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Critical analysis of embodied energy and environmental performance for indoor living walls

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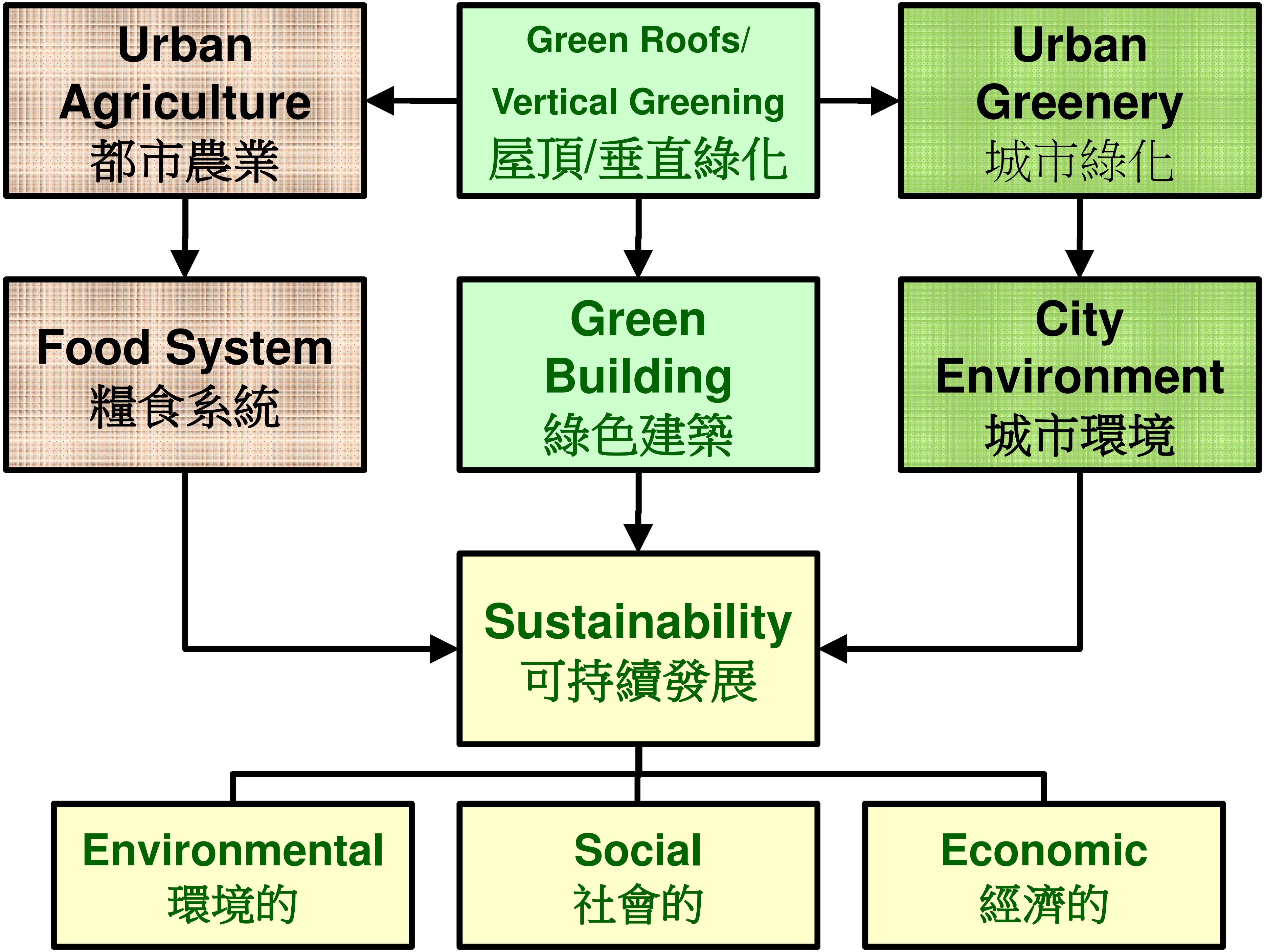
* Acknowledgement: The data and information on embodied energy/carbon came from the dissertation of Mr. MA Tsz Chun.

Introduction


- Hong Kong 香港
  - Land area: 1,104 km^2
  - Population: 7.3 millions
  - Population density: 6,612 persons/ km^2
- High urban density to meet population growth
  - Urban heat island and lack of greenery space
  - Habitat loss, air pollution, climate change
- Promote green roofs and vertical greening t achieve ***urban sustainability***



Urban Agriculture 都市農業
Green Roofs/ Vertical Greening 屋頂/垂直綠化
Urban Greenery 城市綠化
Food System 糧食系統
Green Building 綠色建築
City Environment 城市環境
Sustainability 可持續發展
Environmental 環境的
Social 社會的
Economic 經濟的

Introduction

- Benefits of greenery in urban areas
  - Air temperature control
  - Air pollution
  - Biodiversity & habitat protection
  - Stormwater management
- Green roofs & vertical greening
  - Building integrated vegetation
  - Green infrastructure
  - Urban cityscape

Introduction

- Conventional greening methods
  - Tree planting and urban parks
- Greening initiatives in buildings
  - Roof gardens
  - Sky gardens
  - Green roofs

- How to maximise the greening effects?
  - Vertical greening on wall surfaces
  - Three dimensional greening

An example of living wall (Taipei)

(Source: www.sa-space.com)

Greening on site hoarding boards (Taiwan) 綠化圍板（台灣）

(Photo taken by Dr. Sam C. M. Hui)

D.I.Y. vertical greening systems (Singapore HortiPark)

(Photo taken by Dr. Sam C. M. Hui)

Introduction

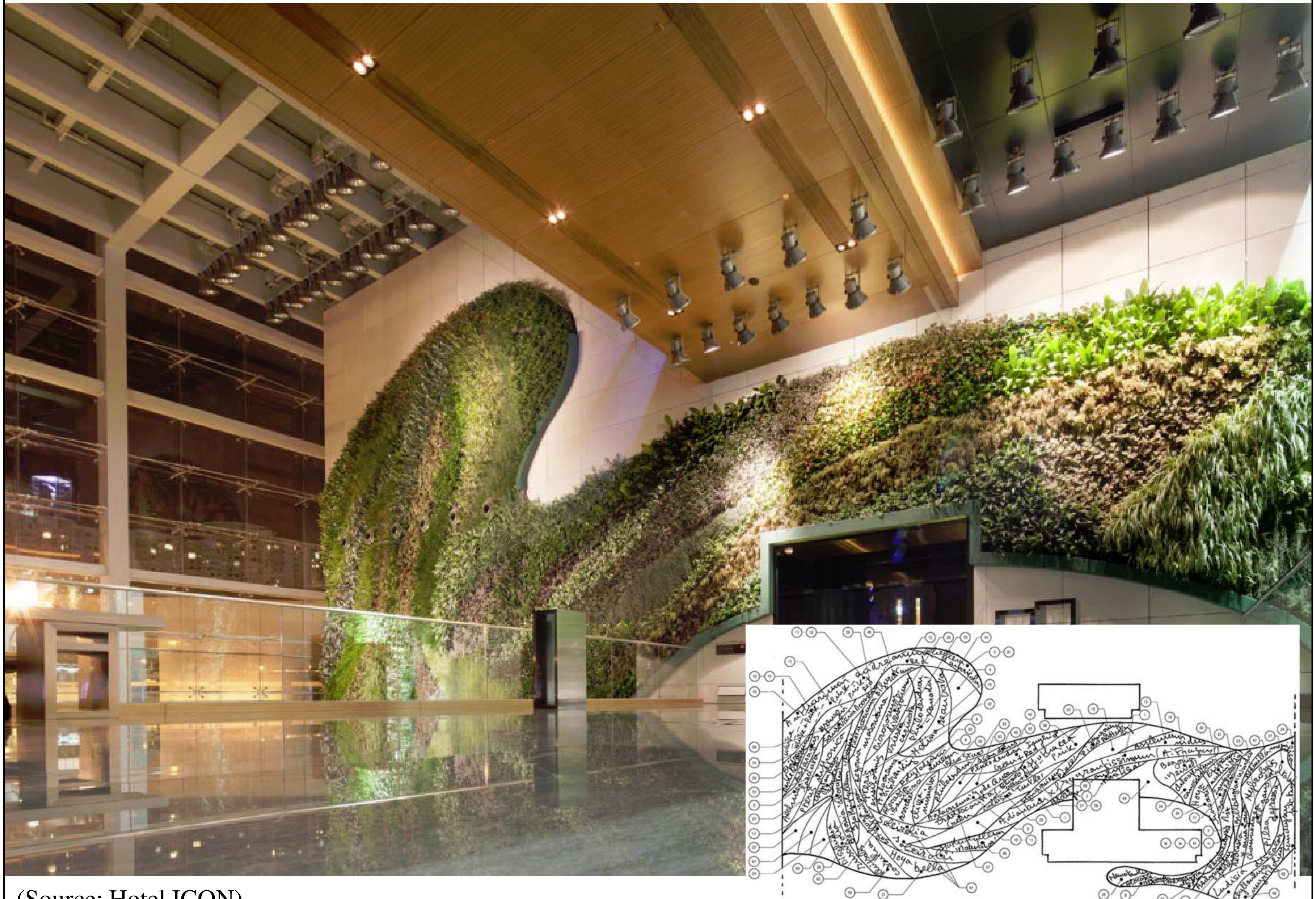
- ***Vertical greening*** – descriptive terms
  - Green walls, living walls, bio-walls, living wall/ cladding, green facades, vertical green, vertical gardens, vegetated wall surfaces
- Possible applications:
  - 1. Building façades or outdoor vertical surfaces
  - 2. Interior walls or indoor vertical surfaces
  - 3. Noise barriers (e.g. along the roads)
  - 4. Slopes and site hoarding boards

