Carbon Footprint Measurement of Construction Materials Using Life Cycle Assessment

Dr Jack C.P. Cheng (Speaker), ***Assistant Professor***
Ir Prof Irene M.C. Lo, ***Professor***
Department of Civil and Environmental Engineering
The Hong Kong University of Science and Technology

Ir Desmond M.S. Sze, ***Operations Manager***
Mr Anfernee K.P. Chow, ***Environmental Officer***
Leighton Contractors (Asia) Limited

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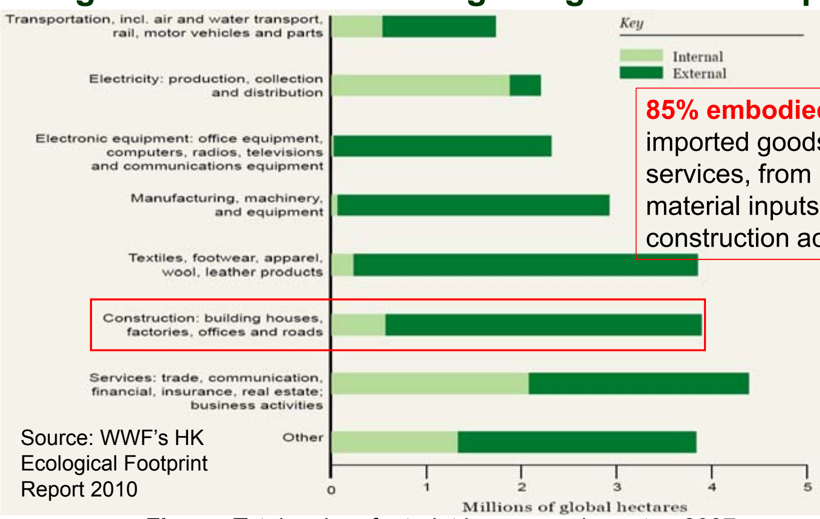
Motivation – The Construction Sector is the 2nd Largest Contributor to Hong Kong Carbon Footprint



85% embodied in imported goods and services, from upstream material inputs to construction activities.

Source: WWF's HK Ecological Footprint Report 2010

Figure: Total carbon footprint by economic sector, 2007

Steel Formwork or Timber Formwork?

- Which one is more environmentally friendly, steel formwork or timber formwork?
  - What is the carbon emission of the transportation from suppliers?
  - What is the carbon emission of the material manufacturing process?
  - What is the amount of steel/timber required in each formwork?
  - What is the **carbon footprint embodied in each unit of steel/timber**?

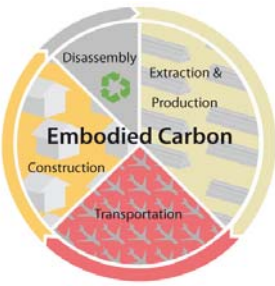
Steel Formwork

Timber Formwork

Embodied Carbon (EC)

- "The embodied carbon of a building material can be defined as the total carbon released over its life cycle. This would normally include (at least) extraction, manufacturing and transportation. Ideally the boundaries would be set from the extraction of raw materials (incl. fuels) until the end of the products lifetime."

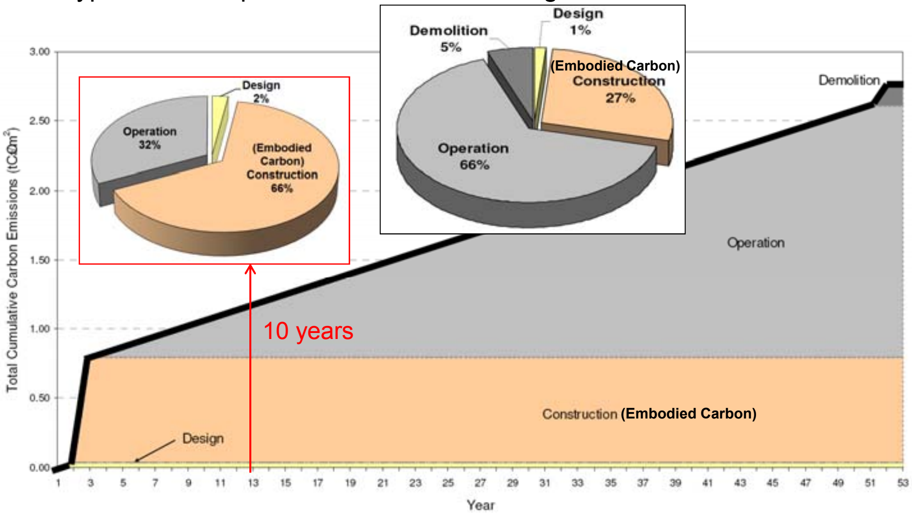
  (Hammond and Jones, 2008)



- There is increasing recognition of embodied carbon for evaluation of low carbon buildings.

