GEOPOLYMER BASED CONCRETES : ENVIRONMENTAL IMPACTS OF CURRENT RESEARCH TRENDS

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Objective

- **Geopolymers are presented as an alternative for clinker based cement**

  Low CO_2 & great durability

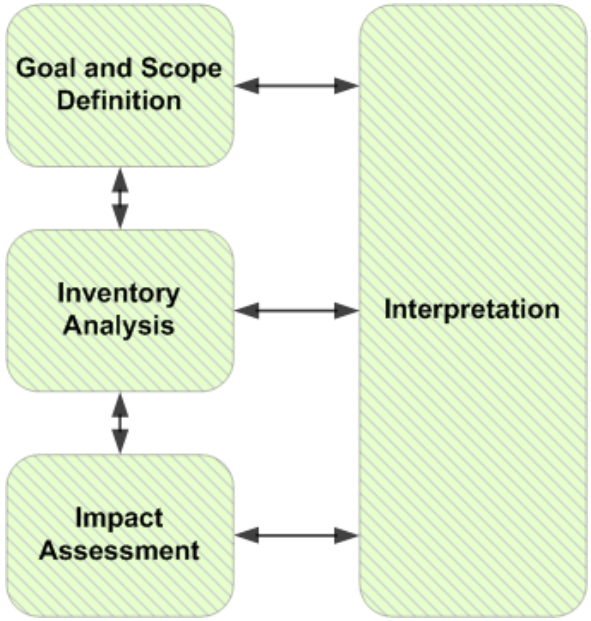
  - **How much lower is it compared to traditional concrete?**
    - *An interesting reduction ?*
    - *A massive diminution ?*
    - *A serious one ?*
    - *A very impressive improvement ?*
  - **Stop adjective, let's use numbers**

- **Very few studies deals with environmental comparison between clinker and geopolymer based concretes**

Objective

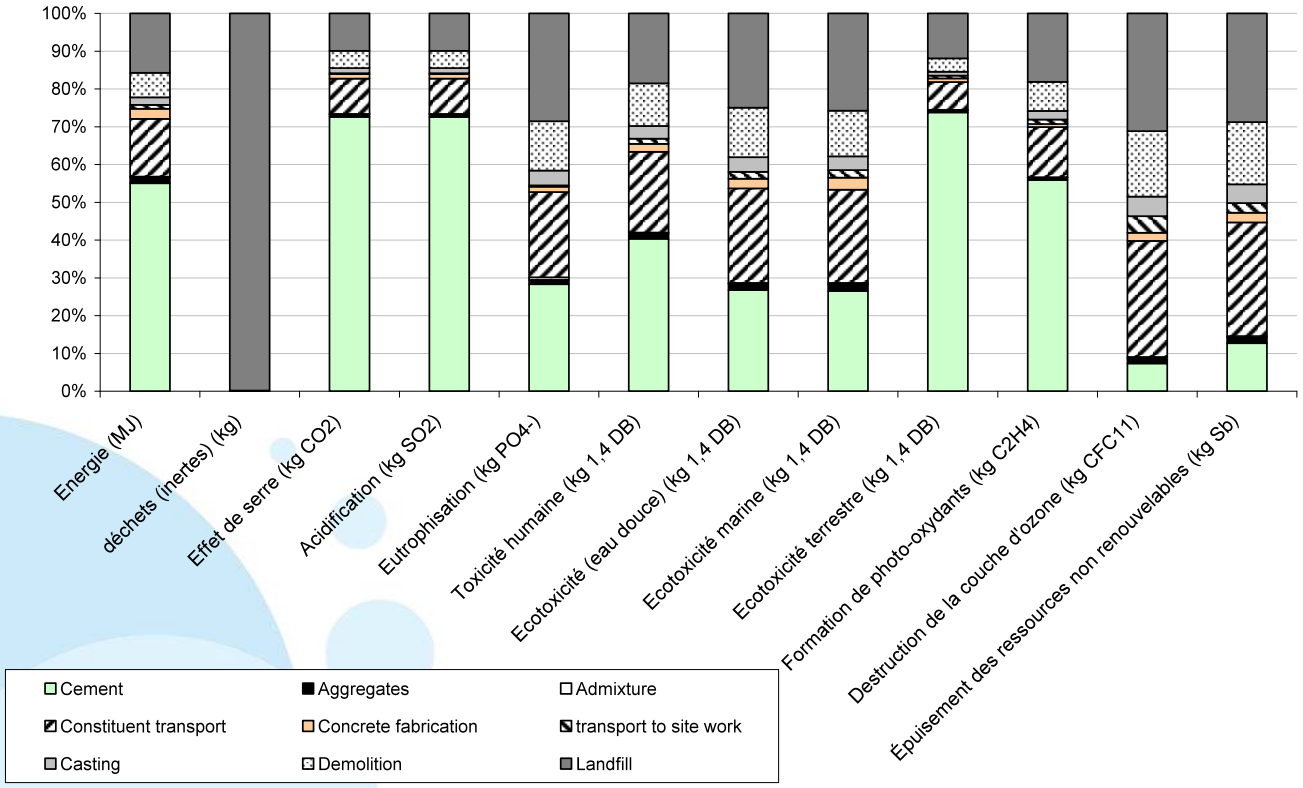
- Evaluate the environmental impact of geopolymer production
- Quantification of improvement compared to technological changes induced
- Life cycle assessment method

