Global Calculator

Global Calculator
Technical documentation

Manufacturing sector

Technical documentation (Part 2 Evolution of materials and emissions)

2015

Preliminary information on this technical documentation

Global Calculator

- This technical documentation highlights the assumptions used in the manufacturing sector of the global calculator model. Introduction material generic to all sectors should be read prior going through this technical document.
- Most of this documentation has been performed to support workshop discussions on the technical choices in the manufacturing sector (in steel, cement, chemicals & across the sector as a whole)
- The global calculator aims at supporting the debate. You are more than welcome to share feedback on the calculator and on this documentation. We aim at continuously refining this analysis with your feedbacks. The expert feedback is incorporated in the analysis through various steps:
  1. It is flagged as feedback to include in the analysis
  2. The analysis documents are refined accordingly
  3. The model is updated and the model results are shown in the presentation

  The dates of the figures used in the model are written Most of the figures in this document date from July 2014. Please note that some minor modifications have been placed in the model since July 2014. In case of differences between the presentation and the model, the model has the most recent estimates.
- All this documentation is open source [(1)]

Legend associated with the consulting process

- Several slides in this technical documentation document are tagged to reflect the stakeholder consultations

Legend:

★	Key slide
Question…	Key feedback asked
Data	Model input
Consultation feedback	Consultation feedback still to take into account
Figures of July 2014	Date of the latest update to the figures in the presentation

Agenda

Global Calculator

2050 evolution of materials and emissions

Materials demand evolution

- Cross sector demand
- Cross sector material switch
- Steel
- Chemicals
- Aluminium
- Cement
- Paper & Timber

Reduction potential on the manufacturing processes

- Resulting emissions
- Discussion on ambition levels across sectors
- Discussion on CCS
- Steel
- Chemicals
- Aluminium
- Cement
- Paper, Timber & Other

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Global Calculator

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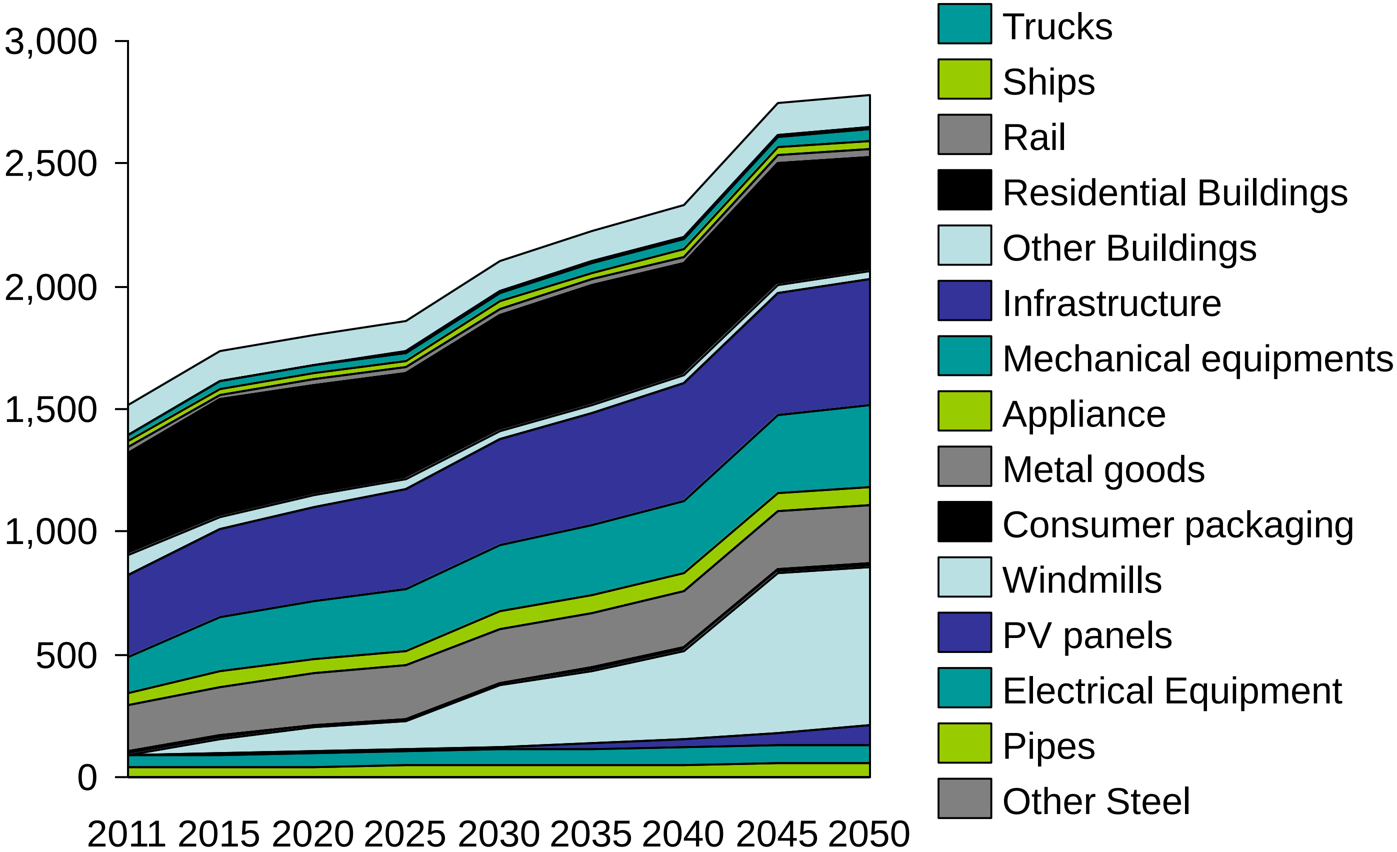
Figures of July 2014

REMINDER: In the model, material demand is driven by product demand

Global Calculator

Steel demand evolution
(Mtons, before design & switch)



Steel example in a pathway with ambition 3

- Product demand determines material demand
- How should product demand be determined?

