Legend:

Key slide

Question… — Key feedback asked

Data — Model input

Consultation feedback — Consultation feedback still to take into account

Global Calculator

Cement Workshop

Products & Manufacturing of the Global Calculator

Workshop of April 23rd 2014 (version of July 17th)

Brussels

Department of Energy & Climate Change

CLIMACT

World Resources Institute

eit Climate-KIC

Climate Media Factory

北京人文创新国际能源科技中心 Energy R&D International

LSE The London School of Economics and Political Science

Imperial College London

EY Building a better working world

国家发展和改革委员会能源研究所 Energy Research Institute, National Development and Reform Commission

Preliminary information on this preread

Global Calculator

- This document
  - Supported workshop discussions of April 23rd 2014
  - Addresses cement assumptions to refine the model
  - Other materials assumptions are addressed through sector specific consultations which are available through these links (steel, chemicals)
  - There is also a cross-sector analysis here

- The model was subsequently updated however it is still a work in progress as of July 2014. Some non processed expert feedback is noted within the document

- You are more than welcome to share feedback and we will try to include it in future version of the analysis. For this reason, this document will continuously update itself until September 1st.

- All this documentation will be open source

Content

• **Introduction to the Global Calculator**	**14-15h**
• Cement demand perspective	15-16h
• Cement manufacturing with lower energy intensity	16h30-18h

Introduction to the Global Calculator 14-15h

Background

Experts & Literature review

Most introduction material is described in the cross sector document

- Background of the global calculator project
- Purpose of the workshop
- Team & model structure

The cross sectoral document is available here

Introduction to the Global Calculator 14-15h

Background

Experts & Literature review

The following stakeholders have been provided with an opportunity to review the cement assumptions (1)

Global Calculator

Cement specific

WBCSD, Cement sustainability Initiative
- Roland Hunziker

US Portland cement association
- David D. Shepherd

Cembureau:
- Alessandro Sciamarelli
- Claude Lorea
- Jessica Johnson,

Japan Cement Association

Cement, Concrete & Aggregates Australia

Lafarge
- Mr. Vincent Mages

Italcementi
- Ms. Manuela Ojan

Cimpor
- Mr. Paulo Rocha

All sectors (interaction planned later)

Think tanks
- WBCSD
- GIZ

Academic
- Tsinghua University
- UK Engineering and Physical Sciences Research Council (EPSRC), author of With both eyes open, Jonathan M Cullen
- Fraunhofer institute
- LBNL (China Energy Group)

NGOs
- Greenpeace
- WWF

Legend	
●	Workshop presence

NOTE: (1) The stakeholders do not validate or endorse the assumptions described in this document, the assumptions are the sole choice of the Global Calculator team

Most referred to analysis has been taken into account to make this model

Global Calculator

Main sources used for this analysis

Organisation	Source
Cambridge	• With both eyes open
IEA	• Energy Technology Perspectives 2012, Pathways to a clean energy system • ETP 2014 data
International Cement Review	• The global cement report (6th edition) • Insights from the global cement report (10th edition) (2013)
IEA-WBCSD	• 2050 Cement Technology Roadmap (2009)
Carbon War Room	• Cement Report 1 (2011)
Mineral product association	• UK cement roadmap (2013)
GNR	• Global Cement Database on CO_2 and Energy Information
European Cement Research academy	• Technical documentation
Cembureau	• the role of cement in the 2050 low carbon economy
IEA	• GHG 2008. CO2 capture in the cement industry. Report 2008/3. Cheltenham, UK: International Energy Agency Greenhouse Gas R&D Programme
Previous consultations	• Similar roadmaps performed in Belgium, UK, Algeria, the Balkans & India

Content

• Introduction to the Global Calculator	14-15h
• **Cement demand perspective**	**15-16h**
• Cement manufacturing with lower energy intensity	16h30-18h

Global Calculator

Cement demand perspective 15-16h

Current situation

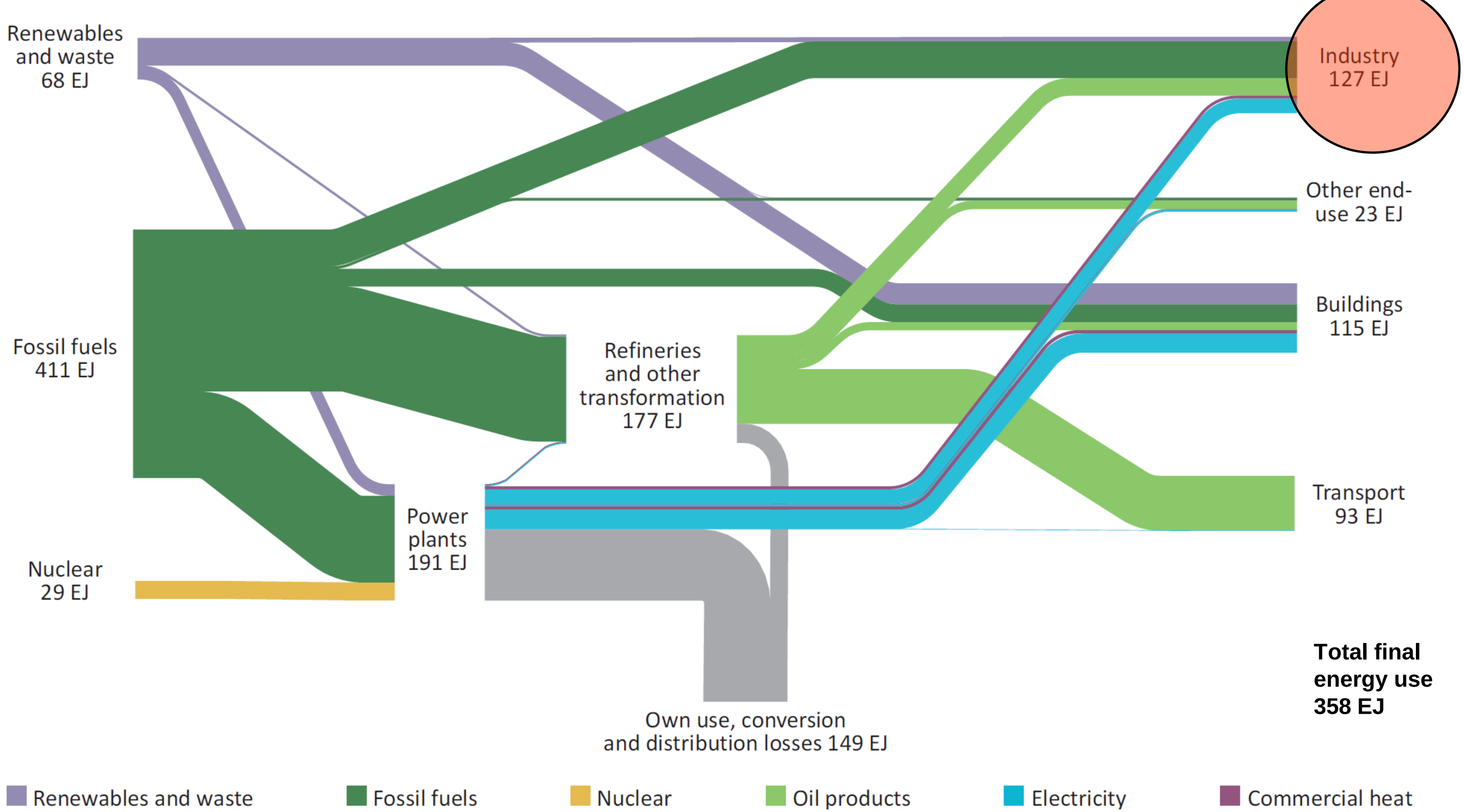
Cement demand drivers

Resulting cement demand at constant technology

Industry is ~35% of final energy use, it mainly relies on fossil fuels

Global Calculator

Energy Sankey in 2009, (EJ)



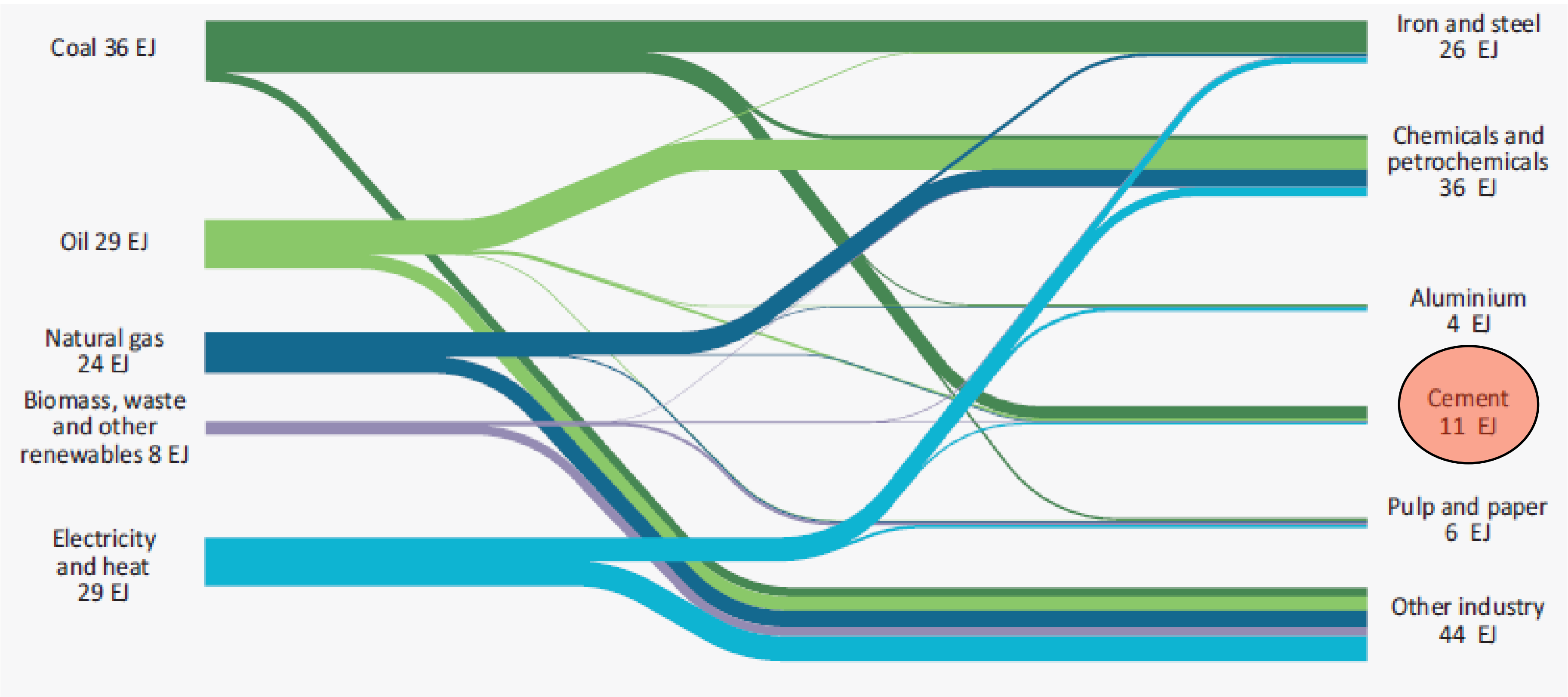
SOURCE: ETP 2012, IEA

NOTES: (1) Worldsteel recently raised the steel specific energy consumptions, this is not yet reflected by this picture
(2) Energy consumption is dominated by fossil fuels in all sectors

Cement represents ~9% of the industry energy use, it also mainly relies on fossil fuels

Global Calculator

Energy Sankey in 2009 for the industry , (EJ)



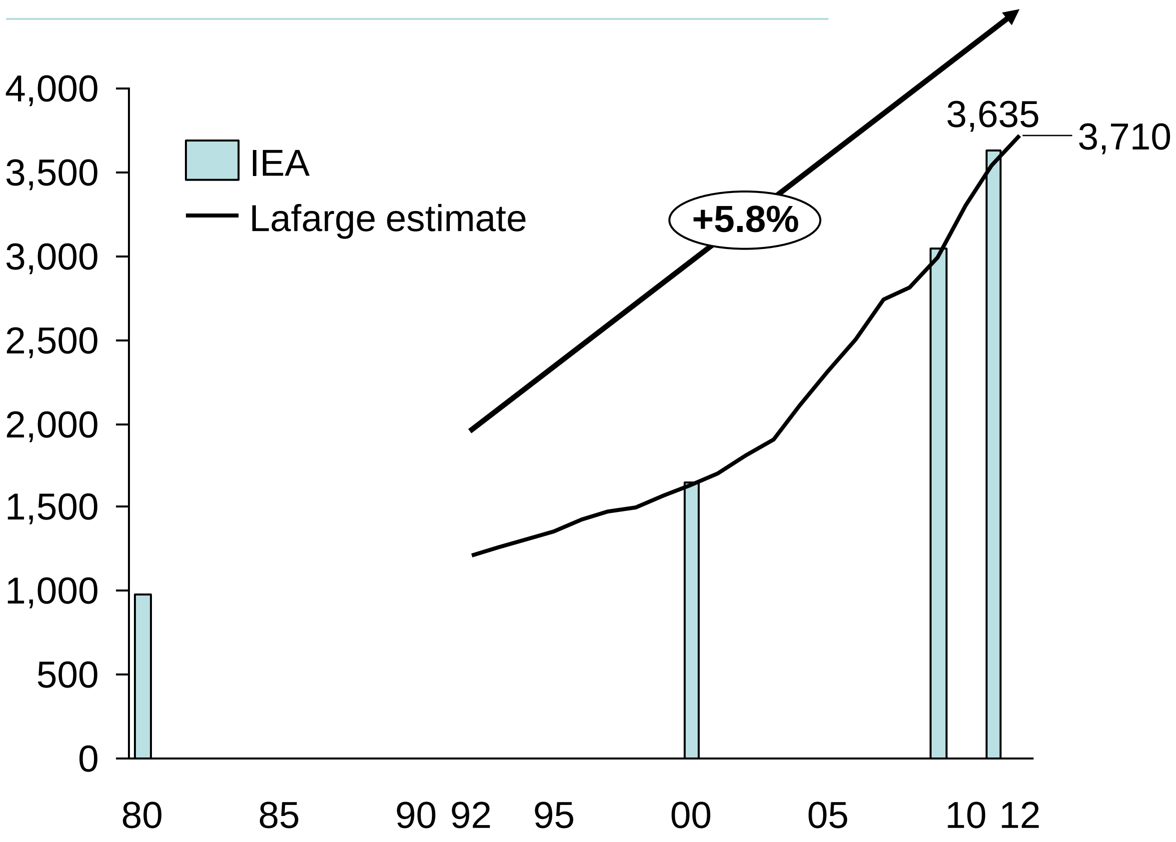
SOURCE: ETP 2012, IEA

NOTES: (1) Worldsteel recently raised the steel specific energy consumptions, this is not yet reflected by this picture
(2) Energy consumption is dominated by fossil fuels in all sectors

Cement production has grown by ~5% per year since 1990

Global Calculator

Historic evolution of cement production
(Mtons)



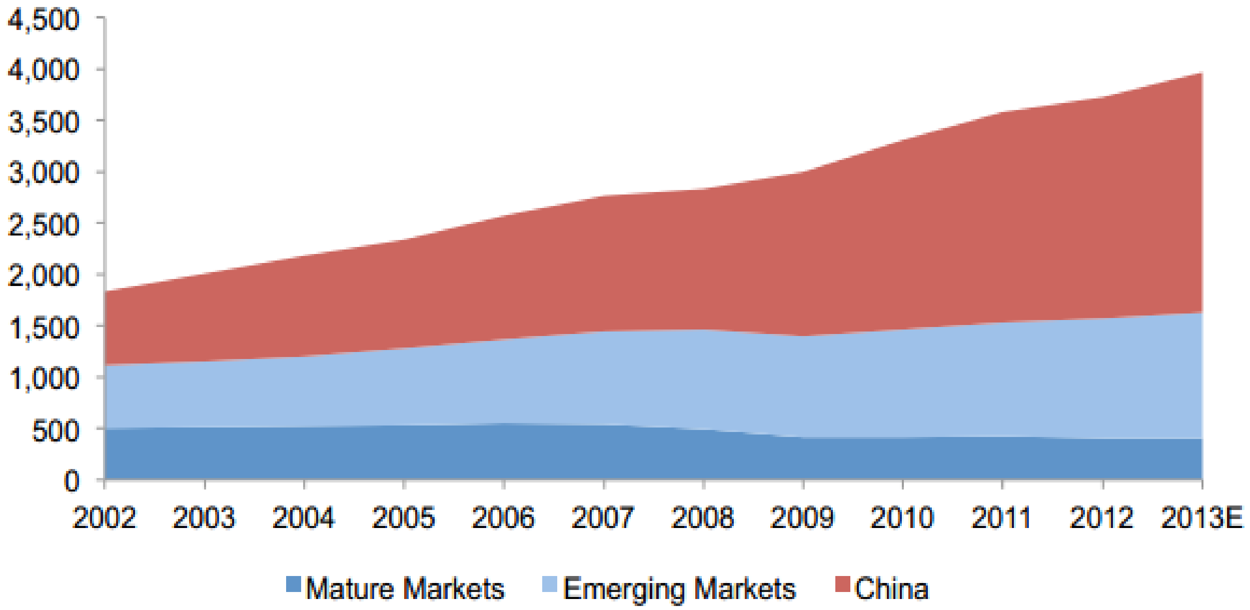
- North American and European demand stagnated from 1970 to 1995, while Chinese demand has expanded at a phenomenal rate

SOURCE: IEA and Lafarge group presentation, With both eyes open

Cement demand is largely driven by China

Global Calculator

Evolution of cement demand
(2002-2013 M tons)



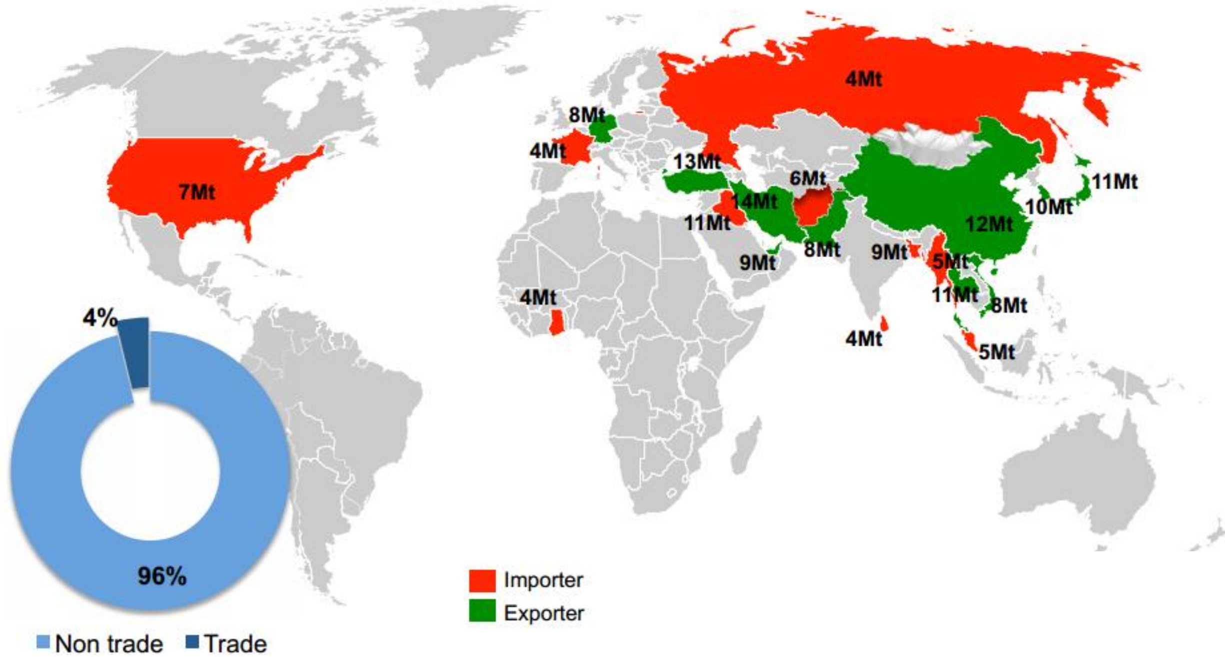
- Global cement demand is dominated by China (39% in 2002 vs 58% in 2012)
- Steady growth in emerging markets
- Mature markets entered into a period of contraction from 2008

SOURCE: International Cement Review, Global cement industry trends

Only 4% of the cement production is internationally traded

Global Calculator

Magnitude of the top 10 importers and exporters
(Mt, 2012)



- Total of 167Mt traded in 2012 (4% of production)
- Top 20 exporters account of 85% of exports
- The major continents produce most of their own cement
- Cement resources are well distributed across the planet
- Cement has limited added value by weight

SOURCE: International Cement Review, Global cement industry trends

Cement demand perspective 15-16h

Current situation

Cement demand drivers

Resulting cement demand at constant technology

1 The analysis starts from the demand for products and derives material production and resource use

Global Calculator

Value chain

Illustrations

Resources

Materials analysis: Rare materials | Iron ore | Sand

Energy analysis: Uranium | Fossil hydro-carbons | Biomass

Materials

Steel | Cement | Aluminium | Chemicals | Pulp & paper

Products

- Taking advantage of the global scope, the materials analysis can include embedded emissions and resources impact
- Part of the product demand is a model input, another is generated by the requirements of other sectors

1

Concrete is often used in addition to steel to make durable products

Global Calculator

Cement materials characteristics

Strong in compression	Cement is strong in compression, yet weak in tension Portland cement makes it settle faster, furthermore it can settle underwater
Durable	Concrete is not sensitive to corrosion (vs steel) nor fire (vs timber)
Practical to handle	Concrete can be poured, which enables easier transport and construction of materials Has a thermal expansion similar to that of steel
Affordable	Cement tends to be cheaper than other durable materials