Indoor Living Walls

- Cover walls or other structures with vegetation
  - Rooted within those structure, or
  - Survive independently on the structure without the need to root in surrounding soil
- Formed by panels and/or geotextile felts
  - Sometimes pre-cultivated and are fixed to a vertical support or on the wall structure
- Become increasingly popular in buildings (e.g. shopping malls, offices and airports)

Examples of indoor living walls (in Hong Kong and Taipei)

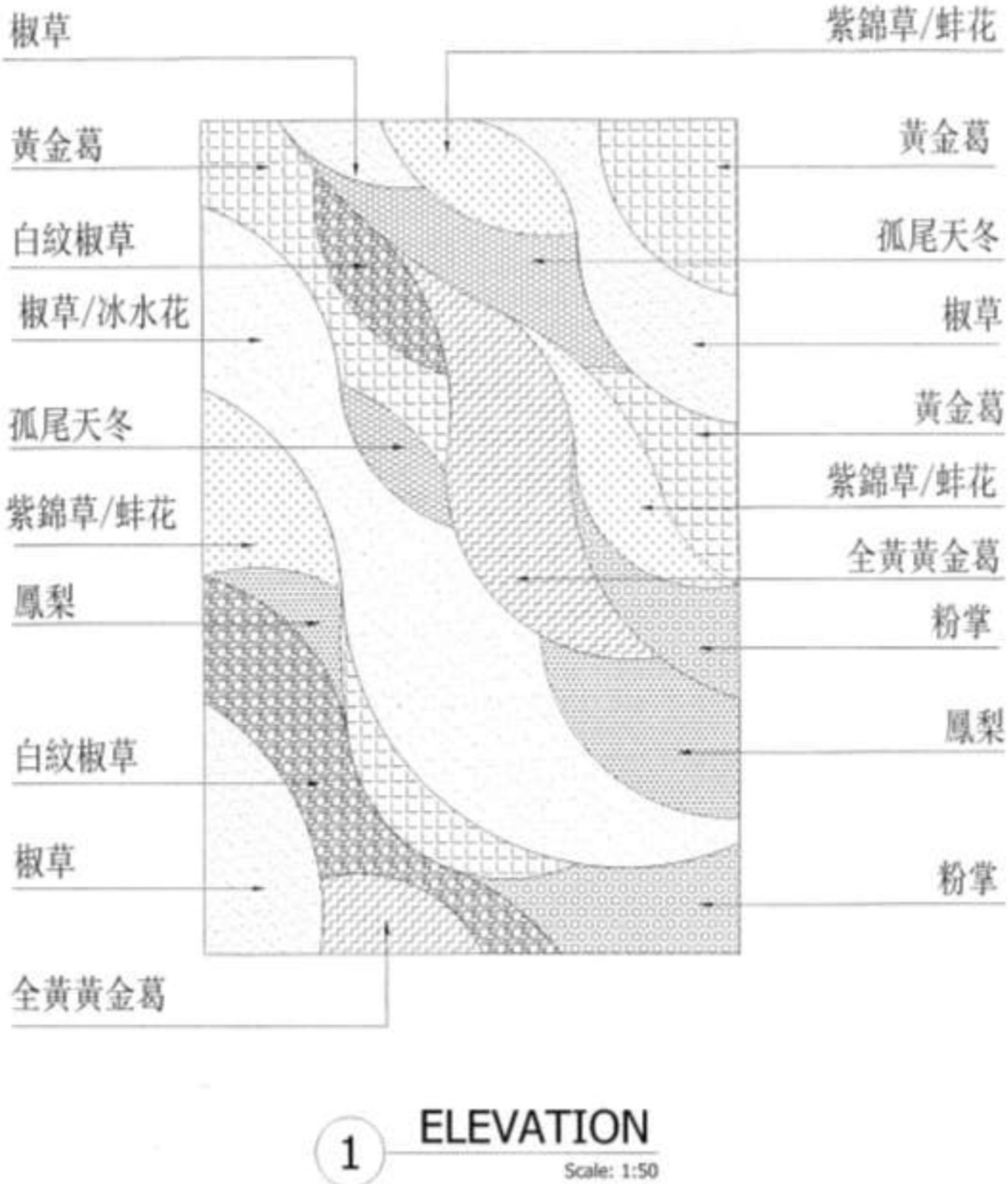
An indoor green wall in a hotel 在酒店的一個室內綠化牆



(Source: Hotel ICON)

Indoor green wall 室內綠化牆

Indoor green wall 室內綠化牆



(City Walk 2, Tsuen Wan)

Indoor Living Walls

- Benefits of indoor living walls
  - Visual and aesthetic aspects (human well-being)
  - Trap dust, reduce air pollution & absorb noise
  - Recycle carbon dioxide by photosynthesis
  - Modulate indoor climate by evapotranspiration and thermal insulation
  - May act as a filter for air-conditioning system and/or a negative ion generator
  - May be used to grow vegetables or flowers

Indoor Living Walls

- Important considerations
  - Provide good aesthetic effects and other ecological and environmental benefits
  - But require materials to build and resources to maintain (e.g. irrigation, lighting)
  - Are the benefits outweigh the costs?
  - Are they sustainable?
  - How to enhance their environmental performance?

Indoor Living Walls

- Current research focused mainly on outdoor façade greening
  - Many studies have been done on outdoor green walls, but very few on indoor living walls
- Need to develop systematic methods for assessing the environmental performance of indoor living walls
  - For planning and designing effective living walls
  - For promoting environmentally sound practices

Life Cycle Assessment (LCA)

- Life cycle assessment (LCA) is a scientific method for evaluating <u>environmental impacts</u>
- LCA is being integrated into green building rating systems, building codes and standards
  - Such as LEED v4, Green Star, California Green Building Code, International Green Construction Code (IGCC), ASHRAE Standard 189.1

Life Cycle Assessment (LCA)