[ISO 14 040 standards]



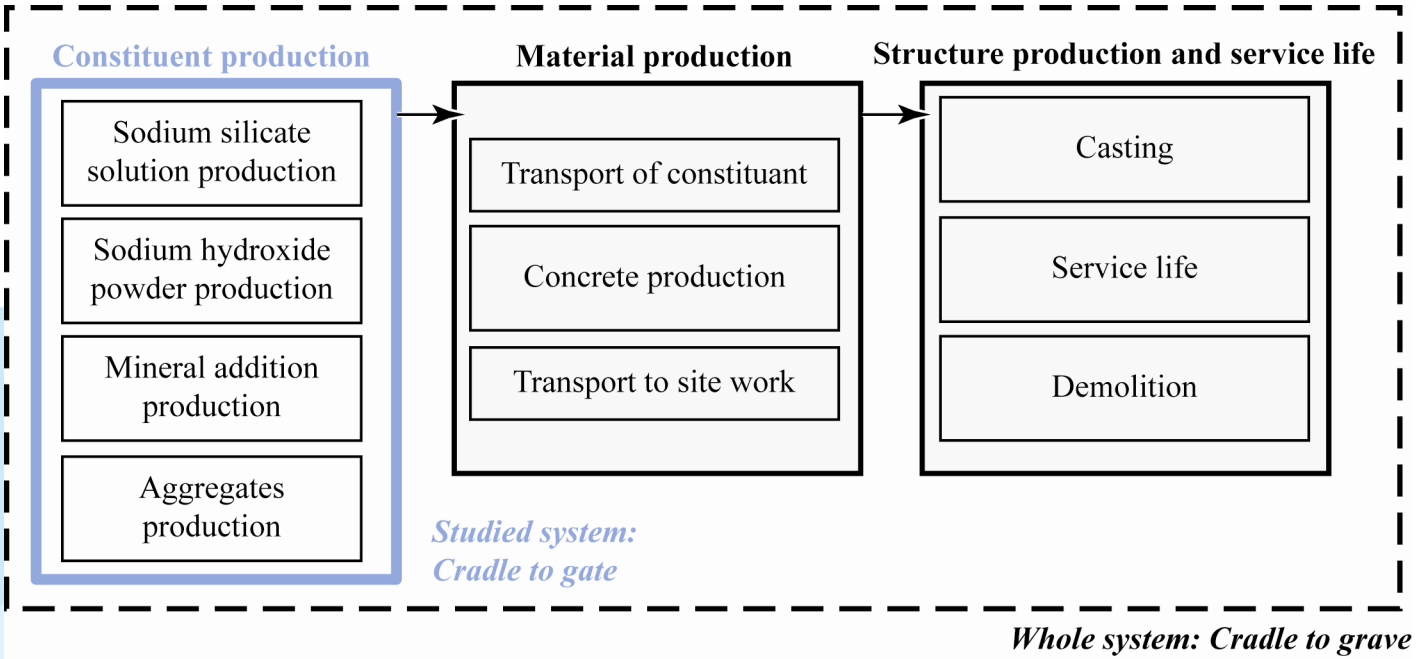
Method: LCA

- ## Boundaries of the system and Functional Unit



Reduce cement production impacts *(and its transport)*
& improve recycling of concrete at the end of life