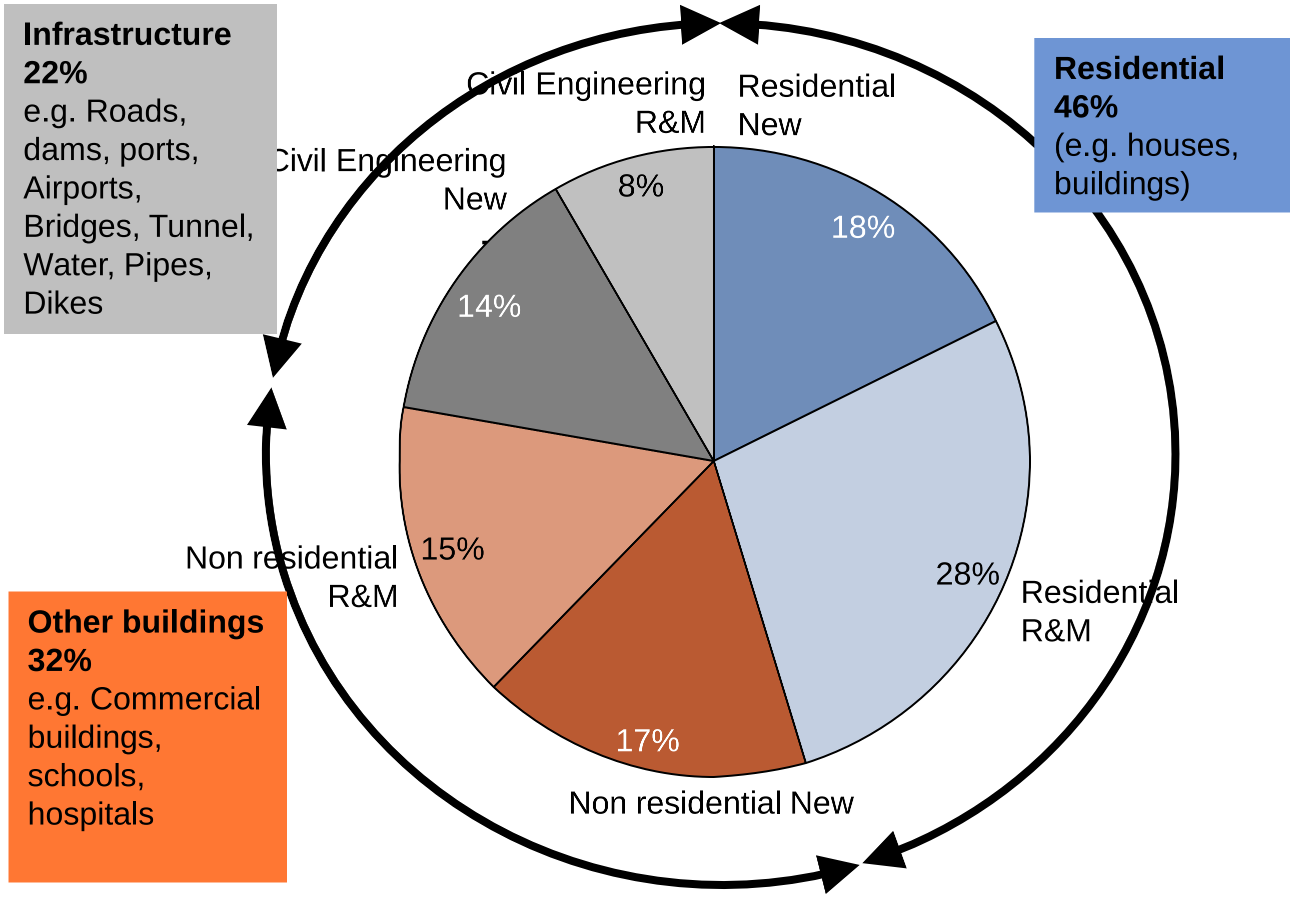
Concrete is used in addition with steel in most applications (steel is strong in tension, and concrete prevents steel from corrosion)

SOURCE: with both eyes open

1 Cement is mainly used for Domestic buildings, Other buildings and Infrastructures

Global Calculator

Construction market in Europe
(Bln €, 2012)(2)



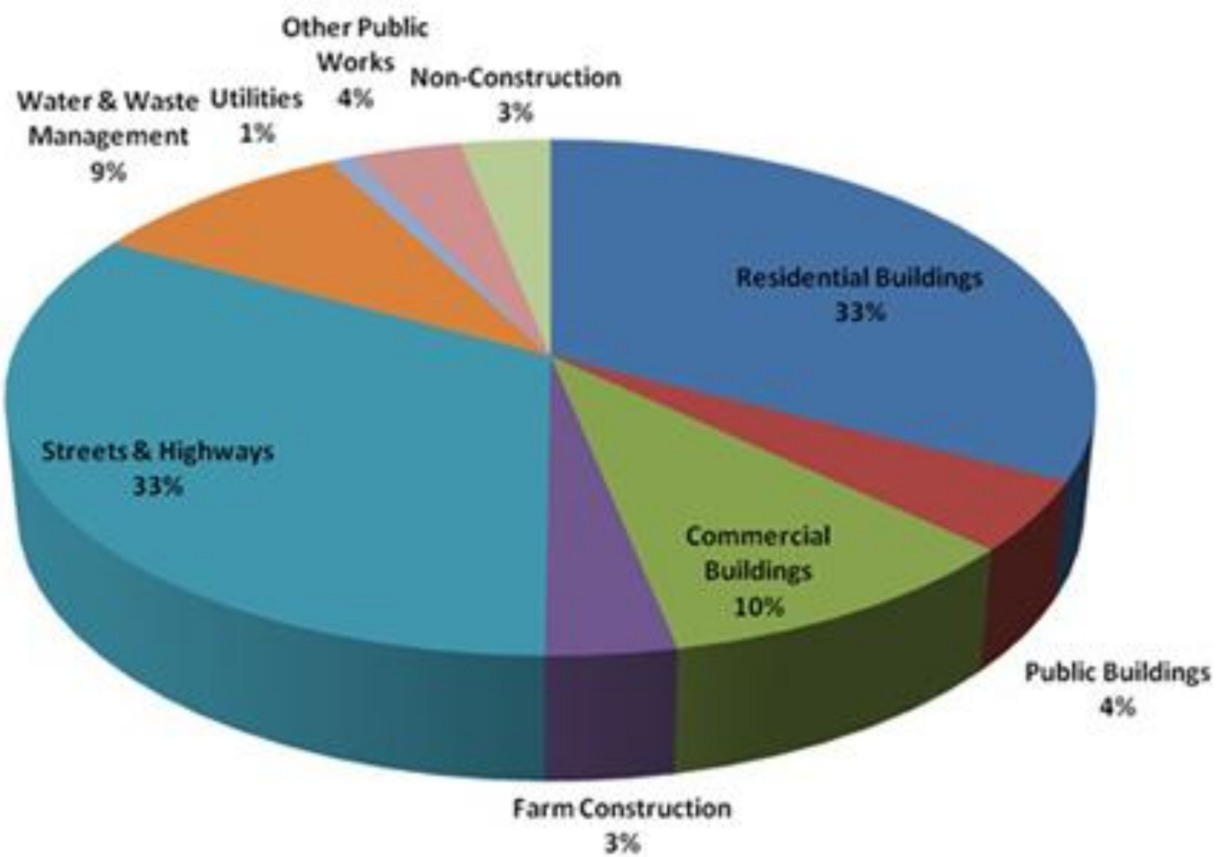
- Cement is mainly used as a binder in concrete, which is a basic material for all types of construction(1)
- The European construction market is an indication of the global cement applications

SOURCE: (1) Cembureau, The role of CEMENT in the 2050 LOW CARBON ECONOMY, (2) with both eyes open
(3) Euroconstruct, VTT, Buildecon, EU 27 (excl Cyprus, Greece, Luxembourg & Malta), plus Noway & Switzerland

1 Cement is mainly used for Domestic buildings, Other buildings and Infrastructures

Global Calculator

Apparent use of Portland cement by market
(%, 2006)



- The US apparent use is used to assess of the global cement applications

SOURCE USGS, PCA

1 Today, this is the model generated demand, it will evolve based on Product demand defined by the other sectors

Global Calculator

Technologies & Products		Amounts (units, 2011)	Intensity (tons/ product)	Cement production (G tons, 2011[2])
Buildings	Residential Buildings	4000 million m² [4]	305 kg cement per m² of buildings [1]	1,200 Gton (33%)
	Other Buildings	830 million m² [4]	745 kg cement per m² of buildings [1]	618 Gton (17%)
	Infrastructure	1750 million m2 [4]	1023 rest kg cement per m² of buildings [1]	1,818 Gton (50%)

Model demand drivers

Total 3,635 Gton (100%)

NOTE: (1) With both eyes open assumes ~60 kg per floor. The model is working with ground surface so including several floor levels. Assuming 8 tons of cement per ton of concrete and a concrete density of 2200kg/m3, one can assess the width of concrete in the buildings. 500kg/m² is close to 2 m depth per square meter

Furthermore, residential buildings typically have half as much steel per concrete, than other buildings (commercial/industrial).

(2) Linking product to material demand for a same year is a modelling simplification; in reality, the material production can happen several years before the product delivery

(4) Of ground surface

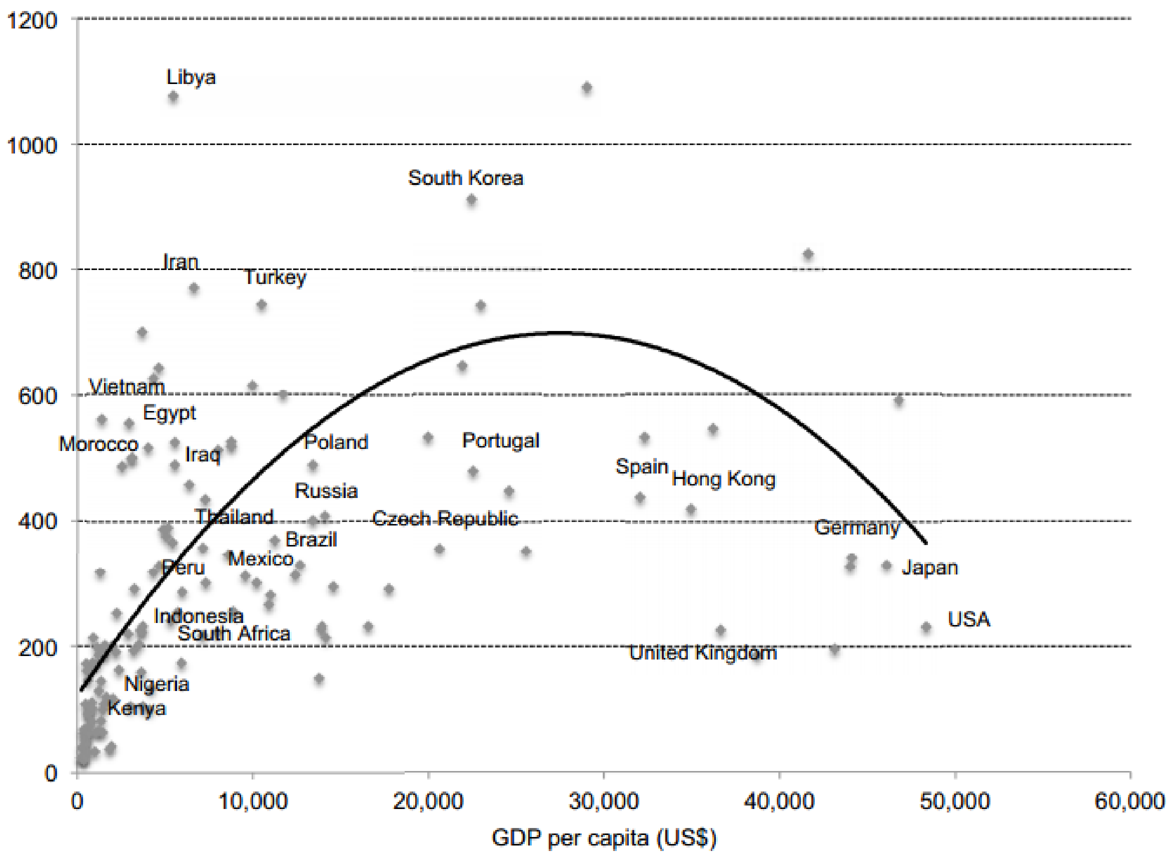
SOURCE: (1) Model, matching buildings estimate to cement and steel demand

Cement demand perspective 15-16h

1 As income/person increases, cement demand increases and then decreases

Cement per capita consumption as function of GDP per capita
(kg, US$, year 2011)[1]

BACKUP



Demand for cement is often correlated to national incomes, up to around $20,000/person, but then declines, when demand for new buildings and infrastructure has been satisfied [1,2]

SOURCES: (1) International Cement Review, Global cement industry trends
(2) With both eyes open

1 Cement demand drivers have been identified

Global Calculator

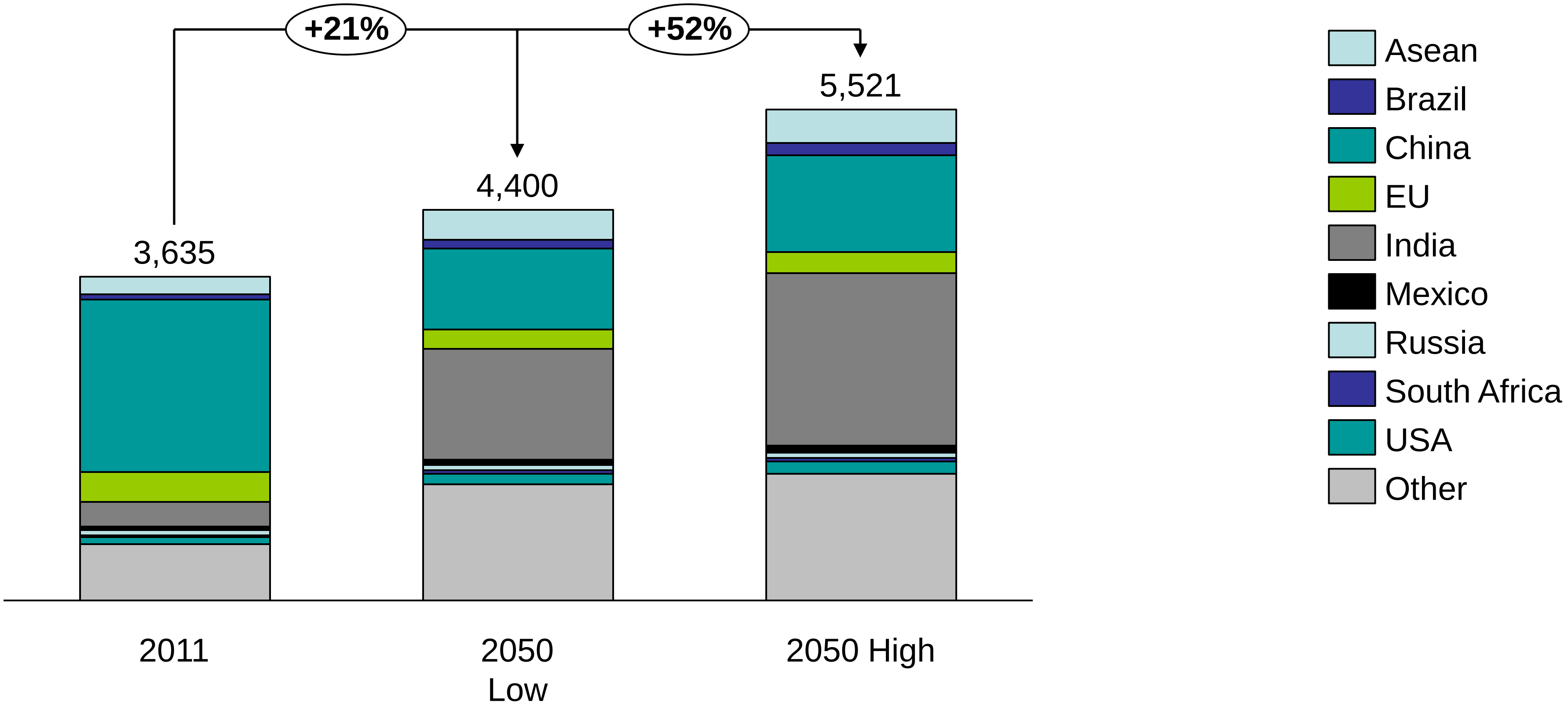
Driver	Rationale	Correlation
Demography	Per capita consumption is ~450kg	Direct correlation
Income	Increase with GDP growth up to ~$20k/person, but then declines, when demand for new buildings and infrastructure has been satisfied	Difficult correlation, as evolution should be modelled per region
New buildings (residential & commercial, & other)	420 kg cement /m² building 1900 kg concrete/ m² of buildings [(1)]	Direct correlation (includes the demography and income)
New infrastructure	450 kg cement/m² building ? 1900 kg concrete per m² of buildings [(1)]	Direct correlation (includes the demography and income) but iteration loop Correlated in model to: • Travel (passenger +freight) evolution • Population (to remove because of double count)

SOURCE: (1) with both eyes open

1 The IEA expects Cement production increase in all scenarios in most regions except for China which starts very high

Global Calculator

Production evolution per scenario per region for Cement
(Mton)



NOTE : IEA figures of 2009 per geographic area have been extrapolated to 2011 using the trends provided in International Cement Review, Global cement industry trends

SOURCE: ETP 2012, IEA

1 Rationale for expected 2050 cement demand

Global Calculator

Population evolution	7 billion people in 2010[3] 8-10 billion people in 2050 [3]
Demand per capita evolution	Per capita • 450 kg of cement per capita in 2011 • 470-590 kg of cement per person by 2050
Regional changes	Per capita • Decrease in China (currently 1218) and Korea (currently 1028) • Increase in other non-OECD countries (from 218 to 480-570) In total • Cement demand is going to be driven by demand in India and China [2] • Cement production more than triples between 2009 and 2050 in India, Africa and other developing countries in Asia (excluding China), with the result that about 45% of all production in 2050 will be in these countries[1]
Market segment changes	No major shift between infrastructure and buildings is expected
In conclusion	• IEA ETP 2012 has 4500Mt to 5500Mt in 2050[2]

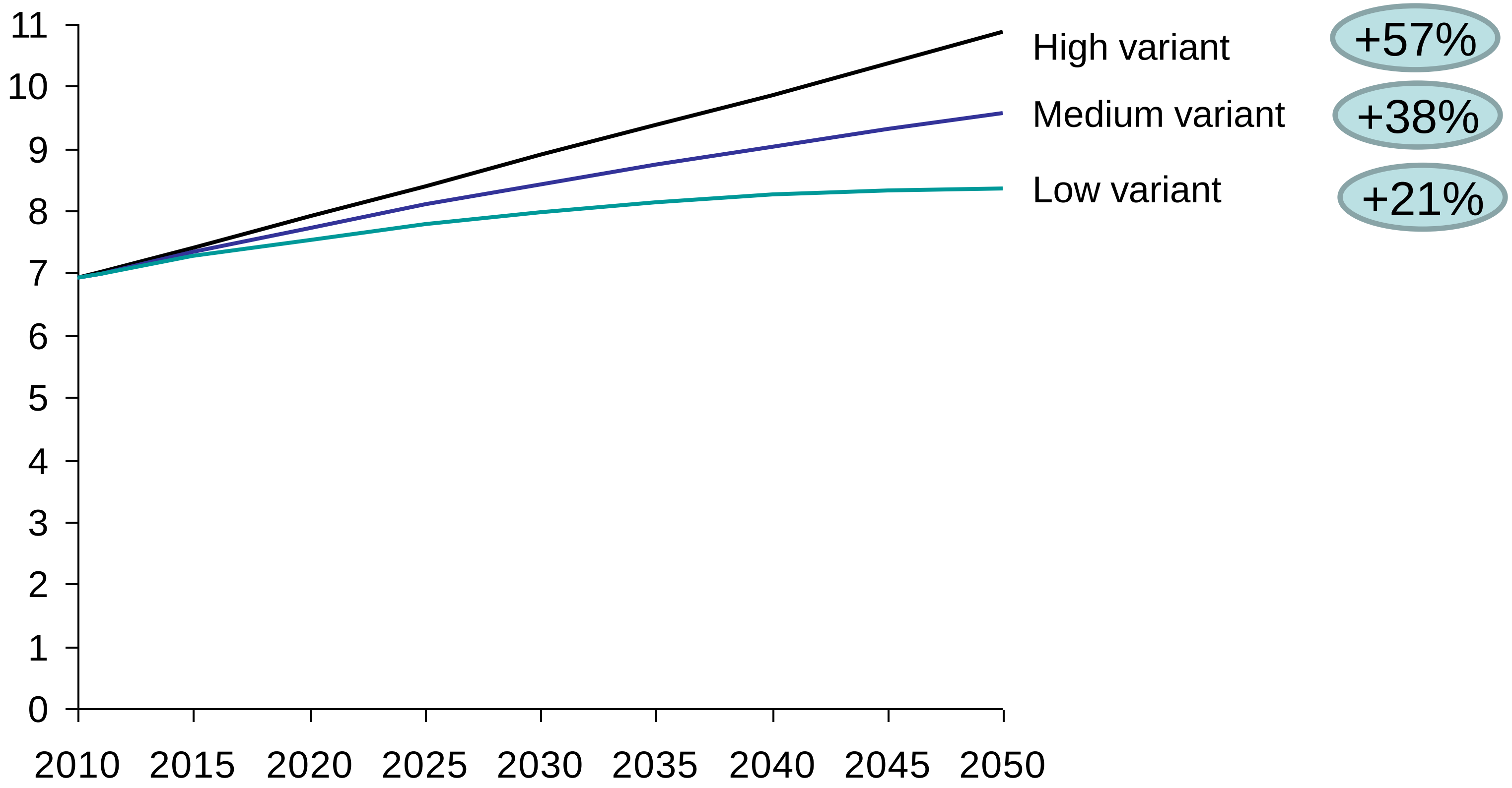
SOURCE: (1) IEA ETP 2012 (2) With both eyes open (3) UN projection scenarios