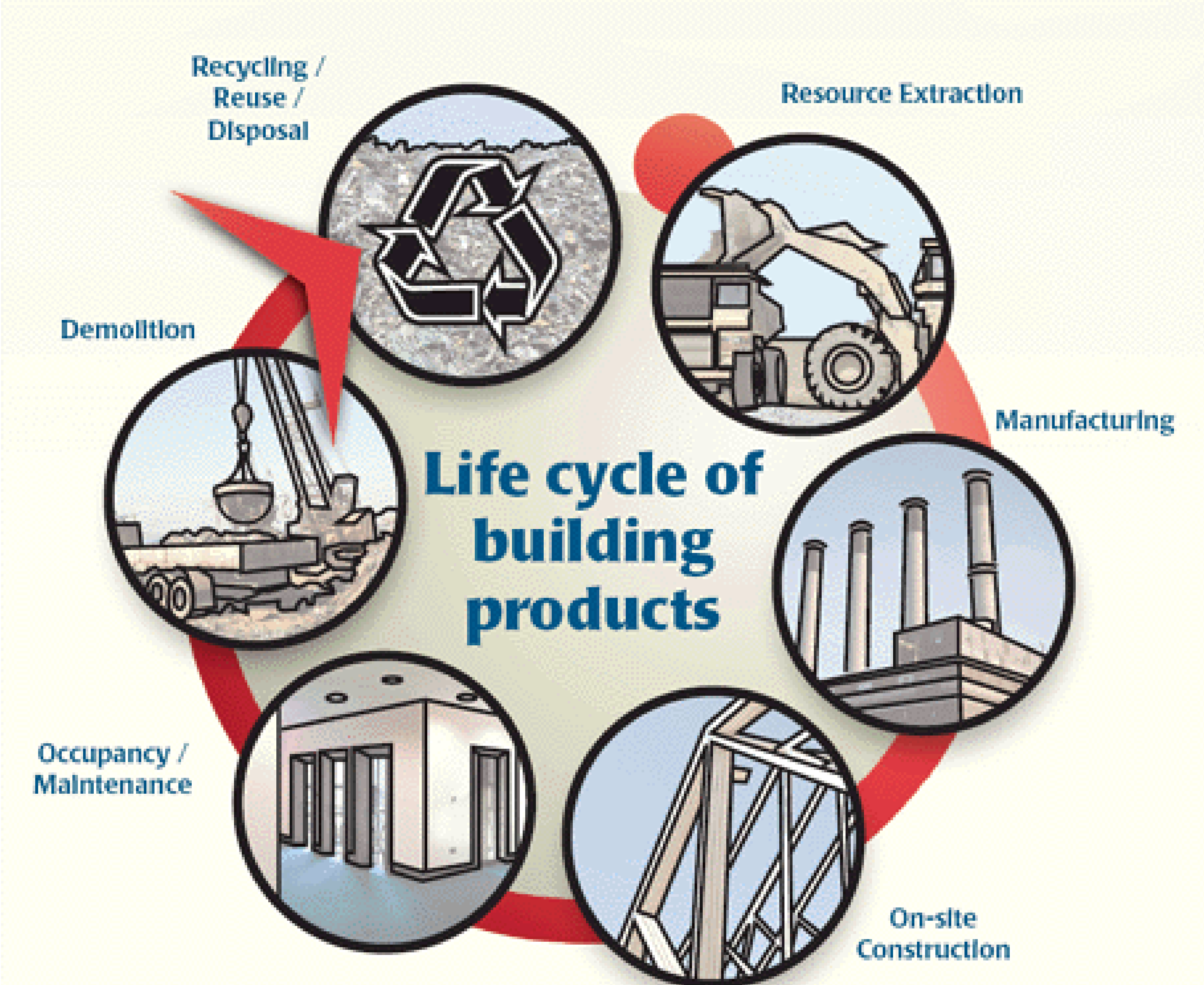
- A brief history of LCA
  - Originated from energy analysis and some claim first LCA carried out by Coca Cola in 1969
  - SETAC (Society of Environmental Toxicology and Chemistry) set first standards in 1990
  - ISO produced series of standards in 1997/98 which were revised in 2006
    - ISO 14040:2006 outlining LCA principles and framework
    - ISO 14044:2006 for requirements and guidelines

Life Cycle Assessment (LCA)

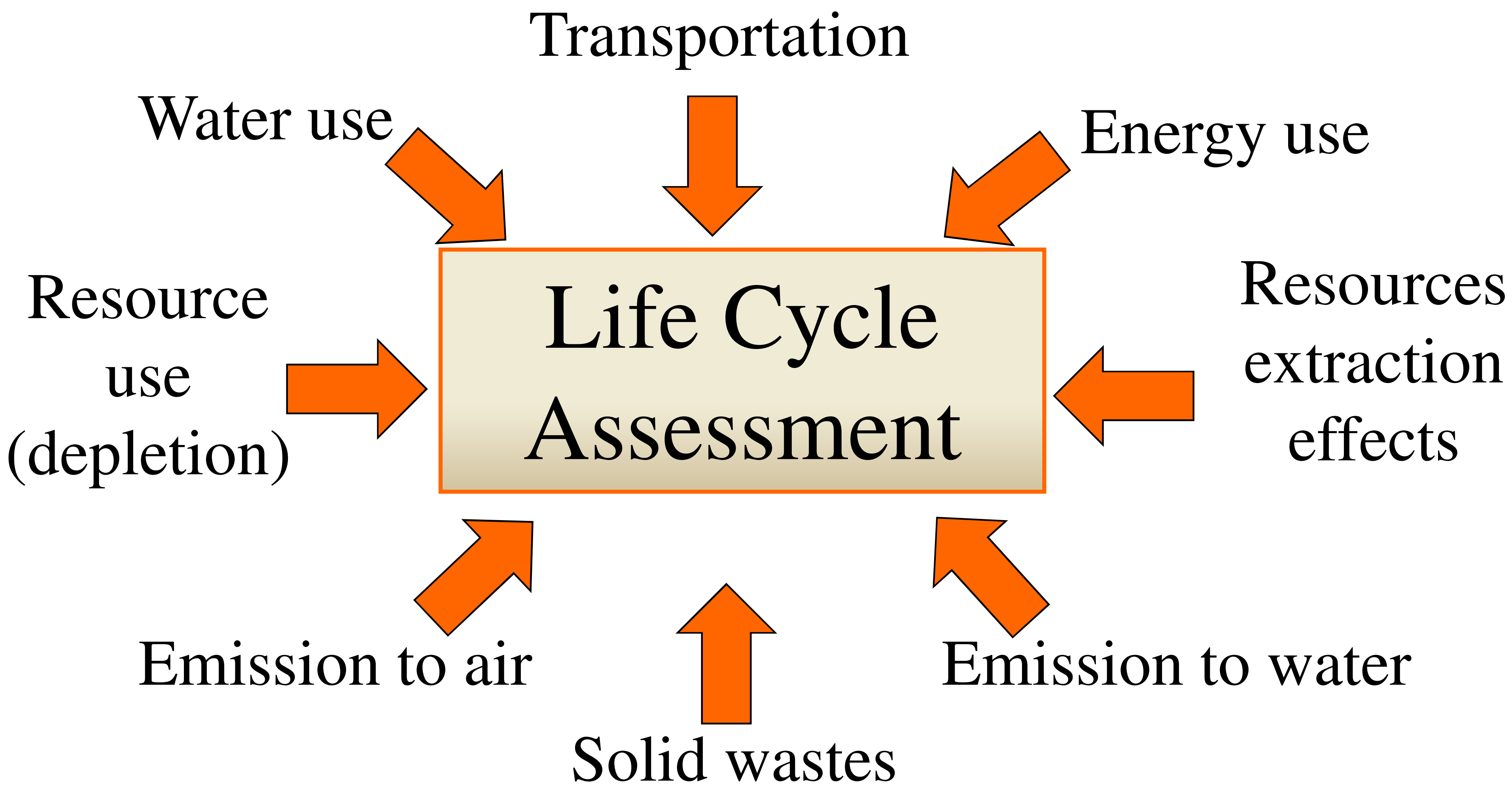
- Definition of Life Cycle Assessment (LCA) [ISO 14040]:
  - "*A compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle*"
- Also called "cradle-to-grave" analysis
- Embodied effects include:
  - Resource use (raw materials, land, water, energy)
  - Emissions to air, water and land

Cradle-to-Grave

Cradle-to-grave is the full Life Cycle Assessment from resource extraction ('cradle') to use phase and disposal phase ('grave').



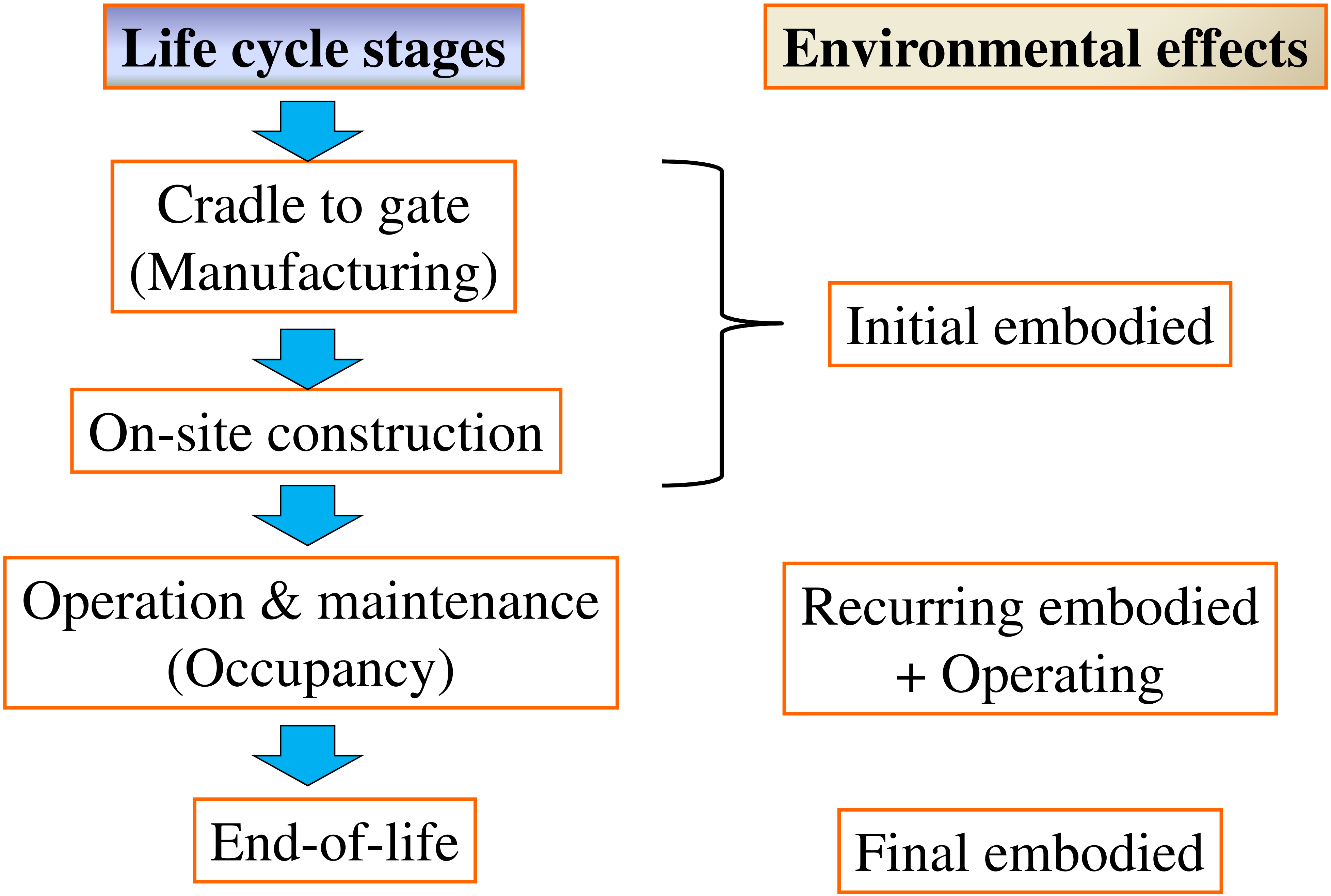
(Source: Athena Institute, www.athenasmi.org)



