Carbon Dioxide (CO_2) Emissions of Concrete

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Presentation Content

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- **Hong Kong Climate Changes and CO_2 Emissions**
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- **Possible Alternatives**
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- **Summary**

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Global Warming

- **Global Warming is caused by sharply increased greenhouse gases emission by human activities**
- **In the building industry, carbon dioxide (CO_2) emission mainly comes from cement production**
- **It accounts for 2% - 3 % of human generated CO_2 production and consumes about 0.5% of total energy consumption.**
- **Concrete, as a material, can never be truly sustainable, but we can reduce its impact on the environment**

Hong Kong Climate

- **The Hong Kong Observatory**
  - No. of "cold days" are declining
  - No. of "hot nights" are increasing
  - Urban areas are warmer than the countries side by 6°C in some of the late evenings

Hong Kong Climate

- Tall buildings in Hong Kong are heated up during the day and release thermal energy over night
- Tall buildings also surround the inner city and inhibit the cooling effect of air circulation

RESULTING HOT WEATHER!!

Hong Kong CO_2 Emissions

In Hong Kong, greenhouse gas emissions are approximately 6 tons CO_2 equivalent per capita

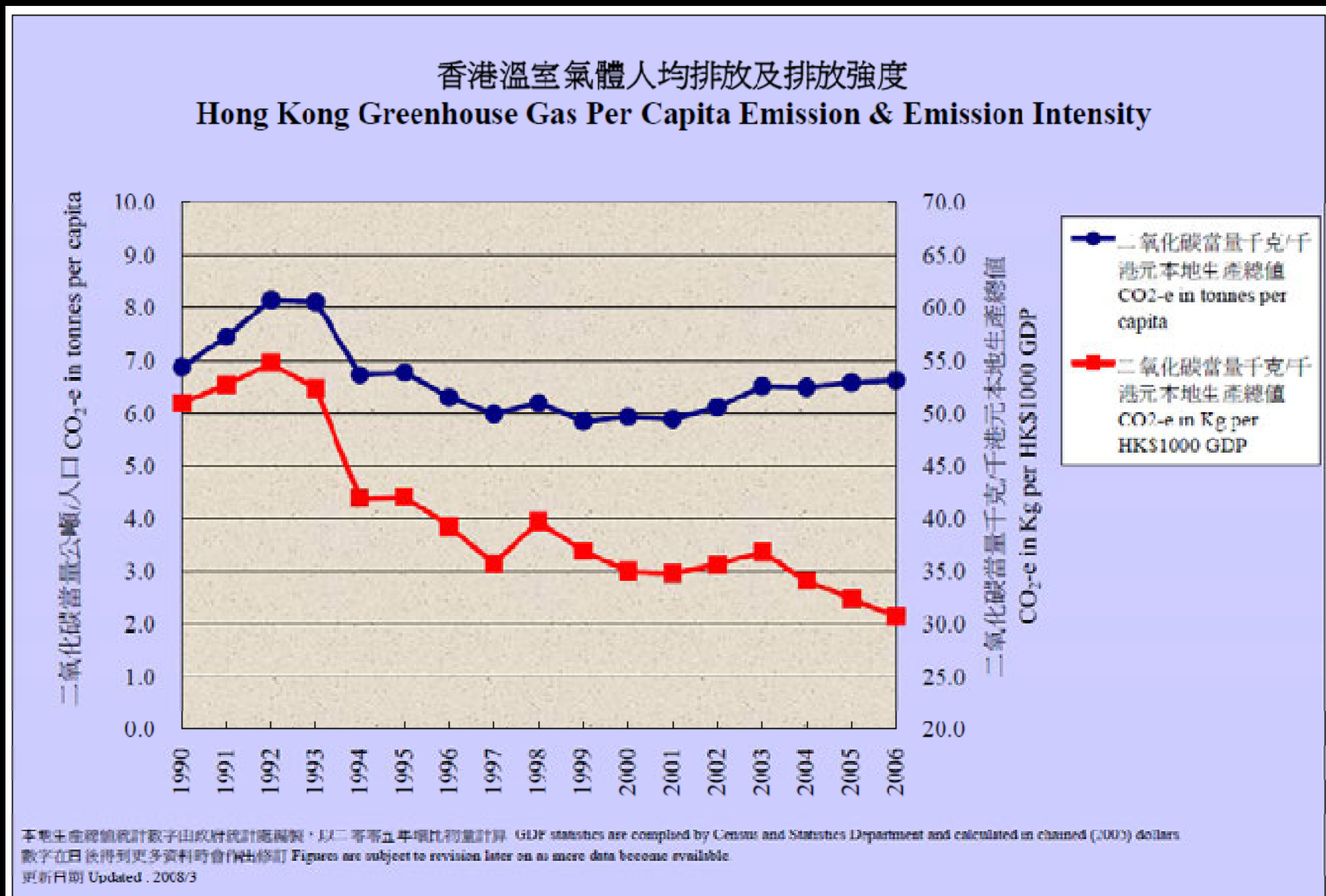

*Figure source from EPD

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Hong Kong CO_2 Emissions (2)

- **CO_2 emission per capita in Hong Kong is relatively low when compare to other international developed countries**