SOURCE: Global Calculator model

REMINDER: Most product demand is defined by sector activity, Some products are driven by the “Product demand” lever,

Global Calculator

Key drivers of demand to be challenged

Group	Products	Model Technologies (grouped)	Demand driven by	Rationale
Transport	Car & Light trucks	Bike, Cars, Motorbike	By transport sector	/
	Trucks	Trucks, Bus		/
	Rail	Trains		/
	Airplanes	Planes		/
	Trucks & ships	Trucks, Ships		/
	Infrastructure (1)	Roads		/
	Batteries	Electric vehicles		/
Buildings	Buildings	Residential/Non-residential	By buildings sector	/
	Infrastructure (1)	Bridges, Roads, Airports	By transport sector	to avoid iteration loop and have it defined in one place
	Mechanical equipment's	Cooker, HVAC	By Buildings sector	/
	Appliances	Various appliances, stoves, lighting		/
Consumer goods	Paper	Print, graphic	By “Product demand “ lever	/
	Metal goods	Consumer products	By “Product demand “ lever	/
	Consumer packaging	Consumer packaging	By “Product demand “ lever	/
	Fertilizers	Ammonia production	By Population	By Land & food sector in v2
Energy/ Electricity	Wind	Onshore, offshore	By energy sector	/
	PV	Solar PV		/
	Electrical Equipements	Transformers	Skipped	to avoid iteration loop
	Electrical cables	Transmition lines		
	Pipes			Not modelled in v1
	Infrastructure (1)	Energy Plants& network	By transport sector	to avoid iteration loop and have it defined in one place
Industry	Infrastructure (1)	Plants of each kind of material	By transport sector	to avoid iteration loop and have it defined in one place
	Paper	Paper	By “Product demand “ lever	/

NOTE: (1) Infrastructure is present in three sectors: Energy, Industry and Transport. The allocation is as follows x,y,z.
It’s demand evolution is currently following the transport demand only.

The lever choices in the other sector generate various product evolutions

Global Calculator

Group	Product	2011 demand (units)		2050 demand per ambition[1] (% evolution vs 2011)
Transport	Cars & light truck	111,3	Million units	300%
	Cars & light truck EV	1,5	Million units	1,331%
	Trucks	5,7	Million units	439%
	Ships	1	K units	184%
	Rail	5	K units	101%
	Airplanes	35	K units	437%
	Batteries	/	Million units	137%
Buildings	Residential Buildings	3932	Million m2	141%
	Other Buildings	830	Million m2	230%
	Infrastructure	1750	Million m2	307%
	Mechanical equipment	160	Million tons	219%
	Appliance	43	Million tons	421%
Consumer goods	Print & Graphic Paper	253	Million tons	152%
	Metal goods	257	Million tons	165%
	Consumer packaging	530	Million tons	152%
Food	Fertilizer	164	Million tons	169%
Energy	Windmills	17600	Units	13,626%
	PV panels	160	Million m2	39,78
	Electrical Equipment	61	Million tons	239%
	Electrical cables	24	Million km	239%
	Pipes	100 000	km	137%
Other	Other	0,0	Million tons	239%

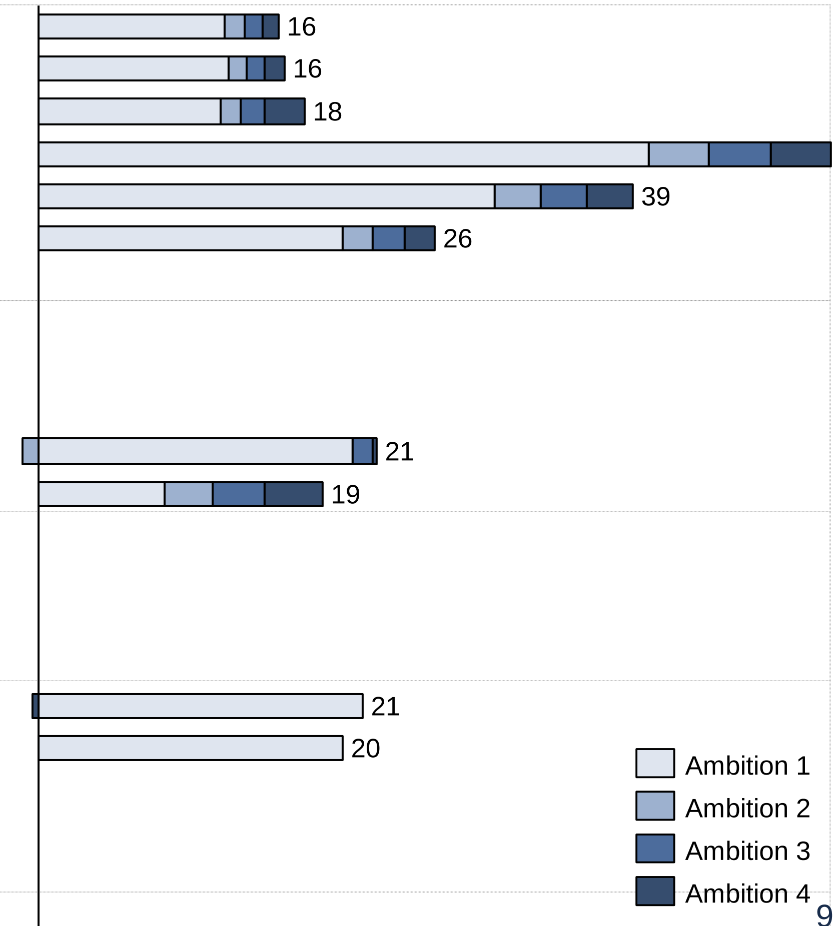
Ambition 4
Ambition 3
Ambition 2
Ambition 1

2011 =100%

NOTE (1) Population follows the average UN projection in all ambitions

The lever choices in the other sector generate various product evolutions

Group	Product	2011 lifetime (years)	Lifetime per ambition (years)
Transport	Cars & light truck	12,2	16
	Cars & light truck EV	12,4	16
	Trucks	12,4	18
	Ships	40	52
	Rail	30	39
	Airplanes	20	26
	Batteries	/	
Buildings	Residential Buildings	/	
	Other Buildings	/	
	Infrastructure	/	
	Mechanical equipment	21,9	21
	Appliance	11,9	19
Consumer goods	Print & Graphic Paper	/	
	Metal goods	/	
	Consumer packaging	/	
Food	Fertilizer	/	
Energy	Windmills	24,1	21
	PV panels	20,0	20
	Electrical Equipment	/	
	Electrical cables	/	
	Pipes	/	
Other	Other	/	