LCA: a methodology for assessing the life cycle environmental performance of products and processes

(Source: Athena Institute, www.athenasmi.org)

Life cycle stages and effects



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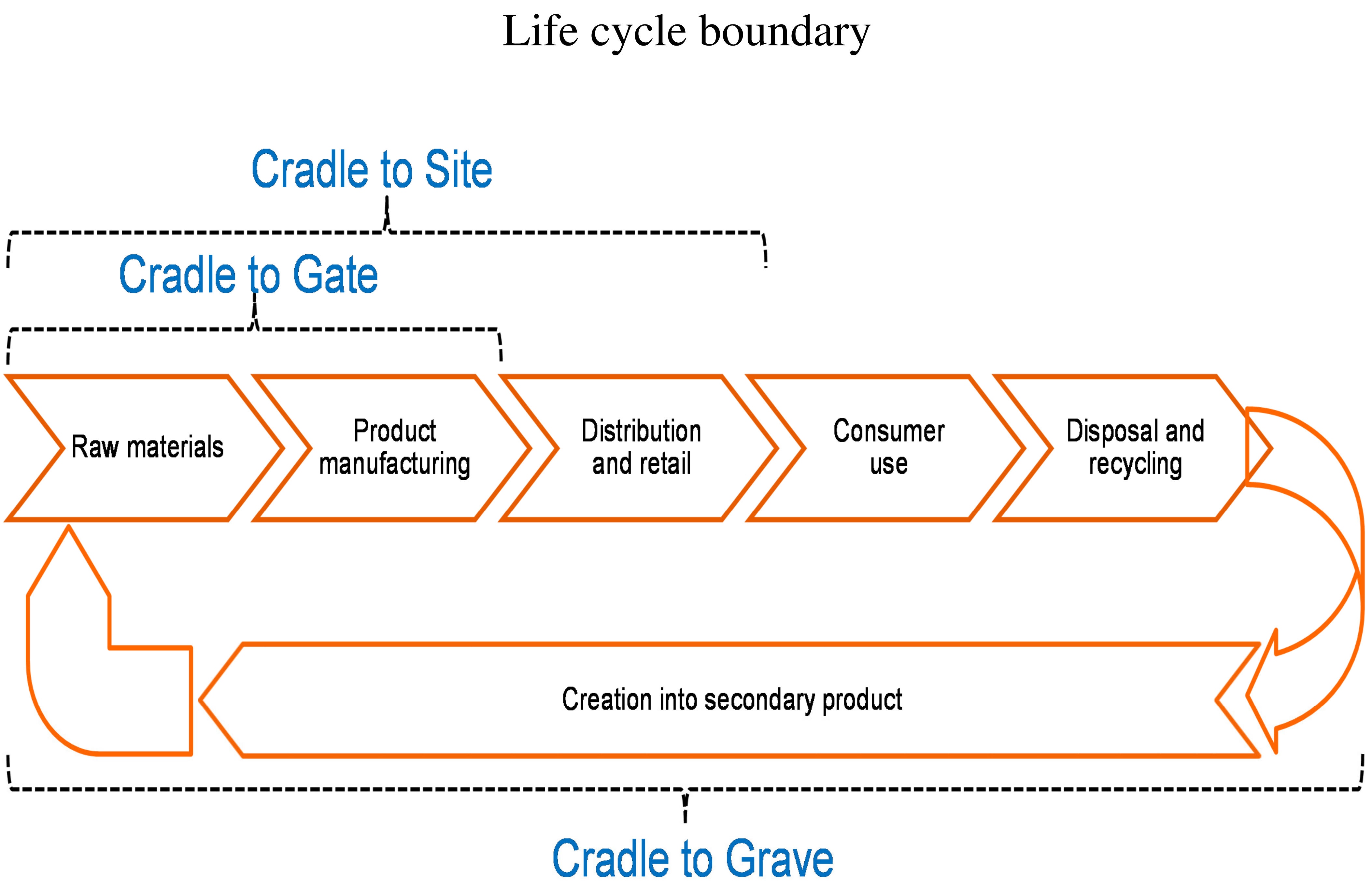
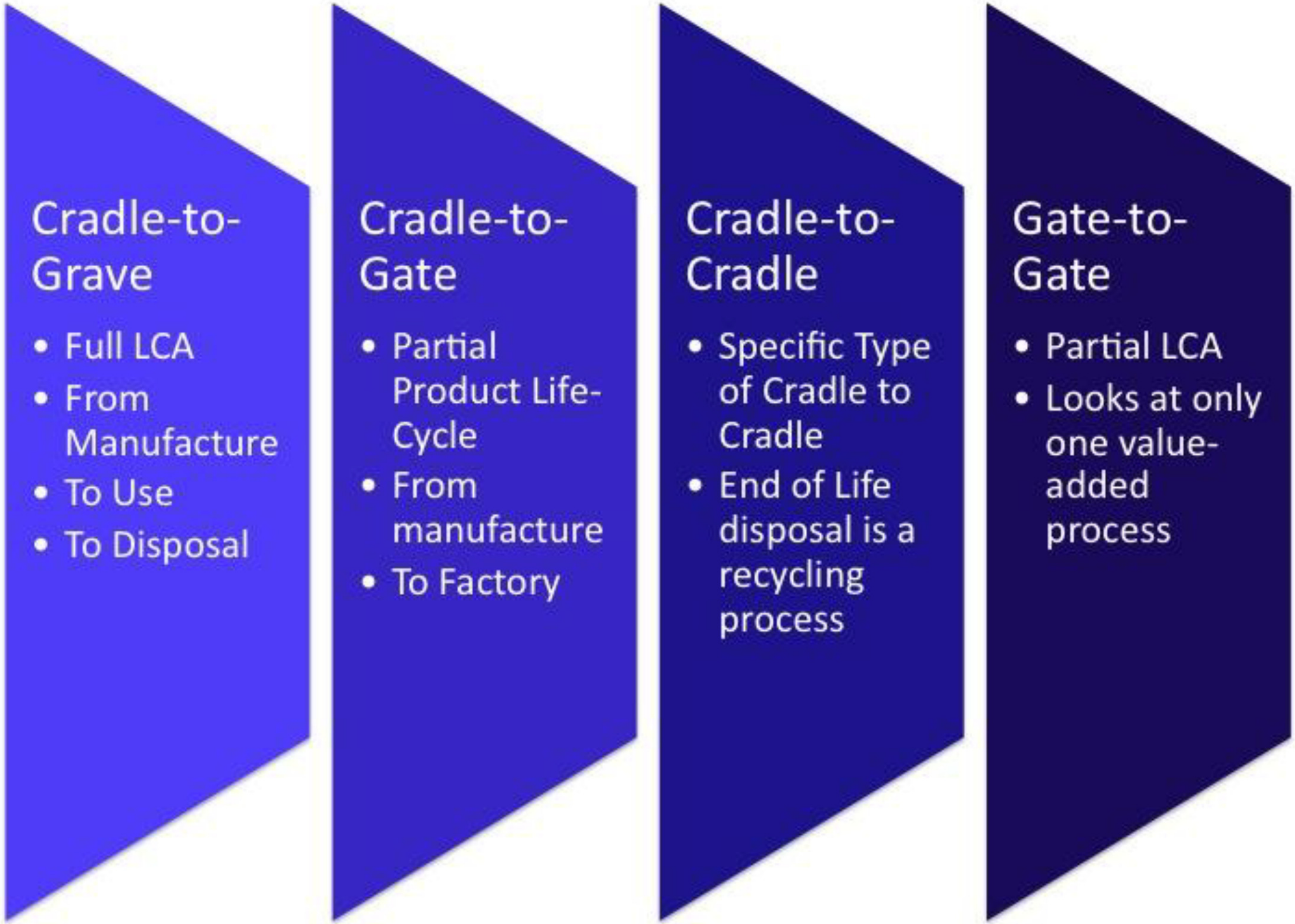