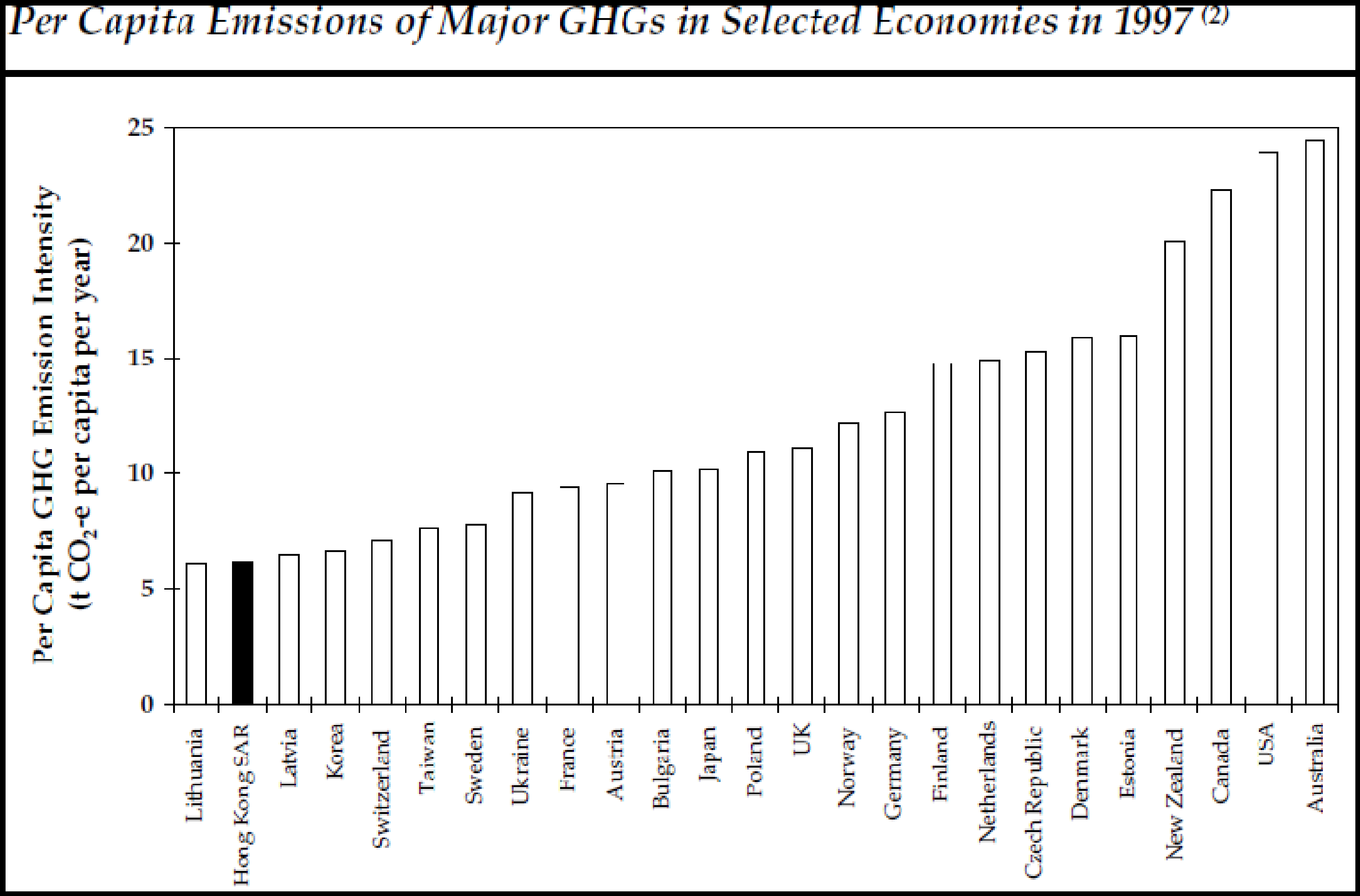

*Figure source from EPD

Hong Kong CO_2 Emissions (3)

- **The largest growth in CO_2 emissions has come from power generation and road transportation**

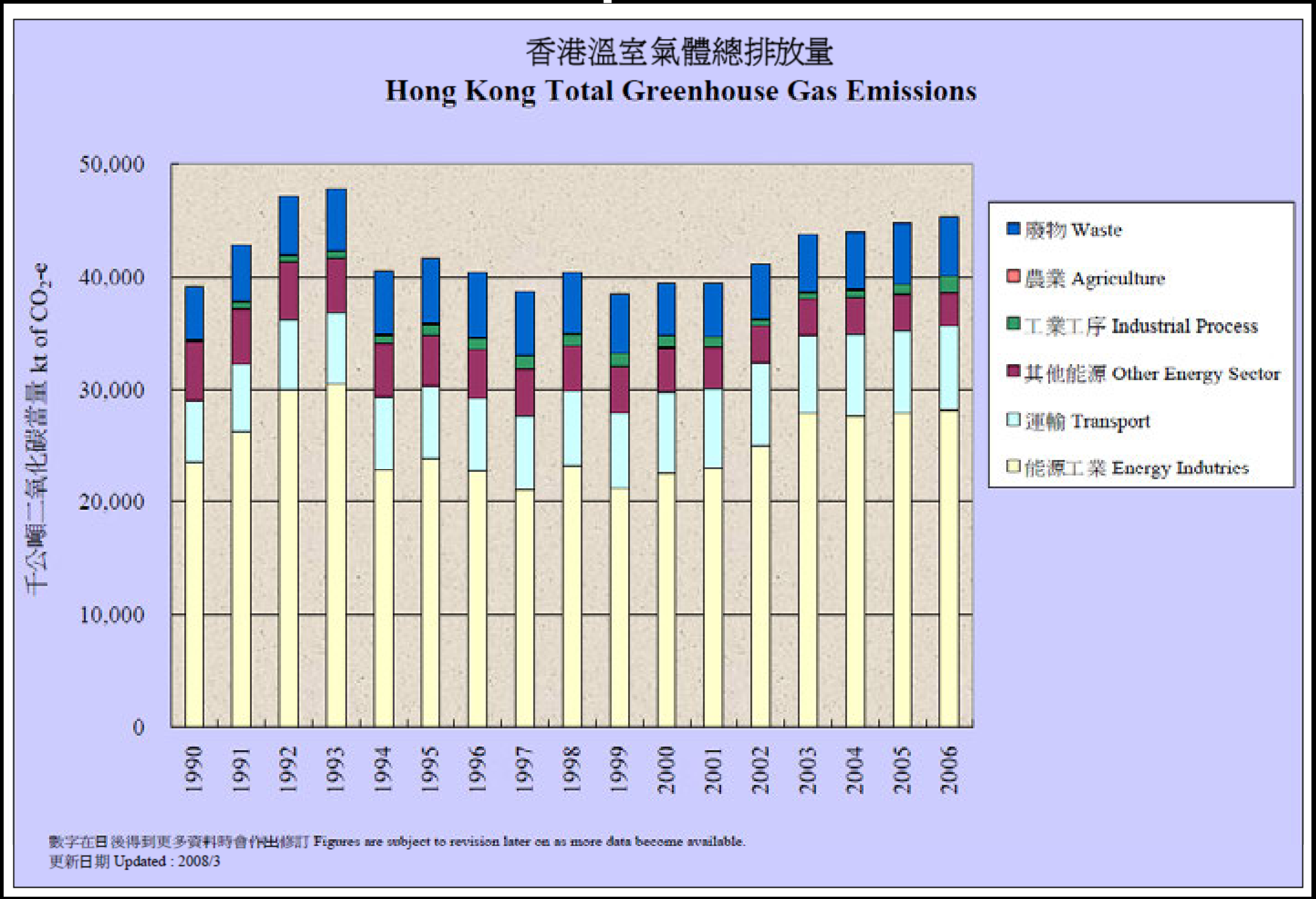

*Figure source from EPD

Carbon FootPrint (t CO_2)