1 By 2050, the world population is expected by the UN to grow by ~20 to 60%

Global Calculator

World population (billions)

2010-2050 growth (%)



SOURCE: http://esa.un.org/unpd/wpp/unpp/panel_population.htm 2012 revision

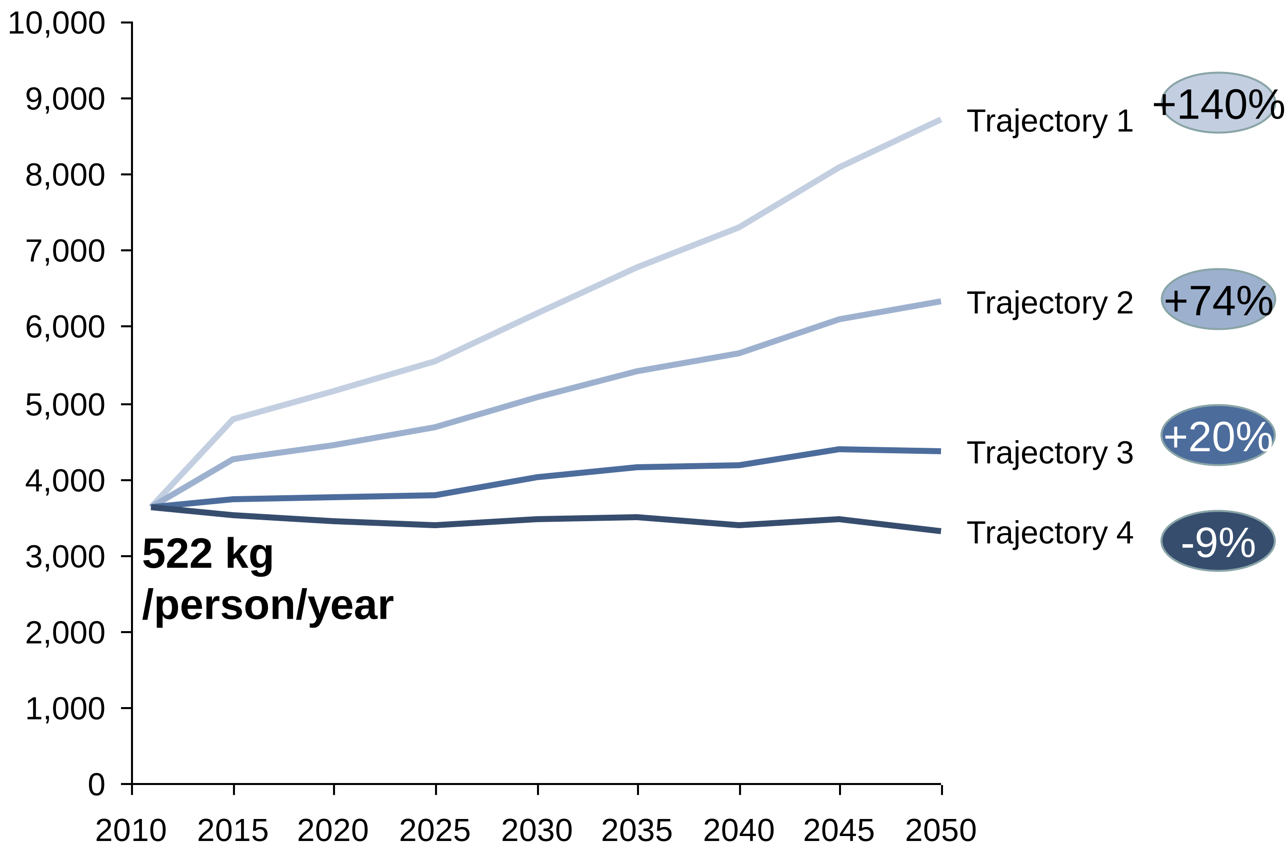
Model growth forecasts
Production according to trajectories 1, 2, 3 & 4 (before design, switch & recycling)

Global Calculator

Cement production per year for different ambition levels (1)
(M tons)

Delta 10-50,%

Implied demand per person



912 kg /person/year

663 kg /person/year

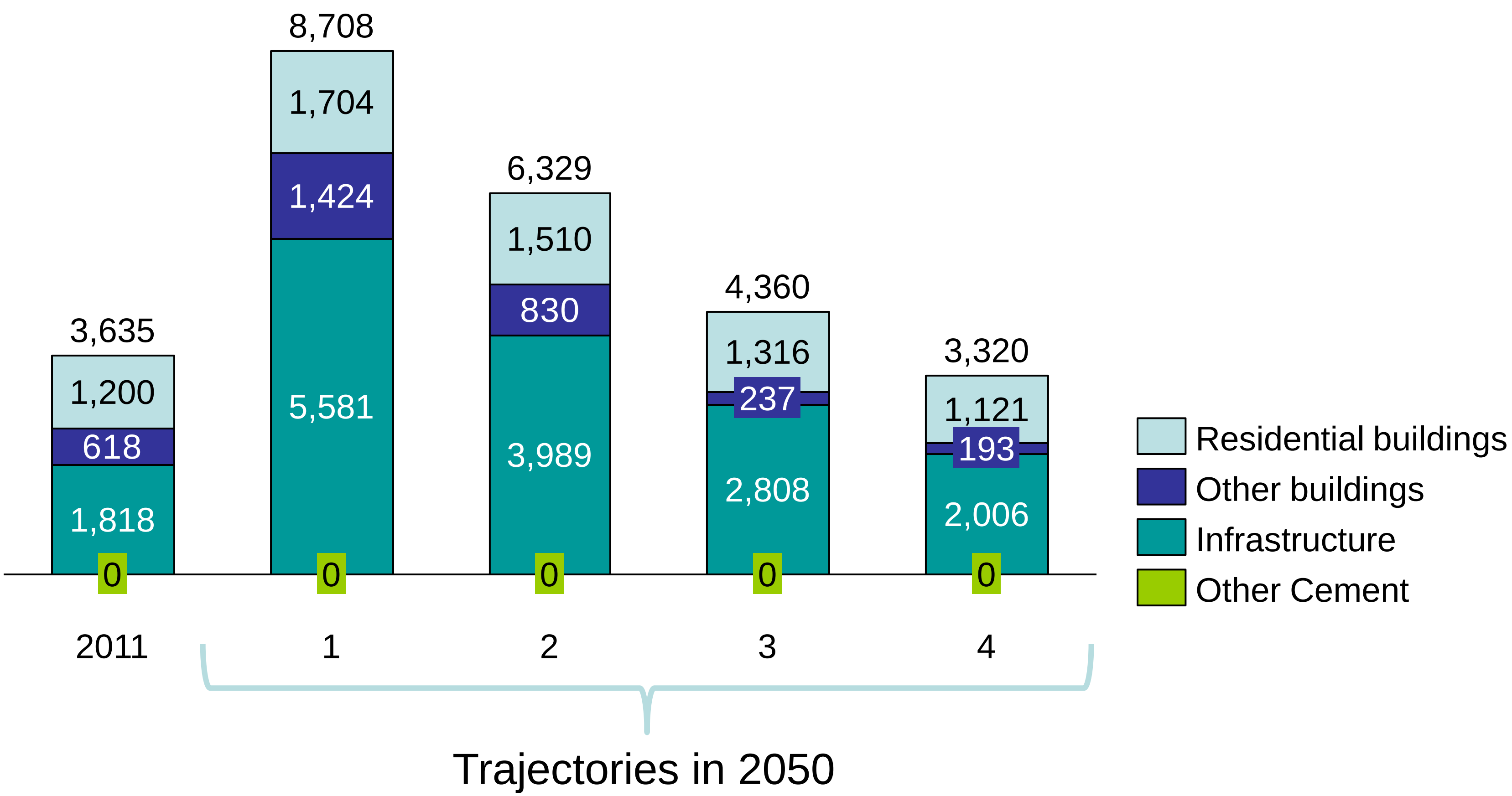
457 kg /person/year

348 kg /person/year

NOTE: (1) The population follows the average UN projection in all four trajectories
SOURCE: IEA ETP 2012, Global calculator model

Model growth forecasts
Drivers in trajectories 1, 2, 3 & 4

Cement production per year for different ambition levels (1)
(M tons)



NOTE: (1) The population follows the average UN projection in all four trajectories
SOURCE: IEA ETP 2012, Global calculator model

Global Calculator

Content

• Introduction to the Global Calculator	14-15h
• Cement demand perspective	15-16h
• **Cement manufacturing with lower energy intensity**	**16h30-18h**

Cement manufacturing with lower energy intensity (-18h)

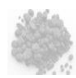
Cement manufacturing process

Estimation of the reduction potentials

Resulting scenarios

Manufacturing chain definition for each technology

Global Calculator

Technology	Raw materials extraction & grinding	Preheating, precalcining, heating & cooling	Blinding and grinding (for cement)	Mixing (for concrete)
Grey clinker • Dry process	 $CaCO_3$ Limestone  SiO_2 Silica, Al_2O_3 Alumina, Fe_2O_3 Iron oxyde Clay	 Powder Substitutes (e.g. sand) Fuels  CO_2	 Clinker  Gypsum Other additions	 Cement Water Aggregates (sand & crushed stones)  Concrete
• Humid process	Idem but no grinding	Idem	Idem but drying in a longer rotary kiln	
White clinker	Idem but no iron intake	Idem	Idem but slower cooking	

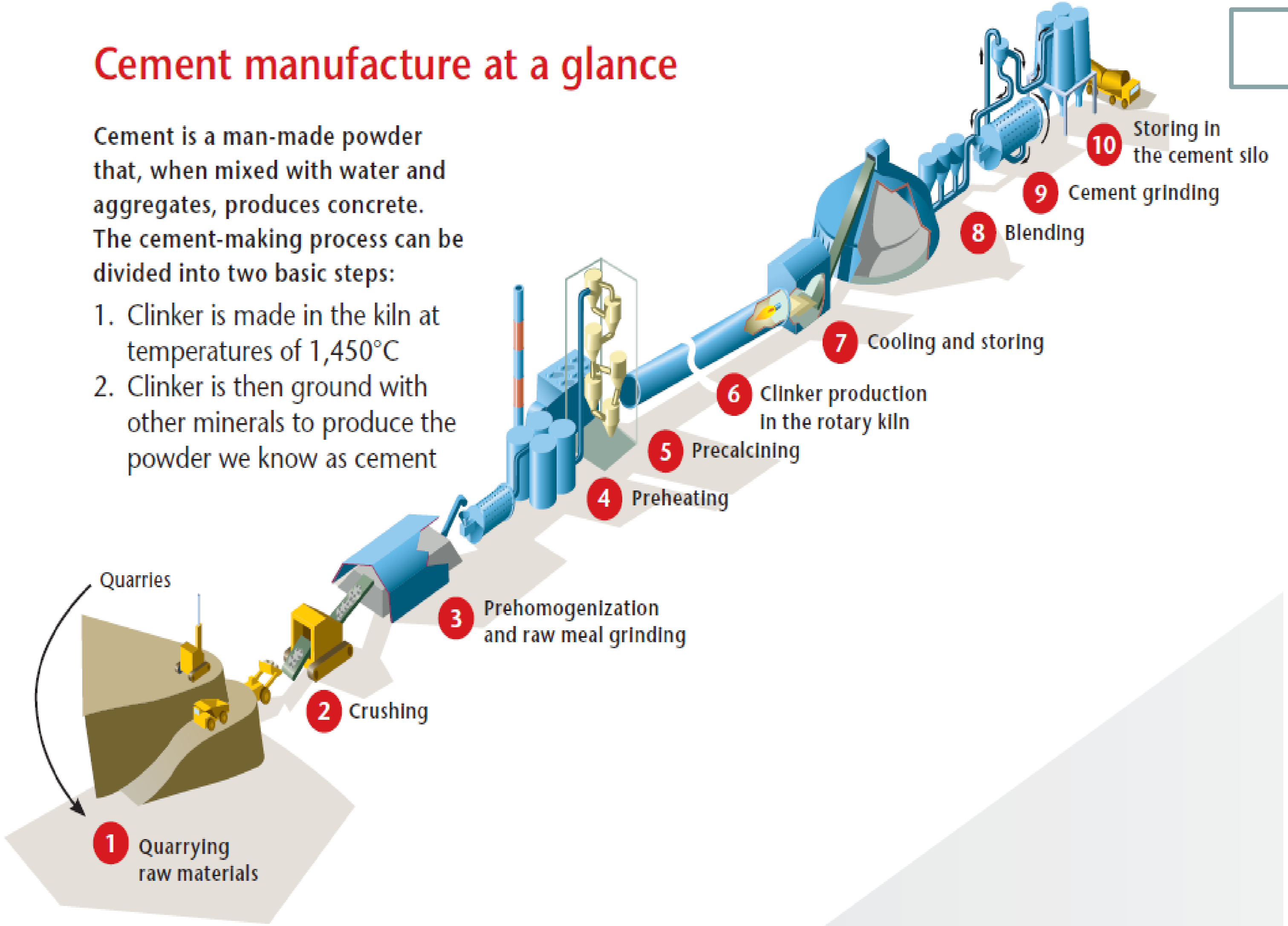
NOTE: The cement typically represents 10-15% of the concrete mix, is then used with water and aggregates (sand & crushed stones)

SOURCE: Climact analysis

Classical illustration of the cement manufacturing chain

Global Calculator

BACKUP

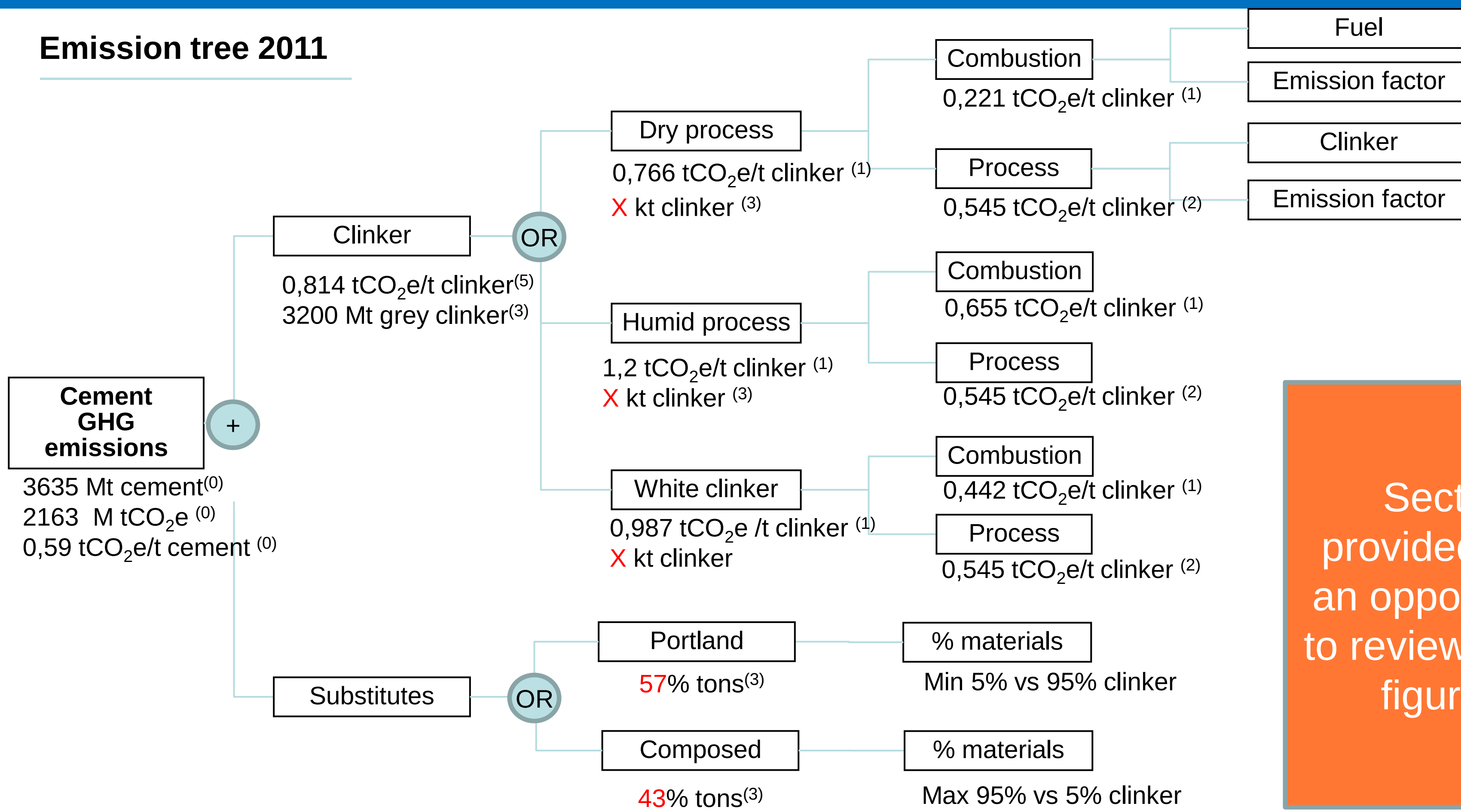


SOURCE: IEA 2009 Cement Technology roadmap

Detailed emission tree

(not modelled, but used to assess the impact of the reduction levers)

Emission tree 2011



Sector provided with an opportunity to review these figures

NOTE: Excludes electricity which is included in the energy sector

SOURCE: (0) IEA 2011 (1) CBR & Holcim 2011 interviews
(2) 2010 Belgian GHG inventory (3) USGS, (4) Climact analysis (5) Febelcem

Assumptions for consumption and emissions are specified

Model assumptions (2011) (1, 2)

Technology		Total
Production (Mt)		3635
Specific Consumption (PJ/MT= GJ/t Cement)	Electricity	0,35
	Solid HC	1,88
	Liquid HC	0,31
	Gaseous HC	0,23
	Biomass & Waste	0,14
	Heat	-
	Total	2,92
Specific emissions (tCO2/t cement)	Combustion CO_2e	0,21
	Process CO_2	0,38
	Process CH_4	0,03
	Process N_2O	0,03
	Total CO_2	0,59
	Total CH_4	0,03
	Total N_2O	0,03
	Total CO_2e	

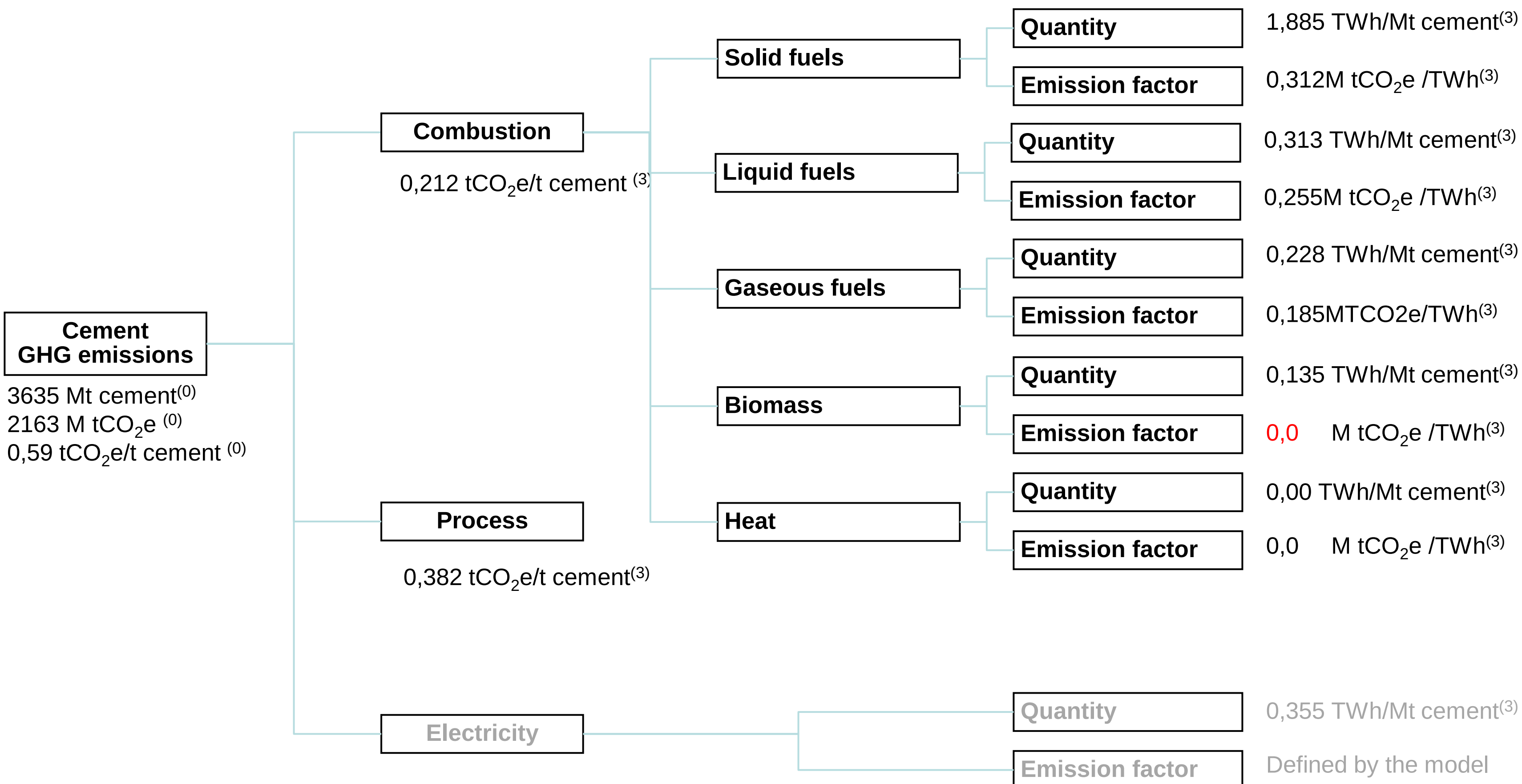
NOTE: scope covers steel & alloys making (but not the use phase nor the materials extraction phase