Life cycle boundary
Cradle to Site
Cradle to Gate
Raw materials
Product manufacturing
Distribution and retail
Consumer use
Disposal and recycling
Creation into secondary product
Cradle to Grave

Different options of life cycle assessment

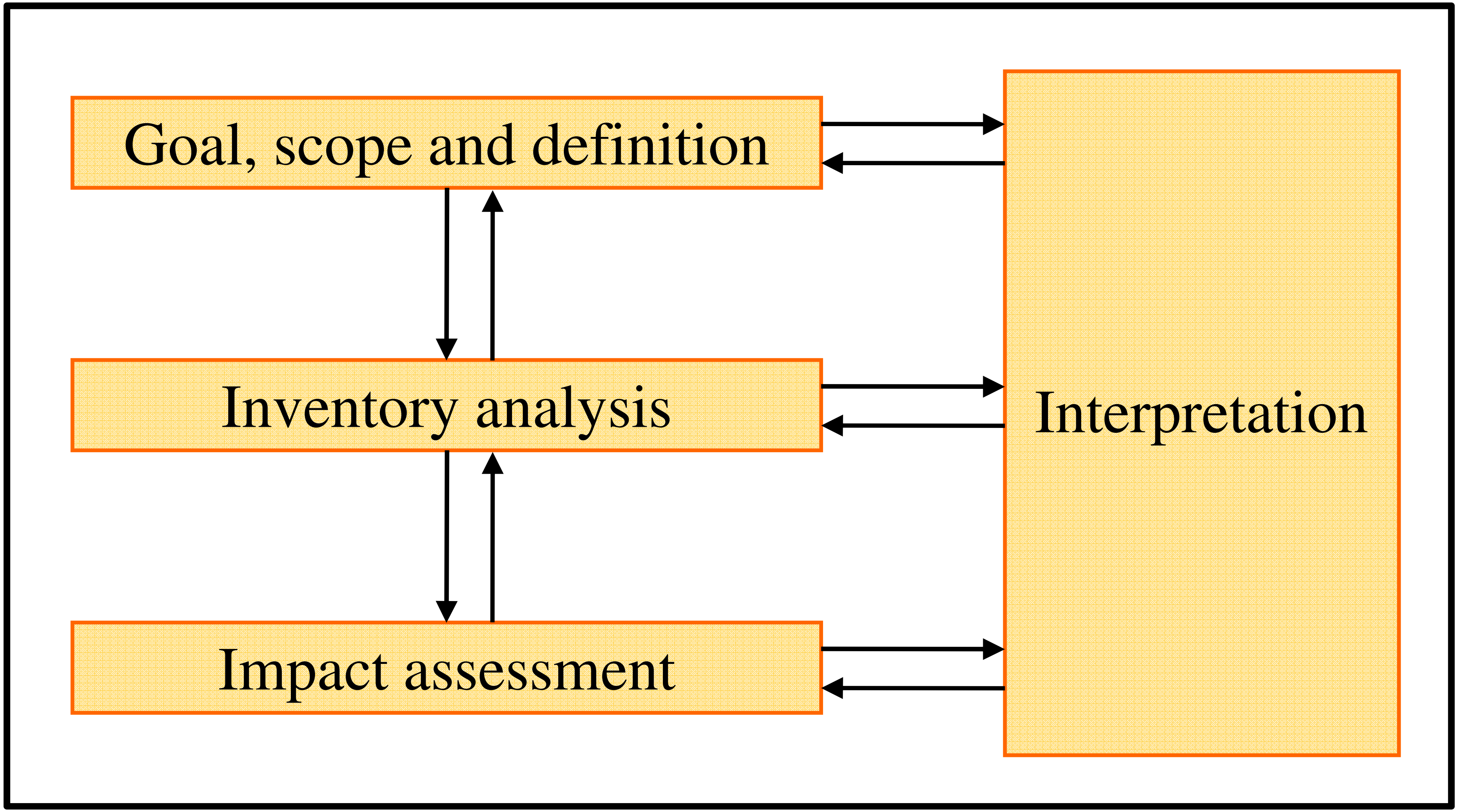


(Source: AIA Guide to Building Life Cycle Assessment in Practice)

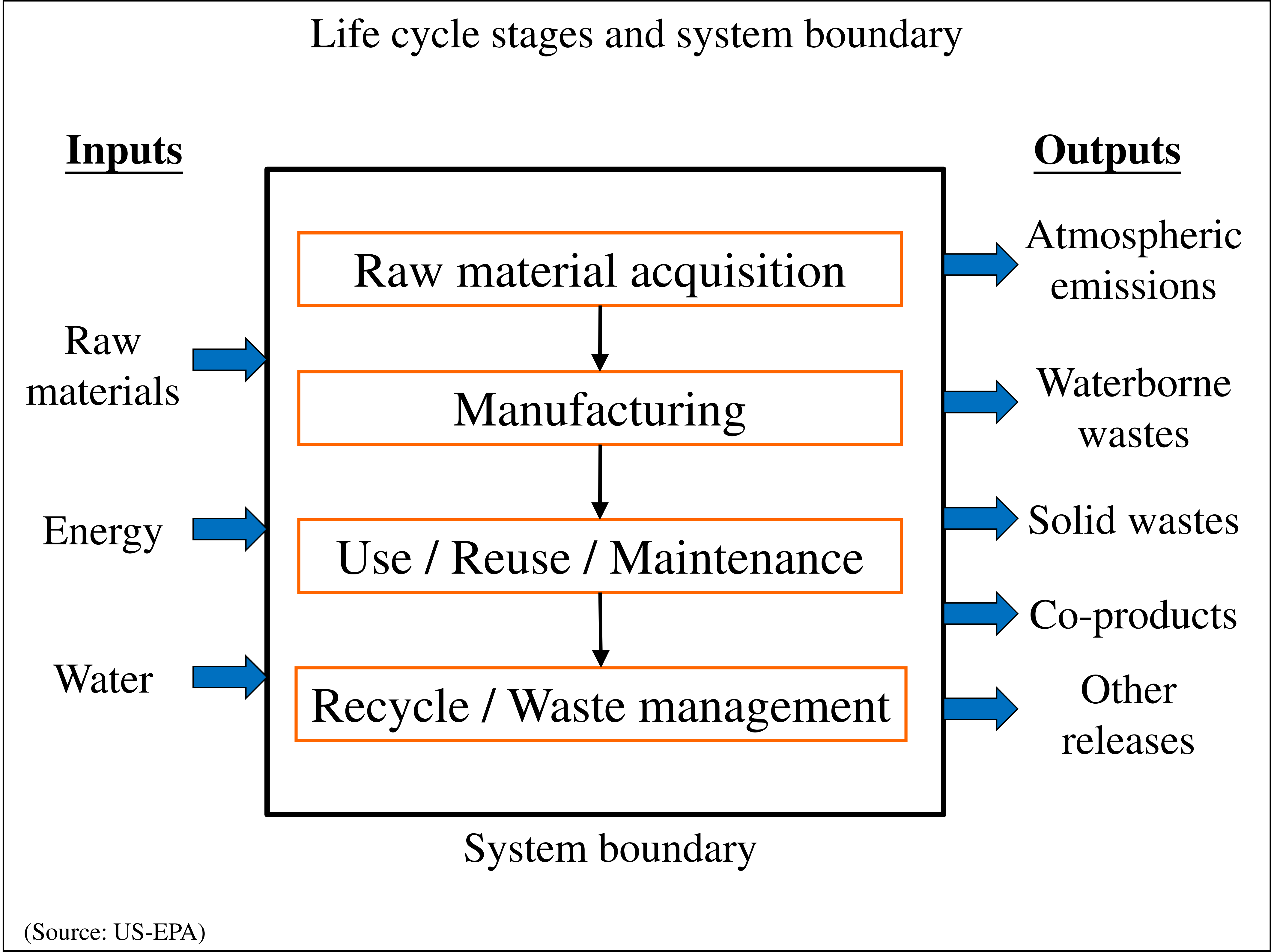
Life Cycle Assessment (LCA)