- **Carbon footprint is used to calculate the amount of damaged caused by an individual, household, institution or business to the environment through harmful carbon dioxide emissions.**

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Carbon FootPrint (t CO_2) – Reducing tCO_2 Emissions

- **Reducing tCO_2 emission is essential for sustainable environment**
- **Can be achieved by:**
  - Calculating the “carbon footprint” and identify routine of most carbon consume activity. Where possible, minimize those activities. E.g. Walking or Cycling instead of driving.
  - Reduce tCO_2 by “Offsetting” carbon emissions. E g. while continue to use current technology such as burn of fossil fuels, but may initiate to find overall reduction in emissions in the process to offset the total emissions.

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Embodied CO_2 (eCO_2)

- **One way to measure carbon footprint in reinforced concrete is by unit of embodied CO_2 (eCO_2)**
- **Definition:**

  "Embodied CO_2 is defined as the CO_2 produced over a defined part of the life cycle of the product. The CO_2 is primarily associated with the consumption of energy over the relevant part of the life cycle, but can also include emissions which occur directly as a result of the production process."

So what does the eCO_2 have to do with reinforced concrete?

- **Let's take a look at some figures…**

ECO_2 (tCO_2/t)	Notes	Source	Author	Country	Year published
0.074	20% fly ash by mass of cement	Environmental life cycle inventory of Portland cement concrete[1]	Athena Sustainable Materials Institute	United States	2002
0.114	Substructure	Steel Construction Institute[2]	Eaton and Amato	United Kingdom	1998
0.129	14% cement by mass of concrete	Environmental life cycle inventory of Portland cement concrete	Athena Sustainable Material Institute	United States	2002
0.180		Australian life cycle inventory of Portland cement concrete[3]	Sima Pro RMIT	Australia	1999
0.202	Superstructure	Steel Construction Institute	Eaton and Amato	United Kingdom	1998

More figures…

Material	EE, GJ/tonne	ECO_2, kg/tonne	IStructE Values ECO_2 (kg/tonne)	Comments
Structural steel sections	24.5-25.5	1799-2450		
	25	**2100**	2030	
Steel reinforcement	11-17.3	460-1190		100% recycled material
	14	**825**	2030	
Steel sheet	14.5-27	1160-2160		
	21	**1660**	2698	
Unreinforced concrete	0.67-3.1	60.2-310		Lower values for lower strength material
	0.95	**120**	163 (reinforced)	Higher values if cement is CEM1 with no pfa or ggbs in mix
Softwood	4.1-13	430-1450		
	7.2	**1100**	1644	
Hardwood	5.5-15.9	430-1640		Lower values for locally sourced, air dried timber
	9.7	**1140**	2136	
Glass	8.5-18.5	80-1130		
	14	?	1130	
Aluminium extrusion	120-184	6780-10190		33% recycled content
	153.5	**8490**	29200	

eCO_2 of reinforced concrete (1)

- **When comparing eCO_2 of concrete 0.12t/t with cement 0.88t/t or with other building materials (e.g. steels) 0.82t/t, the eCO_2 of concrete is relatively not that high.**

Sources of eCO_2 for Reinforced Concrete

Comes from:

- **Constituent materials**
- **The fuel and process used to manufacture Portland Cement**
- **The amount of Portland Cement replacement**
- **The strength class of the concrete and the resulting mix composition**
- **The level of steel reinforcement**
- **Transports impacts of the aggregate and cement**

eCO_2 from Concrete Constituents (1)

Portland Cement

- **Portland cement has very high embodied CO_2 content**
- **Cement manufacture is energy intensive**
- **Recent data on global CO_2 emissions from cement manufacture give an overall average of 0.88 ton CO_2 per ton of cement produced. This figure includes all types of cement.**