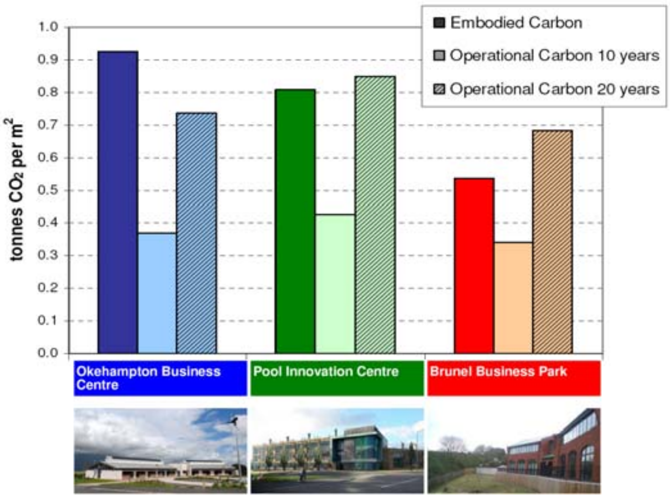
Importance of Embodied Carbon

- A typical carbon profile for an office building:



Source: South West of England Regional Development Agency. (2010). "Embodied Carbon – Sustainable Offices"

Importance of Embodied Carbon
– Case Studies of 3 Office Buildings in UK



Source: South West of England Regional Development Agency. (2010). "Embodied Carbon – Sustainable Offices"

Motivation – We Need a Local Construction Material Embodied Carbon Database for Hong Kong

- An embodied carbon database for construction materials can (1) provide a benchmark for green material selection and green label development, and (2) provide a basis for prediction and estimation of carbon footprint.
- Embodied carbon values are **region-specific**.

Region	Construction Life Cycle Inventory (LCI)	Institution	System Boundary
Swiss	**Ecoinvent**	Swiss Centre for Life Cycle Inventories	Gate-to-gate
Europe	**ELCD** (European reference Life Cycle Database)	European Union	Cradle-to-gate
United Kingdom	**ICE** (Inventory of Carbon and Energy)	University of Bath, UK	Cradle-to-gate
China	**CLCD** (Chinese reference Life Cycle Database)	Sichuan University, China; IKE Environmental Technology Co. Ltd	Cradle-to-gate
Korea	**Korea LCI Database**	Korea Institute of Industrial Technology; Ministry of Environment	Cradle-to-gate
Hong Kong	**None**		

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United Kingdom	**ICE** (Inventory of Carbon and Energy)	University of Bath, UK	Cradle-to-gate
China	**CLCD** (Chinese reference Life Cycle Database)	Sichuan University, China; IKE Environmental Technology Co. Ltd	Cradle-to-gate
Korea	**Korea LCI Database**	Korea Institute of Industrial Technology; Ministry of Environment	Cradle-to-gate
Hong Kong	**ECO-CM Database**	Dept. of Civil and Environmental Engineering, HKUST	Cradle-to-site; C-to-G; G-to-G

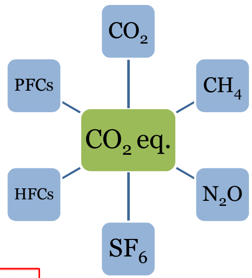
Objectives

- To investigate the **carbon footprint of Hong Kong construction materials** (e.g. cement) based on the concept of **Life Cycle Assessment (LCA)**, by collecting **first-hand data** from the industry.

- To **develop a carbon footprint database** of commonly used construction materials in Hong Kong for the **"cradle-to-site" life cycle**. Such a database could help to lower the construction's carbon footprint by providing a benchmark and a basis for estimation.