- The LCA process has four phases:
  - 1) Goal, scope and definition
    - Defines purpose of study, boundaries & functional units
  - 2) Life cycle inventory (LCI)
    - Provides inventory of input/output data
  - 3) Life cycle impact assessment (LCIA)
    - Assess the magnitude and significance of the impacts
  - 4) Life cycle interpretation
    - Provides conclusions and recommendations (areas for improvement)

Life cycle assessment framework
(an iterative process)



(Source: US-EPA)


Life cycle stages and system boundary
Inputs
Raw materials
Energy
Water
Raw material acquisition
Manufacturing
Use / Reuse / Maintenance
Recycle / Waste management
System boundary
Outputs
Atmospheric emissions
Waterborne wastes
Solid wastes
Co-products
Other releases
(Source: US-EPA)

Embodied Energy/Carbon

- LCA with embodied energy and carbon (EE and EC) follows the general frameworks of LCA, but only focuses on EE and EC
  - Also called life cycle energy analysis (LCEA)
  - Embodied energy (EE): MJ/kg (megajoules of energy needed to make a kilogram of product)
  - Embodied carbon (EC): tCO_2/kg (tonnes of carbon dioxide created by the energy needed to make a kilogram of product)

Embodied Energy/Carbon

- An accounting method to find the sum total of the energy and carbon (dioxide) emission necessary for an entire product life-cycle
  - Can help assess environmental impacts & achieve carbon reduction
  - Embodied energy (EE) can be divided into:
    - Initial EE and Recurrent EE
  - Carbon emissions of building materials are made up of direct and indirect carbon emissions

Embodied Energy/Carbon

- Practical considerations:
  - Very few databases on EE and EC data
  - EE and EC calculations were built up by 3 life cycle stages for the indoor living wall systems and components:
    - 1. Embodied stage: Material (initial), transportation (initial), recurrent energy/carbon
    - 2. Construction stage: Construction energy/carbon
    - 3. Operation stage : Operation energy/carbon
  - The sum is the total life cycle energy/carbon

Embodied Energy/Carbon

- Investigation on 5 cases:
  - Bare wall (brick)
  - Planter boxes type living wall system + bare wall
  - Felt layers type living wall system + bare wall
  - Mineral wool type living wall system + bare wall
  - Foam type living wall system + bare wall
- The functional unit adopted is 1 m^2 of wall area and a fictitious façade of 100 m^2 (20 m length $\times$ 5 m height) is used as the basis

Table 1. LCA with embodied energy analysis

Life Cycle Stages	**Energy Breakdown** (MJ/m^2)	**Types of Living Walls**				
		1. Bare Wall	**2. Planter Boxes**	**3. Felt Layer**	**4. Mineral Wool**	**5. Foam**
Embodied Stage	Material (initial)	743.05	2017.30	1620.37	1533.17	1655.41
	Transportation (initial)	20.06	27.71	20.67	20.66	20.67
	Recurrent Energy	0.00	301.33	2751.22	683.86	2891.41
Construction	Construction Energy	23.15	89.75	71.61	70.41	73.36
Operation	Operation Energy	0.00	5466.38	5466.67	5466.53	5466.38
Total Life Cycle Energy (MJ/m^2)		786.26	7902.48	9930.54	7794.63	10107.24

Table 2. LCA with embodied carbon analysis

Life Cycle Stages	**Carbon Breakdown** (kg CO_2/m^2)	**Types of Living Walls**				
		1. Bare Wall	**2. Planter Boxes**	**3. Felt Layer**	**4. Mineral Wool**	**5. Foam**
Embodied Stage	Material (initial)	88.27	141.47	142.24	147.28	135.17
	Transportation (initial)	0.50	1.39	0.57	0.57	0.57
	Recurrent Carbon	0.00	32.15	136.48	50.32	108.22
Construction	Construction Carbon	2.81	5.40	5.52	5.92	5.21
Operation	Operation Carbon	0.00	622.56	622.59	622.58	622.56
Total Life Cycle Carbon (kg CO_2/m^2)		91.58	802.97	907.42	826.67	871.73

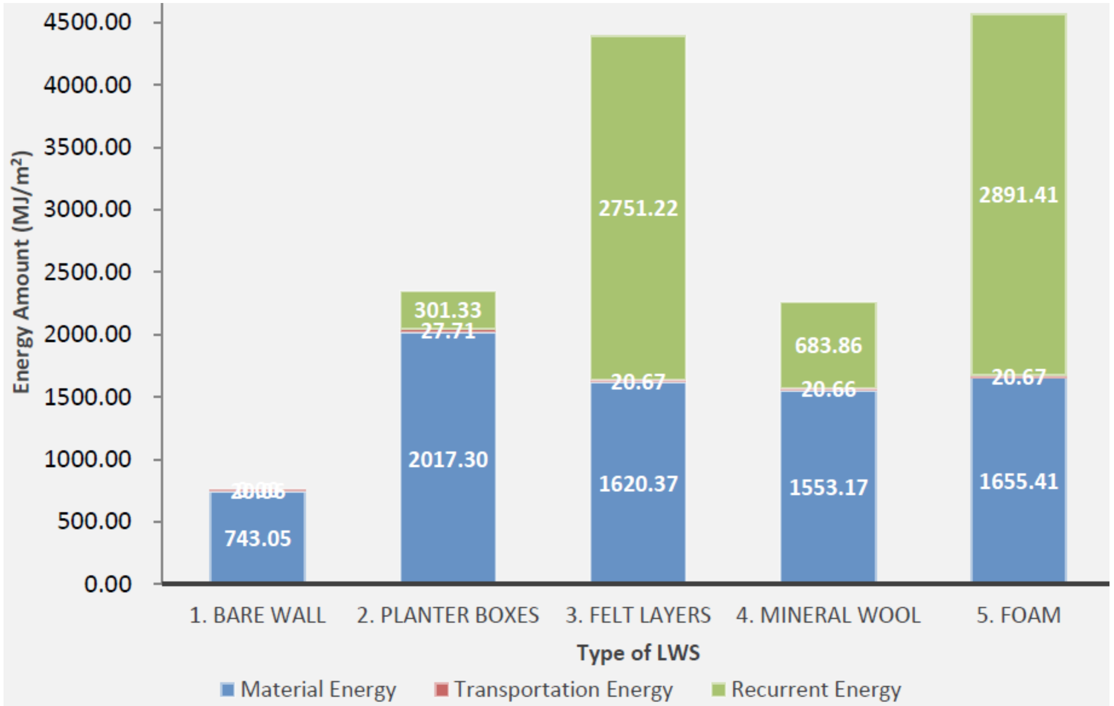


Figure 3. Comparison of embodied energy for living wall systems

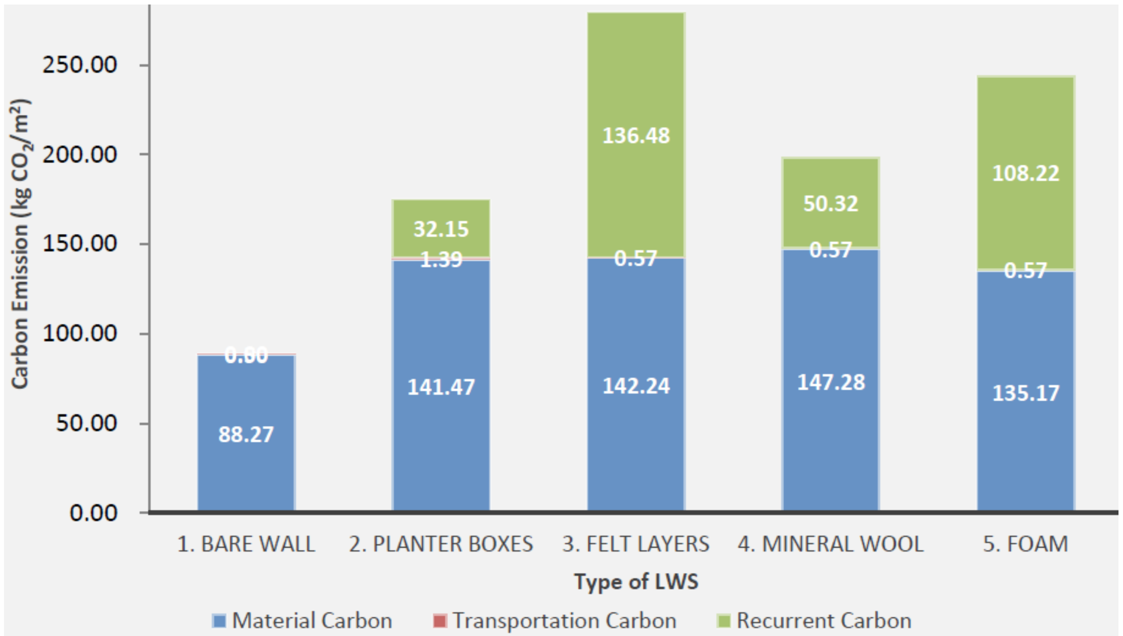


Figure 4. Comparison of embodied carbon for living wall systems

Embodied Energy/Carbon

- Indoor living walls could be more environmentally sound if the following measures are applied:
  - Recycled materials (for the components)
  - Renewable energy (provide electricity for pumping and lighting)
  - Sustainable design and maintenance practices, e.g.
    - Have access to natural daylight and air through windows and/or skylights
    - Integrate with rainwater or greywater recycling systems