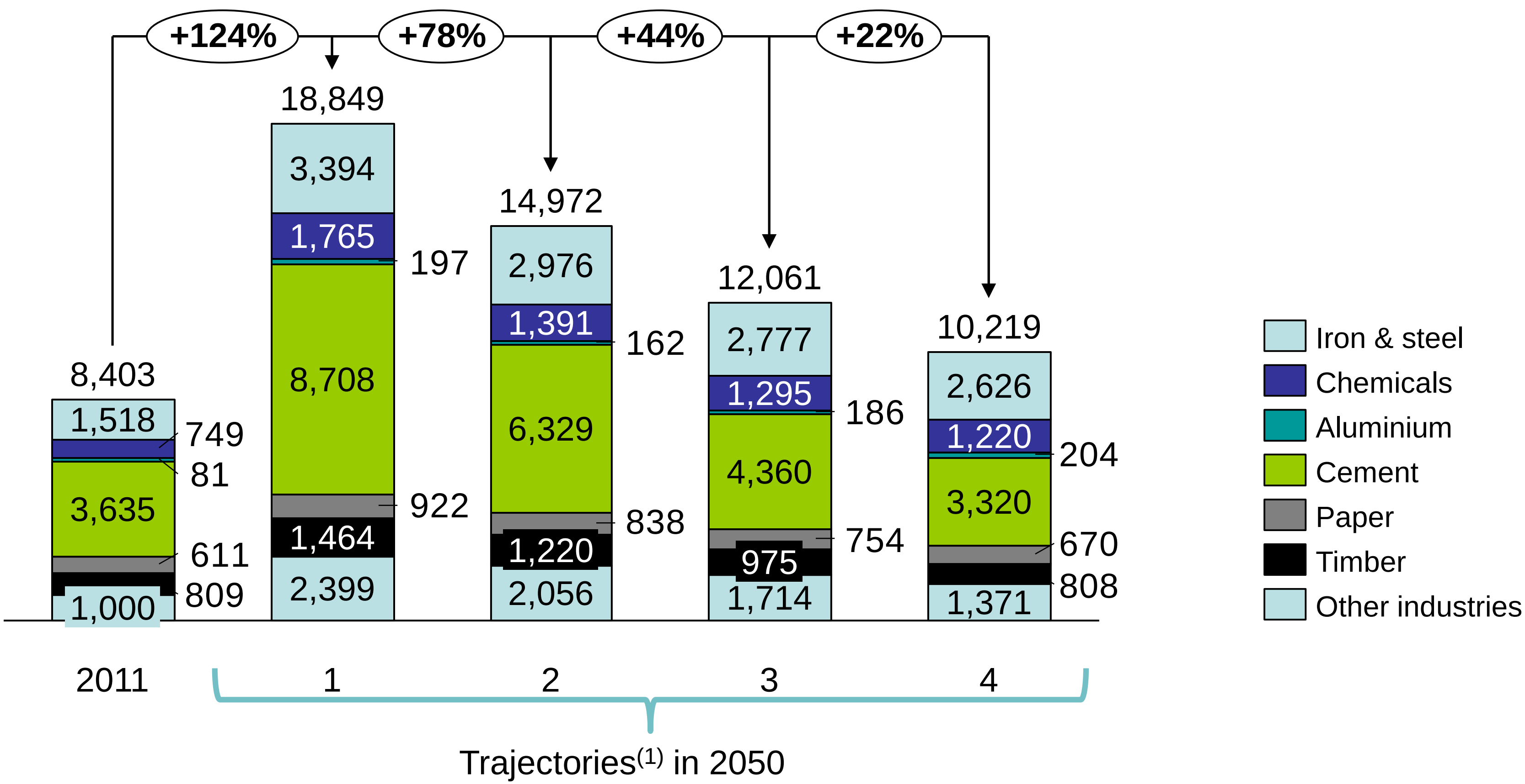


NOTE (1) Population follows the average UN projection in all ambitions

Total

Materials demand growth in trajectories 1, 2, 3 & 4 (1)

Annual Total production per ambition level(1), by product
(M tons)



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

Figures of July 2014

Global Calculator

Total

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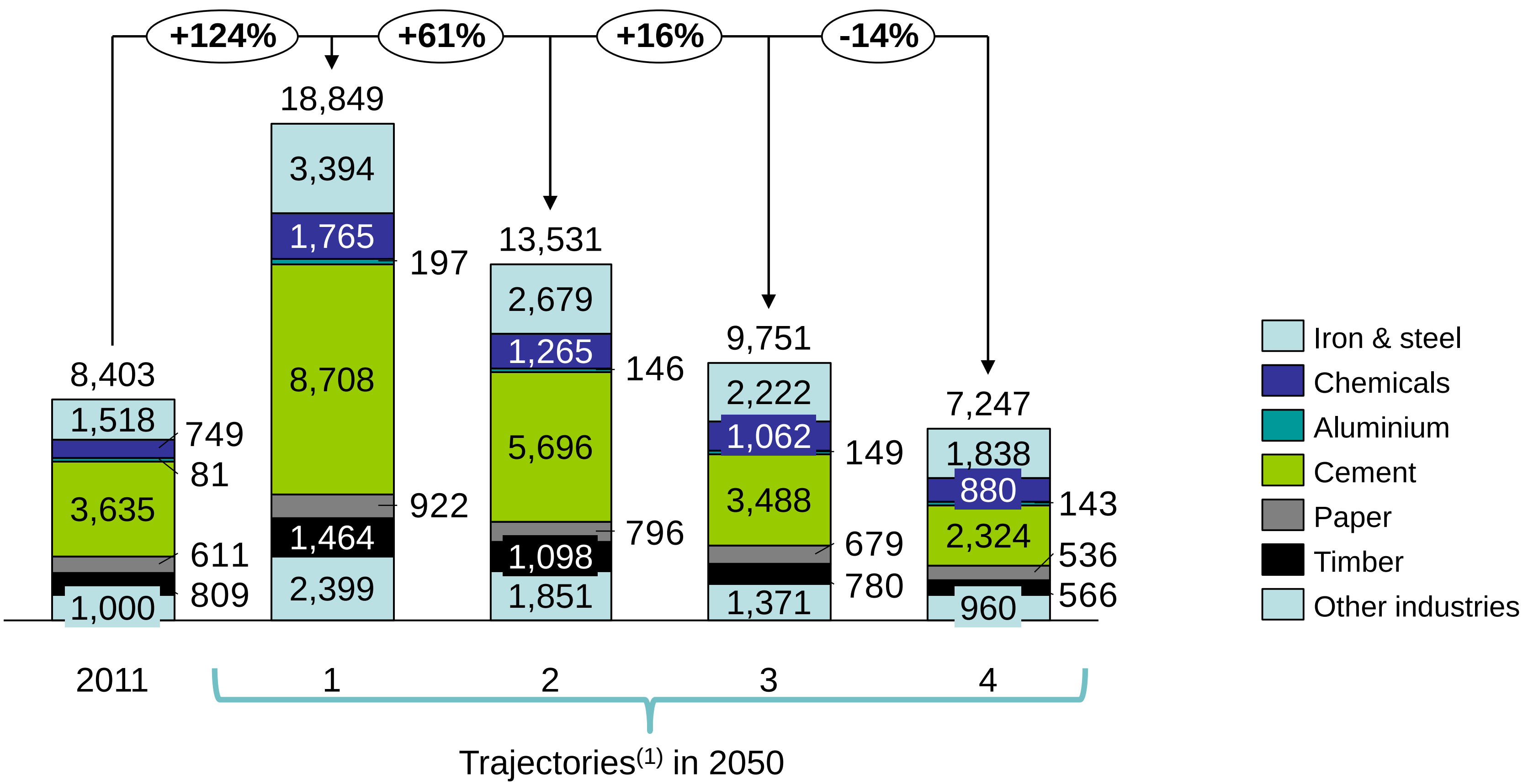