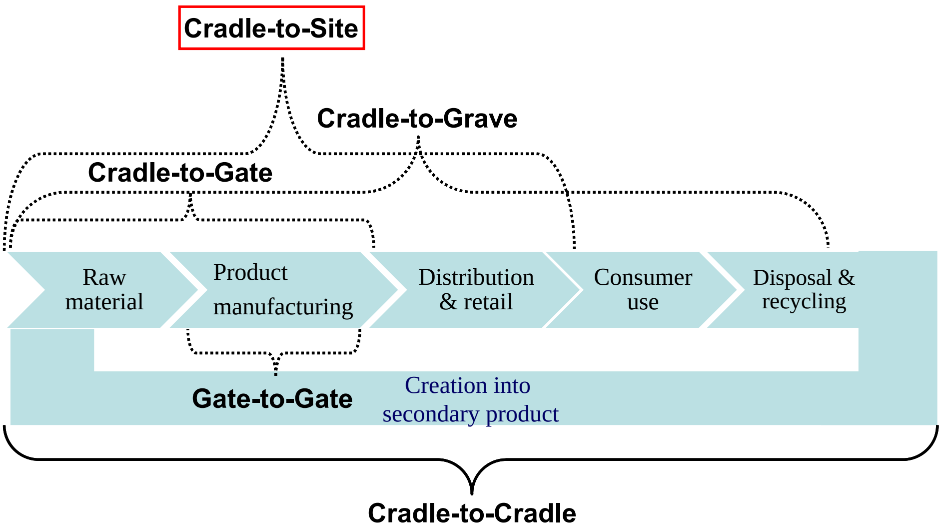
Both CO_2 and CO_2-e Are Measured

- Greenhouse gases (GHGs) refers to the gases that trap heat in the atmosphere. (USEPA, 2009)
- We not only measure the carbon footprint in terms of carbon dioxide (CO_2), but in terms of carbon dioxide equivalent (CO_2-e) using the six GHGs identified in Kyoto Protocol (1997):
  - Carbon dioxide (CO_2)
  - Methane (CH_4)
  - Nitrous oxide (N_2O)
  - Hydro-fluorocarbons (HFCs)
  - Per-fluorocarbons (PFCs)
  - Sulfur hexafluoride (SF_6)



$$CO_2\text{-}e = \sum_i (GHG_i \times Global\_Warming\_Potential_i)$$

Boundary of Life Cycle



Method 1: 'Localization' of Other Carbon Databases

Cradle-to-Gate

- Refer to embodied carbon databases in other countries
- Assume the same manufacturing process
- Adjust the fuel and electricity emission factors based on the supplier locations to "localize" the cradle-to-gate values

Cradle-to-Site

- Cradle-to-Gate + Transportation
- Consider transportation means, fuel types, distance, etc.

Example: Wood Boards from New Zealand

Energy sources for (plywood) wood boards production according to Bath U ICE				
Energy source	% of Embodied Energy from energy source	Emission Factors for NZ (t CO_2/MWh)	Emission Factors for NZ (t CO_2/MJ)	Equivalent emission factor for NZ (t CO_2/MJ)
Coal	0.0%	✗		
LPG	0.0%			
Oil	5.6%	0.2667 [1]	7.40833E-05	4.14867E-06
Natural gas	39.5%	0.202 [1]	5.61111E-05	2.21639E-05
Electricity	54.9%	0.159 [2]	4.41667E-05	2.42475E-05
Other	0.0%			
Total	**100.0%**			**5.05601E-05**

Unit conversion:
1 MWh = 3600 MJ

(Multiply)

Embodied Energy of Timber, Plywood in ICE database	**15**	MJ/kg
NZ-based Embodied Carbon of Timber, Plywood in ICE database:	**0.77**	kg CO_2/kg

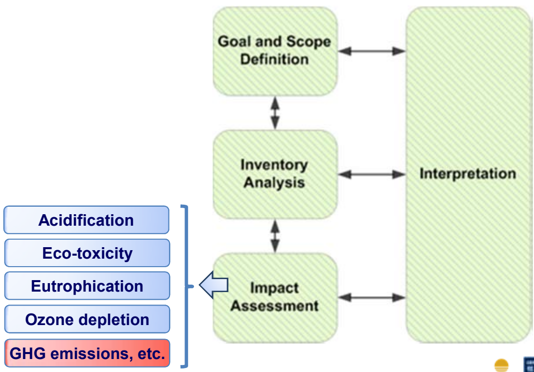
In Bath U ICE:
Timber, Plywood:
EE: 15 MJ / kg
EC: 0.81 kg CO_2/kg

+ transportation ➔ Cradle-to-site

[1] UNEP (2000): The GHG Indicator: UNEP Guidelines for Calculating Greenhouse Gas Emissions for Businesses Organizations.
[2] International Energy Agency, Electricity Information Database 2007 and CO2 Emissions from Fuel Combustion Database 2006

Method 2: Life Cycle Assessment (LCA)

- **Life cycle assessment (LCA)** is a technique evaluating the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. (ISO 14040:2006)
- LCA can assist in identifying opportunities to improve the environmental performance of products at various points in their life cycle.