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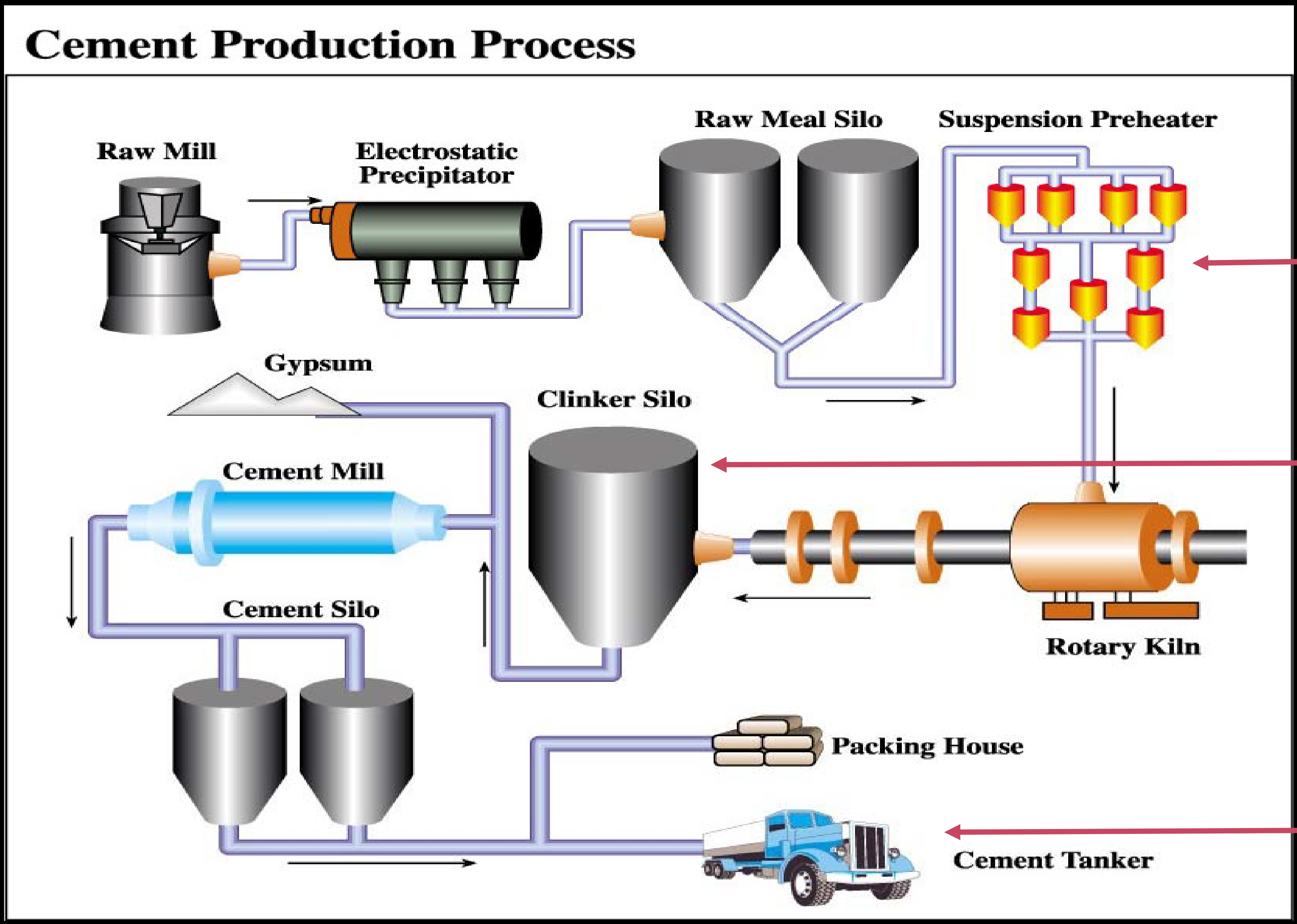
Cement Production Process

The major CO_2 emissions arise from three sources:



- Combustion of fuel to heat the kiln
- Decarbonisation of limestone
- Vehicle emissions during transport of materials

*Figure source from www.lootahgroup.com

eCO_2 from Concrete Constituents (2)

Aggregates

- Aggregates have a very low embodied CO_2 compared to Portland cement and contribute only 3% to the total for reinforced concrete.
- Transportation of the aggregate to the batching plant and to site accounts for most CO_2 emission.

Transport	UK Environmental Agency transport emissions (gCO_2 / t km)
Road	317
Rail	41
Water	9

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eCO_2 from Concrete Constituents (3)

Other major constituents

- **The eCO_2 figure presented is based on fair estimate in UK industry.**

Material	eCO_2 (tCO_2 /t)
CEM I (Portland cement)	0.822[4]
Coarse aggregate	0.008[5]
Fine aggregate	0.0053[4]
Water	0.000000249[4]
Reinforcement steel	0.97[4] (predominately recycled)

eCO_2 from Concrete Constituents (4)

Secondary Cementitious Material

- **eCO_2 source data is available for Finland, UK and US. Though there is variation between the source data, PFA and GGBS has significantly lower eCO_2 value than Portland Cement**

Material	Finnish eCO_2 [11] (tCO_2 /t)	UK eCO_2 (tCO_2 /t)	US eCO_2 (tCO_2 /t)
Portland cement	0.670	0.822 [4]	0.900 [1]
Fly ash	0.0053	0.011 [a] - 0.025 [12]	0.002 [13]
GGBS	0.026	0.050 - 0.070 [15]	0.028 [15]

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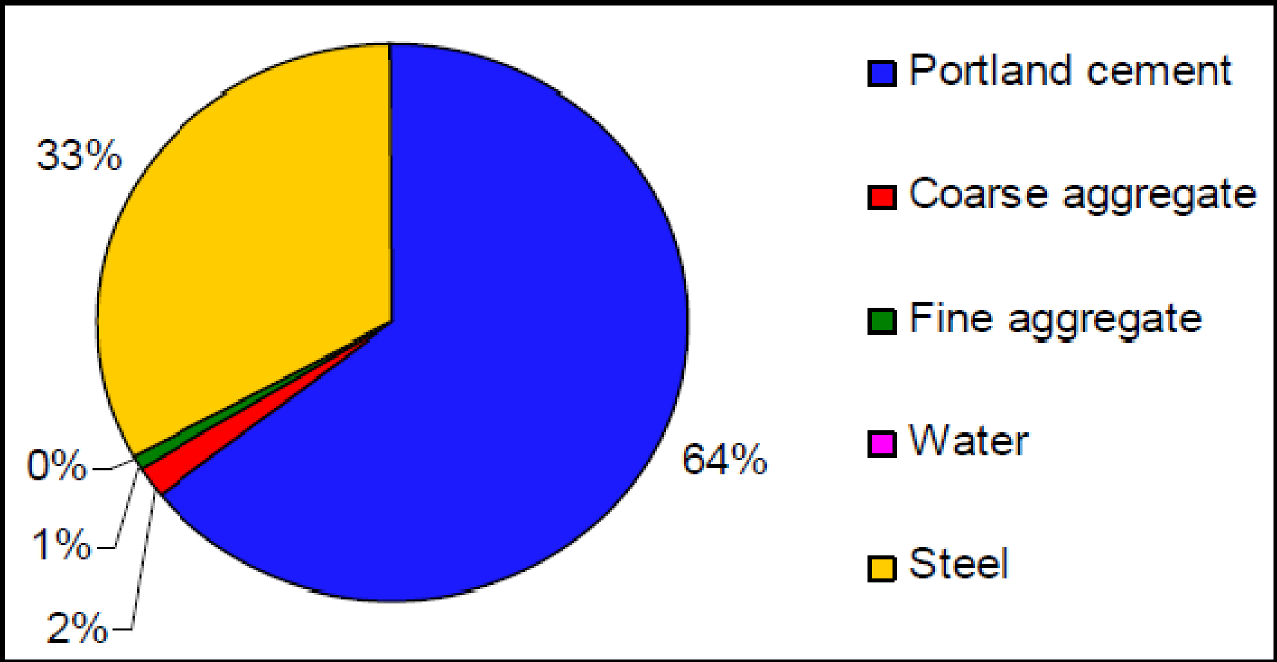
eCO2 from Concrete Constituents (5)