SOURCE: (1) IEA (2) MIDREX.com website

Emission tree
(modelled)

Global Calculator

Model Emission tree 2011



Cement specific emission factor for biomass & waste could be added in future version of the model

SOURCE: (0) IEA 2011, (2) 2010 Belgium GHG inventory (3) 2010 Walloon region energy balance, (4) Climact analysis

Global Calculator

Cement manufacturing with lower energy intensity

Cement manufacturing process

Estimation of the reduction potentials

Resulting scenarios

Material demand / product:
Design, Switch & Recycling levers are assessed

List of actions & levers assessed

Design

- Changing product and material specifications to answer the same needs with less materials

Smart design

Switch

- Change materials to enable a low carbon product (over the product lifetime)

In buildings/Infr. : To green plastics & to timber

Recycling

- Recycle the product or the material

Product recycling

Material recycling

Steel/composed cement

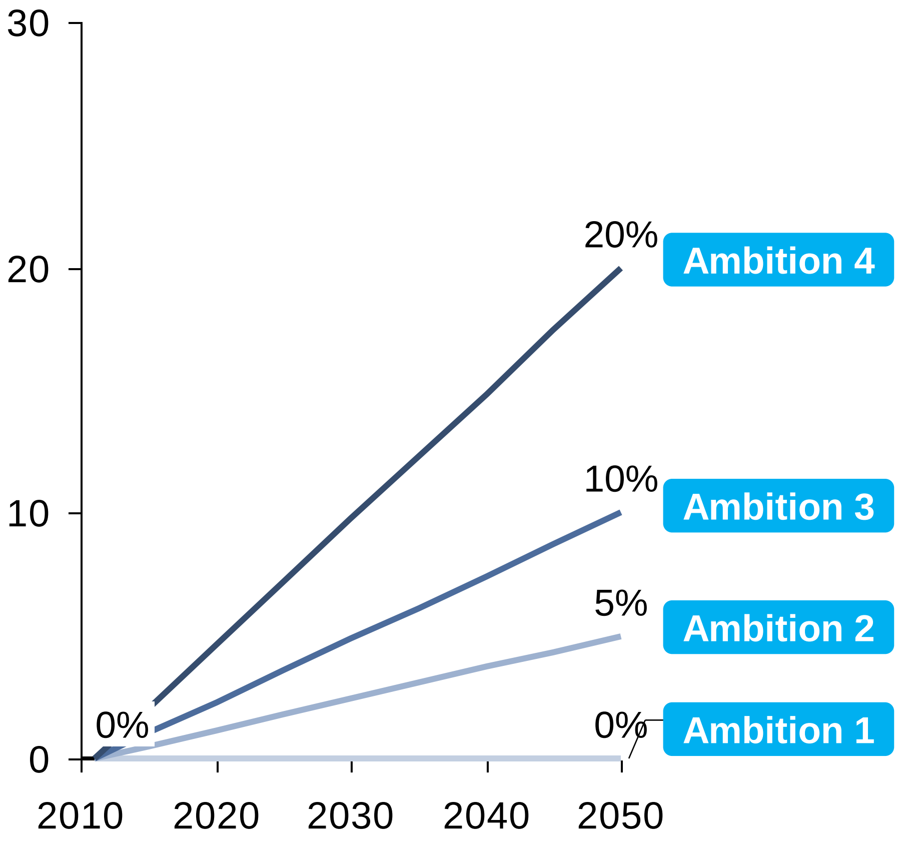
SOURCE: Climact

2 Smart design

Better specified cement can fulfil the same requirements with lower volumes

Global Calculator

Cement demand reduction enabled by smart design (%)



Rationale for a smarter design

- Use of optimized moulds could enable to use up to 40% less concrete in some places [(1)]
- Concrete strength is proportional to the amount of cement in the mix, so lower strength concrete can use less cement
- Current rationalisation of mixes on a site leads to above required use of cement
- Use of stainless steel, or plastic coated bars removes the need for concrete to protect the steel(to use with caution as stainless steel is more emissions intensive)

Product life time is not addressed in this section, it is however expected to have a major impact, with a high proportion of Chinese buildings currently lasting 20-30 years while they could be stretched to 150….

SOURCE: With both eyes open

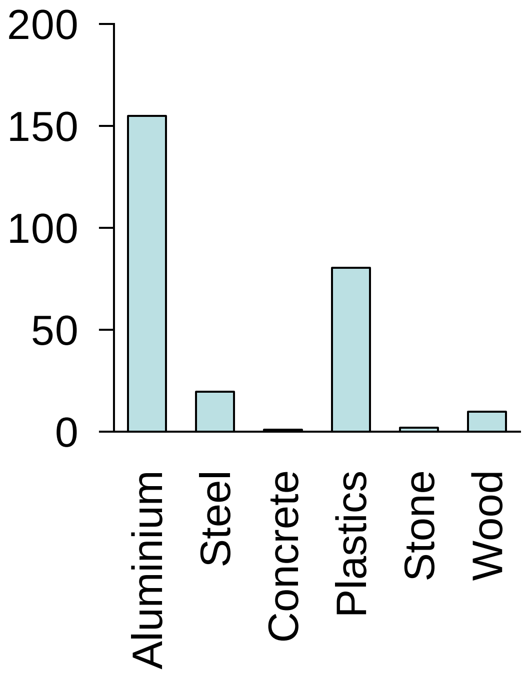
(1) With both eyes open (Orr et Al. (2010), research of efficient concrete shapes

2 Material switch

Cement is one of the cheapest option to build durable constructions

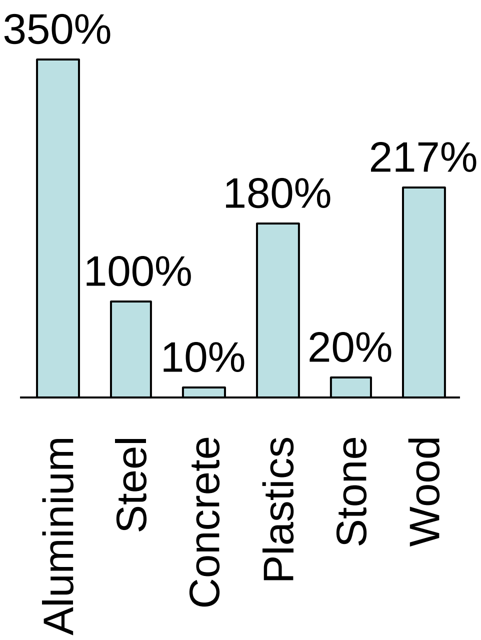
Global Calculator

Embodied energy
(Gj/t)



Embodied energy to convert the material in useful form

Relative useful costs [(1)]
(% relative to steel at 100%)



Relative cost per tonne to convert the materials in useful form

- Concrete has a relatively low embodied energy and cost required to convert it in useful form
- Cement substitutes all have advantages and drawbacks

NOTE : (1) Refer to "With both eyes open" for more details on the definition of useful costs
SOURCE: (1) With both eyes open

2 Material switch

Cement can be substituted by less CO_2 intensive materials

Global Calculator

Materials which can replace /be replaced by concrete

	Characteristics		Cement replacement assumption	
	Advantages	**Weaknesses**	**Buildings**	**Infrastructure**
Aluminium	Strength Recyclability	Higher cost & embodied energy	Not modelled	Not modelled
Steel	Strength Recyclability Compatibility (rebar)	Higher cost & embodied energy Requires protection against corrosion	Not modelled (2)	Not modelled (2)
Plastics (Composite materials, glass/ carbon fibres reinforced epoxies)	Strength	No recyclability Higher embodied energy	Up to 5% concrete can be replaced by insulation materials (HVC)	Up to 5% concrete can be replaced by insulation materials (HVC)
Stone & Masonry	Strength lower embodied emissions	Must be reinforced with mortar (from cement) Cannot be reinforced or moulded into shapes	Not modelled	Not modelled
Timber	high strength and stiffness per density (1)	Less durable, requires protection against fire and rot, less stable	Up to 20% concrete can be replaced by timber	Not modelled

NOTE : (2) Historically, two product mixes are used in constructions. The “Continental approach” uses more concrete, while the “British approach” uses more steel.

SOURCE: (1) With both eyes open (Orr et Al. (2010), research of efficient concrete shapes

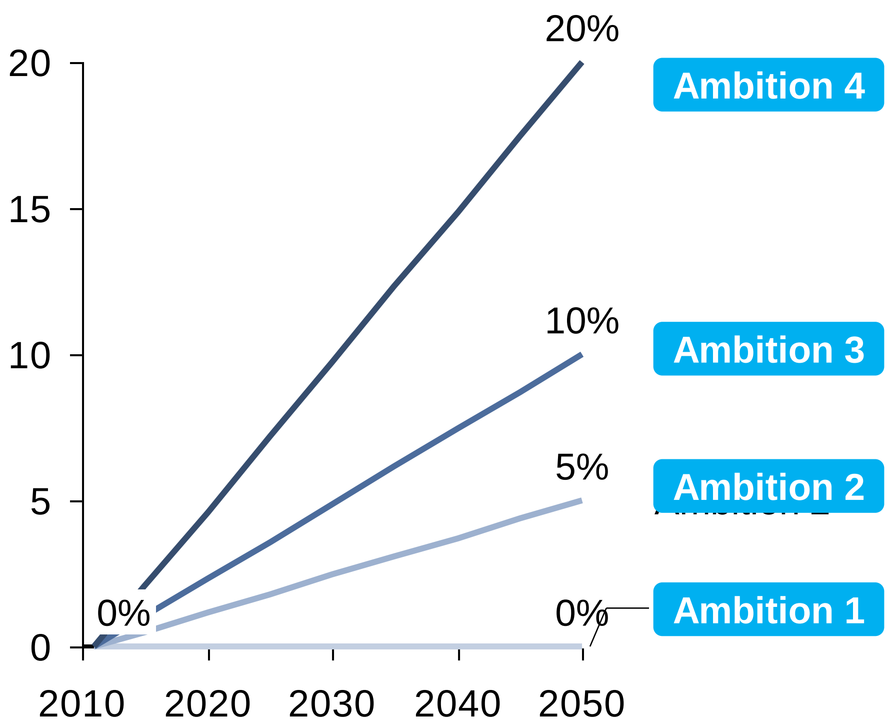
2

Material switch

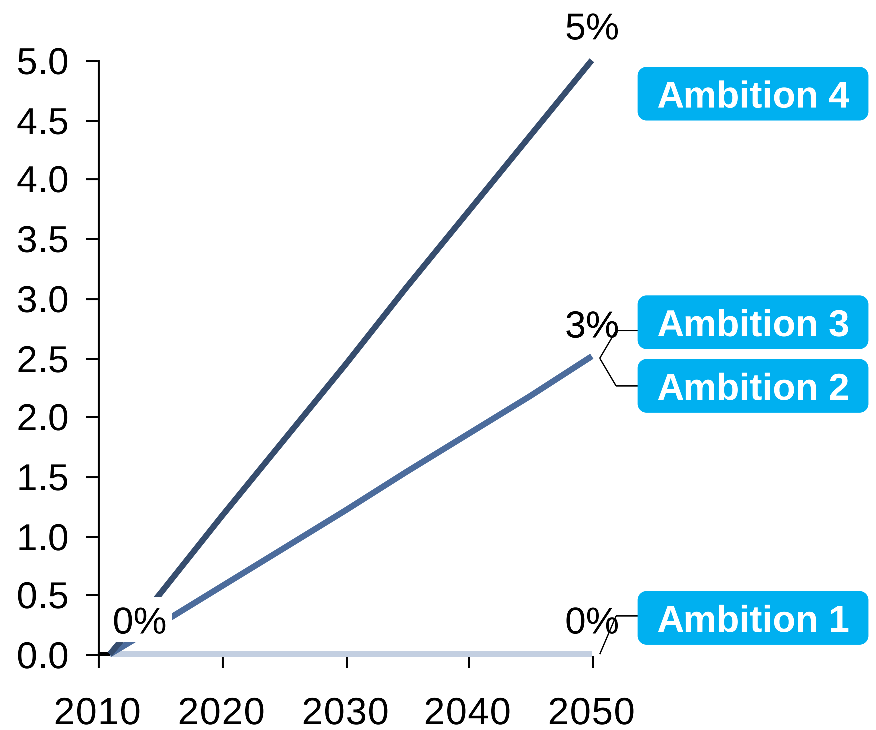
Proposed lever ambitions

Global Calculator

Proportion of cement replaced by timber (%)



Proportion of cement replaced by chemical insulation materials (%)



- Timber being less stable & less homogeneous, a higher security factor must be taken into account when timber is used for the structure of buildings
- Biomass impacts is represented by the model

NOTE: (1) Amount of one material required to replace another material is approximated through the specific Young modulus
(2) Assumption this material switch does not impact the product life

2

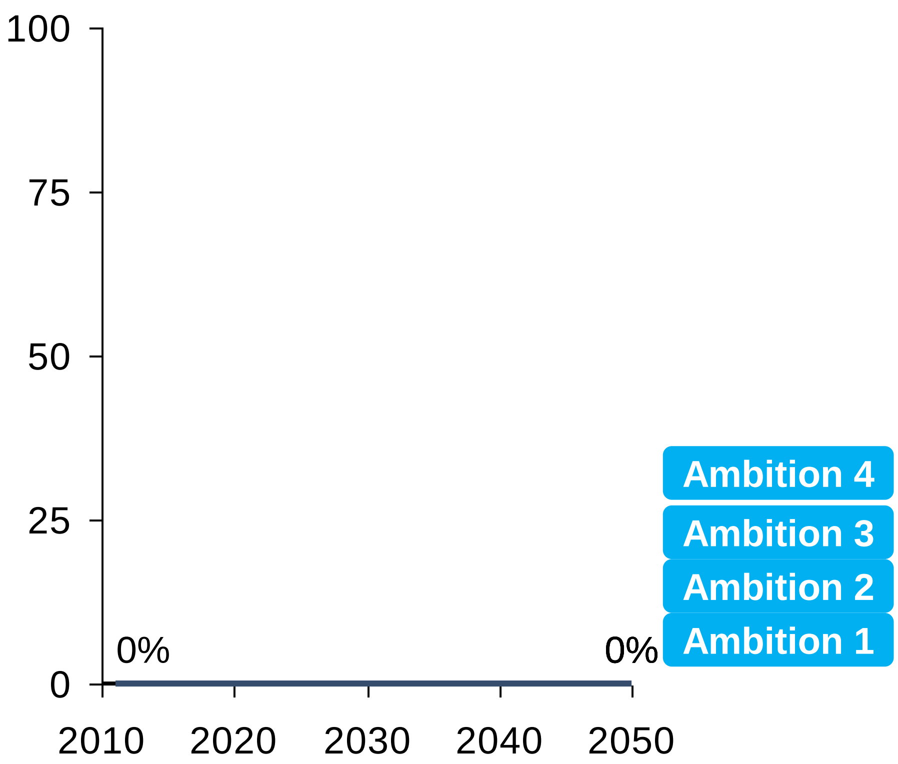
Material recycling: Aggregate

Cement is not recycled, but reused as a an aggregate

Global Calculator

Proportion of cement recycled

(%)



Rationale on recycling potential

- Reversing the reaction that makes cement requires theoretically at least 1GJ/t, so cement is currently not “recycled” at present
- Creating block components reusable at the end of life is an option (with 2 technical options)
  - Chemical connectors(1)
  - Mechanical connections, to provide a “Lego” interface (2)
- Concrete can be crushed to make a aggregate which can be used to make concrete if mixed with new cement. However extra cement is required to bind the wider range of particle sizes in crushed concrete. This is then typically used for roads and infrastructures. This is not really recycling and is therefore addressed in the composed cement lever

NOTE: (1) Being researched in Japan, cfr Noguchi et al. (2011)
(2) This is typically expected with composite steel and cement blocks with a steel to steel interface

SOURCE: With Both Eyes Open

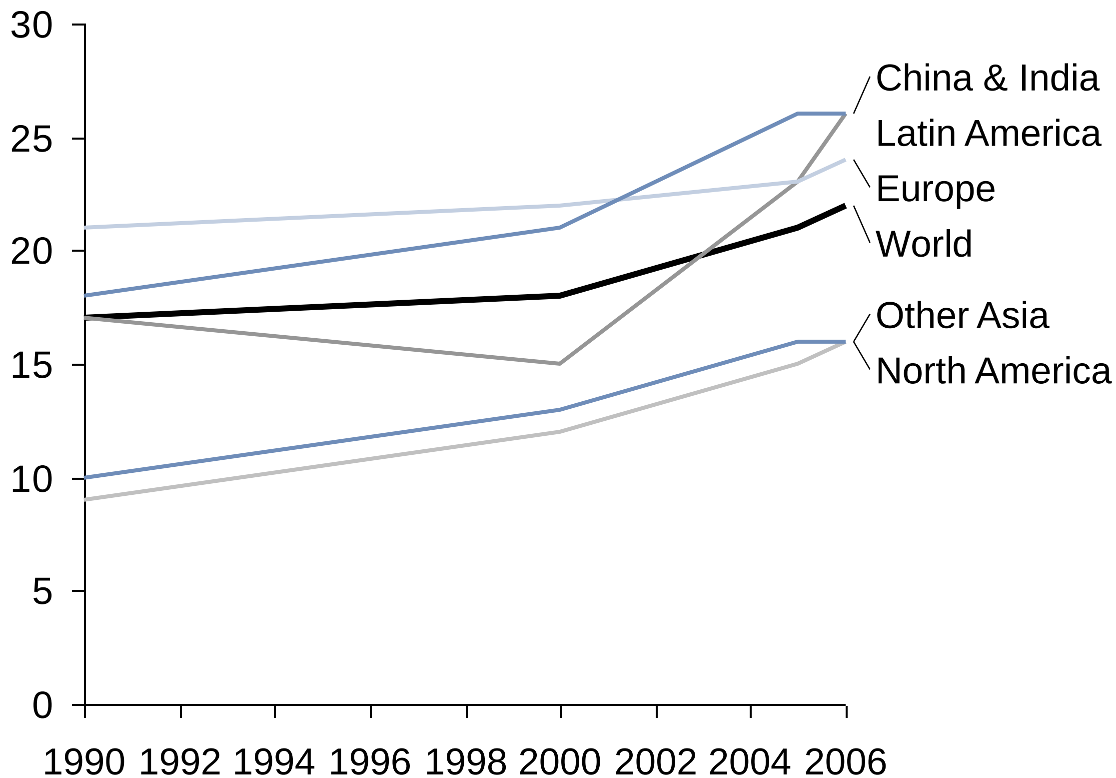
Material recycling: Composed cement

2

Composed cement market share has increased historically…

Global Calculator

World and regional cement substitutes evolution
(% of the cement production)



- Mineral components can be added to the clinker to obtain de cement (flying ashes, blast furnace slag, others), if those are superior to 5%, we get composed cement. Steel cement is a type of composed cement
- Substitute share has increased globally and across all regions. China & India recently increased very firmly

NOTE: Composed cement includes steel cement
SOURCE: WBCSD Cement Sustainability initiative

2

Material recycling: Composed cement

There is a resource limit to the amount of clinker that can be substituted

Types of clinker substitution	Impact on the cement characteristics	Availability
Ground Granulated Blast Furnace Slag (GGBS)	Adds long term strength and durability (but lower initial strength and slower curing)	250 Mt/year
Pulverised Fly Ash (PFA)	Improves concrete workability and long term strength (but lower initial strength)	900 Mt/year
Pozzolan	Improves durability and workability (but lower initial strength)	300 Mt/year
Limestone	Improves workability but reduces strength and durability	Widely available
Crushed concrete	Does require slightly more cement	3500 Mt/year

Annual supplies of GGBS, PFA & Pozzolan currently total 1450 Mt
And Limestone substitution has also downsides and is only used in level 4
Including crushed cements enables close to 5000 Mt

NOTE: Mineral components can be added to the clinker to obtain de cement (flying ashes, blast furnace slag, others), if those are superior to 5%, we get composed cement. Steel cement is a type of composed cement

SOURCE: With Both Eyes Open, IEA Cement roadmap, Carbon war room (WBCSD 2009, Holcim 2009)