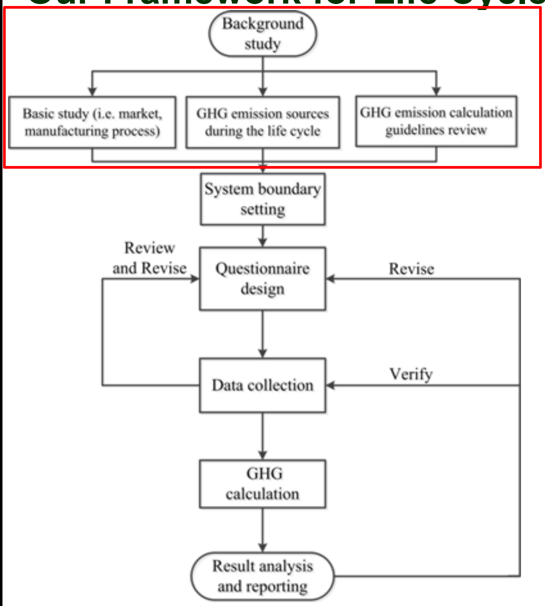


Standards

- The following standards are referenced when we developed our methodology framework.

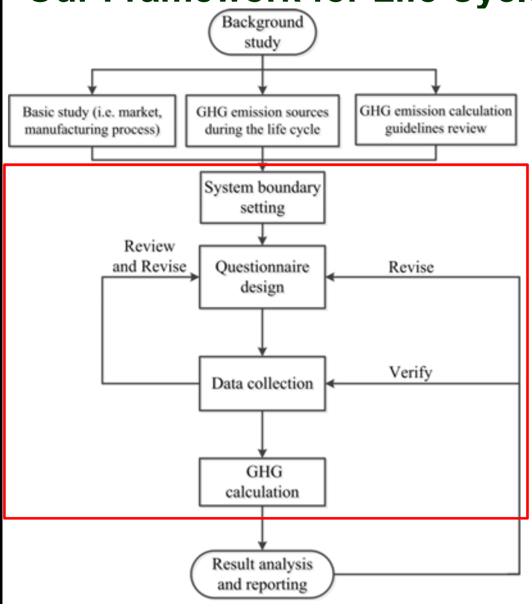
Standards	Areas
ISO 14040:2006 Environmental management - Life cycle assessment - Principles and framework	LCA
ISO 14044:2006 Environmental management - Life cycle assessment - Requirements and guidelines	LCA
ISO 14064-1:2006 Greenhouse gases - Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals	GHG Auditing (Organizational)
PAS 2050:2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and service	GHG Auditing (Product)
ISO 14067 Carbon footprint of products -- Requirements and guidelines for quantification and communication **(Not yet released)**	GHG Auditing (Product)

Our Framework for Life Cycle Carbon Measurement



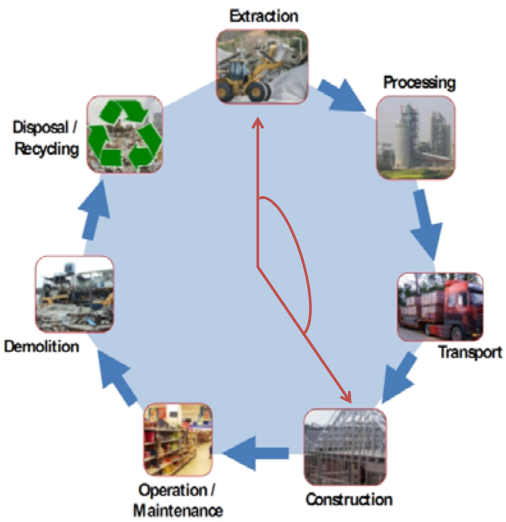
- **Background study** (for each construction material):
  - Identify the material suppliers who supply the construction material to the Hong Kong market
  - Study the material types and manufacturing process
  - Develop the process map and the possible GHG emissions in each process
  - Review standard GHG emission calculation and auditing guidelines for the material, if any

Our Framework for Life Cycle Carbon Measurement



- Set the system boundary
- Design the questionnaire according to the background study and system boundary
- Contact the suppliers for data collection
- Calculate using standardized methods, e.g. IPCC

Example: Cement – Scope of Measurement



Cradle-to-site life cycle:
- Raw materials extraction
- Manufacturing process
- Transportation to site

Cement is presented as an illustrative example in the following.
- One of the most important and commonly used building materials.