- **Boundaries of the system and Functional Unit**
  - Reduced to the **production** of the geopolymer constituents



Method: LCA

- **Boundaries of the system and Functional Unit**
  - Reduced to the **production** of the geopolymer constituents
  - Comparison for 1m^3 with the same **mechanical properties**

Method: LCA

- ## Boundaries of the system and Functional Unit
  - Reduced to the **production** of the geopolymer constituents
  - Comparison for 1m^3 with the same **mechanical properties**
    - » **Use Ferret equation:** $$f_c \approx K.Rc_{28}.\left(\frac{V_{cement}}{V_{paste}}\right)^2$$
    - » **Calculate cement quantity that provide the same strength as geopolymer based concrete**
    - » **Compare with 2 different concretes made with:**
      - » **CEM I: 95% Ordinary Portland Cement**
      - » **Currently used cement: 70% OPC, 30% Supplementary cementitious material**

Method: LCA

- **Boundaries of the system and Functional Unit**
  - Reduced to the **production** of the geopolymer constituents
  - Comparison for 1m^3 with the same **mechanical properties**
- **Inventory**
  - Technical data:
    - Geopolymer mix design come from literature and personal experiments
  - Environmental data:
    - Generic database, characteristic of European practice= EcoInvent
  - Specific questions for allocation on Fly ash and blast furnace slag

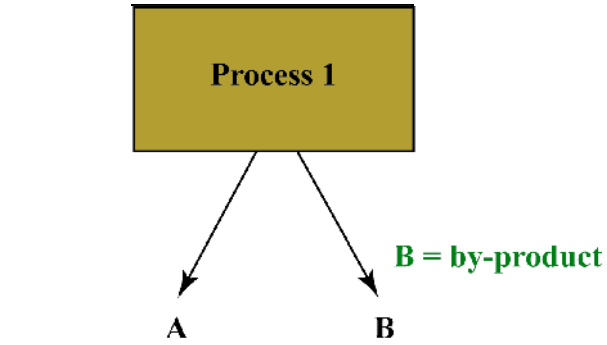
Method: allocation

What are the environmental impacts of these materials?

Supplementary Cementitious materials:

Fly ash: waste from *coal power industry*

Blast furnace slag: waste from *iron industry*



2 allocation methods are tested:

- No allocation: SCM = Waste

- Economic allocation: SCM = by-product

Method: LCA

- **Boundaries of the system and Functional Unit**
  - Reduced to the **production** of the materials
  - Comparison for 1m^3 with the same **mechanical properties**
- **Inventory**
  - Technical data:
    - Geopolymer **mix design come from literature** and personal experiments
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Method: LCA

- **Boundaries of the system and Functional Unit**
  - Reduced to the **production** of the materials
  - Comparison for 1m^3 with the same **mechanical properties**
- **Inventory**
  - Technical data:
    - Geopolymer **mix design come from literature** and personal experiments
  - Environmental data:
    - Generic database, characteristic of European practice= **EcoInvent**
  - 2 allocation procedures are tested
- **Impact calculation**
  - Global evaluation of all impact categories = **CML indicators**

- **Global warming potential of the different components**

Components [kg]	global warming Potential (GWP100) [kg CO_2 eq.]
CEM I	$8.44\ 10^{-1}$
FA *(No allocation)*	$5.26\ 10^{-3}$
FA *(economic allocation)*	$2.10\ 10^{-1}$
BFSG *(No allocation)*	$1.69\ 10^{-2}$
BFSG *(economic allocation)*	$4.08\ 10^{-1}$
Metakaolin (MK)	$1.00\ 10^{-1}$
Soda powder	$4.32\ 10^{-1}$
Sodium silicate	1.08
Sand	$2.40\ 10^{-3}$
Gravel	$4.29\ 10^{-3}$
Water (Tap water)	$1.55\ 10^{-4}$
Plasticizer	$7.49\ 10^{-1}$