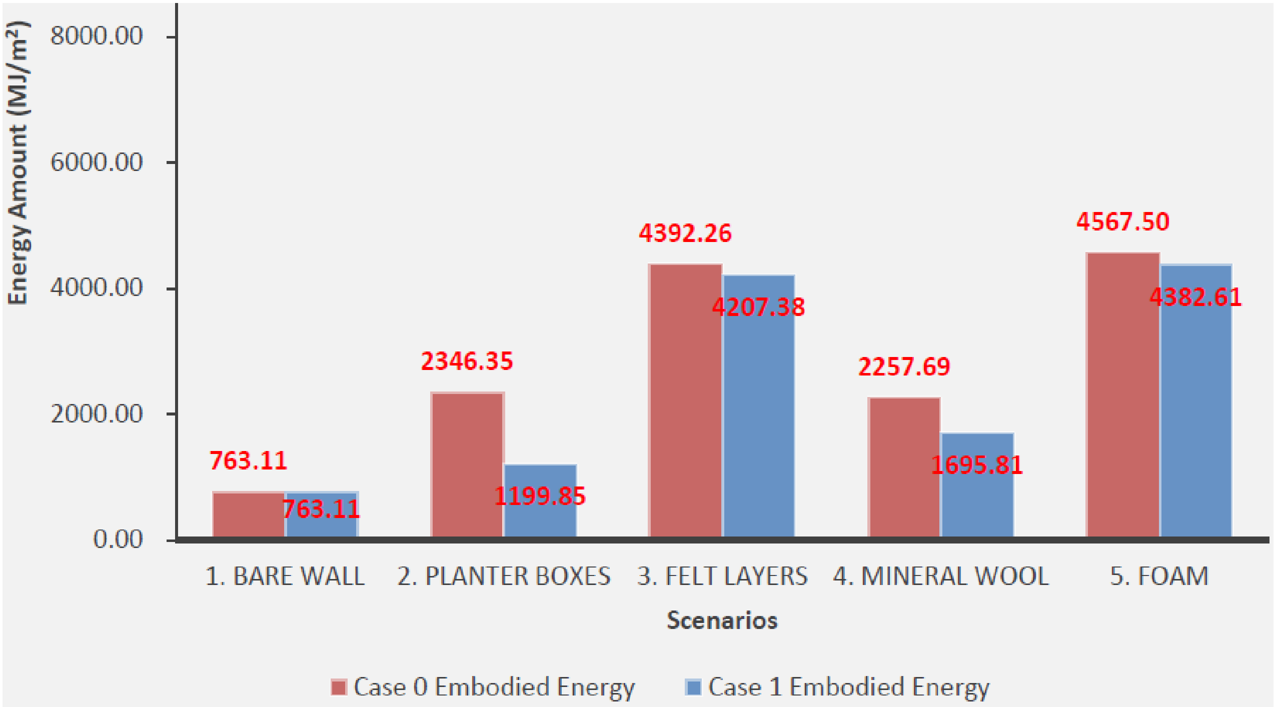


Figure 5. Effects of recycling materials on embodied energy for living wall systems

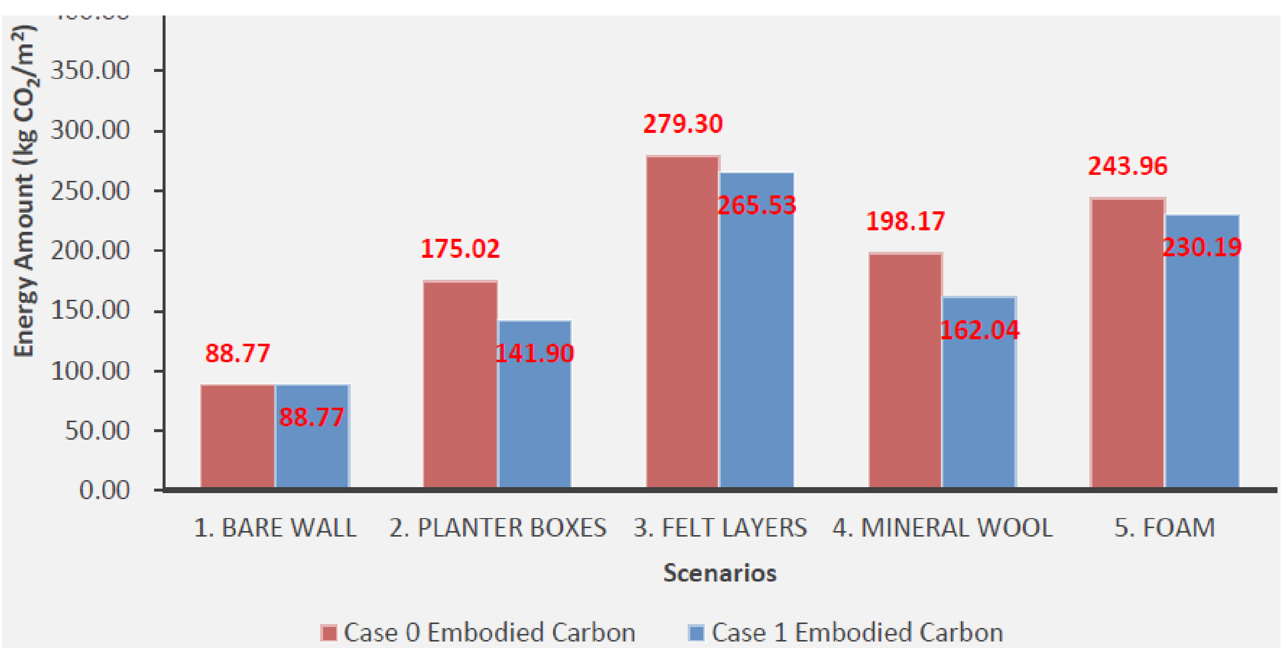


Figure 6. Effects of recycling materials on embodied carbon for living wall systems

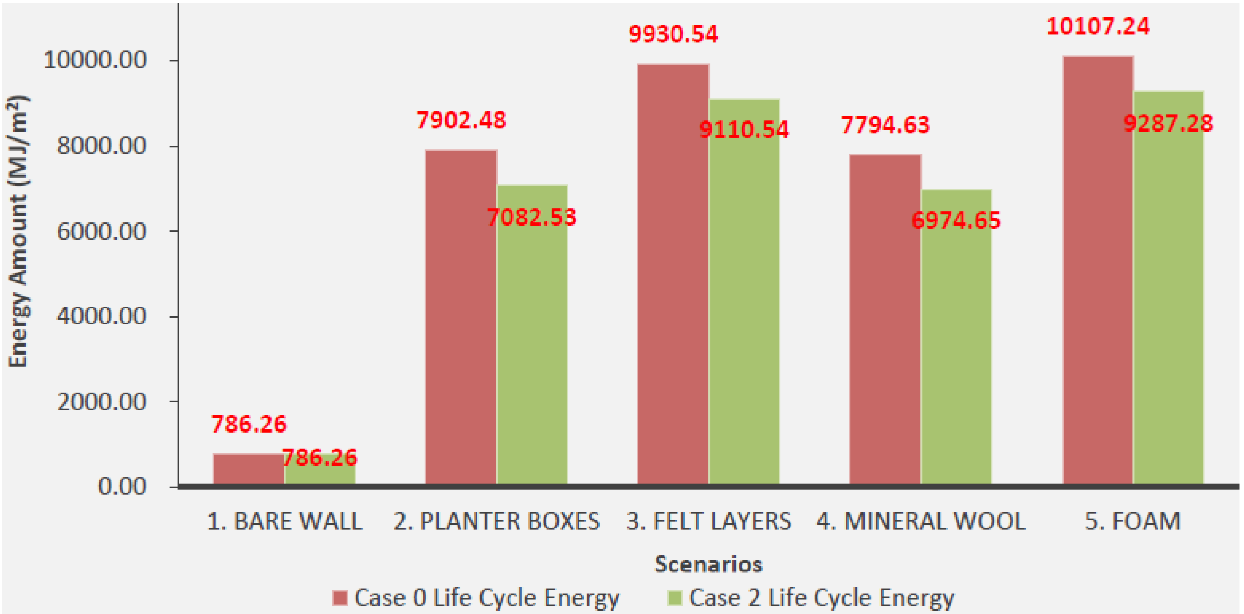


Figure 7. Effects of renewable energy for operation stage on life cycle energy for living wall systems