Types of Cement

- According to American Society for Testing and Materials (ASTM):

Types and Applications of Standard Portland Cement (ASTM C150)				
Types	**Name**	**Composition**	**Limitation**	**Application**
Type I	Ordinary	55% (C_3S), 19% (C_2S), 10% (C_3A), 7% (C_4AF), 2.8% MgO, 2.9% (SO_3), 1.0% Ignition loss, and 1.0% free CaO	$C_3A \leqq 15\%$	General use; when special properties are not required, floors, reinforced concrete structures, pavements, etc.
Type II	Moderate Sulfate Resistance	51% (C_3S), 24% (C_2S), 6% (C_3A), 11% (C_4AF), 2.9% MgO, 2.5% (SO_3), 0.8% Ignition loss, and 1.0% free CaO	$C_3A \leqq 8\%$	General use; has moderate sulfate resistance and heat of hydration; large piers, heavy abutments, retaining walls.
Type III	High Early Strength	57% (C_3S), 19% (C_2S), 10% (C_3A), 7% (C_4AF), 3.0% MgO, 3.1% (SO_3), 0.9% Ignition loss, and 1.3% free CaO	$C_3A \leqq 15\%$	When high early strength is required, fast-track construction, suitable in cold wheater.
Type IV	Low Heat of Hydration	28% (C_3S), 49% (C_2S), 4% (C_3A), 12% (C_4AF), 1.8% MgO, 1.9% (SO_3), 0.9% Ignition loss, and 0.8% free CaO.	$C_3A \leqq 7\%$, $C_2S \geq 40\%$, $C_3S \leqq 35\%$	When low heat of hydration is required, used when mass of construction, such as large dams.
Type V	High Sulfate Resistance	38% (C_3S), 43% (C_2S), 4% (C_3A), 9% (C_4AF), 1.9% MgO, 1.8% (SO_3), 0.9% Ignition loss, and 0.8% free CaO	$C_3A \leqq 5\%$, $(C_4AF) + 2(C_3A) \leqq 20\%$	High sulfate resistance is required, 0.2-2.0% weight mater soluble sulfate in soils or 1500-10800 ppm sulfate in water

Types of Cement

- According to National Standard of People's Republic of China:

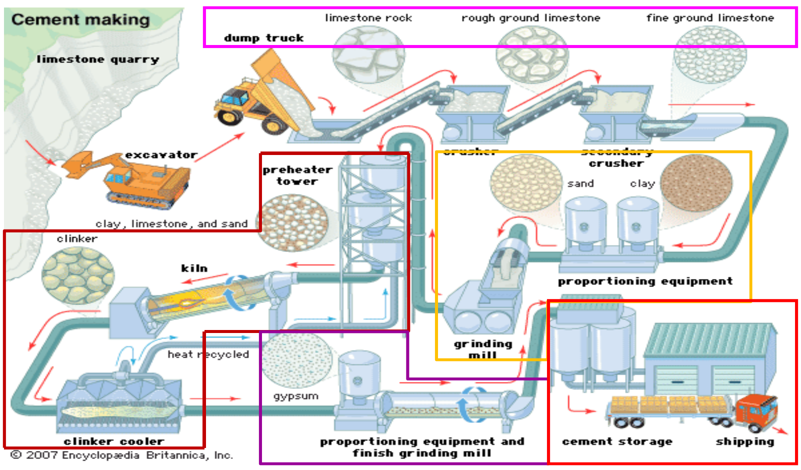
GB175-2007 Common Portland Cement				
Types	**Composition**	**Code**	**Additional constituents**	**Strength grade**
Portland cement	clinker, 0-5%mixed materials, gypsum	**P.I**	No	42.5/42.5R/52.5/ 52.5R/62.5/62.5R
		P.II	≦5% slag, limestone	
Ordinary portland cement	cilinker, 5-20%mixed materials, gypsum	**P.O**	5-20% slag, fly-ash, pozzolana	42.5/42.5R/52.5/ 52.5R
Slag portland cement	clinker, 20-70%mixed materials, gypsum	**P.S.A**	20-50% slag	32.5/32.5R/42.5/ 42.5R/52.5/52.5R
		P.S.B	50-70% slag	
Fly-ash portland cement	clinker, 20-40%mixed materials, gypsum	**P.F**	20-40% fly-ash	32.5/32.5R/42.5/ 42.5R/52.5/52.5R
Pozzolana portland cement	clinker, 20-40%mixed materials, gypsum	**P.P**	20-40% pozzolana	32.5/32.5R/42.5/ 42.5R/52.5/52.5R
Composite portland cement	clinker, 20-50%mixed materials, gypsum	**P.C**	20-50% slag, fly-ash, pozzolana, limestone	32.5/32.5R/42.5/ 42.5R/52.5/52.5R

