# Sustainable Cements
# *Challenges and Opportunities*

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# Concrete, Sustainability and Society

Concrete is the top engineering material contributing to anthropogenic $CO_2$ emissions: ~8%

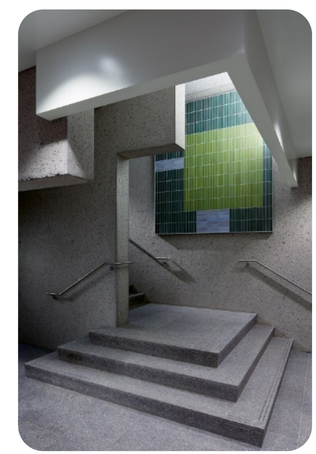
~95% of all concrete used around the world is based on Portland cement

4.1 billion tons of cement manufactured in 2017 (USGS)

- ~1 ton of $CO_2$ released into atmosphere per ton of cement
- Also important to assess energy and water (for concrete) requirements

Portland Cement Powder

Potable Water



Binder for Concrete

# Cement Manufacturing

<u>$CO_2$ sources:</u>

- Chemistry ~ 55%

$$CaCO_3 \rightarrow CaO + CO_2$$

- Fuel ~ 45%

<u>Total ~1 t $CO_2$ /t cement</u>

Kiln temperature 1450 °C

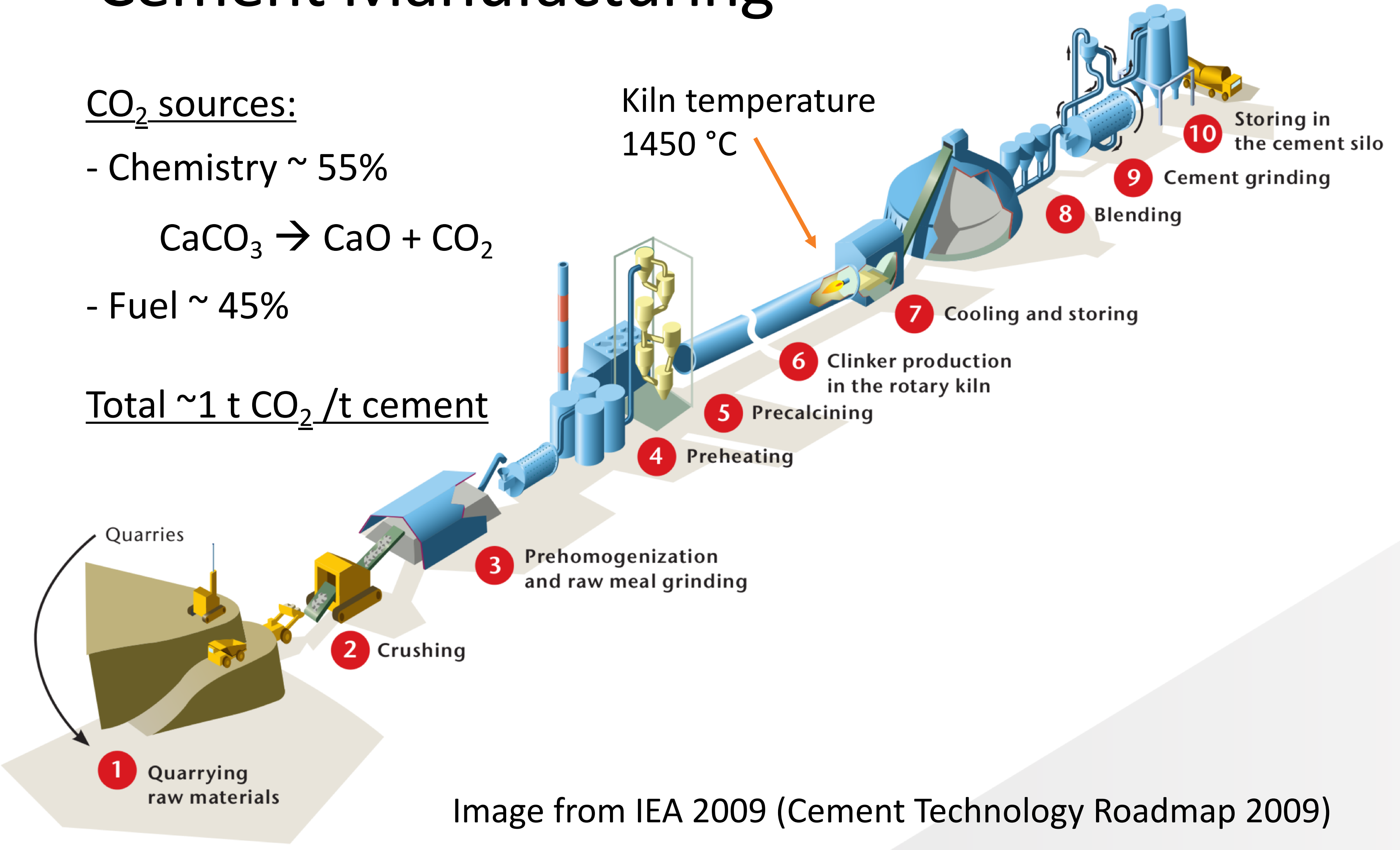


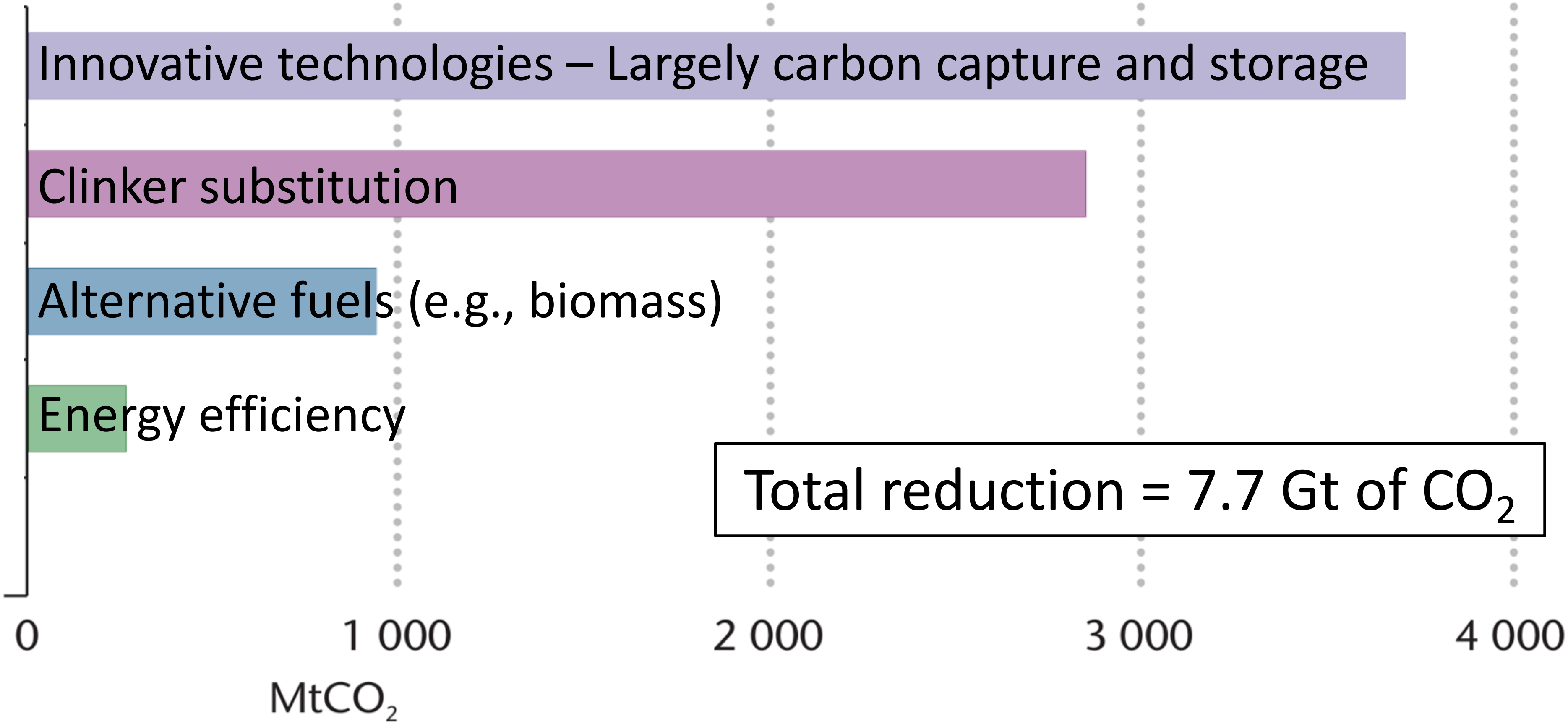

Image from IEA 2009 (Cement Technology Roadmap 2009)

# Methods to Mitigate Energy and $CO_2$ Impact

Outlined by International Energy Agency

- Carbon capture and storage
  - Any new cement plant should have associated CCS plant ($$)
- Clinker substitution
  - Need to understand the structure and reactivity of industrial by-products and processed minerals
- Alternative fuels (e.g., biomass)
- Energy efficiency
  - Large cost but low savings in $CO_2$ emissions