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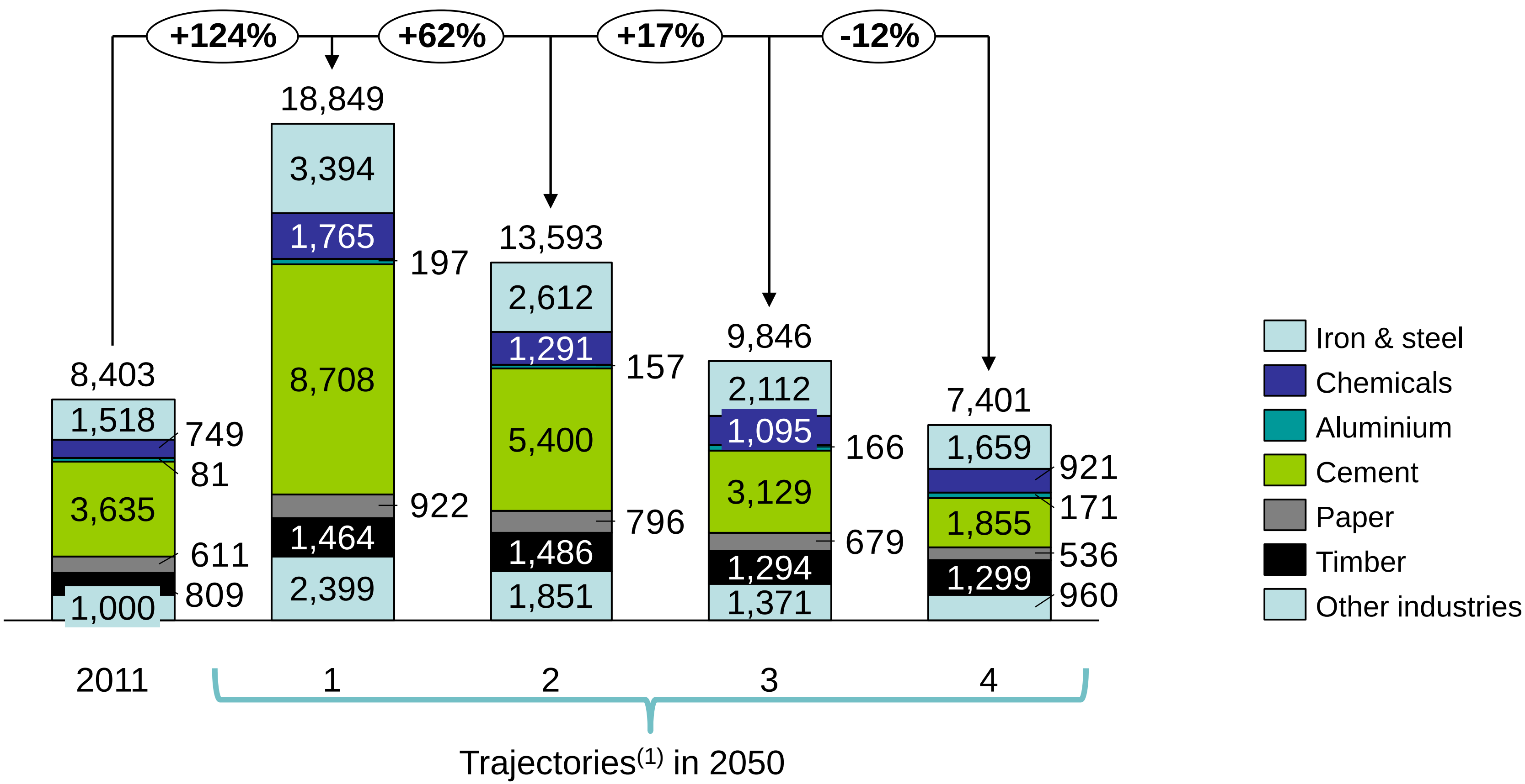


NOTE: (1) The population follows the average UN projection in all four trajectories
SOURCE: IEA ETP 2012, Global calculator model