For a typical C32/40 mix

- **The eCO_2 is contributed by each of the concrete constituents is as follows:**



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Variations of eCO_2 in Concrete Strength and Mix Design

- **eCO_2 also varies by strength class (i.e. the amount of cement content in the mix)**

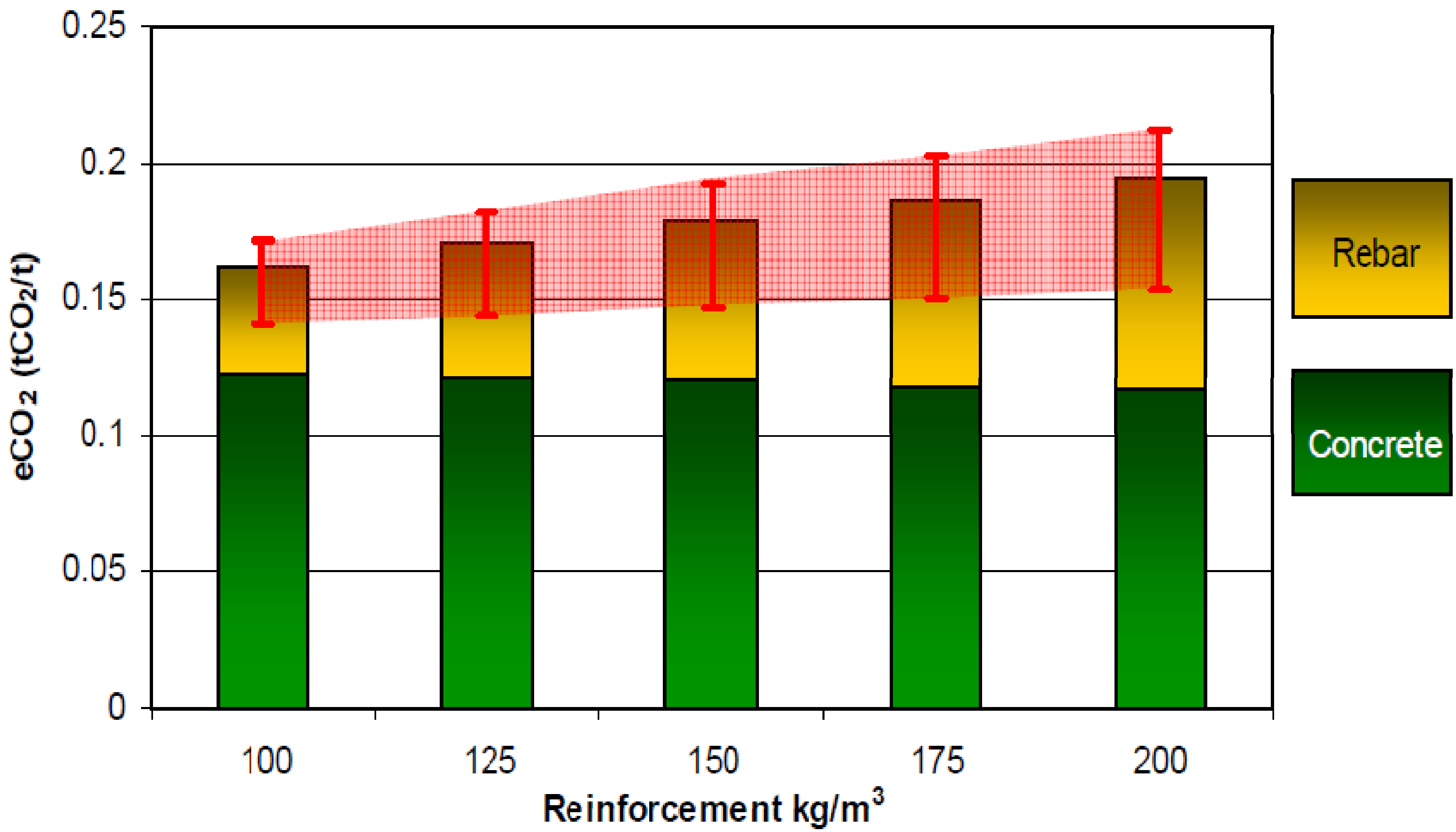
Class	Cement (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Water (kg/m^3)	ECO_2 (tCO_2 /t)
C8/10	180	1025	912	189	0.07
C25/30	290	1053	826	176	0.11
C28/35	320	1059	801	174	0.12
C32/40	350	1066	773	174	0.13
C40/50	430	1000	796	174	0.15
C50/60	450	1175	600	149	0.16

eCO_2 in Reinforcement

- **eCO_2 varies only slightly with steel reinforcement**
- **Reducing cement content will have greater effect than reducing the weight of reinforcement**

kg/m^3 of steel reinforcement	100	125	150	175	200
tCO_2/t of reinforced C32/40 concrete	0.16	0.17	0.18	0.19	0.194

Level of Reinforcement with respect to eCO_2 levels



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What to Do?
Possible Alternatives

1. Reduce CO_2 emissions using other types of cement manufacturing process
2. Reduce Portland cement consumption
3. Reduce primary aggregate usage

Possible Alternatives 1
Reduce CO_2 Emissions through Other Cement Manufacturing

Examples of Possible Approaches –

- **Magnesium Based Chemistry instead of Calcium Based Chemistry**
- **Sample product includes:**
  - CeramiCrete
  - EcoCement

CeramiCrete

- **Product developed by Argonne National Labs (a US Department of Energy Laboratory)**
- **Uses magnesium-based chemistry instead of Portland cement's calcium-based chemistry**
  - Product formed by mixing magnesium oxide and soluble phosphate powder with water to form a phosphate ceramic (No CO_2 producing carburization process involved)