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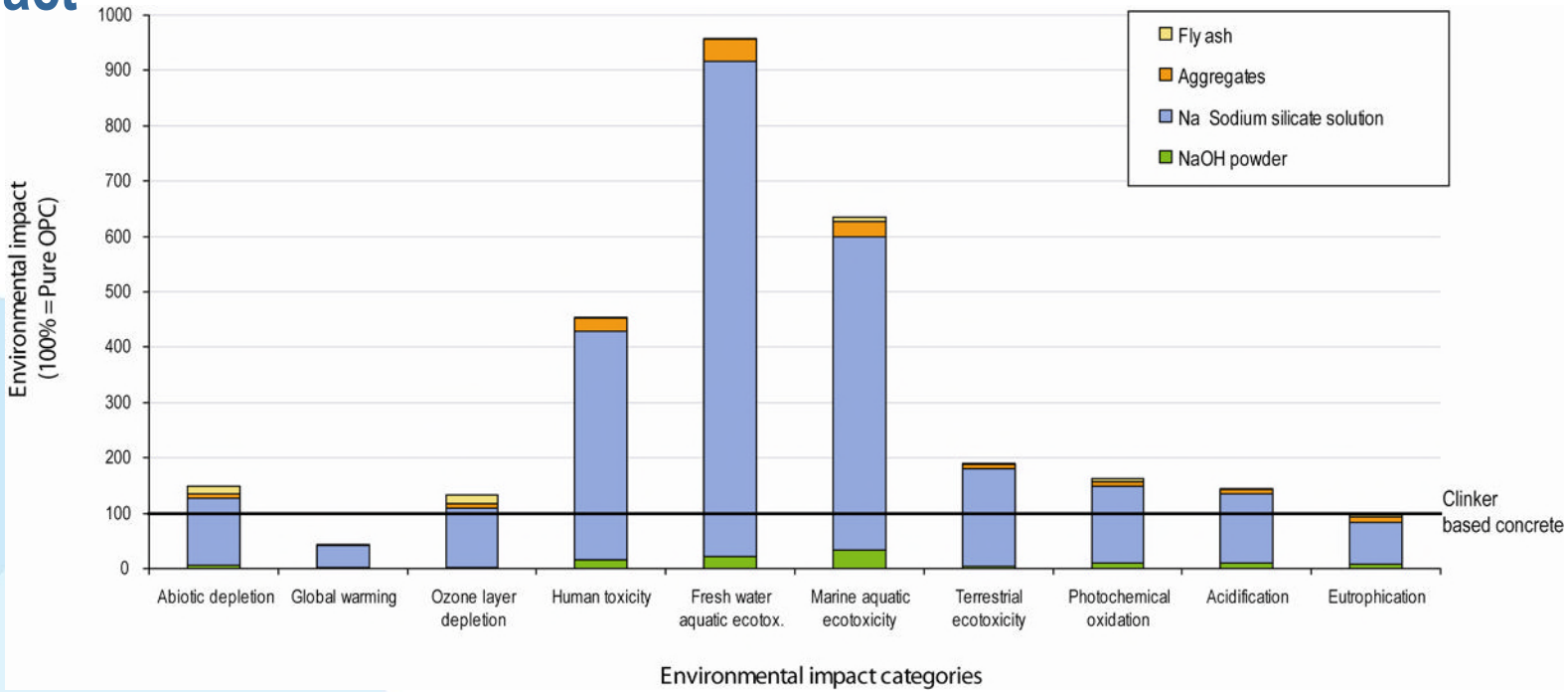
Results: Detail for one mix design

- **Fly ash based geopolymer**

Constituent [kg/m^3]	Fly ash	Sodium hydroxide powder	Sodium silicate solution	Sand	Gravel	Compressive strength [Mpa]
geopolymer concrete mix design	477	13	120	554	1294	57