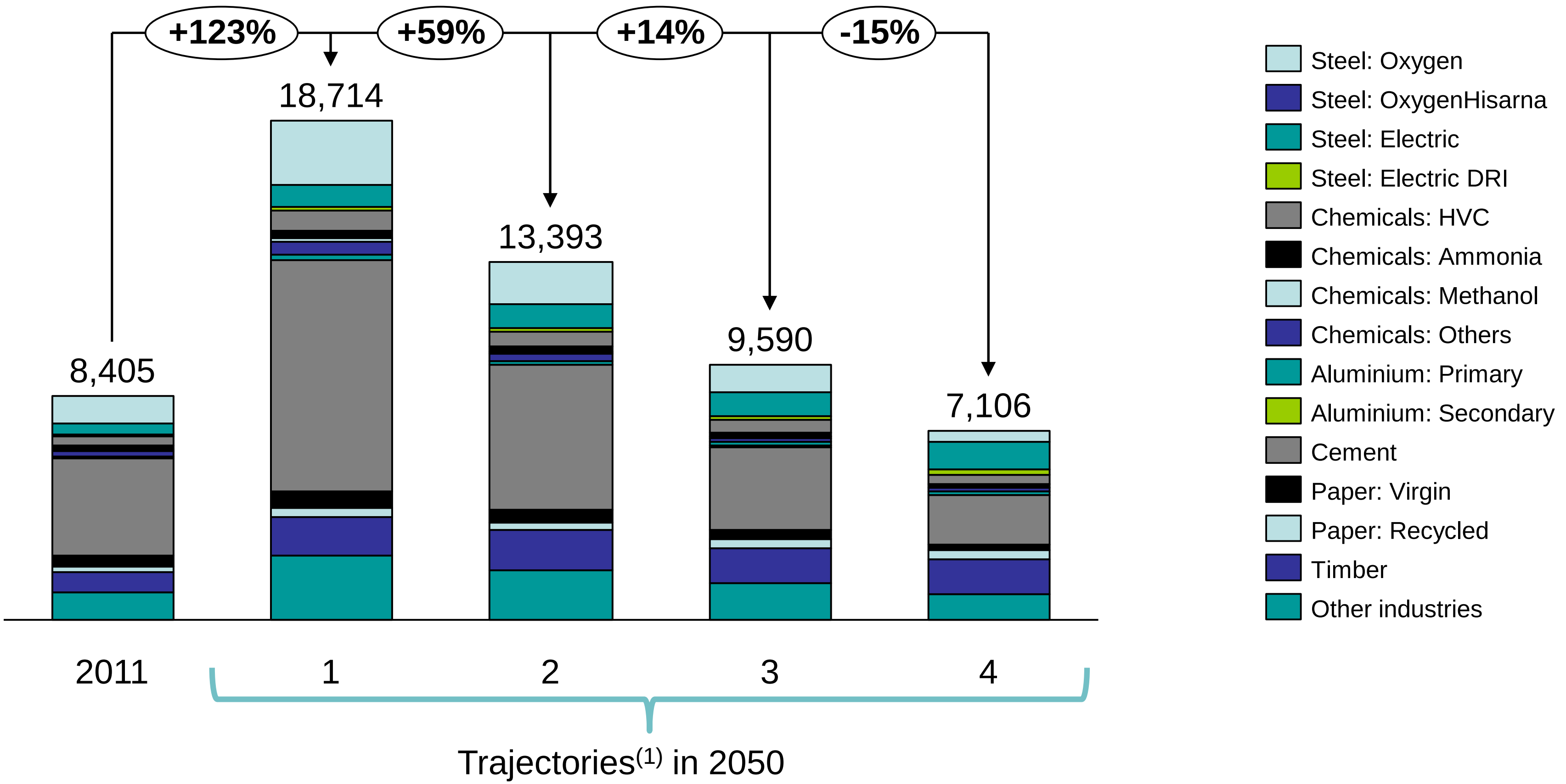
Figures of July 2014

Global Calculator

Total

Materials demand growth in trajectories 1, 2, 3 & 4 [1]

Annual Total production per ambition level[1], by product
(M tons)

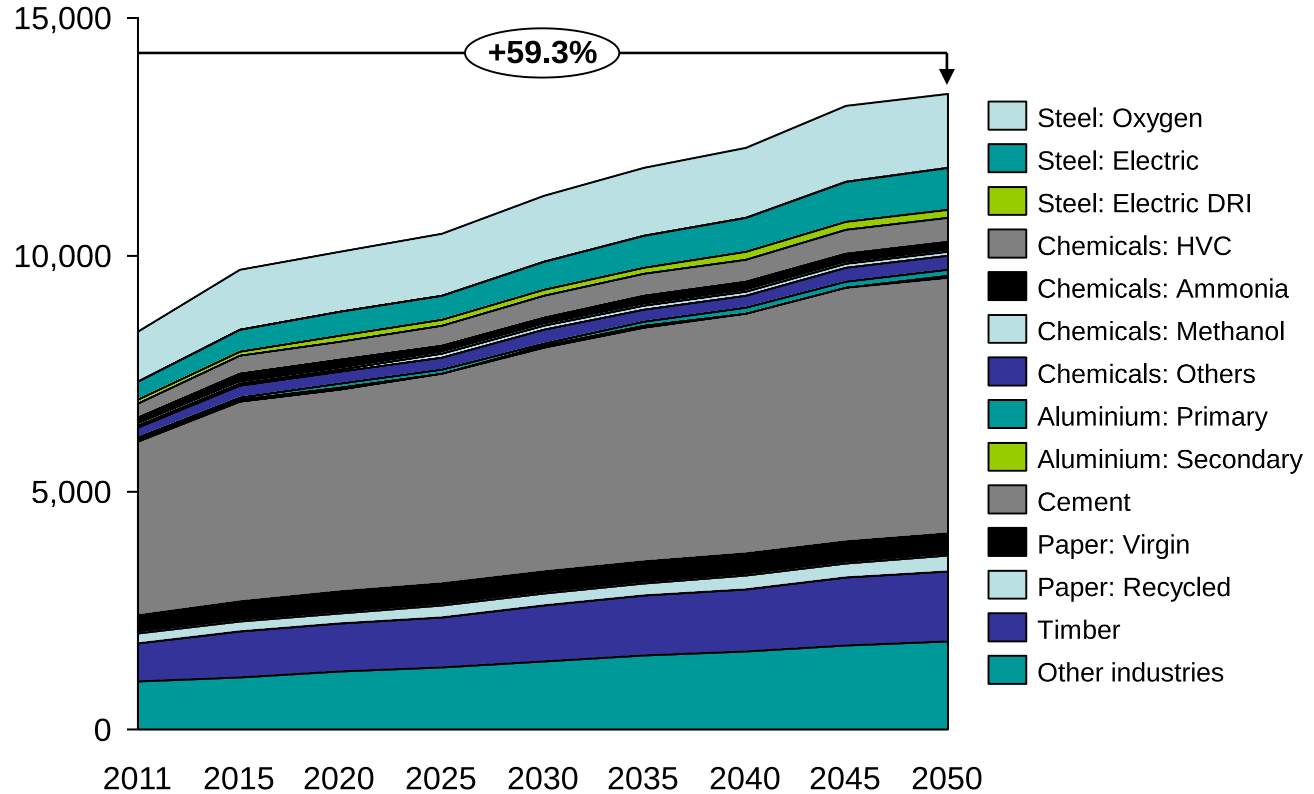


NOTE: (1) The population follows the average UN projection in all four trajectories
SOURCE: IEA ETP 2012, Global calculator model

Total industry

Materials demand growth with ambition 2 (1)

Production evolution per industry with an ambition 2, (Mton)



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

Agenda

Global Calculator

2050 evolution of materials and emissions

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Each material has a different set of properties

