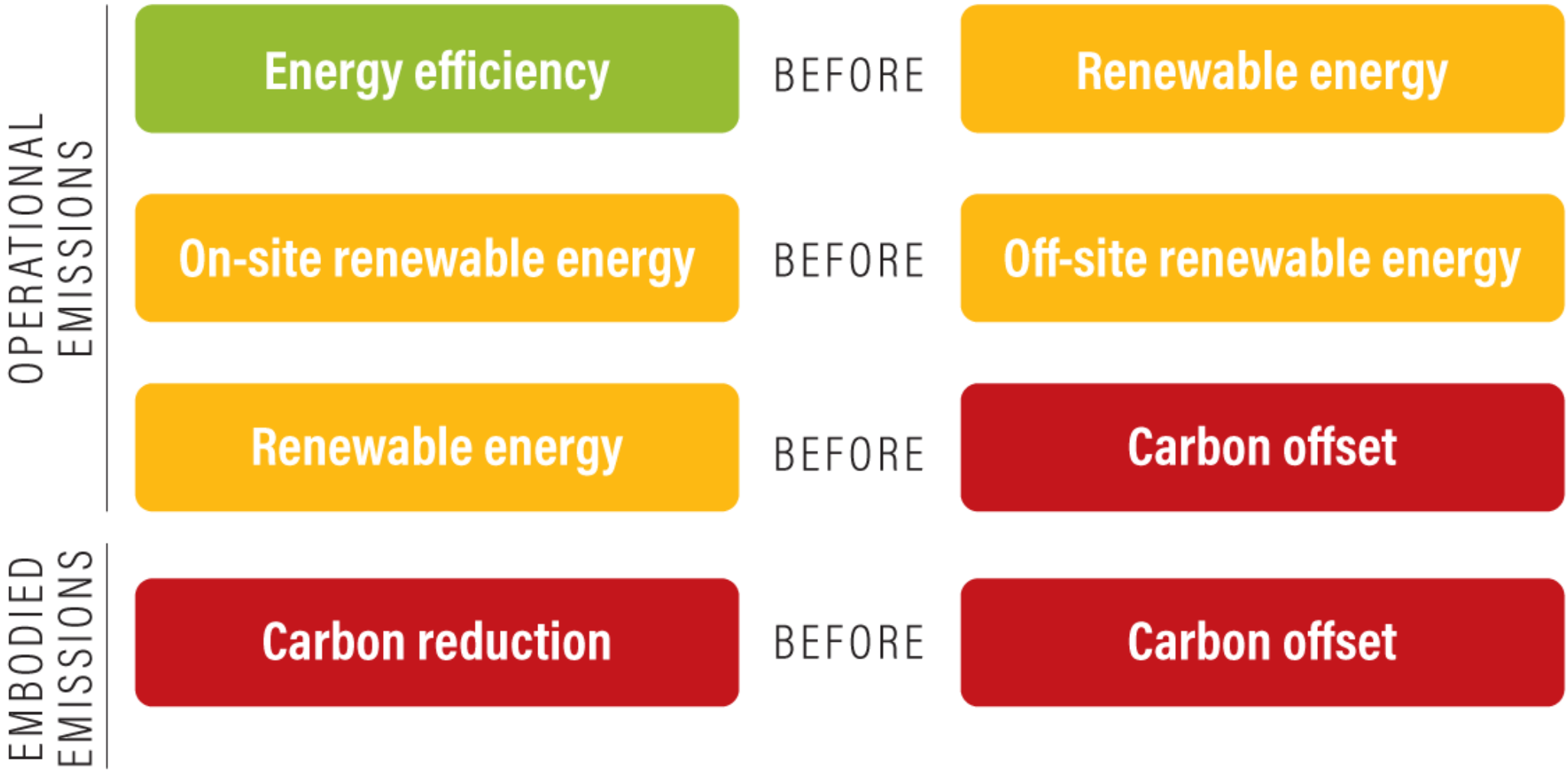
…or the Passive Systems won't work

Basic building design MUST be climate responsive



(Image: Norbert Lechner, "Heating, Cooling, Lighting")

How to achieve Zero Carbon Buildings (ZCBs)?

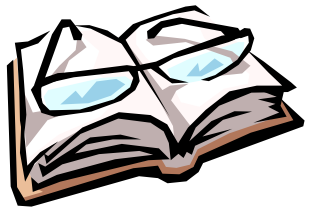


(Source: https://wrirosscities.org/ZeroCarbonBuildings)

Recommended design strategies for ZCB

- At the outset, the building project should take into account building energy efficiency and use of renewable energy
- Select the appropriate building site; allow opportunity to apply renewable energy and to reduce transportation and food production needs
- Optimise passive design strategies to protect the natural and comfortable environment in order to reduce energy demand
- Conserve water and reduce the demand for hot water
- Appropriately select materials in order to reduce the environmental impacts
- Reduce energy use in all aspects of the building operation
- Consider building energy efficiency first before introducing renewable energy offsets

Further Reading



- Life Cycle Costing (US-GSA)
  https://www.gsa.gov/node/81412
- Carbon Footprint Management Toolkit for Sustainable Low-Carbon Living (CityU)
  http://www.cityu.edu.hk/aerc/cft/
- Zero Carbon Buildings for All (World Resources Institute)
  https://wrirosscities.org/ZeroCarbonBuildings