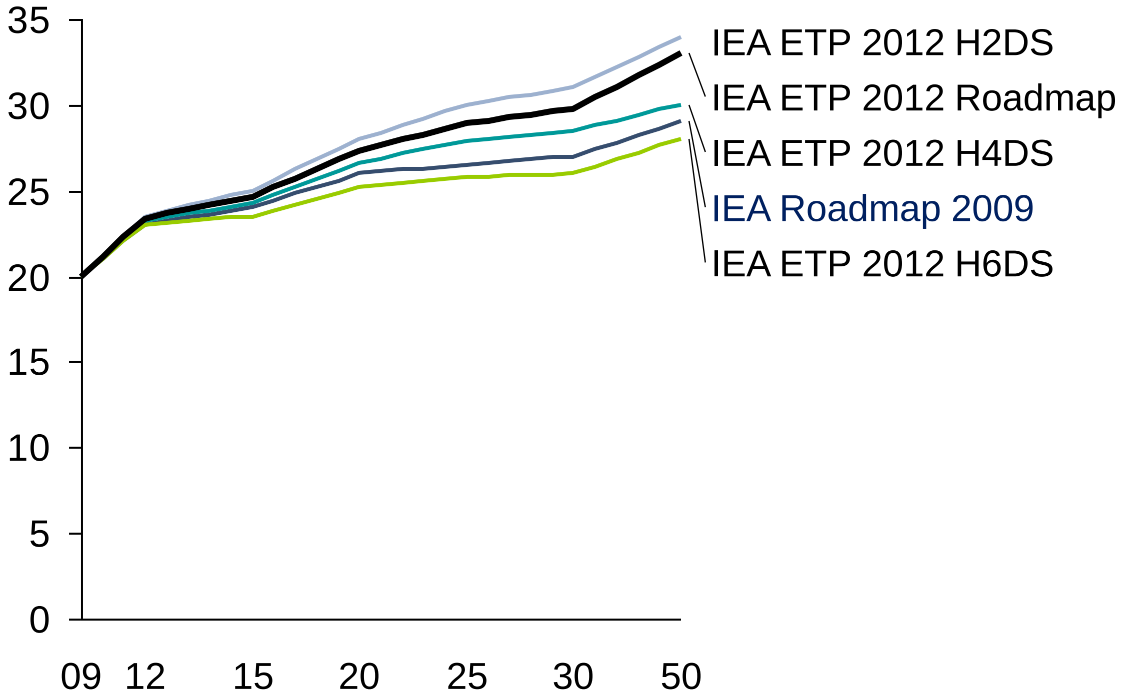
Material recycling: Composed cement

2

IEA scenarios forecast a substitution rate between 28-34%

Global Calculator

Cement substitution
(%)



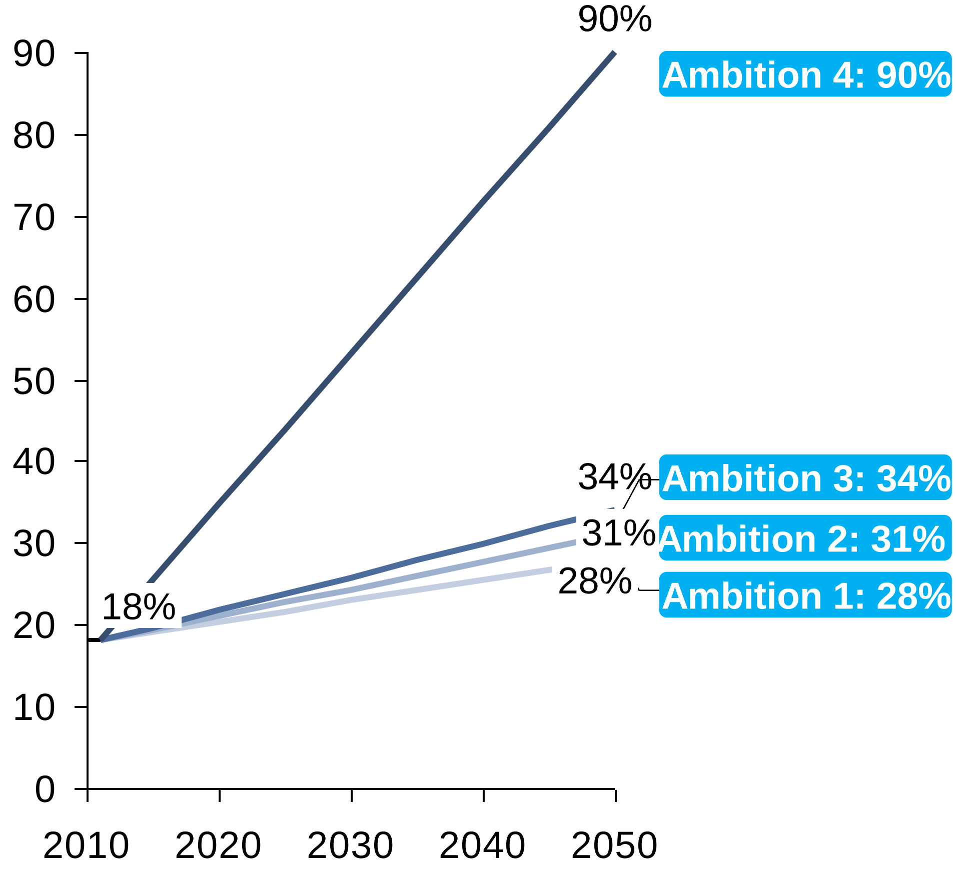
- Prefabricated sector requires Portland cement (95% clinker) to dry faster (2)
- Other applications can be satisfied with CEM III C cement (10% clinker and 90% steel slag). This cement can reach higher solidity levels than Portland cement but takes longer to dry (2)
- The access to substitution mineral components is getting harder (2).
- Upper boundary, in case of high growth demand, with current substitute production is of 1450/5521 Mtons, neglecting lime, corresponds to 26% others
- If the cement industry were to use significantly more steel slag, its price would be expected to increase (2)

NOTES: Major hypothesis: no emissions are allocated to the steel slag, considering it as a waste from the steel sector
Substitution potential is not applicable to white cement
Intermediary figures are a Climact assumption for 2,4 & 6 DS

SOURCE: (1) IEA ETP 2012 and IEA 2009 Cement Roadmap (2) Fortea CBR and Holcim consultations, Febelcem annual report

2 Material recycling: Composed cement
Proposed lever ambitions

Proportion of substitutes in the cement composition (%)



Rationale for the different ambitions

4	• Ambition for a 100% transition to CEM III C, which is possible but will imply higher storage costs • Implies a substitution rate of 90% • We could consider it applied to all except prefabricated industry (if quantified by the sector)
3	• Ambition aligned with IEA 2DS roadmap
2	• Intermediary ambition
1	• Ambition aligned to the IEA 6DS roadmap

SOURCE: Cement consultation, Climact analysis

3

Carbon intensity of material production

Process improvements, fuel mixes, energy efficiency & CCS are then assessed

Global Calculator

List of actions & levers assessed

Process improvement

- Towards fuels which emit less CO_2

Fuel substitution

- Modification of processes

Energy efficiency

- Reduce mechanical and thermal losses
- Recuperate thermal energy (CHP)

End of pipe technologies

- Carbon capture and storage

Dry process

"Green cement"

Biomass

Waste

Insulation

Preheating, precalcining

Fluidized bed technology

CHP/ heat recovery

CCS implementation

NOTE: Process choice has consequences on applicability of other levers Some combinations are exclusive whilst others can be added in sequential order

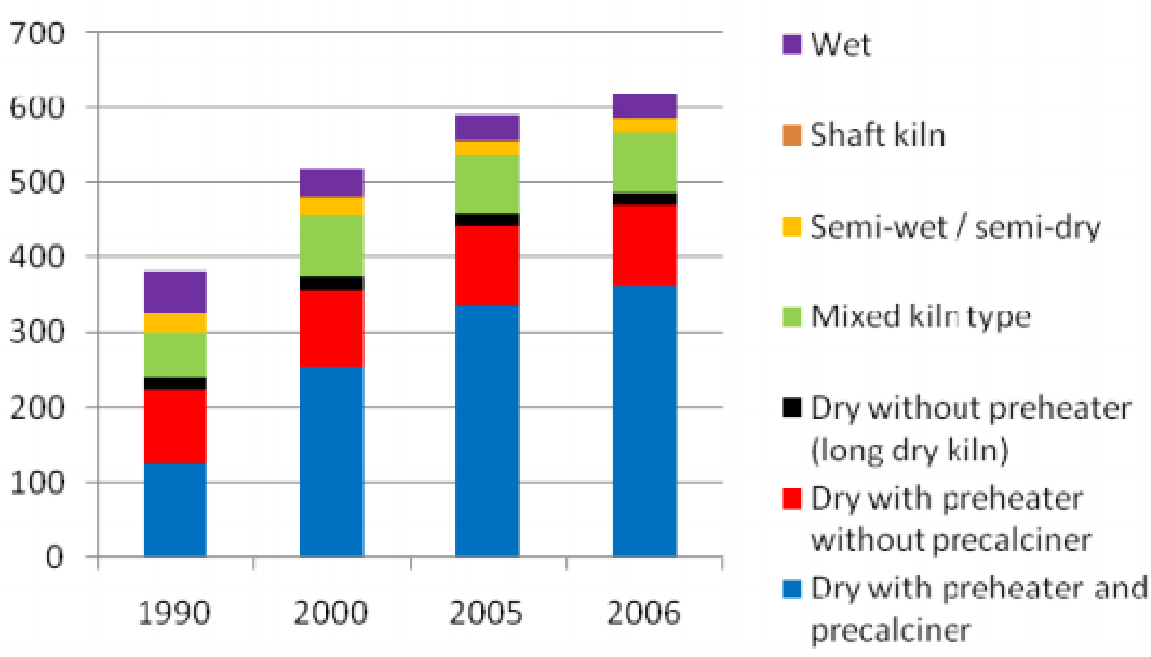
SOURCE: (1) (redundant with Ulcored while we represent HIsarna in this analysis

3

Process improvements

The share of BAT clinker production is increasing (along the dry technology, with preheater and precalciner)

Clinker production per technology
(M tons clinker)



- The choice of using a dry or humid choice is linked to the exploited quarry type
- We assume this improvement is included in the IEA specific consumption projections (in energy efficiency improvements)
- « green concrete », a new low carbon process (using magnesium oxyde instead of calcium), enables to obtain cement through a less CO_2 intensive process. It is currently not modelled (1)

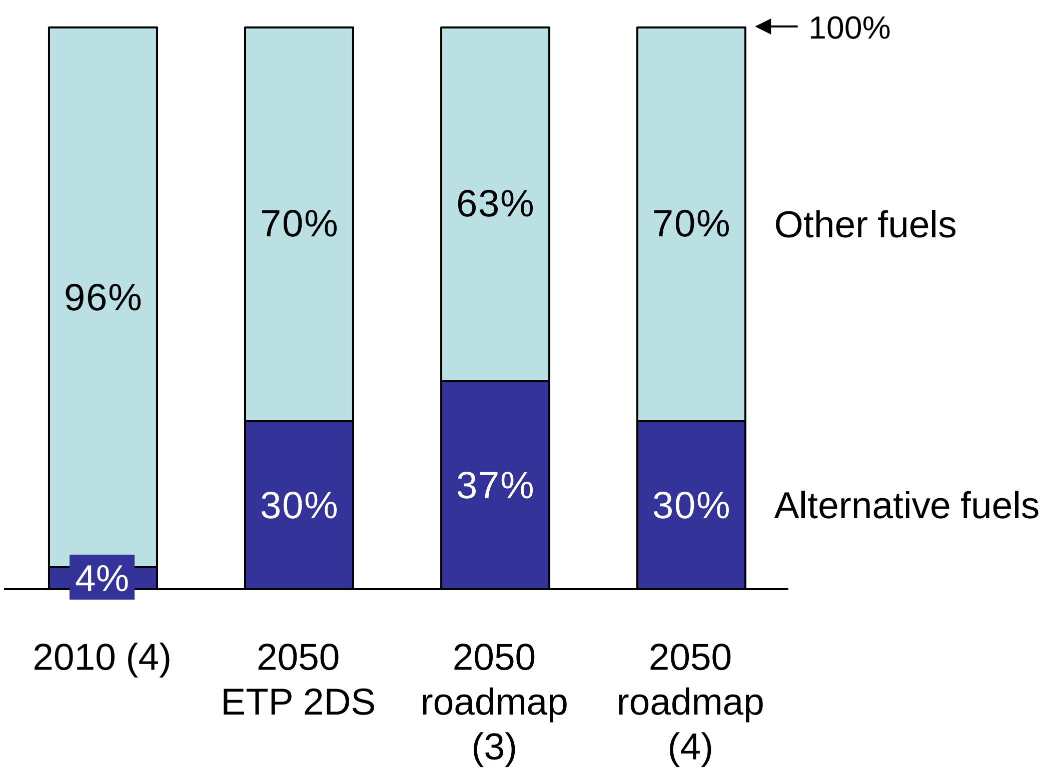
NOTE : (1) Green concrete not considered mature technologically; the entity commercializing it does not exist any more. Furthermore, there is a lack of available data on the technology

SOURCE: GNR participants to the CSI

Alternative fuels

The alternative fuels proportion has strongly increased and reaches one the highest European levels

Alternative fuel consumption in the cement sector
(%)



Current situation
- assumption mostly biomass and not waste

Potential evolution
- 30% biomass in 2DS
- 0% risk (waste and biomass could become inaccessible)
- 100% potential (contrarily to some industries, cement does not absorb the biomass and waste impurities)

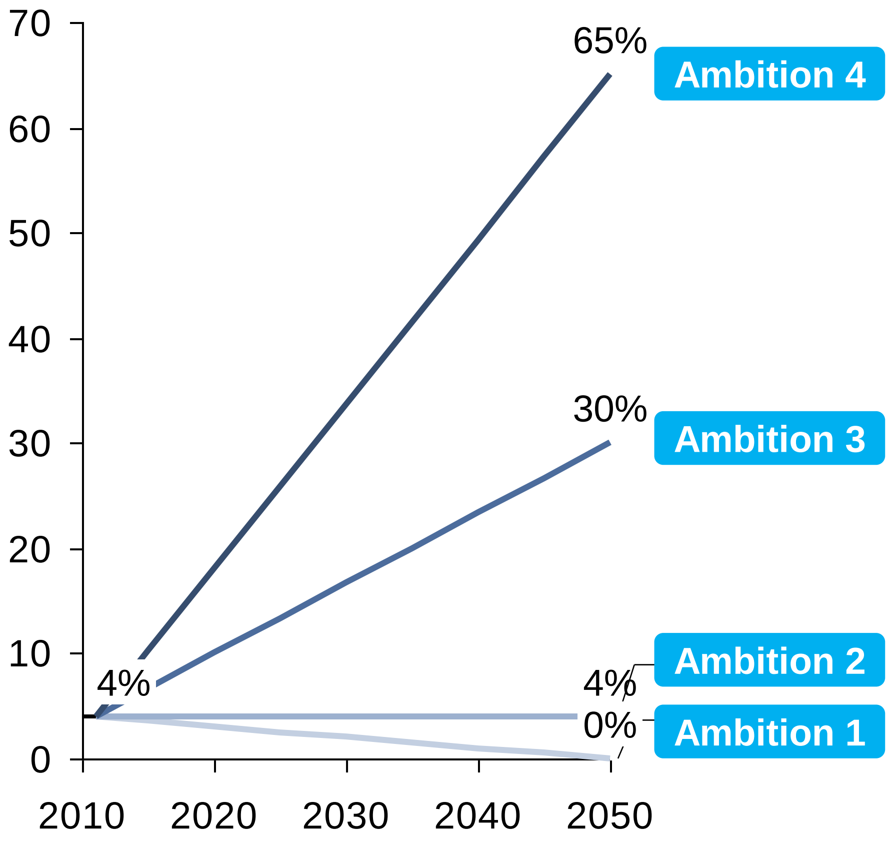
Barriers:
- There are access problems to alternative fuels (biomass and waste)
- There are currently no financial incentives for waste incineration

NOTE: We assume biomass & waste combustion emissions at 0 in the first version of the calculator
SOURCE:,(3)IEA Cement Technology RoadMap (4) IEA ETP 2012

3 Alternative fuels

Portion of alternative fuels in 2050

Proportion of alternative fuels
(%)



Rationale for the different ambitions

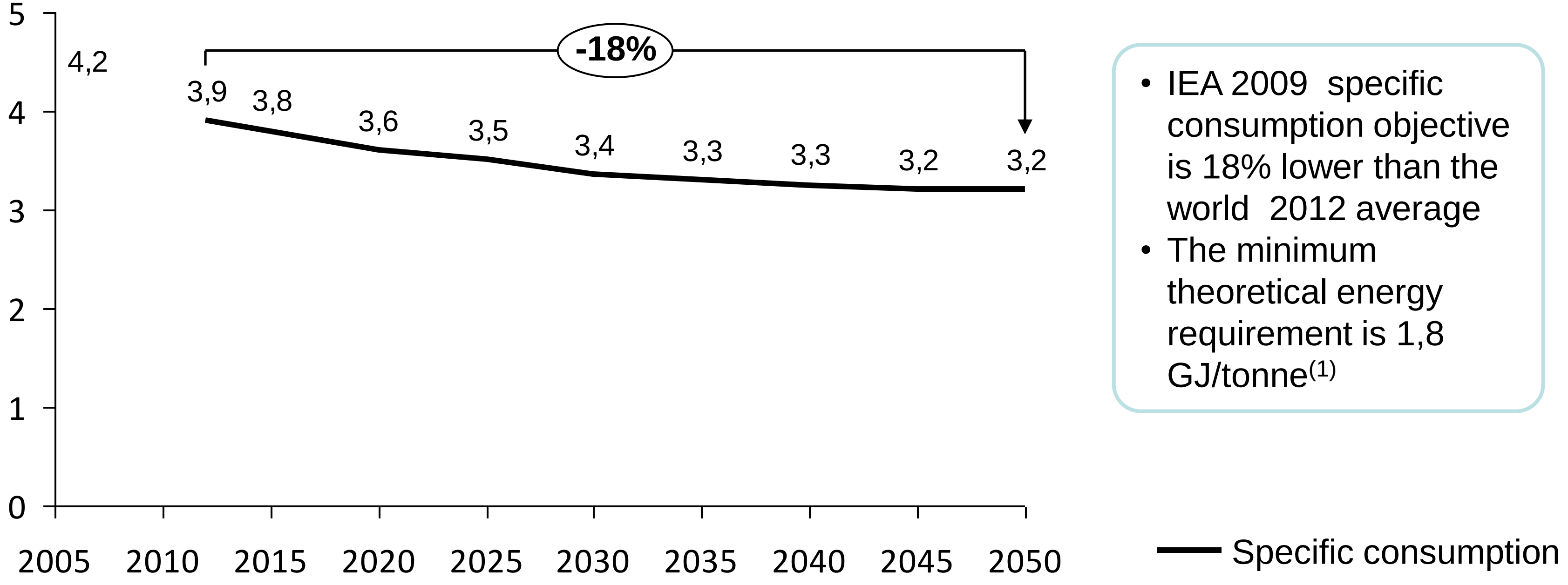
4	• **Entire mix (65%= 100% of coal)**
3	• **Strong increase (30%= 46% of coal**
2	• **Constant use of substitutes (4 %=6% of coal)**
1	• **Biomass is too expensive or inaccessible**

SOURCE: Cement consultation, Climact analysis

Energy efficiency

Clinker energy efficiency can increase by more than 15%

Specific consumption evolution forecast
(Gj/t clinker)



- IEA 2009 specific consumption objective is 18% lower than the world 2012 average
- The minimum theoretical energy requirement is 1,8 GJ/tonne(1)

NOTES: Energy efficiency improvements are expected to be lower in white cement
The later only represents 2% of the production

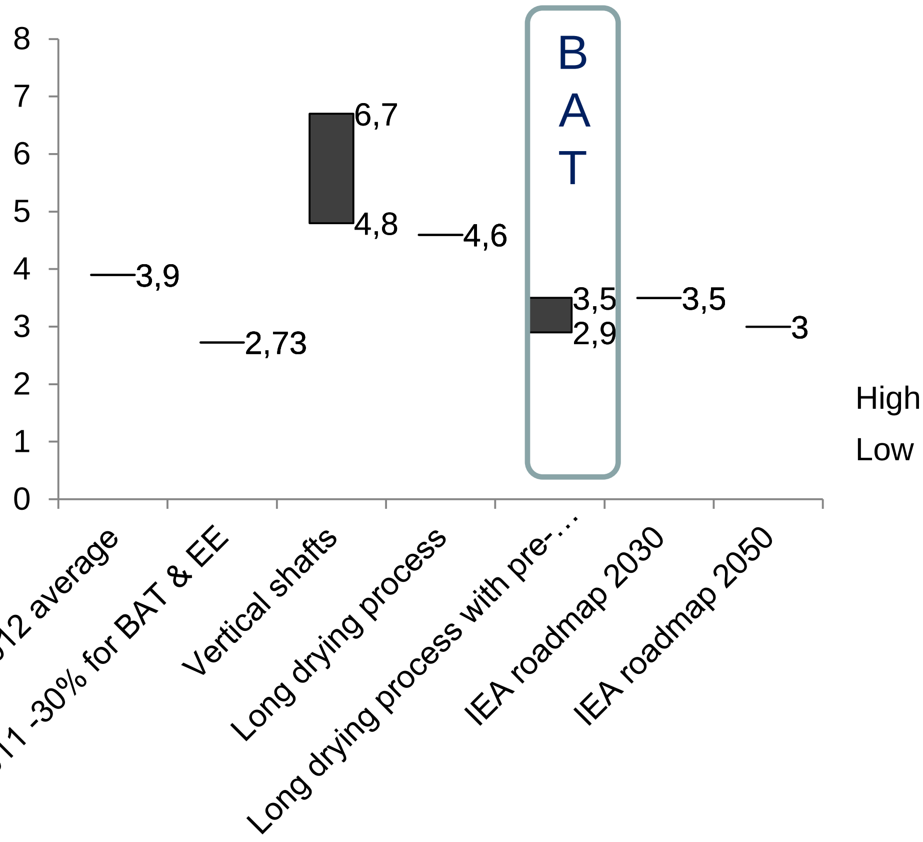
SOURCE: IEA 2009 technology roadmap
(1) With both eyes open (p.64 'Cement chemistry', Taylor, H., 1990)

Energy efficiency

Efficiency gains encompass process improvements

Global Calculator

Current Specific consumption
(Gj/t clinker)