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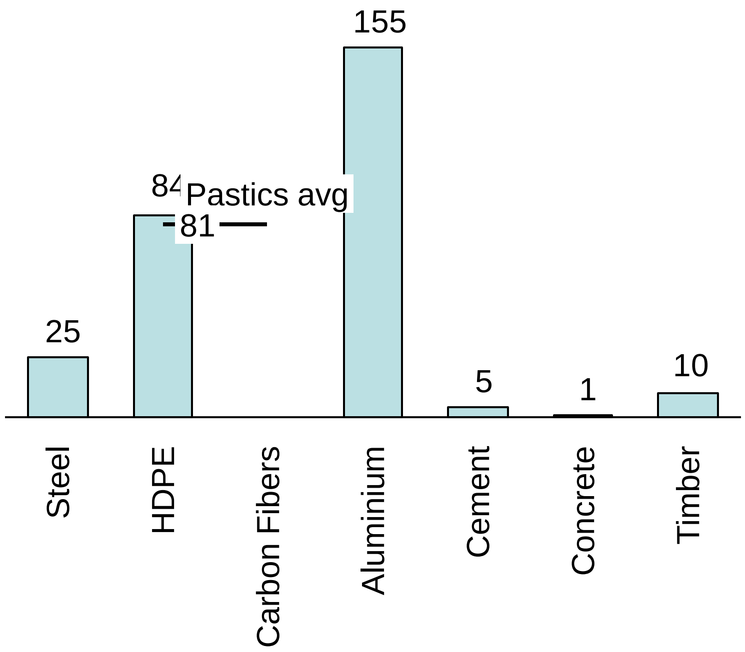
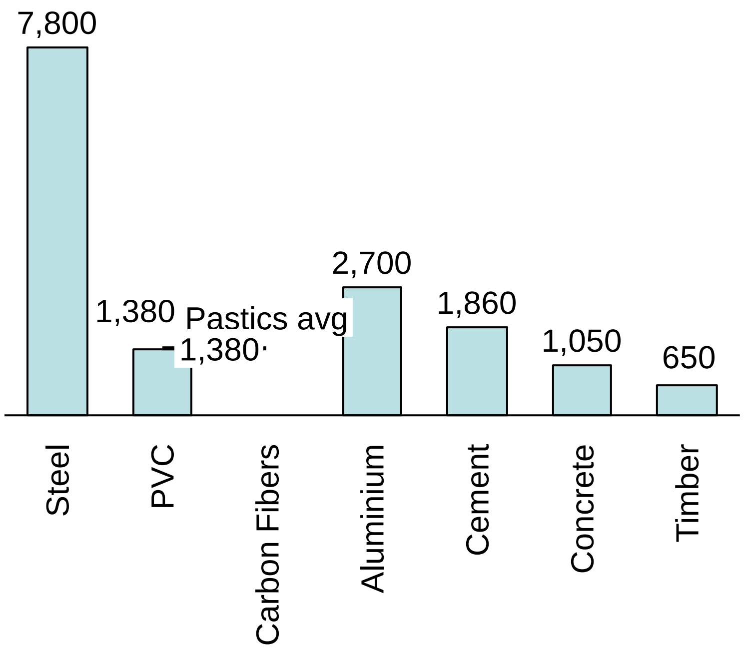
Embodied Energy
(MJ/Kg)



Density
(Kg/m³)



- Embodied energy reflects the amount of energy needed to produce a kg of the material in the model before any effieicny lever is applied

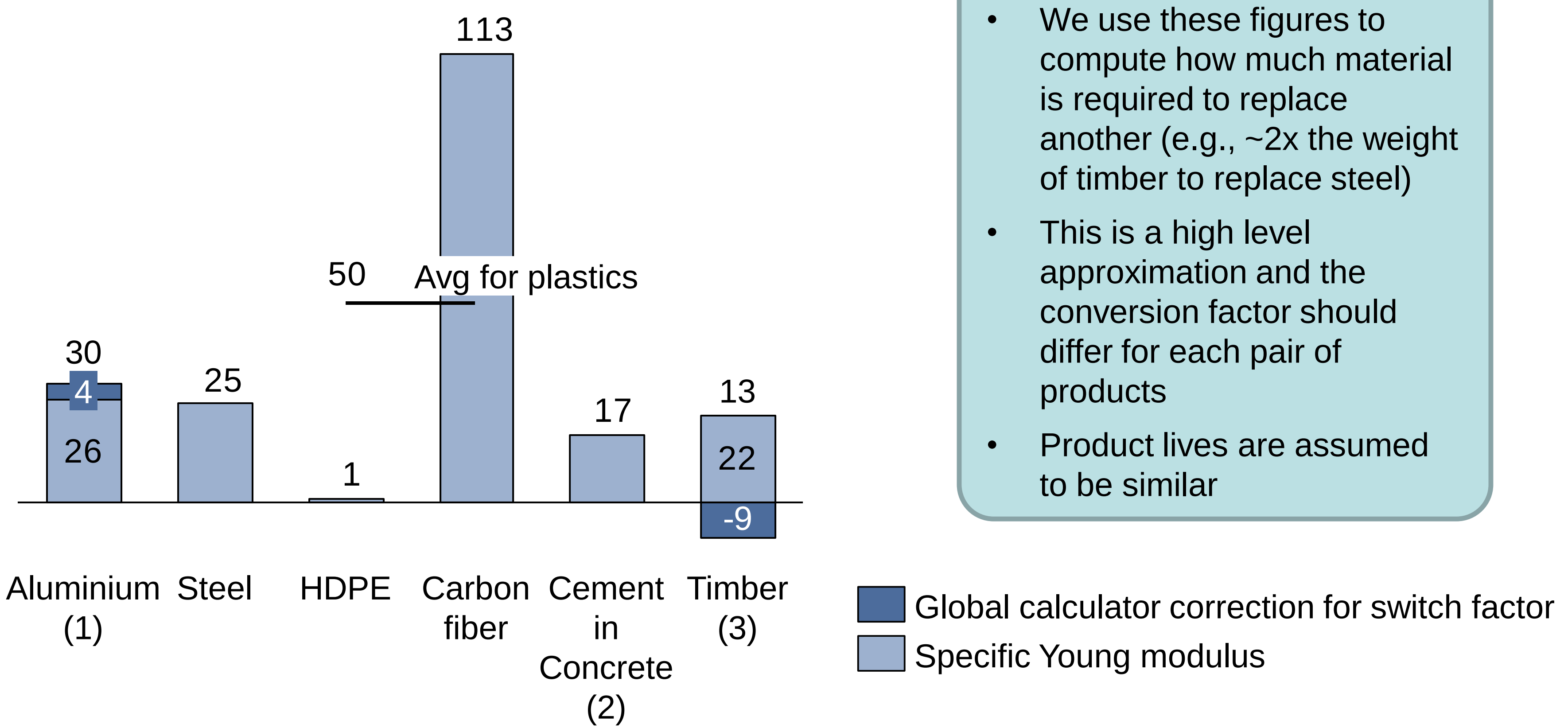
- Density reflects xxxx

SOURCE : Bath construction database

The specific Young modulus indicates how much of a material is required to replace another

Global Calculator

Specific Young modulus
(Young modulus in Gpa, divided by density)



Rationale

- We use these figures to compute how much material is required to replace another (e.g., ~2x the weight of timber to replace steel)
- This is a high level approximation and the conversion factor should differ for each pair of products
- Product lives are assumed to be similar

NOTE: (1) Tweaked to 20% more than steel, to represent the fact 20% less mass is typically required in transport applications
(2) Assuming 8% cement per ton concrete
(3) Assuming Pine, then removing 40% to account to material discontinuity safety factor