Types of Cement

- According to European Committee for Standardization:

Types of Cement Under EN 197-1 (European Standard)				
Types	**Name**	**Description**	**Amount of clinker [weight-%]**	**Additional components [weight-%]**
CEM I	**Portland cement**	Comprising Portland cement and up to 5% of minor additional constituents	**95 – 100**	0 – 5
CEM II	**Portland composite cement**	Portland cement and up to 35% of other single constituents	**65 – 94**	0 – 5
CEM III	**Blast furnace cement**	Portland cement and higher percentages of blast furnace slag	**5 – 64**	0 – 5
CEM IV	**Pozzolanic cement**	Portland cement and up to 55% of pozzolanic constituents (volcanic ashes)	**45 – 89**	0 – 5
CEM V	**Composite cement**	Portland cement, blast furnace slag or fly ash and pozzolana	**20 – 64**	0 – 5

Cement Manufacturing Process Map



① raw materials extraction

② raw meal preparation

③ clinker production

④ cement production

⑤ cement packaging

(Source of picture: http://www.sbmchina.com/cement_plant/)

Identify Possible GHG Emissions for Cement

Stages	Input	Process	Equipment	GHG emission
(1) Raw materials extraction (2) Raw meal preparation	Fuel	Extraction	Truck/Ship	Transport
	Electricity	Crushing	Crusher	Electricity consumption
		Proportioning	Weigh-feeders	
		Grinding	Raw Grinding mill	
		Homogenizing	Homo silo	
(3) Clinker production	Fuel	Preheating	Preheater	Fuel combustion + Chemical reaction
	Fuel	Calcination	Rotary kiln	
	Electricity	Rapid cooling	Grate Cooler	Electricity consumption
		Conditioning	Conditioning Tower	
		Dust Collecting	Electrostatic Precipitator	
		Gas driving	Induced draft fans (ID Fan)	
		Finish grinding	Finishing Grinding mill	
	Imported Clicker	Clinker production	N/A	Clinker production from other factory
(4) Cement production (5) Product packaging and transportation	Electricity	Finish grinding	Finish grinding mill	Electricity consumption
		Storage	Cement silo	
		Packaging	Packaging machine	
	Fuel	Dispatching	Truck/Barge	Transport

Chemical reaction: Carbonates + heat → CaO/MgO + CO_2 (Calcination)
($CaCO_3$/$MgCO_3$)

Guidelines for GHG Emission from Cement Manufacturing

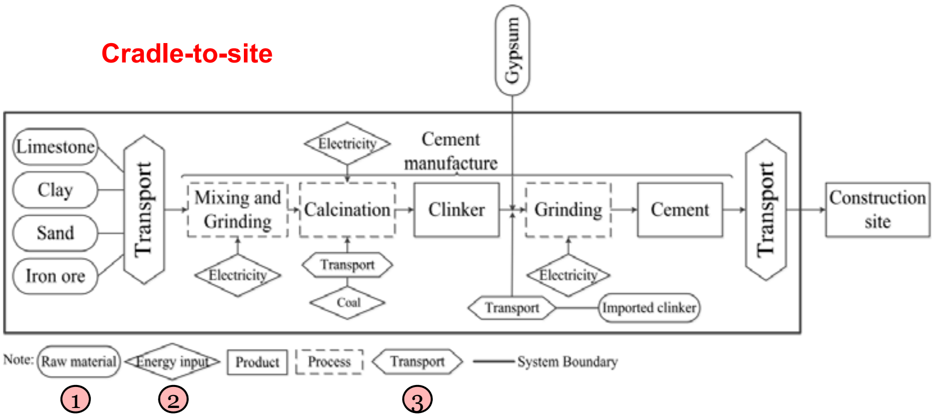
- **IPCC Guidelines** for National Greenhouse Gas Inventories (IPCC, 2006)
- **GHG Protocol** Corporate Accounting and Reporting Standard (WBCSD/WRI, 2004)
- **CSI** - CO2 Accounting and Reporting Standard for Cement Industry (WBCSD/CSI, 2011)