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CeramiCrete

- **Developed as a material for solidifying industrial waste**
- **Used for repairing roads**
  - E.g. Illinois Tollways and Chicago Skyway (US)
- **Major drawback for the choosing this material for constructing the whole road is cost. It is 3 to 4 times more expensive than Portland cement.**

CeramiCrete

Ceramicrete concrete repair material intact and supporting vehicle traffic on surface road cracks

*Figure source from www.anl.gov/techtransfer/Available Technologies/Material Science/Ceramicrete/Ceramicret pothole.html

EcoCement

- **Product developed by TecEco (Australian research and development company)**
  - Another magnesium-based material being marketed as an alternative
- **Made by blending reactive magnesium oxide (magnesia) with Portland cement.**
  - Magnesia is currently made from magnesite ($MgCO_3$) using energy to drive off the CO_2 from the carbonate (CO_3).
- **Can be mixed with fly ash or ground granulated blast furnace slag**
  - Offers better environmental credentials

EcoCement

- **Environmental claims:**
  - Less energy is used to make magnesia than Portland cement
  - When use as porous concrete (e.g. concrete pavements), it can absorb CO_2 from the atmosphere. (though this is also true for PC porous concrete due to process called carbonation!)
- **Major Drawback:**
  - The environmental impact and availability of extracting magnesite from the ground not known
  - Magnesite is not available globally, source in China, impact of transportation
  - Limited applications for porous concrete
  - EcoCement is not readily available in commercial scale

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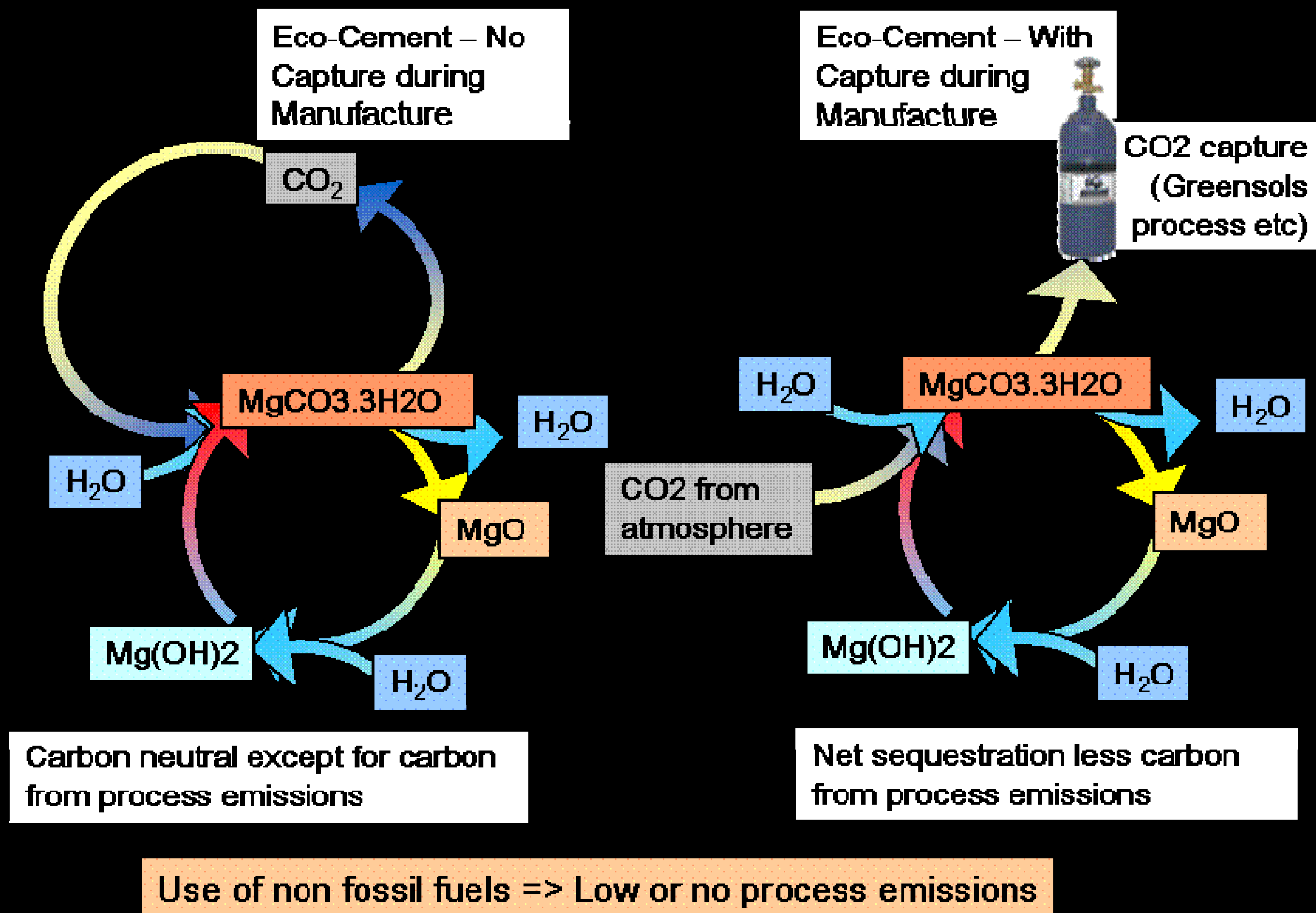
Reduce Portland Cement Consumption
EcoCement



Note the CO_2 capturing during manufacturing can also be achieved if technology is available for Portland Cement Concrete

*Figure source from www.tececo.com/simple.eco-cement.php

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Possible Alternatives 2
Reduce Portland Cement Consumption

- **Secondary cementitious materials**
  - Ground granulated blast-furnace slag (GGBS)
  - Pulverized fly ash (PFA)

Other Examples of Possible Approaches

- **C-Fix**
- **Air and foam-based concretes**

Reduce Portland Cement Consumption
Ground granulated blast-furnace slag (GGBS)

- **GGBS is generally used in proportions of 40-70% of the total cementitious materials content in structural concrete, and up to 95% in specialist applications.**
- **55% GGBS can reduce the embodied CO_2 content of a typical C32/40 concrete from approx. 115 kg CO_2/ton to approx. 60 kg CO_2/ton.**

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Reduce Portland Cement Consumption
Ground granulated blast-furnace slag (GGBS)

Major Drawback:

- Sources of GGBS not readily available in Hong Kong. i.e. not economical to import blast furnace slag from steel mill.
- Current specification not cater to adopt the use of blast furnace slag as substitution.
- In UK current demand for ggbs exceeds its production by approx. 50%, i.e. needs importation (though by sea) and maybe not truly sustainable.