Several factors support the specific consumption reduction:

- The rising proportion of dry process with pre-heaters and pre-calciners
- The energy price increase

If all plants used BAT, the average world specific consumption could be reduced by 1,1 Gj/ton cement

SOURCE: IEA ETP 2012

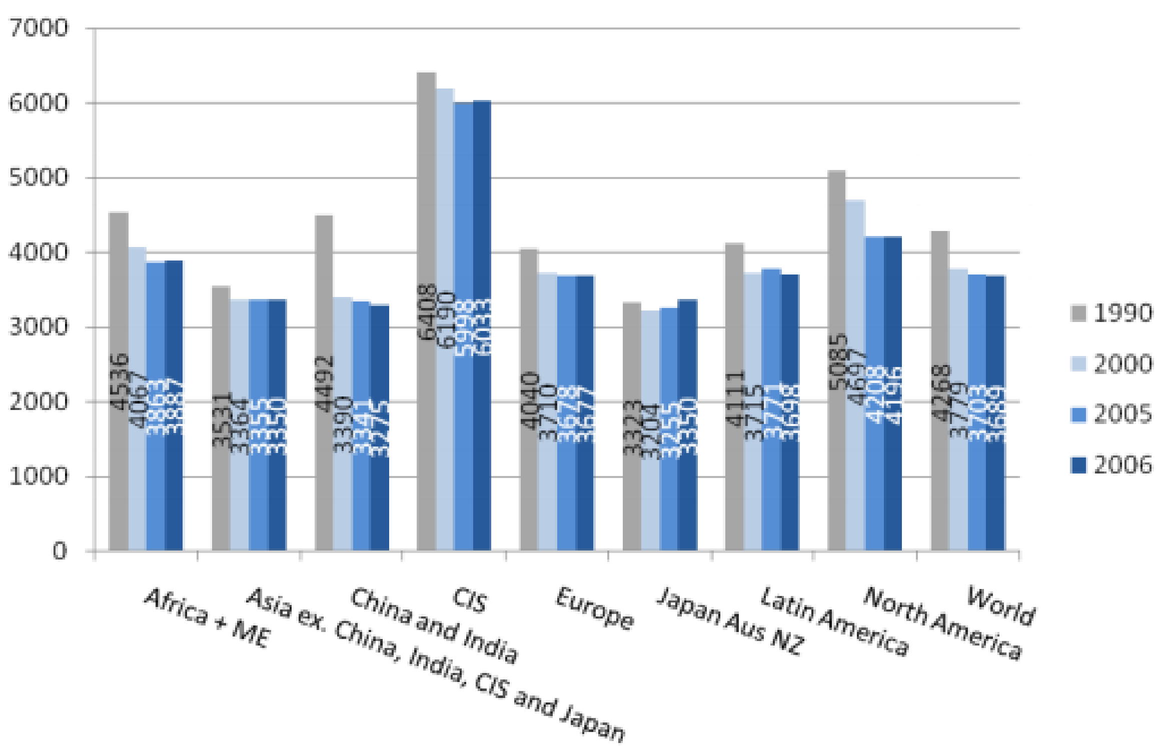
3 Energy efficiency

There are significant regional differences

Global Calculator

Specific consumption evolution

(Mj/t clinker)[1]



- Two thirds of the people making cement are in china, while china only produces 40% of the worlds cement, this is because they are in small factories using older technologies [2]
- India is also know for currently having old factories[2]
- Old factories often use the wet process [2]
- There is more improvement potential in developed countries (as developing countries have recently invested in new technologies) [3]

Feedback appear contradictory; recommendations?

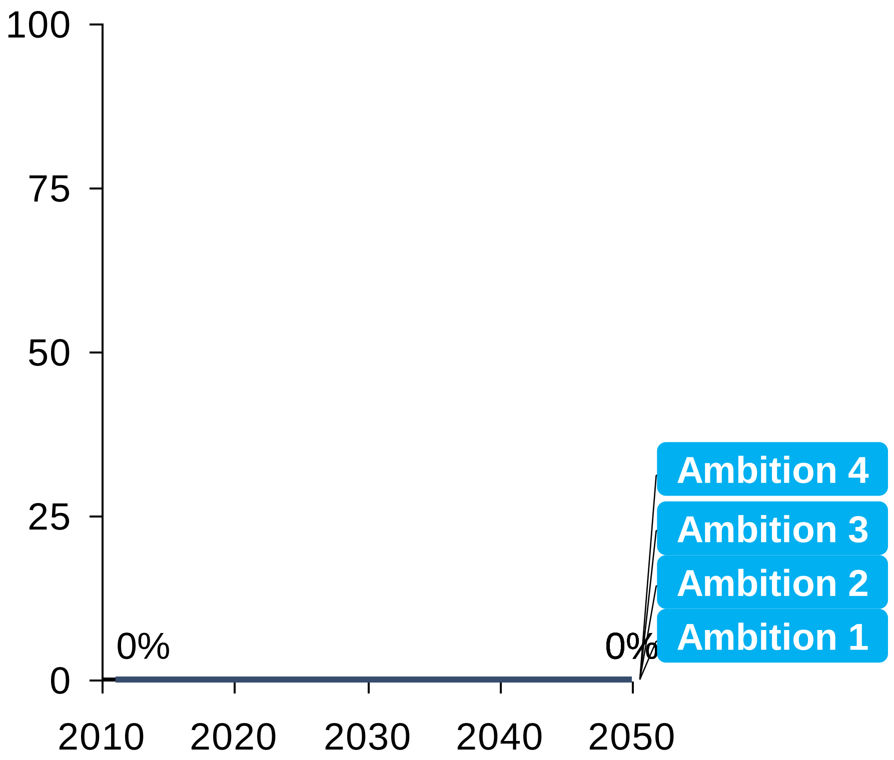
SOURCE: (1) Cement Sustainability initiative (2) with both eyes open (3) ETP

3 Energy efficiency (CHP)

Proposed lever ambitions

Global Calculator

Percentage of electricity production through CHPs (%)

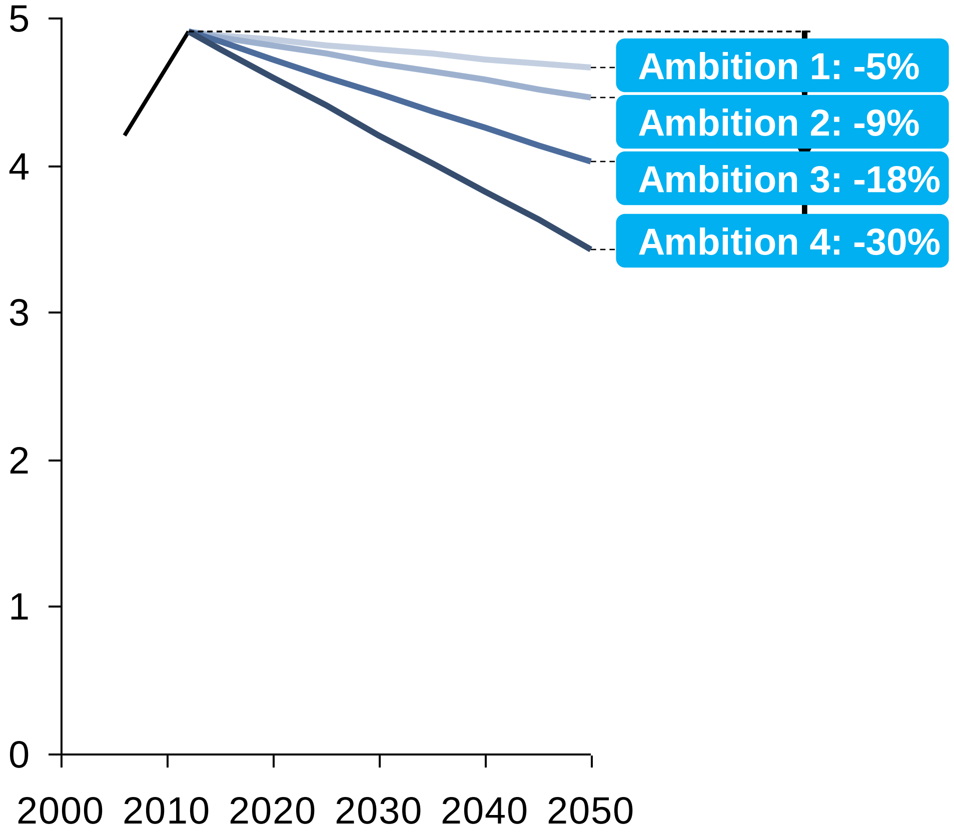


SOURCE: Cement consultation, Climact analysis

3 Energy efficiency
Proposed lever ambitions

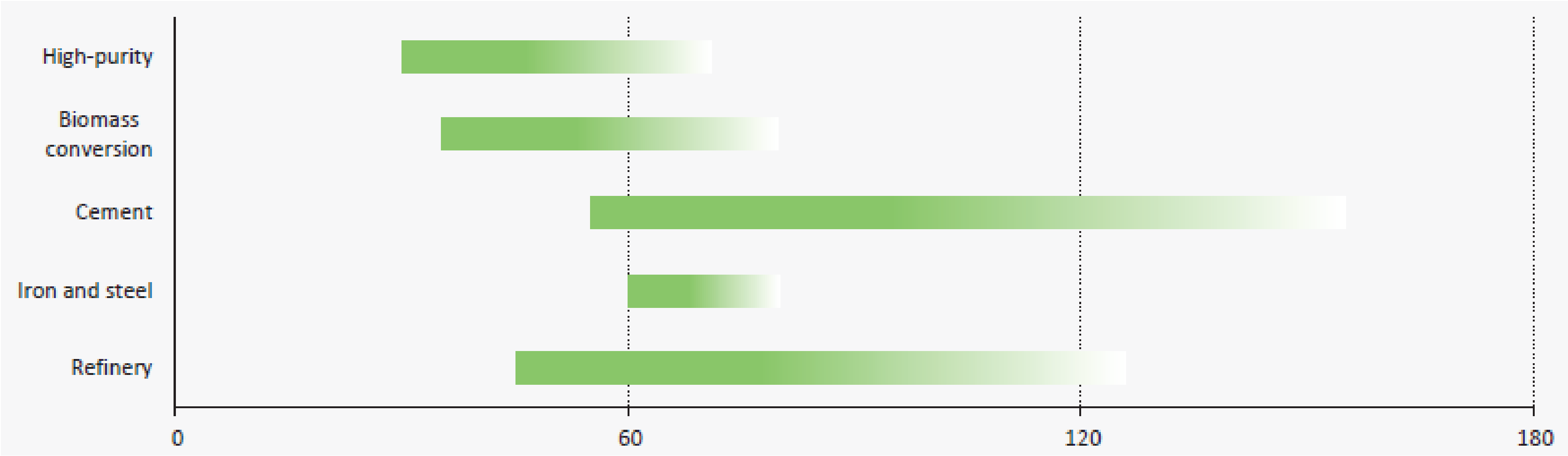
Global Calculator

Specific consumption improvements
(Gj/ton clinker, % reduction vs 2010)



SOURCE: Cement consultation, Climact analysis

Typical ranges of costs of emission reductions from industrial applications of CCS
(USD/tCO_2e avoided)



- ~50%-70% of all new large plants and 30%-45% of retrofitted plants equipped with CCS by 2050 in the 2DS
- Deploy 120 to 140 kilns with CCS by 2030, 300 to 400 by 2040 and 500 to 700 by 2050
- Capture costs of USD 100 € (2030) and USD 75 € (2050) for PC and USD 50 € (2030) and USD 40 € (2050) for oxyfuels.

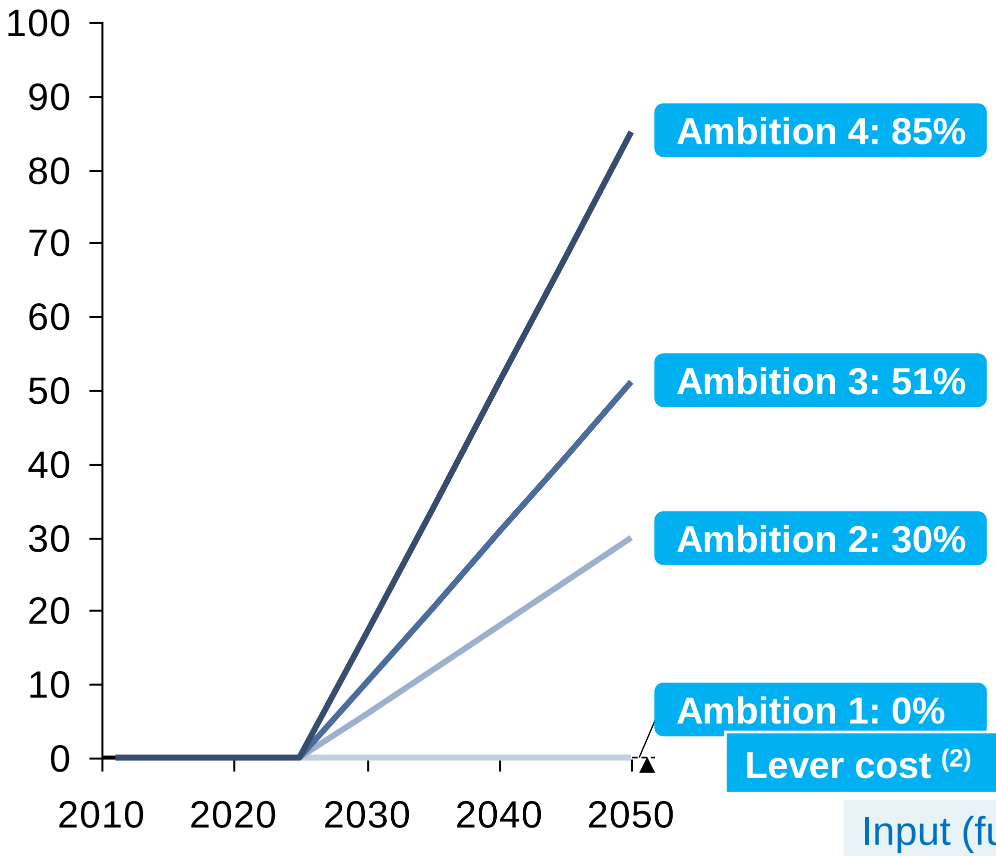
NOTE: The range of costs shown here reflect the regional average costs of applying CCS in each sector, and, therefore, the overall cost of abatement in a sector will be affected by the assumed level of CCS uptake in each sector (IEA, 2009 and IEA and UNIDO 2011). These costs include the cost of capture, transport and storage, but do not assume that storage generates revenues (i.e. CO_2 storage through enhanced oil recovery (EOR) is not considered as a storage option.

SOURCE: ETP 2012, IEA

3 Carbon Capture & Storage
Proposed lever ambitions

Global Calculator

Emissions capture rate by CCS
(%)



Rationale for the different ambitions

4	• All sites, 85% capture rate
3	• Ambition 3 aligned to ETP 2012 ambition of 40-45% plants • ~50%-70% of all new large plants and 30%-45% of retrofitted plants equipped with CCS by 2050 in the 2DS
2	• Only largest sites
1	• No implementation

Lever cost (2)

Input (fuel & material)	0,33 TWh Elec/Mt captured
Other opex	$20 USD/ton captured
Capex	$60 USD/ton captured

SOURCE: Cement consultation, Climact analysis

Global Calculator

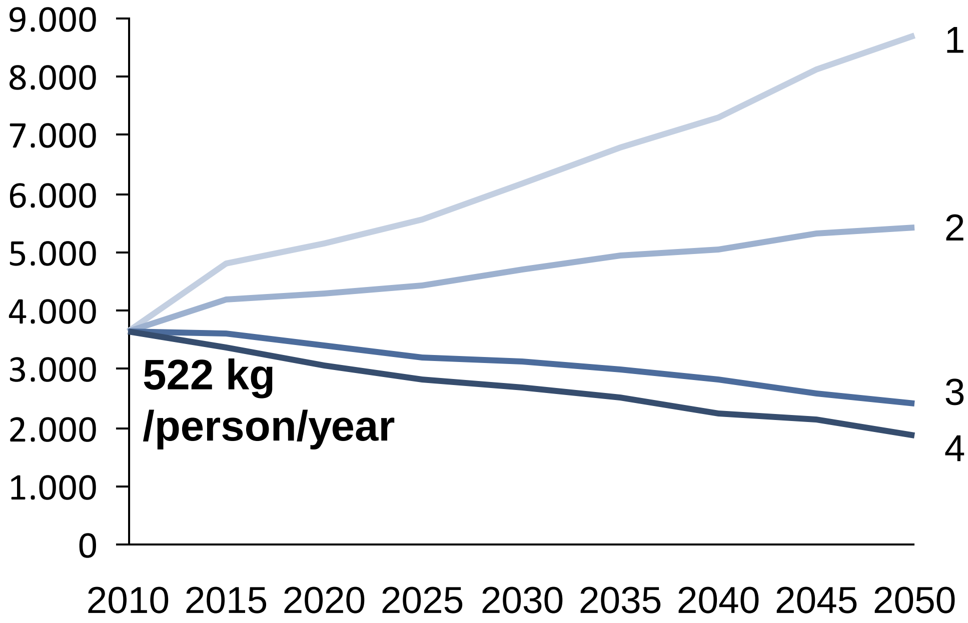
Cement manufacturing with lower energy intensity

Reduction potential

Final Materials demand according to different trajectories (after design, switch & recycle)

Global Calculator

Cement Production Trajectories for different ambition levels (simulating a constant clinker rate)[1,2]
(Mton cement)



Trajectory	Delta 10-50,%	Implied demand per person
1	+140%	912 kg /person/year
2	+49%	565 kg /person/year
3	-14%	328 kg /person/year
4	-49%	194 kg /person/year

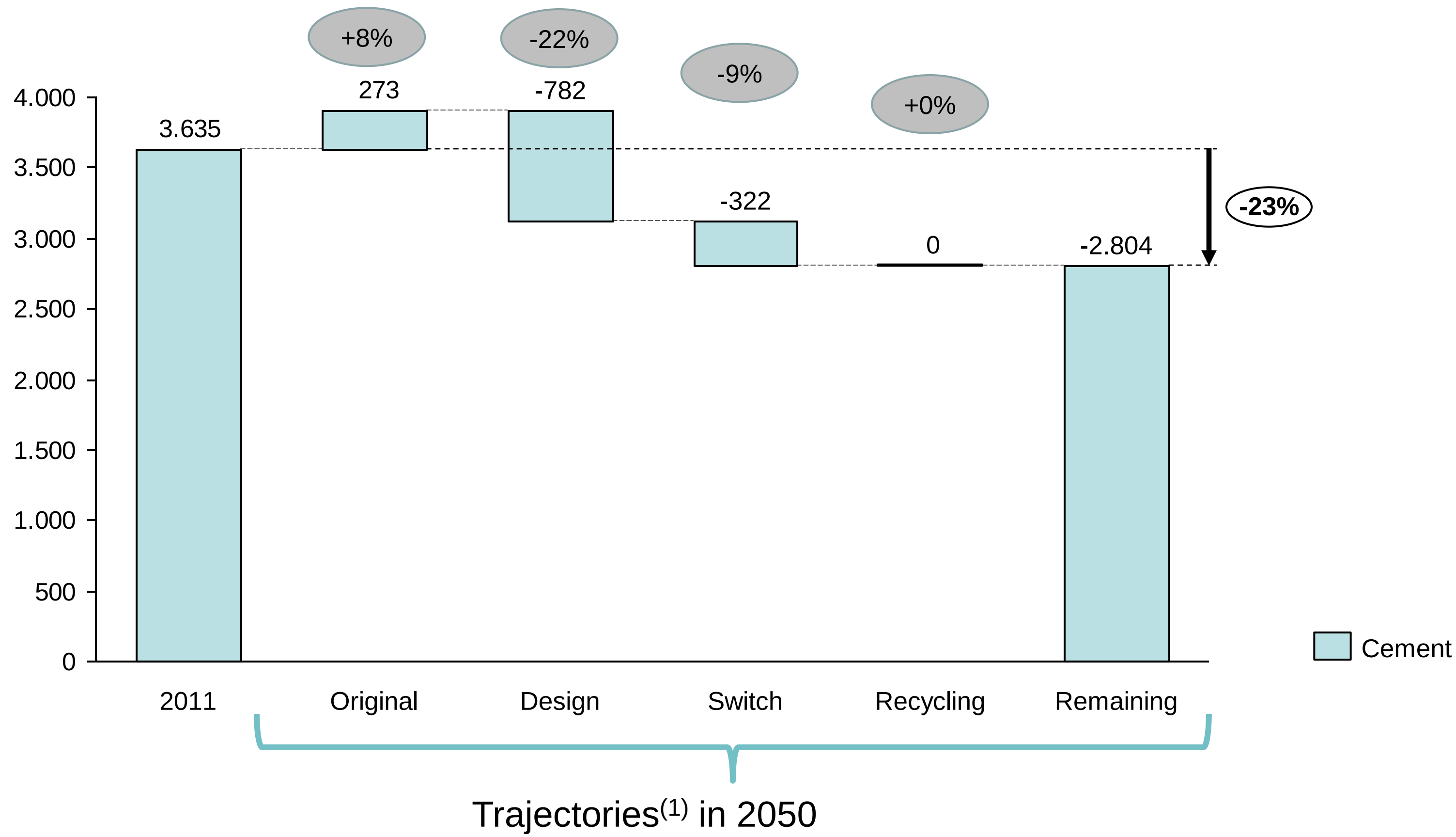
NOTE: (1) The population follows the average UN projection in all four trajectories
(2) Other sectors are impacted by these transitions (e.g. additional productions are created in the timber sector)