SOURCE : Wikipedia Specific modulus

Figures of July 2014

Global Calculator

Material switches in Transport

Groups	Products	Units	Composition per unit (tons, (vs 2011)) 2011	Ambition 1	Ambition 4
Transport	**Cars & light truck**	units	Steel: 1,150 ton Alu: 0,15 ton HVC: 0,1 ton Methane: 0,02 ton Other chem: 0,07ton	idem	**Replace** • 20% steel by aluminium • 20% steel by carbon fibres
	Trucks	units	Steel: 3,030 ton Alu: 1 ton HVC: 0,3 ton Methanol:0,06ton Other chem: 0,2ton	idem	**Replace** • 20% steel by aluminium • 20% steel by carbon fibres
	Ships	units	Steel: 0,462 ton	idem	Idem
	Rail	units	Steel: 6,875 ton	idem	Idem
	Airplanes	units	Alu: 63 ton	idem	**Replace** • 50% alu by carbon fiber (HVC)

Figures of July 2014

Global Calculator

Material switches in Buildings

Groups	Products	Units	Composition per unit (tons, (vs 2011)) 2011	Ambition 1	Ambition 4
Buildings	**Buildings (residential & others)**	m² (ground surface)	Steel: 0,202 ton Alu: 0,008 ton HVC: 0,02 ton Methanol: 0,004ton Other chem: 0,004 ton Cement:0,560 ton Bricks: not modelled Timber: 0,22 ton	idem	**Replace** • 20% steel by timber • 20% concrete by timber • 5% concrete by insulation materials (HVC)
	Infrastructure	m² (ground surface)	Steel: 0,187 ton Alu: 0,001 ton Cement0,450 ton	idem	**Replace** • 5% concrete by insulation materials (HVC)
	Mechanical equipment	tons	Steel: 0,750 ton Alu: 0,013 ton	idem	idem
	Appliance	Million tons	Steel: 0,17 ton Alu: 0,02 ton HVC: 0,43 ton Methanol: 0,08ton Other chem: 0,28ton	idem	idem

Figures of July 2014

Global Calculator

Material switches in Consumer goods and Energy

Groups	Products	Units	Composition per unit (tons, (vs 2011)) 2011	Ambition 1	Ambition 4
Consumer goods	**Print & Graphic Paper**	Million tons	Paper: 1 ton	idem	idem
	Metal goods	Million tons	Steel: 0,750 ton Alu: 0,03 ton	idem	idem
	Consumer packaging	Million tons	Steel: 0,021 ton Alu: 0,023 ton HVC: 0,240 ton Methanol: 0,04ton Other Chem: 0,157ton Paper: 0,516 ton	idem	idem
	Fertilizer	tons	Ammonia: 1 ton	idem	idem
Energy	**Windmills**	2MW Units	Steel: 350 tons HVC: 30 tons	idem	idem
	PV panels	m2	Steel: 2 kg Alu: 2 kg HVC: 5 ton	idem	idem
	Electrical equipment	tons	Steel: 0,750 ton Alu: 0,03 ton	idem	idem
	Electrical cables	Km	Alu: 0,3 ton	idem	idem
	Pipes	meter	Steel: 0,4 ton	idem	idem

- In packaging, both a tendency to more (e-shipping) and to less (more lightweight, tailored to needs) packaging
- Check expectations with EU packaging federation

Open questions

Global Calculator

Discussion topics on material switch

Trends	• Impact of urbanisation on the proportion of Steel/Cement in buildings
Intellectual capital	• Which working groups compare the applicability of materials • Which dimensions should be taken into account • Vedh has a working group • Others ?
Other dimensions to take into account	• All products could keep similar lifetimes • Timber is less uniform, so a safety margin needs to be included (current assumption of +40% requirements) • Fiber glass cannot be recycled and are harder to repair
Costs	• How to you suggest to account of the costs associated with each material? Use the embedded energy of each material?
Magnitude orders	• Overall substitution rate through the above is limited, even in level 4: • -11% steel, -1% aluminium, -16% cement

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Global Calculator

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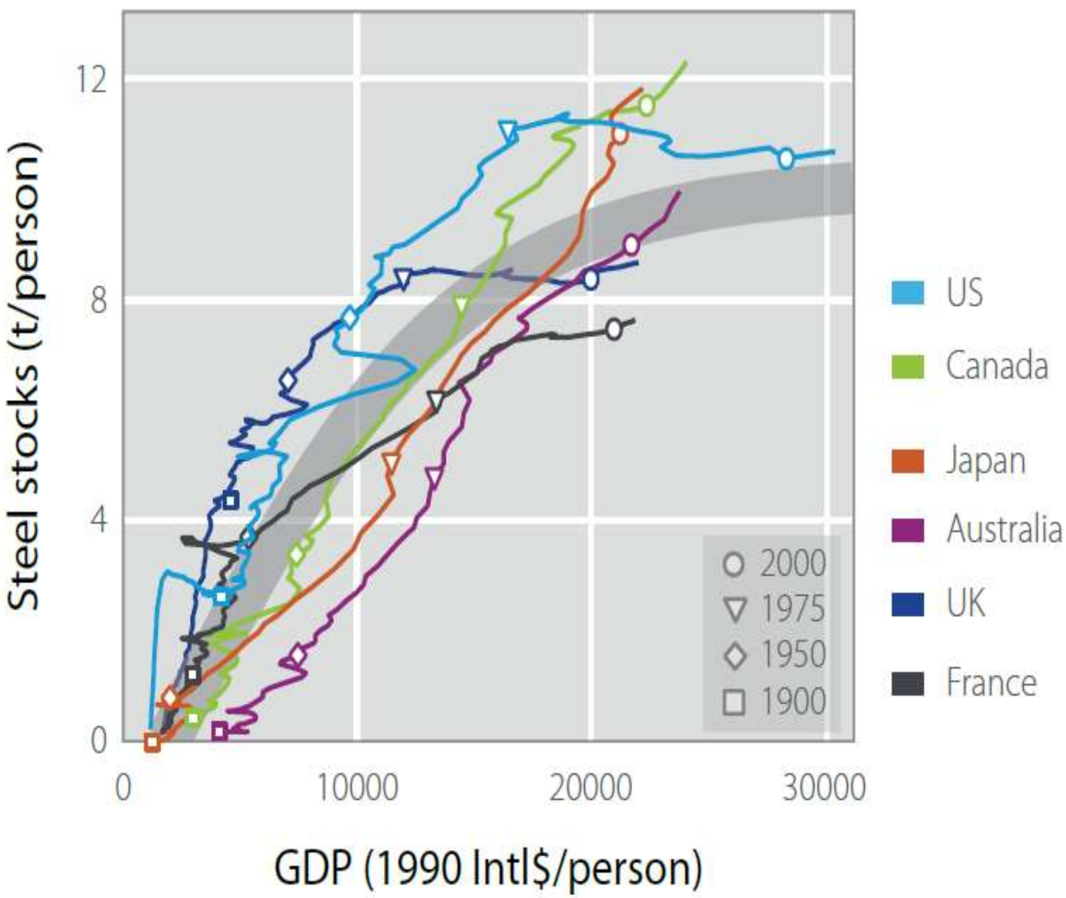
1