Reduce Portland Cement Consumption
Pulverized Fly Ash (PFA)

- **Fly ash is generally used in proportions of 25-30% of the total cementitious materials content in structural concrete**
- **30% fly ash can reduce the embodied CO_2 content of a typical C32/40 concrete from approx. 115 kg CO_2/ton to approx. 85 kg CO_2/ton.**
- **Sources readily available in Hong Kong.**

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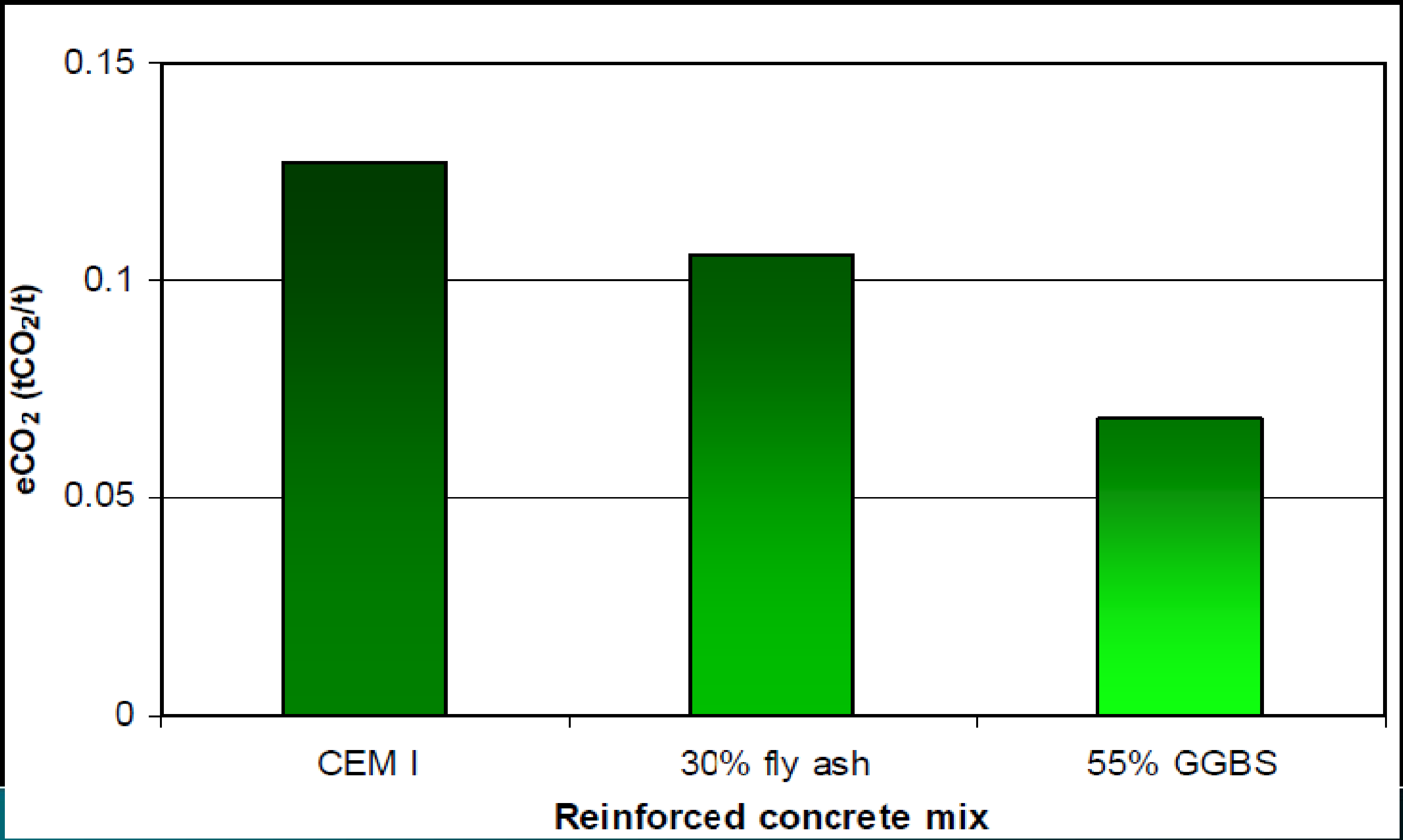
Reduce Portland Cement Consumption
eCO_2 in GGBS & PFA

- **For C32/40 concrete mix, reduction of eCO_2 is shown through use of secondary cementitious materials.**



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Reduce Portland Cement Consumption
eCO_2 in GGBS & PFA

- **More figures is shown in terms of percentage saving of eCO_2 through use of secondary cementitious materials.**

C32/40	eCO_2 (tCO_2 /t)	eCO_2 saving
CEM1	0.13	-
30% fly ash	0.11	17%
55% GGBS	0.07	48%

Reduce Portland Cement Consumption
C-Fix

- **Product developed by Shell and stands for carbon fixation.**
- **A carbon-rich thermoplastic binder made from dense, carbon-rich residue left over after crude oil has been refined.**
  - Mixed using standard asphalt techniques at a temperature of about 200ºC.
- **Applications include use in breakwater blocks, modular road constructions, paving blocks, and liquid-tight, acid-resistant floor elements.**

Reduce Portland Cement Consumption
C-Fix

- **Use of one ton of *C-Fix* composite (binder + aggregate) fixes 150kg of CO_2. i.e. net saving to reduce 150kg of CO_2**
  - Calculated by assuming 1 ton of composite contains 60kg of carbon, which equates to 170kg of CO_2
- **Major drawback:**
  - **Limited use in structural applications where it is subject to pressure and high temperatures due to some degree of creep with time.**
  - **Product depends on crude oil processing i.e. extract, refine, and burning products**
  - **Ideally if less crude oil is used, CO_2 levels in the atmosphere would be lower automatically and no residue would be produced. i.e. No need for alternative**

Reduce Portland Cement Consumption
Air and Foam Based Concrete

- **Foam-based concretes and Autoclaved aerated concrete (AAC) products (with up to 60-70% air content)**
  - Provide suitable alternative material for low strength applications because they use less cement per cubic metre, and little or no aggregate.
- **Australia's CSIRO developed another aerated cementitious (cement-based) product, *Hessle*, that is as strong as normal concrete, is lightweight, and provides up to five times the thermal insulation properties of concrete.**
  - Reduces CO_2 emissions by increasing the energy efficiency of the building and reducing the energy used during transportation and construction of the lightweight elements.