IPCC: Intergovernmental Panel on Climate Change
WBCSD: World Business Council for Sustainable Development
WRI: World Resources Institute
CSI: Cement Sustainability Initiative

System Boundary for Cement

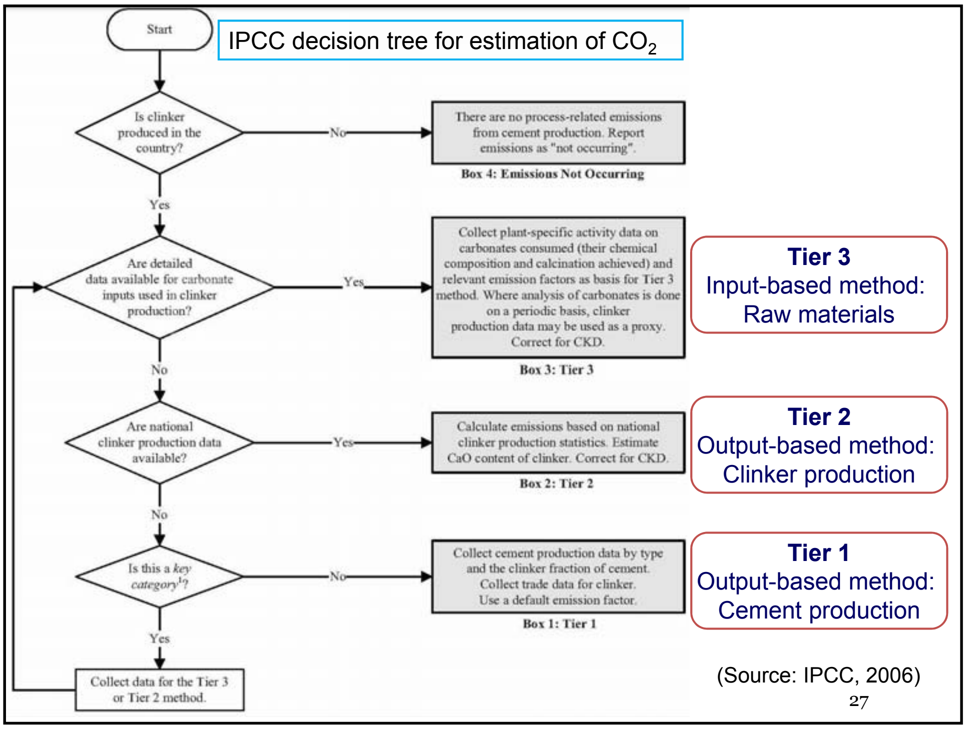
- According to the background study, system boundary for LCA is set.
- The system boundary for Portland cement in the study is as follow.

Cradle-to-site



Questionnaire Design for Cement

- Questionnaire was designed based on the background study and system boundary.
- The questionnaire consists of three main parts:
  - **Part I: Calcination CO_2**
  - **Part II: Energy use**
    - Fuel combustion for manufacturing
    - Electricity consumption
  - **Part III: Transportation of raw materials and cement product**



Questionnaire Delivered to Collect Data for Cement

- Bilingual questionnaire (English and Chinese)
- The main body of the questionnaire contains 11 sections, consistent with the requirements of the methods:

Research Questionnaire on
"Developing a Database of Embodied Carbon of Building Materials in Hong Kong"