# Cumulative $CO_2$ Emissions Reduction from 2020 to 2050 (2 °C Scenario, Low Variability)




Beyond 2 °C Scenario: Total reduction = 10.9 Gt of $CO_2$

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Clinker substitution

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Alternative fuels (e.g., biomass)

Energy efficiency

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Innovative disruptive technologies

Alternative cementitious materials

# Status Quo

Modern day construction relies heavily on Portland cement concrete

- Reproducible quality around the world
- Heavily controlled by construction standards/codes

The main binder responsible for strength of concrete (and contributes to durability) is calcium-silicate-hydrate

- Altering the chemistry of the binder may change macroscopic properties (seen as a risky approach)

Conservative approaches making a dent on the $CO_2$ emissions

- Clinker substitution (for example, limestone-calcined clay cements)
- Still based on Portland cement chemistry

# Innovative Disruptive Technologies

Eliminate the need to produce Portland cement clinker

Examples include

- Alkali-activated materials
- Carbonate cements
- Calcium aluminate cements
- Super sulfated cements
- Calcium sulfoaluminate cements
- …

Varying levels of $CO_2$ reduction compared with Portland cement

Challenge to make inroads in an ultra-conservative industry

# Alternative Cements - Commercialization

Alkali-activated concrete

Carbonate concrete

89% reduction of Portland cement using alkali activation

Calcium sulfoaluminate concrete

http://solidiatech.com/applications/;
https://ctsrapidsetcement.com.au/gallery-videos/

# Alkali-activated Concrete

Metallurgical Slags

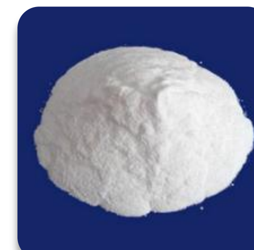
Fly Ash

Calcined Clays

Aluminosilicate Rich Powders

\+

Alkaline Activator



| **Binder chemistry** | **Cement Notation** |
| --- | --- |
| Calcium-(sodium)-alumino-silicate-hydrate | C-(N)-A-S-H |
| ◦ Alkali-activated high-Ca materials (e.g., blast furnace slag) | |
| Sodium-alumino-silicate-hydrate | N-A-S-(H) |
| ◦ Alkali-activated low-Ca materials (e.g., calcined kaolin) | |

~40-80% reduction in $CO_2$

Binder for Concrete

# Role of Fundamental Research

Long-term performance of certain blended Portland cements and AAMs is not well established

- Do not have 150 years of data on sustainable cements, in contrast with Portland cements

Need to predict long-term performance

- Key role of fundamental research (including modeling across length scales) to provide this information

Long-term performance is linked to material durability

- Performance can be compromised due to ***instabilities*** in the ***atomic structure*** of the ***main binder gel***
- Performance is lost due to material degradation, which is controlled by the concrete ***pore structure (and permeability)***