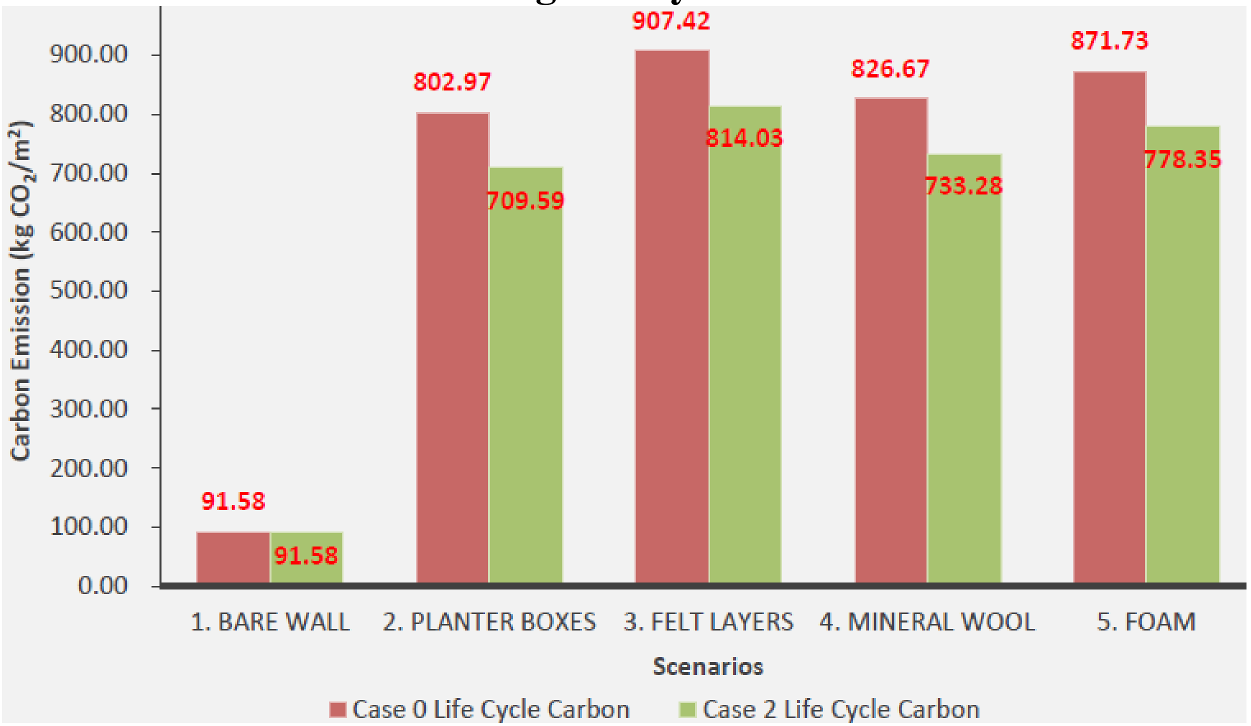


Figure 8. Effects of renewable energy for operation stage on life cycle carbon for living wall systems

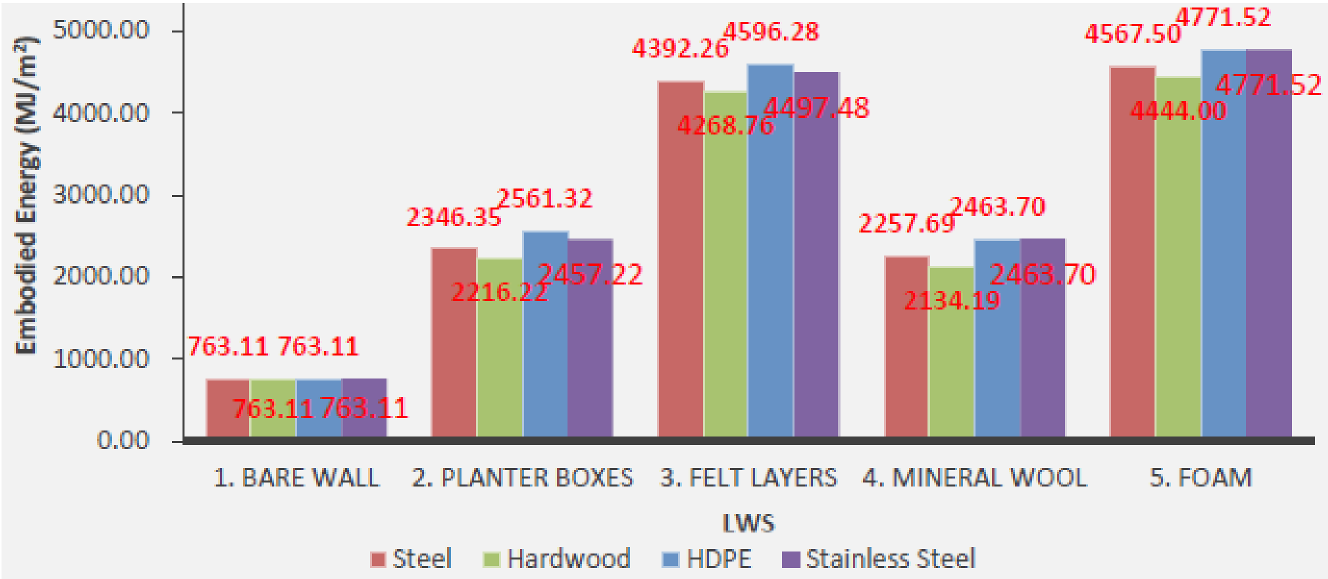


Figure 9. Effects of material substitution of support structural frame on embodied energy for living wall systems

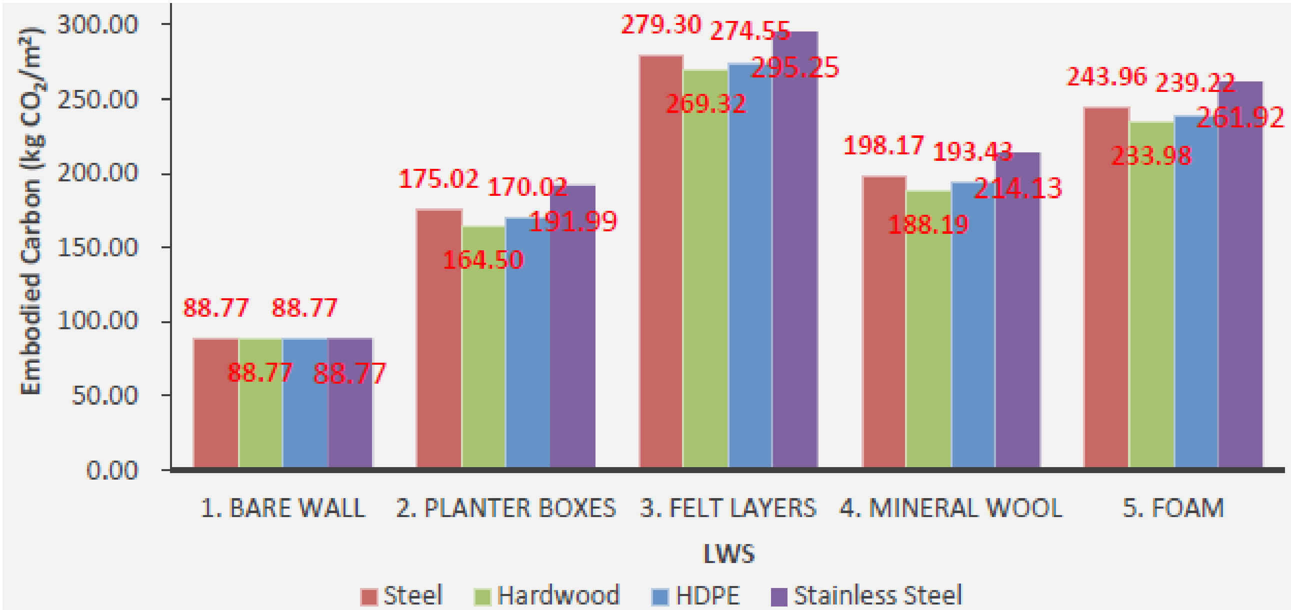


Figure 10. Effects of material substitution of support structural frame on embodied carbon for living wall systems

Conclusions

- Indoor living walls are growing very fast
- LCA with embodied energy/carbon has been used for assessing their environmental impacts
- Could be more environmentally sound if recycled materials, renewable energy and sustainable design and maintenance practices are applied
- Essential to improve their performance as people now spend most of time staying indoor

THANK YOU 多謝 !!

(More information: www.hku.hk/bse/greenroof/)