SOURCE: IEA ETP 2012, Global calculator model

Reduction potential
Details for ambition level 3

Global Calculator

Cement production for ambition level 3
(M tons, % of 2011)

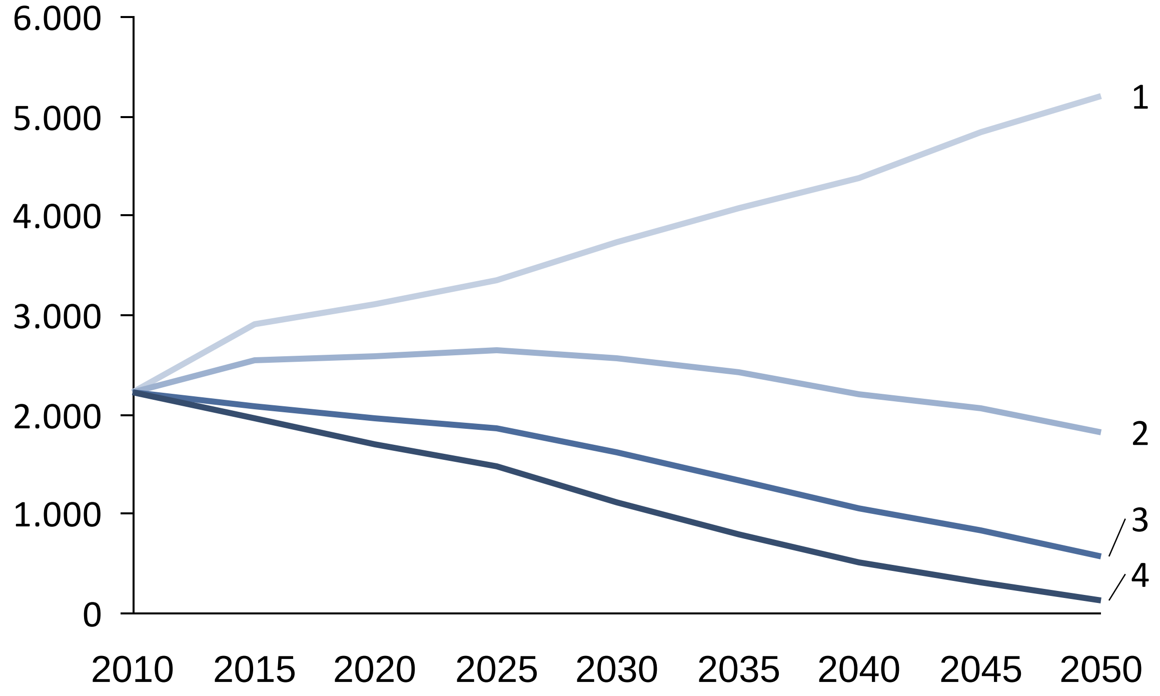


NOTE: (1) The population follows the average UN projection in all four trajectories
(2)Assuming biomass emits, not including electricity related emissions
SOURCE: IEA ETP 2012, Global calculator model

Reduction potential
Emissions according to different trajectories

Global Calculator

Cement GHG emission trajectories for different ambition levels[1,2,3]
(Mton CO_2e)



	Delta 10-50,%	Specific emissions
1	+135%	596 kg /ton cement
2	-18%	334 kg /ton cement
3	-74%	201 kg /ton cement
4	-95%	70 kg /ton cement

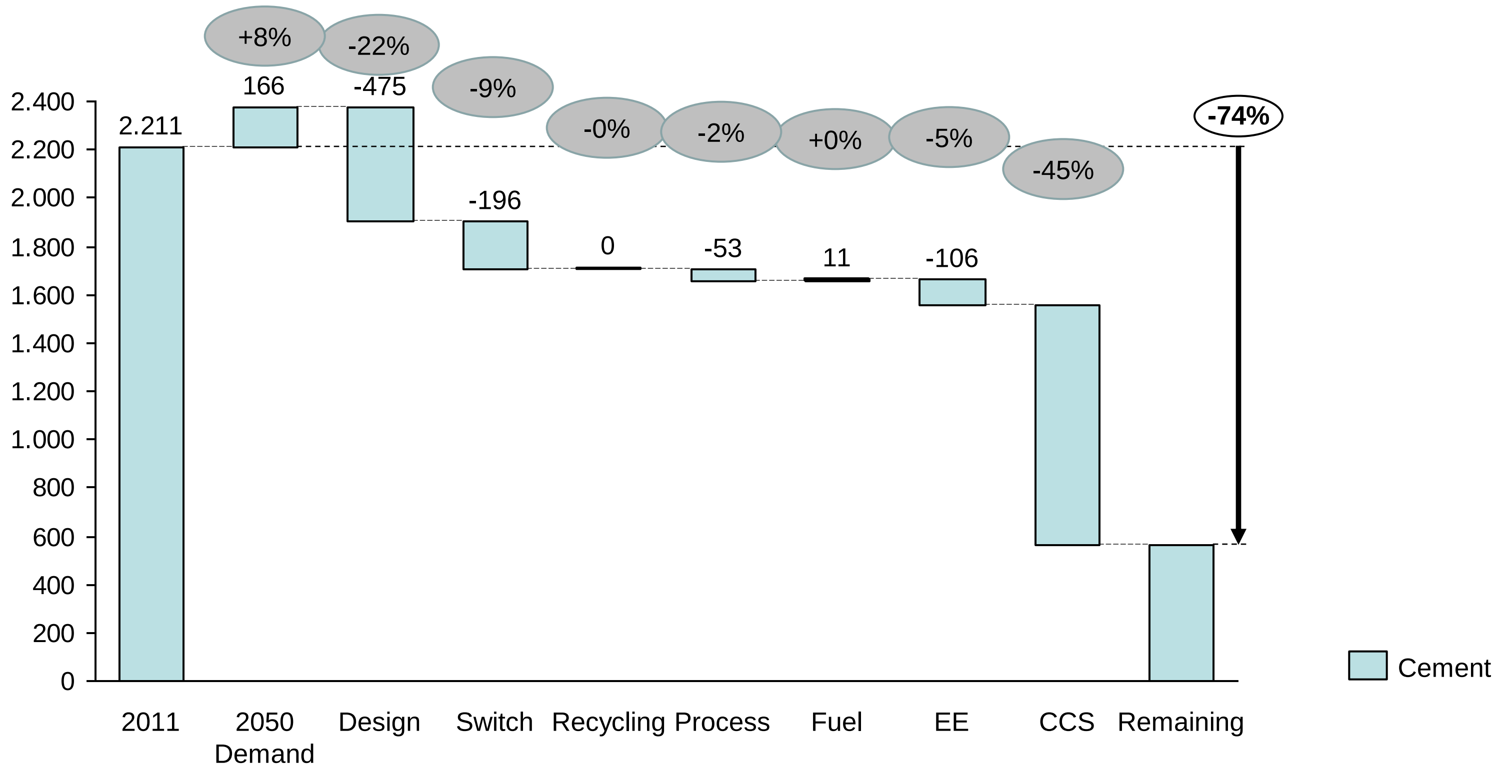
NOTES: (1) The population follows the average UN projection in all four trajectories
(2) Excluding biomass related reductions & electricity related emissions
(3) Other sectors are impacted by these transitions (e.g. additional emissions are created in the timber sector)

SOURCE: IEA ETP 2012, Global calculator model

Reduction potential
Details for ambition level 3 (1)

Global Calculator

Cement GHG emissions in 2050, for ambition level 3(1,2), using different levers(3)
($MtCO_2e$, % of 2010)



NOTES: (1) The population follows the average UN projection in all four trajectories
(2) Excluding biomass related reductions & electricity related emissions
(3) Other sectors are impacted by these transitions (e.g. additional emissions are created in the aluminium and plastics sectors)
Percentage reductions are calculated vs the 2010 baseline

SOURCE: IEA ETP 2012, Global calculator model

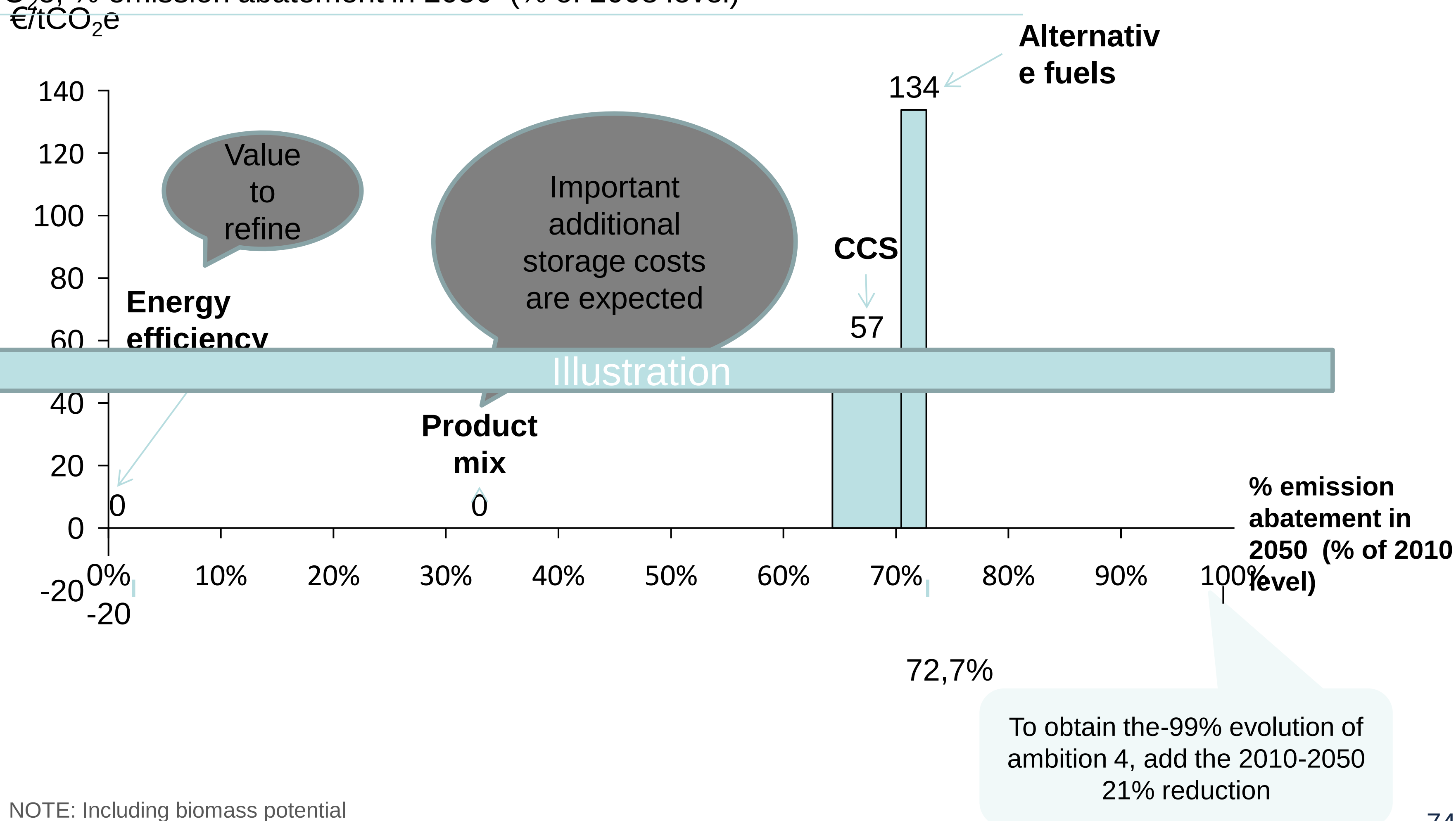
Costs

In cement, most of the potential comes from the use of compos Calculator

Illustration

GHG abatement curve for the year 2050 (trajectory 2, ambition 4)

€/tCO_2e, % emission abatement in 2050 (% of 2008 level)



NOTE: Including biomass potential

SOURCE: IEA ETP 2012, Global calculator model

Thank you.

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Backup

Existing studies

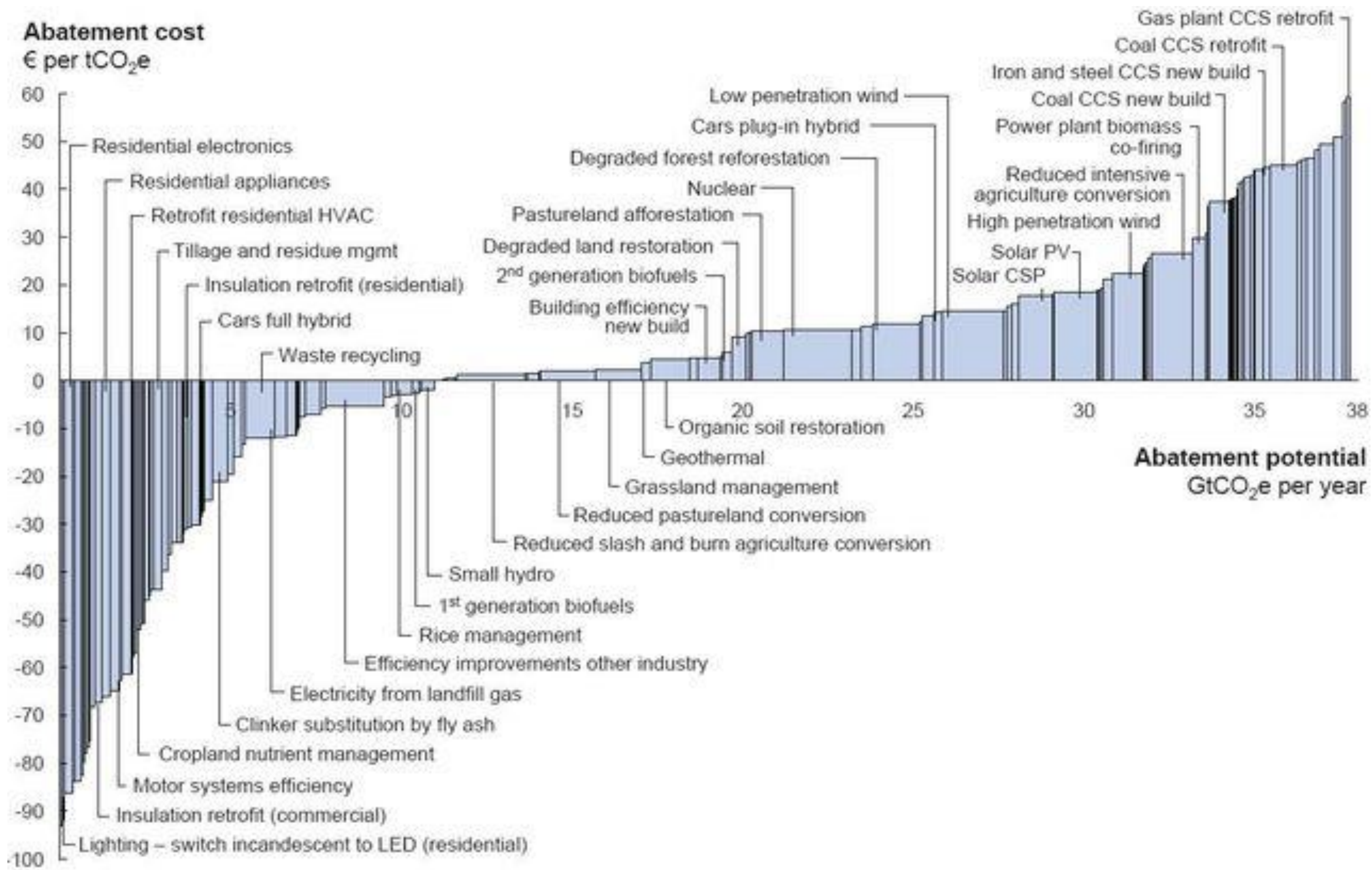
Other informations on the sector

Industry overview

Existing studies suggest at least a total 50% improvement is feasible

Global Calculator

Example of a study – McKinsey global abatement cost curve



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.0

Table 1.1 Global marginal abatement costs and example marginal abatement options in the 2DS

	2020	2030	2040	2050
Marginal cost (USD/tCO_2)	30-50	80-100	110-130	130-160
Energy conversion	Onshore wind Rooftop PV Coal w CCS	Utility scale PV Offshore wind Solar CSP Natural gas w CCS Enhanced geothermal systems	Same as for 2030, but scaled up deployment in broader markets	Biomass with CCS Ocean energy
Industry	Application of BAT in all sectors Top-gas recycling blast furnace Improve catalytic process performance CCS in ammonia and HVC	Bio-based chemicals and plastics Black liquor gasification	Novel membrane separation technologies Inert anodes and carbothermic reduction CCS in cement	Hydrogen smelting and molten oxide electrolysis in iron and steel New cement types CCS in aluminium
Transport	Diesel ICE HEV PHEV	HEV PHEV BEV Advanced biofuels	Same as for 2030, but wider deployment and to all modes	FCEV New aircraft concepts
Buildings	Solar thermal space and water heating Improved building shells	Stability of organic LED System integration and optimisation with geothermal heat-pumps	Solar thermal space cooling	Novel buildings materials; development of "smart buildings" Fuel cells co-generation

Notes: HVC = high-value chemicals, FCEV = fuel-cell electric vehicle, LED = light emitting diode.

Table 2.5 Share of technology contribution to industry CO_2 emissions reduction potential by 2020

Industry sector	Average energy efficiency	Recycling and energy recovery	CCS	Fuel and feedstock switching/ alternative materials	Total savings (Mt CO_2)
Iron and steel					354
Cement		na			119
Chemicals					440
Pulp and paper					49
Aluminium			na		7
Total					969

Note: Share of emissions reduction potential by 2020 denoted as follows: ≥50%; 10≤ ≤50% ; ≤10%; Average energy efficiency includes improvements to existing facilities and the use of BATs as new facilities are built.

Key point *Over the next decade, improvements in energy efficiency in the five major sectors play the greatest part in reducing CO_2 emissions from industry.*

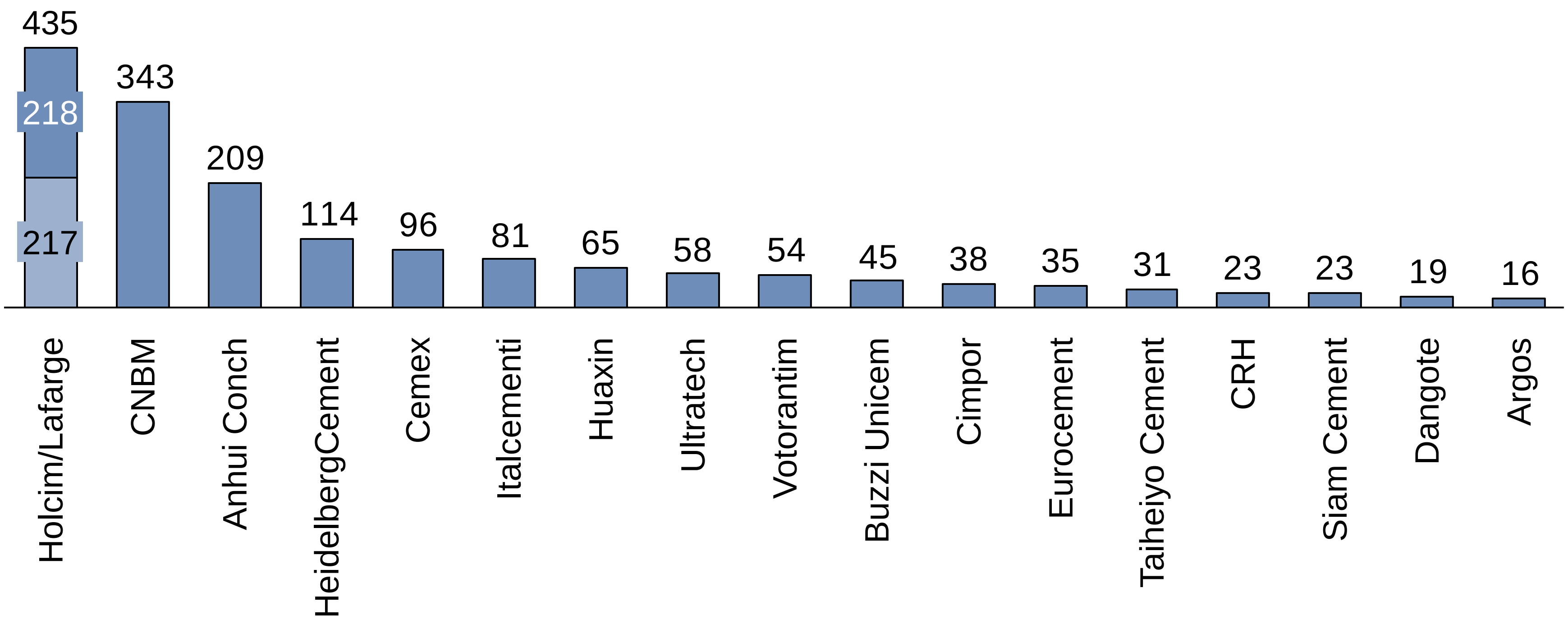
Global Calculator

Backup

Largest cement producers

Global Calculator

Cement capacities of largest producers
(M tons per year 2012)