- **Impact**



Sodium silicate solution controls environmental impacts
ONLY Global warming is lower

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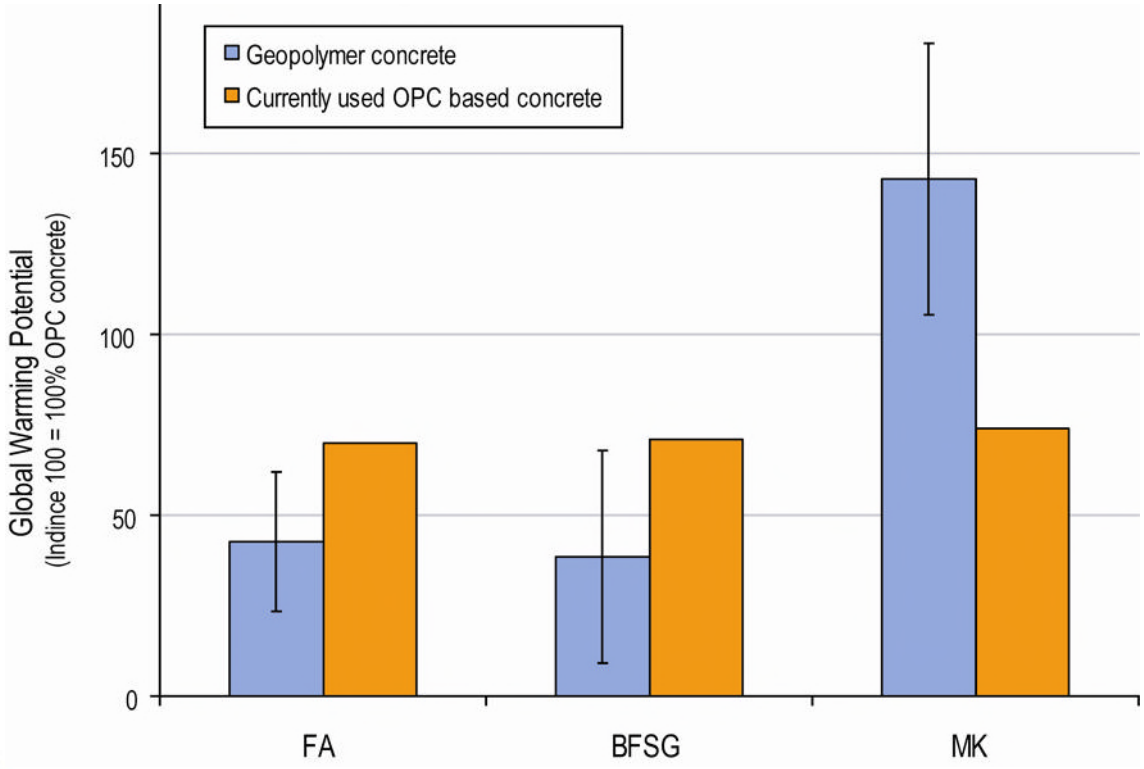
Results: different geopolymer types

- **Concretes made with:** Fly ash, Blast furnace slag or metakaolin
  - **No allocation (waste)**



Mean FA based geopolymer has 25% improvement than currently used concrete

BFSG geopolymer has lower impact,
But would be similar if compared to CEM III with 80% BFSG and not 30%...

Only for CO_2:
Watch out for transfer pollution!