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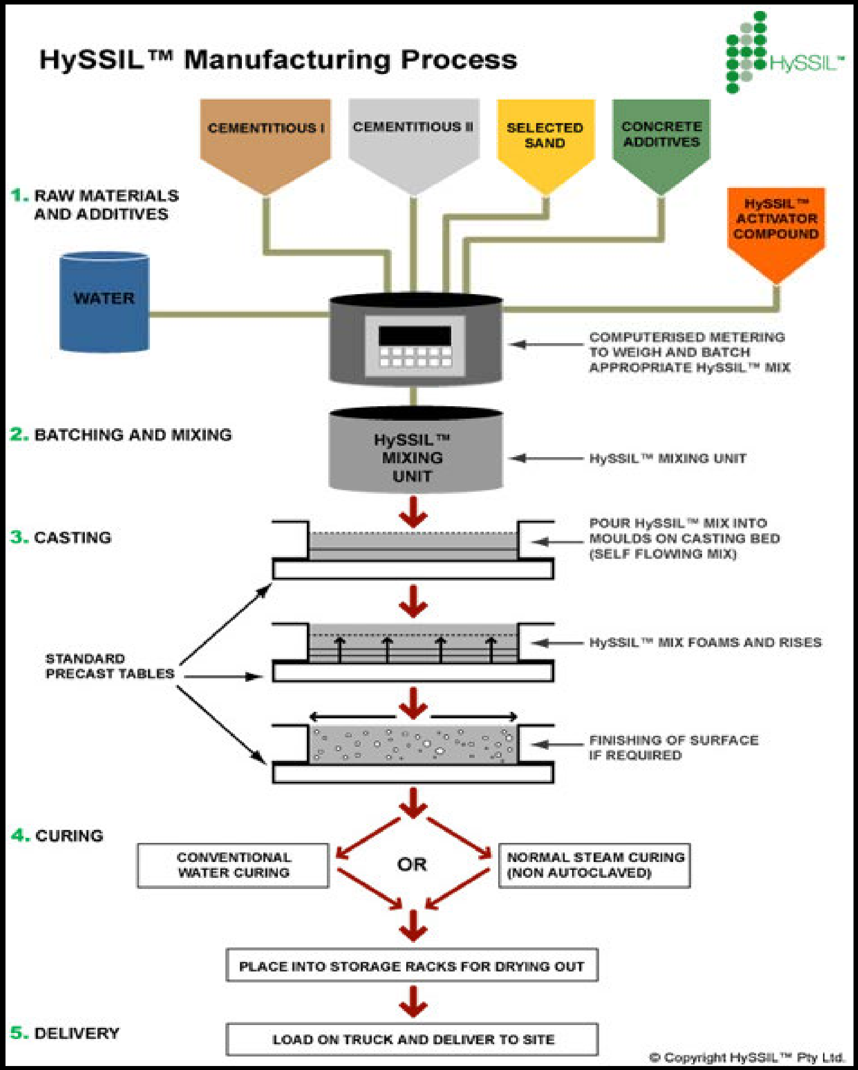
Reduce Portland Cement Consumption
Air and Foam Based Concrete

- **Major Drawbacks:**
  - **Foam-based concrete and AAC cannot replace normal structural concretes – only strengths of up to 15N/mm^2 can be achieved.**
  - **AAC manufacture process requires high temperature and high pressure steam cure in an autoclave.**
    - Energy (in terms of CO_2 emissions) used to operate the autoclave has to be balanced against the savings made by reducing the cement content.

Reduce Portland Cement Consumption
Air and Foam Based Concrete



*Figures source from www.hyssil.com/technology.htm

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Possible Alternatives 3
Reduce Primary Aggregate Usage

- **Recycled aggregate**
- **Provisions included in BS 8500-2**
  - Composition & use
- **Only coarse aggregate**
- **High demand as fill and road base**

Recycled aggregate stockpile

Challenges

- **The listed Portland cement substitutes products are rather new, largely unproven and not readily available**

- **Portland cement concretes are cheap, well established and readily-available materials, any alternatives will have to compete on costs and demonstrate advantage(s) over Portland Cement.**

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Challenges

- **Lack of Material Specifications**
  - Current exclusions (e.g. GGBS)
  - Need some changes forthcoming
- **Recycled Aggregate supply**
  - Location (transportation)
  - Continuity
  - Supplier reluctance
  - Cost

Summary 1

- **Global Warming is caused by the sharply increased greenhouse gases (GHG) emission by human activities with cement production accounting for 2% - 3% of CO_2 emission or 0.88t CO_2 per ton of cement produced.**
- **The most significant GHG emitted in Hong Kong is carbon dioxide and significant source comes from electricity generation.**

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Summary 2

- Transportation (in general) is the second largest source of CO_2 emissions in Hong Kong.
- In the context of increased local environmental awareness, all industries have obligation of contributing towards alleviating global environmental problems

Every Little Bit Helps!

Summary 3

In Construction Industry

- **Concrete, as a material, can never be truly sustainable, but there are things we can and should do to reduce its impact on the environment**
- **Search for alternatives to cement will undoubtedly grow as pressure increases to meet CO_2 emission targets.**

Summary 4

In Construction Industry

- **Portland cement concretes are cheap, well established and readily-available materials, any alternatives will have to compete on costs and need further researches.**
- **Therefore, use of PFA or GGBS is recommended to be maximized**

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Thank You

Q & A

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