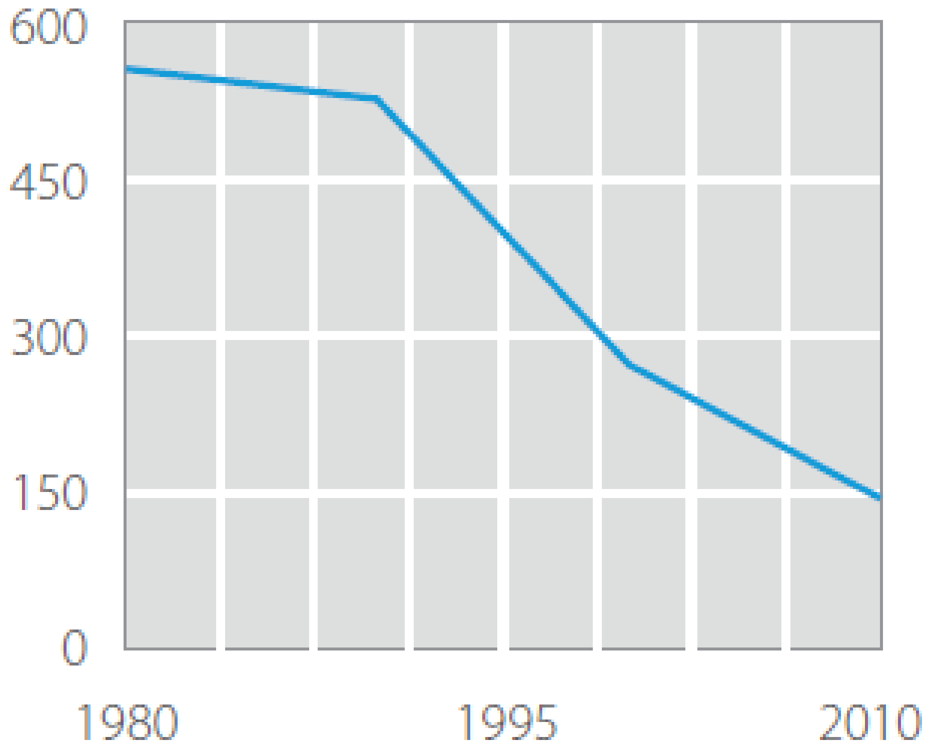


SOURCE: International Cement Review, Global cement industry trends

Energy efficiency
Cement productivity has significantly improved in recent years

Global Calculator

Employees per Mt output



- There have been large historical improvements in cement production productivity

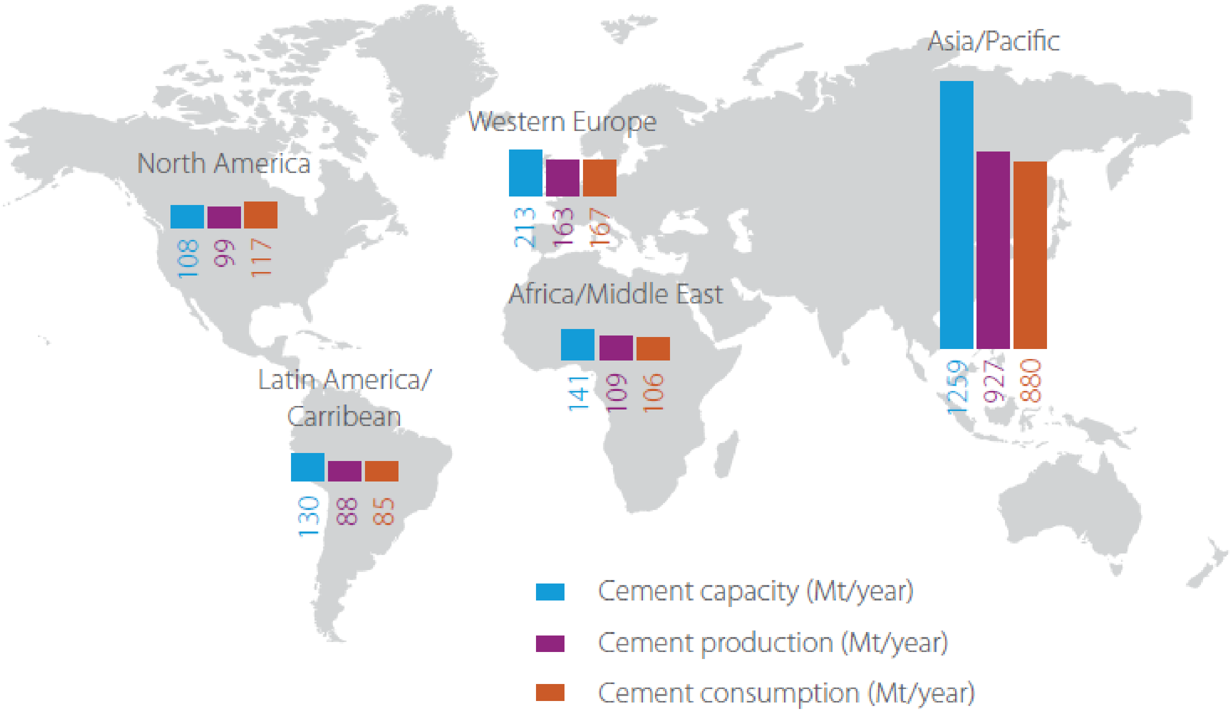
SOURCE: With Both Eyes open

International trade of cement is limited

Global Calculator

Cement capacity, production and consumption
(M tons/year)

BACKUP



- The major continents produce most of their own cement
- Cement resources are well distributed across the planet
- Cement has limited added value by weight

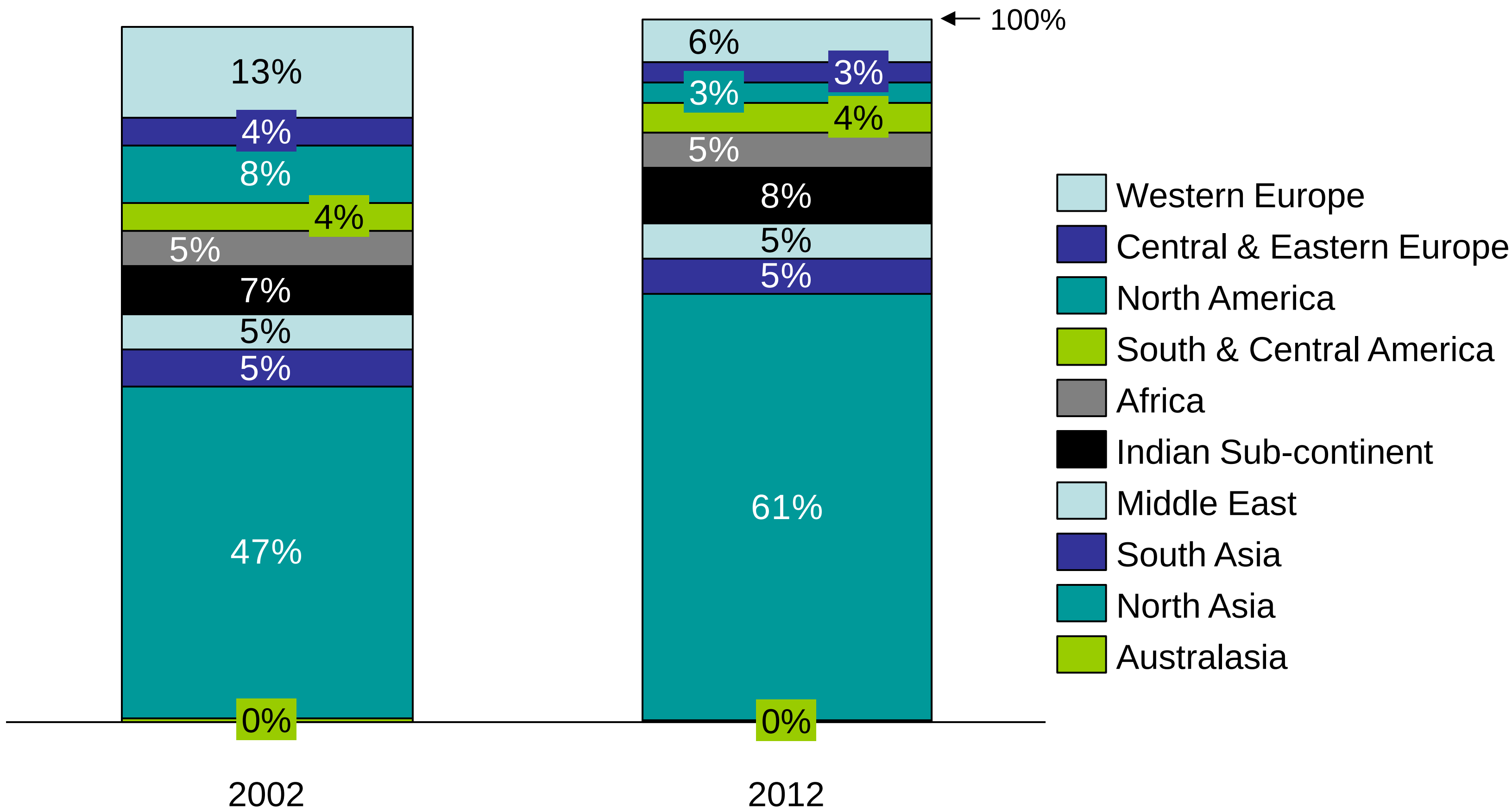
SOURCE: With both eyes open (Batelle 2002, based on 1999 figures)

North Asia has significantly grown while the share of other markets has declined

Global Calculator

Evolution of cement demand by region
(2002-2012 %)

BACKUP



SOURCE: International Cement Review, Global cement industry trends

Global Calculator

Backup

Existing studies

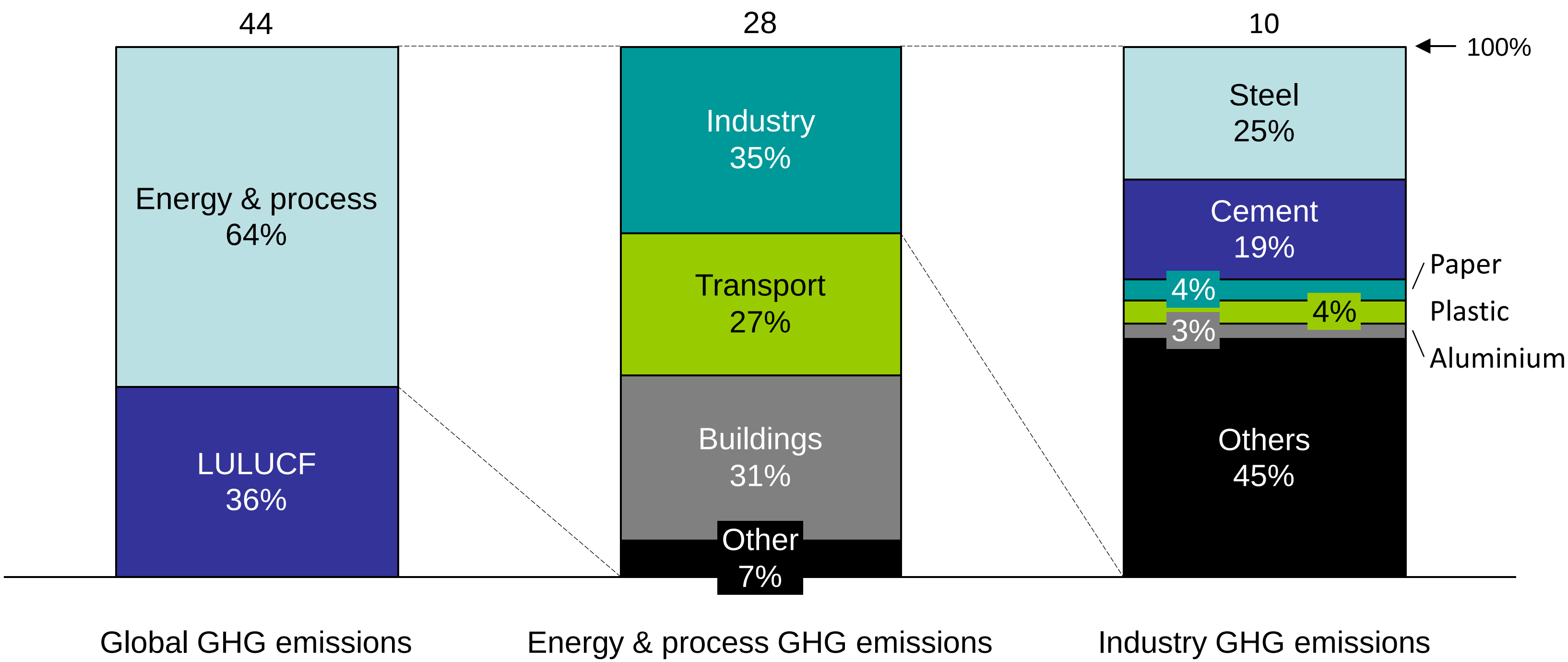
Other informations on the sector

Industry overview

Industry represents 22 % of total emissions and is made up of 5 main industries

Global Calculator

Global anthropogenic GHG emissions in 2005
($GtCO_2e$)

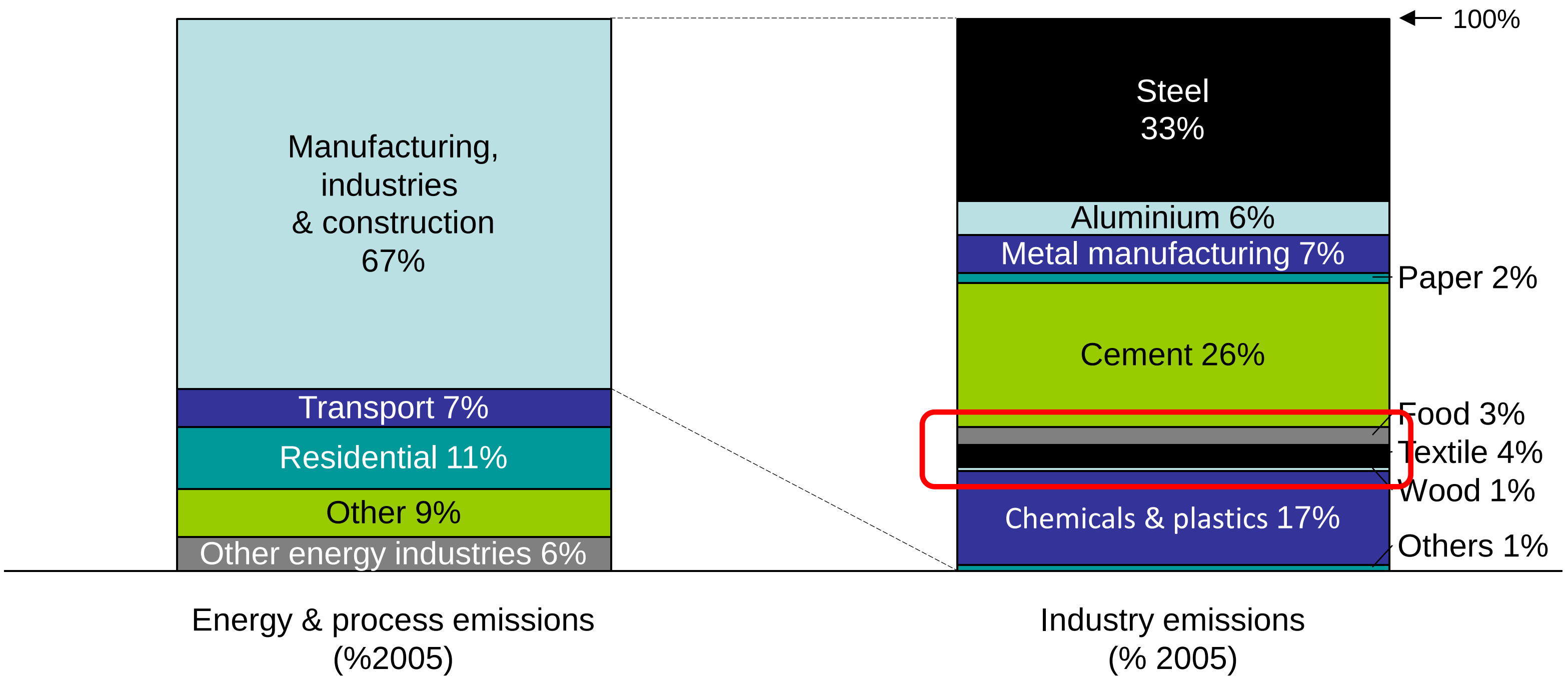


SOURCE: IEA 2008 on year 2005

These 5 sectors are representative of the whole industry. Assembly from materials to finished products is not a major energy or emissions segment

Global Calculator

China anthropogenic GHG emissions in 2005
(%)



SOURCE: China government statistics: Linwei, 2011 for year

Large developing economies are moving up in global manufacturing

Global Calculator

Top 15 manufacturers by share of global nominal manufacturing gross value added

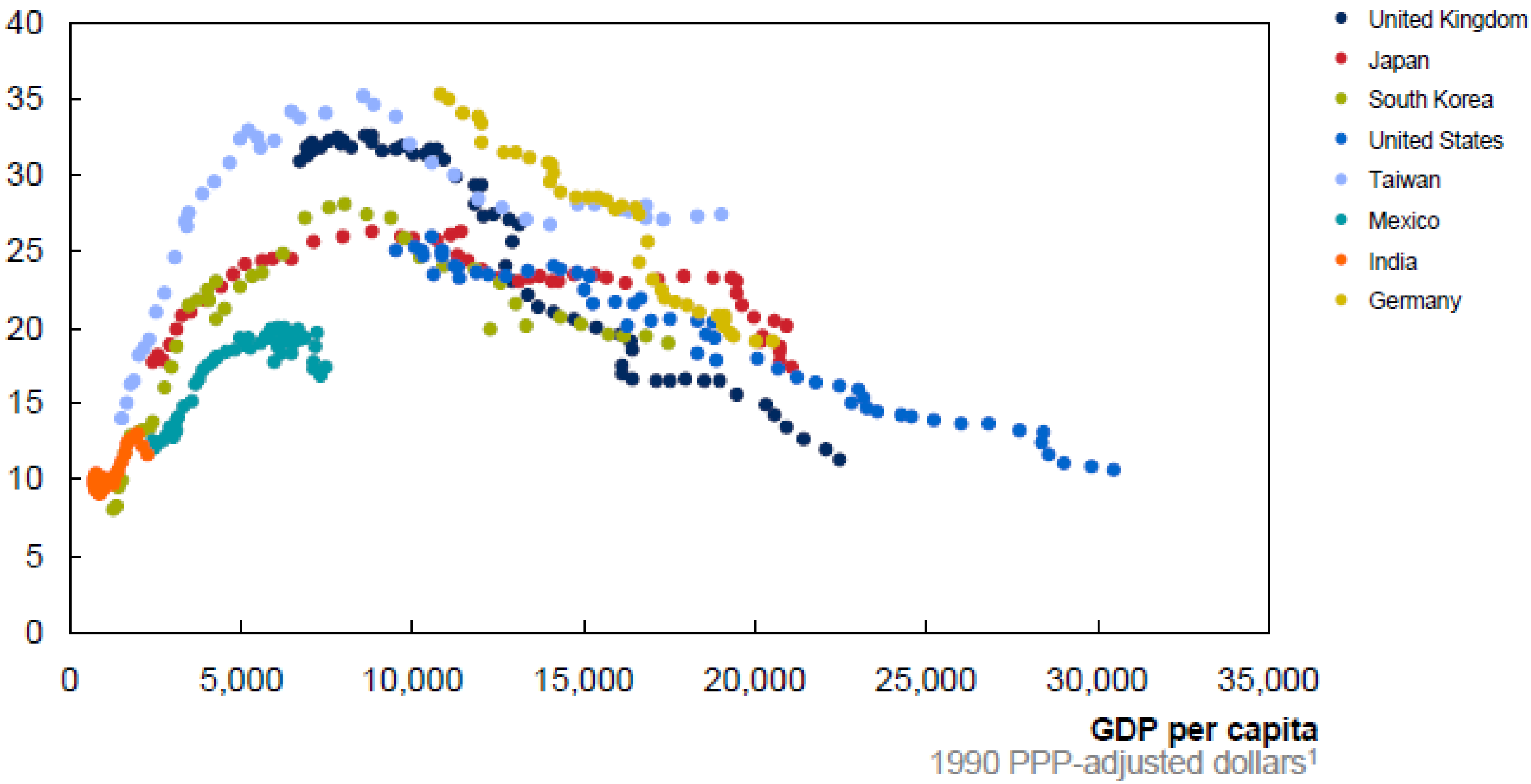
Rank	1980	1990	2000	2010
1	United States	United States	United States	United States
2	Germany	Japan	Japan	China
3	Japan	Germany	Germany	Japan
4	United Kingdom	Italy	China	Germany
5	France	United Kingdom	United Kingdom	Italy
6	Italy	France	Italy	Brazil
7	China	China	France	South Korea
8	Brazil	Brazil	South Korea	France
9	Spain	Spain	Canada	United Kingdom
10	Canada	Canada	Mexico	India
11	Mexico	South Korea[1]	Spain	Russia[2]
12	Australia	Mexico	Brazil	Mexico
13	Netherlands	Turkey	Taiwan	Indonesia[2]
14	Argentina	India	India	Spain
15	India	Taiwan	Turkey	Canada

1 South Korea ranked 25 in 1980.
2 In 2000, Indonesia ranked 20 and Russia ranked 21.
NOTE: Based on IHS Global Insight database sample of 75 economies, of which 28 are developed and 47 are developing. Manufacturing here is calculated top down from the IHS Global Insight aggregate; there might be discrepancy with bottom-up calculations elsewhere.
SOURCE: IHS Global Insight; McKinsey Global Institute analysis

Manufacturing's share of total employment fall as the economy grows wealthier, following an inverted U pattern

Global Calculator

Manufacturing employment
(% of total employment)



1 Adjusted using the Geary-Khamis method to obtain a 1990 international dollar, a hypothetical currency unit that allows international comparisons adjusted for exchange rates and purchasing power parity (PPP).

SOURCE: GGDC 10-Sector Database: "Structural change and growth accelerations in Asia and Latin America: A new sectoral data set," *Cliometrica*, volume 3, Issue 2, 2009; McKinsey Global Institute analysis