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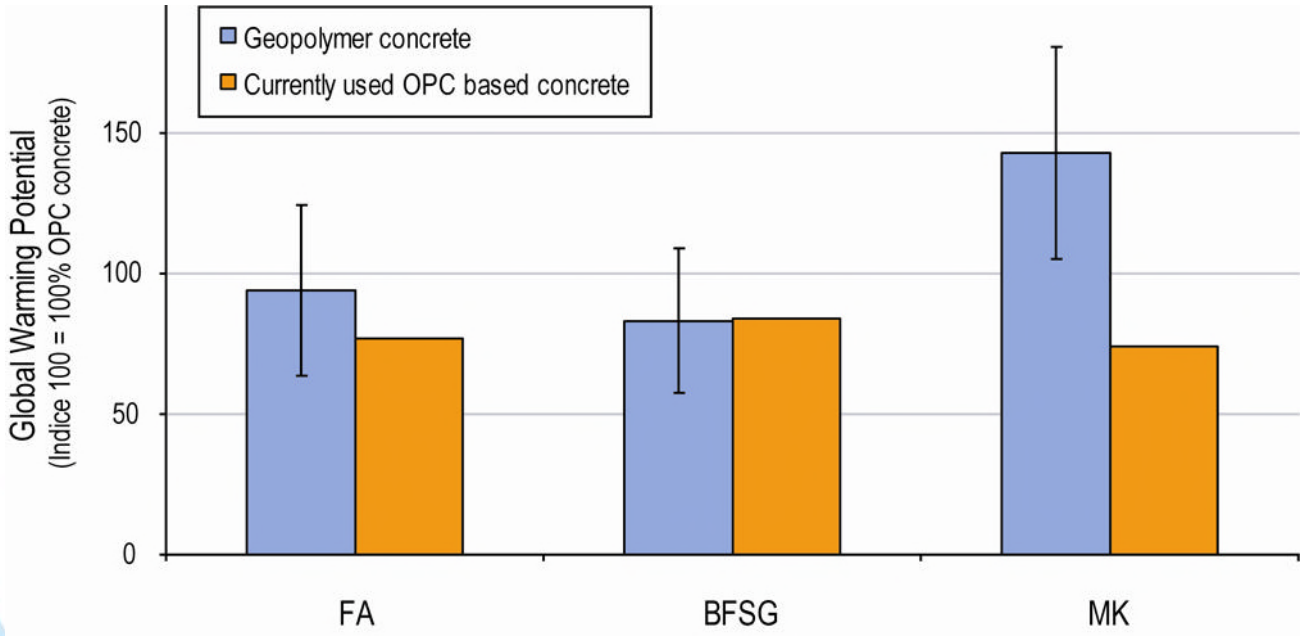
Results: different geopolymer types

- **Concretes made with:** Fly ash, Blast furnace slag or metakaolin
  - **Economic allocation (by-product)**



No sensitive improvement of using geopolymer compared to currently used cement

Only for CO_2:
Watch out for transfer pollution!

Discussion

- **Geopolymers have to be used for waste that can not be used as supplementary cementitous materials**

  (high alkali or heavy metals content)

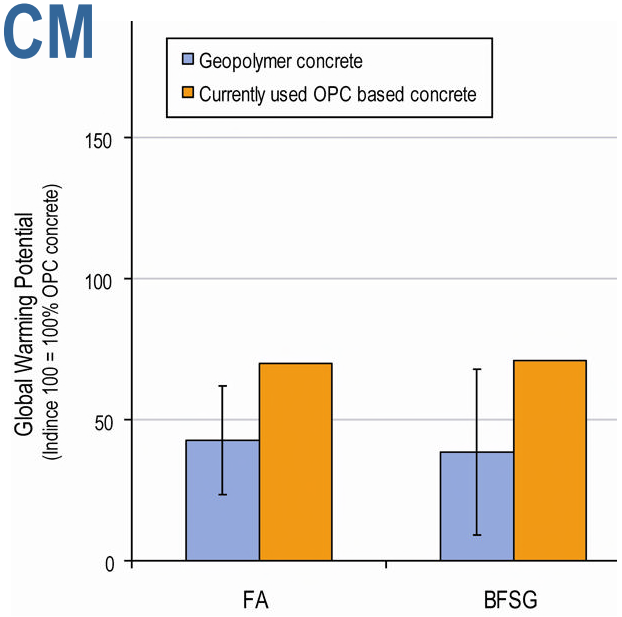
  - New resource
  - No allocation question when it is a waste

- **FA and BFSG geopolymers = similar as optimal technology with clinker & SCM**

  - 50% of FA substitution
    - » **5 to 20 % improvement if no allocation**
  - 80% of BFSG substitution
    - » **No real improvement**