"建立香港建築材料碳排放資料庫" 研究調查問卷

A. Company information

Part I: Calcination CO_2

B. Raw materials
C. Raw meal
D. Clinker
E. Cement kiln dust
F. Bypass dust

Part II: Energy use

G. Electricity consumption
H. Fuel combustion

Part III: Transportation

I. Raw materials transport
J. Product transport

K. Other information and comments

Carbon Calculation – Part I: Calcination CO_2

- CSI methods data requirements

Input-based method ↔ similar to IPCC Tier 3	
Simple method A1	Detailed method A2
Raw meal consumed for clinker; CKD/BypassD* leaving the kiln system	Raw meal consumed for clinker; CKD/BypassD leaving the kiln system; Additional raw materials
Output-based method ↔ similar to IPCC Tier 2	
Simple method B1	Detailed method B2
Clinker production; Raw meal : clinker ratio; CKD & BypassD leaving the kiln system; Emission factor default value = 0.525 tCO_2/tClinker	Clinker production; Raw meal : clinker ratio; CKD & BypassD leaving the kiln system; Emission factor corrected for MgO/CaO/Ca-Si, Mg-Si import

*CKD: cement kiln dust
*BypassD: Bypass system dust
Source: CSI, 2011

Carbon Calculation – Part II: Energy Use

Fuel combustion

- **CO_2 emission = Fuel consumption$_{type}$ × Fuel emission factor$_{type}$**
- Fuel emission factor:
  - Default value (IPCC, 2006; CSI, 2011)
  - Country-specific value (HKEPD, 2010)

Electricity

- **CO_2 emission = Electricity consumption × Electricity emission factor**
- Electricity emission factor
  - Supplier-specific value (HKEPD, 2010; CLP; HEC)
  - Country grid factor

IPCC: Intergovernmental Panel on Climate Change
CSI: Cement Sustainability Initiative
HKEPD: Hong Kong Environmental Protection Department
CLP: China Light & Power Company
HEC: Hongkong Electric Company

Carbon Calculation – Part III: Transportation

Parameters	IPCC	WRI	HKEPD
Fuel consumption and type	√	√	√
Vehicle type	√	√	√
Distance	√	√	
Weight of freight		√	

- The most accurate: based on fuel consumption and type
- Commonly applied: based on distance and weight

IPCC: Intergovernmental Panel on Climate Change
WRI: World Resources Institute
HKEPD: Hong Kong Environmental Protection Department

Results for the Cement Example

	GHG Source	kg CO_2 / kg clinker	kg CO_2–e / kg clinker	kg CO_2 / kg cement	kg CO_2–e / kg cement
A	Raw materials	8.385×10^{-3}	2.295×10^{-2}	7.267×10^{-3}	1.989×10^{-2}
B	Calcination	0.551	0.551	0.478	0.478
C	Energy use	0.397	0.399	0.379	0.381
D	Imported clinker	/	/	0.058	0.058
E	Transportation (Raw material & fuel)	0.060	0.081	0.052	0.070
F	Transportation (Product)	0.004	0.004	0.003	0.003
Cradle-to-site total (A+B+C+D+E+F)		1.020	1.058	**0.977**	**1.010**
Gate-to-gate total (B+C+D)		0.948	0.950	**0.915**	**0.917**
Cradle-to-gate total (A+B+C+D+E)		1.016	1.054	**0.974**	**1.007**

Selected Construction Materials

- The construction materials to be covered include but not limited to:
  - Aluminum
  - Brick
  - Cement
  - Ceramics
  - Concrete
  - Glass
  - Gypsum board
  - Steel
  - Wood/Timber






ECO Construction Materials Database

- **ECO-CM:** Embodied Carbon Of Construction Materials, or ECO-friendly Construction Materials

Under development

http://ihome.ust.hk/~cejcheng/ec/

Benefits to the Industry

- Provide a benchmark for selection of green materials and development of green labels
- Provide a basis for prediction of carbon emissions in infrastructure and building construction
- Help lower the construction's carbon footprint
- Help meet the carbon footprint reduction target (e.g. 50-60% reduction of carbon intensity for Hong Kong)

	2005	2020	Reduction
Carbon intensity (kg CO_2-e/HK dollar)	0.029	0.012 - 0.015	↓ 50-60%
Total GHG emissions (million tonnes)	42	28-34	↓ 19-33%
Per capita GHG emissions (tonnes)	6.2	3.6-4.5	↓ 27-42%

- Thank You -

Questions and Answers

Contact

Dr Jack C.P. Cheng *(cejcheng@ust.hk)*

Ir Prof Irene M.C. Lo *(cemclo@ust.hk)*

Department of Civil and Environmental Engineering

The Hong Kong University of Science and Technology