» **What is the durability comparison ?**

Need of durability experiments



Discussion

- **Geopolymers have to be used for waste that can not be used as supplementary cementitous materials**

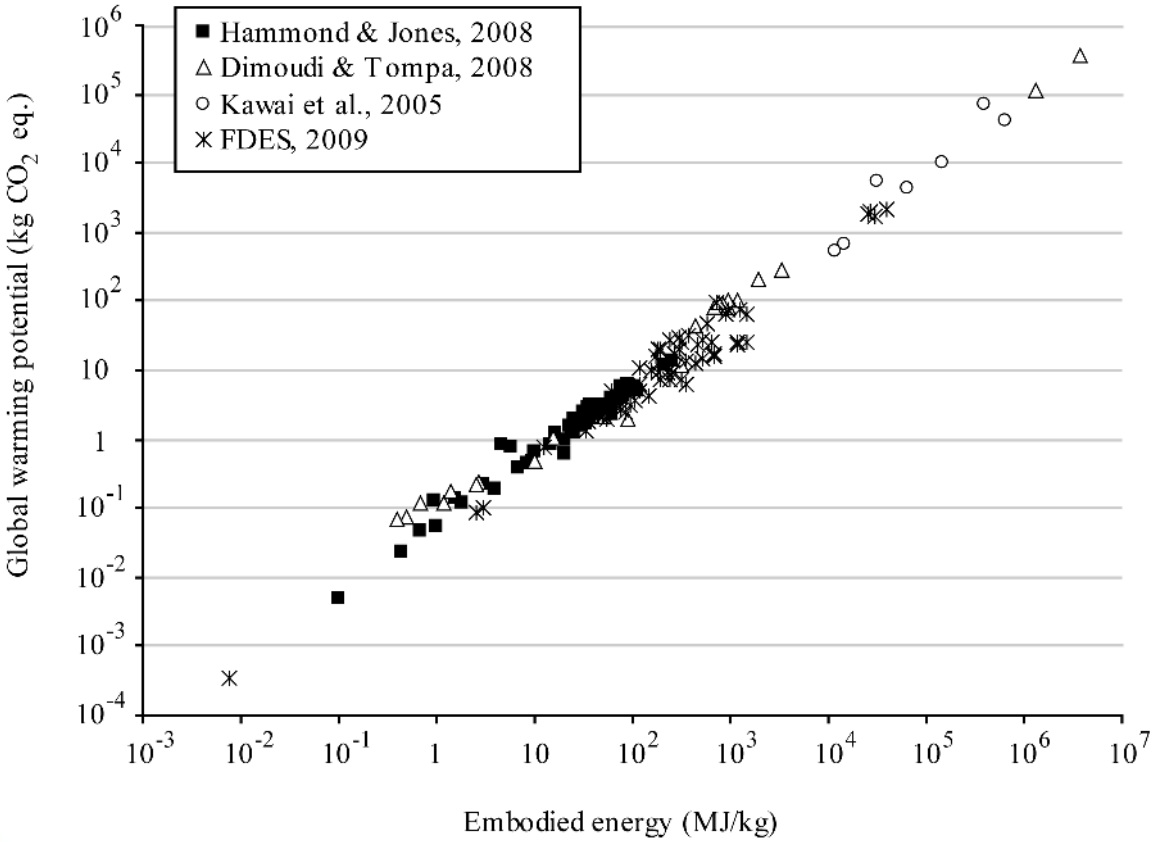
  (high alkali or heavy metals content)

  - New resource
  - No allocation question when it is a waste

- **FA and BFSG geopolymers: similar as "green" cement**
  - 50% of FA substitution
  - 80% of BFSG substitution
    - » **Need durability comparisons !**

- **MK geopolymers: Need better mix design**
  - Use of plasticizers efficient for MK in alkaline environment
  - Replace sodium silicate by another silicon source
  - Combine MK with slags

energy


Hammond & Jones, 2008
Dimoudi & Tompa, 2008
Kawai et al., 2005
FDES, 2009
Global warming potential (kg CO_2 eq.)
Embodied energy (MJ/kg)
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}