As income /person increases, steel demand increases, an upper boundary is experienced in some countries

Global Calculator

Evolution of steel per capita consumption as function of GDP per capita
(ton/person, 1990 International $/person)[1]



- Steel Demand can be correlated to national incomes, up to ~$20-000 /person, but then the increase declines, when demand for new products, buildings & infrastructure has been satisfied
- Steel stocks appear to saturate between 8 & 12 tons /person [2][1]
- This indicates we will reduce our consumption to a level were we will consume what needs to be replaced

SOURCES: (1) With both eyes open, Copyright 2012 UIT Cambridge Ltd.
(2) NTNU & Cambrige University (2014 04 10 International Materials Education Symposium)

Rationale for expected 2050 Iron & steel demand (1/2)

Global Calculator

Rationale for assessing future steel production

Population evolution	7 billion people in 2010[3] 8-10 billion people in 2050 [3]
Demand per capita evolution	Per capita • 201 kg/capita in 2010 • 225-270 kg/capita in 2050 [4] • 270-319 kg/capita in 2050 [1]
Regional changes	We expect continuing growth in the steel production, driven by developing areas[3], where steel will be vital in raising the welfare of developing societies. In these regions, more than 60% of steel consumption will be used to create new infrastructure[2]
Market segment changes	• Increasing share of manufactured steel goods vs buildings & infrastructure (building and infrastructure construction slows in China into 2050, and China's demand for steel containing goods such as cars & domestic appliances increases) [4]
Total range	• Based on the above indicative range between 1608 to 3190 M tons in 2050 • IEA ETP 2012 has 2438 to 2943 M tons in 2050

SOURCE: (1) IEA ETP 2012 (2) With both eyes open (3) UN projection scenarios (4) WorldSteel

1

Rationale for expected 2050 Iron & steel demand (2/2)

Global Calculator

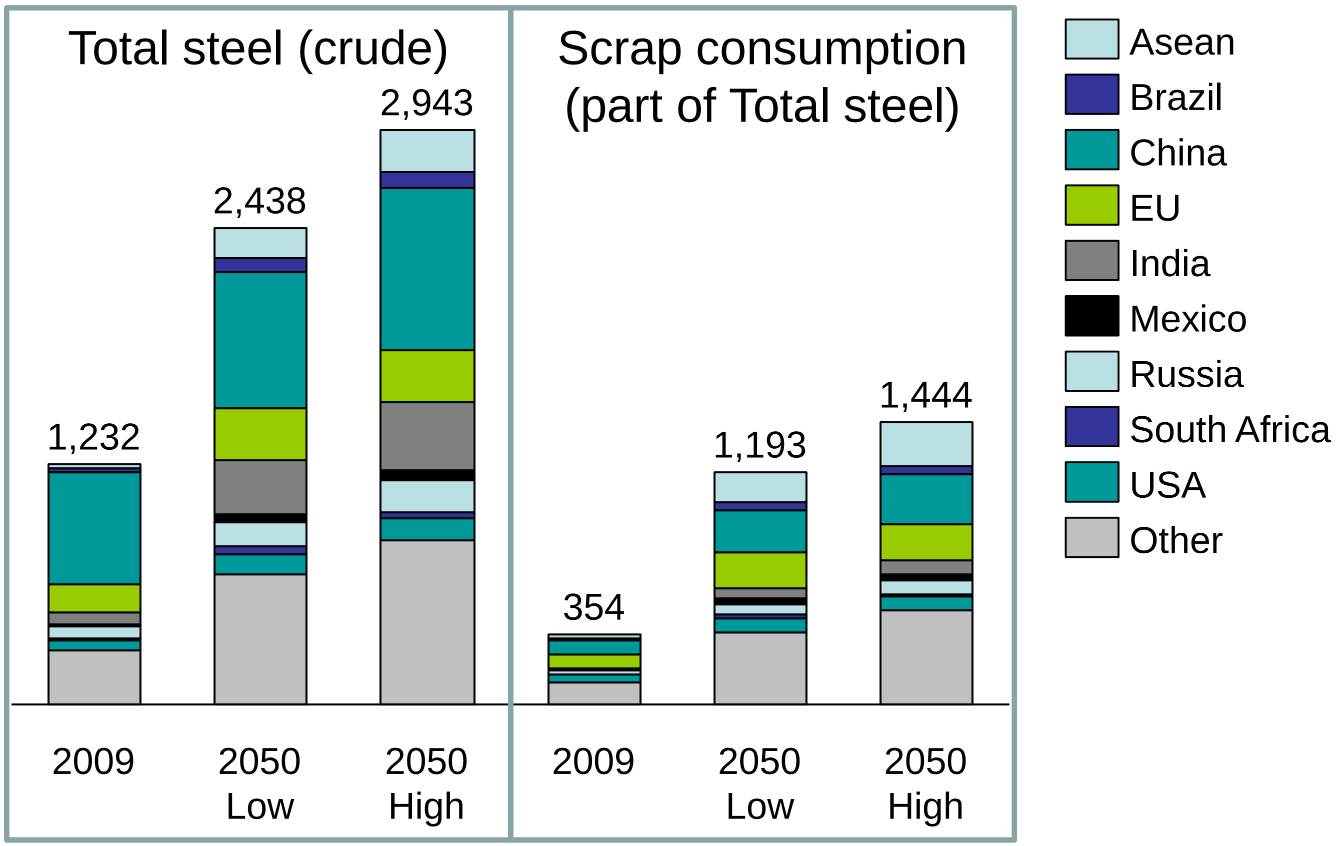
Technologies & Products	Evolution driven by	Assumptions (if by product demand)
Buildings Residential	Building model	/
Buildings Others	Building model	/
Infrastructure	Transport demand (pass. & freight)	linked to transport demand
Electrical equipment	Product demand lever	100-175% evolution by 2050
Mechanic equipment	Building model	/
Consumer packaging	Product demand lever	80-110% evolution by 2050
Appliance	Building model	/
Metal goods	Product demand lever	80-120% evolution by 2050
Cars & light truck	Transport model	/
Trucks	Transport model	/
Ships	Transport model	/
Rail	Transport model	/
Windmills	Supply model	/
PV panels	Supply model	/
CCS + oil pipes	Not linked in this version of the model	/
Other Steel	Product demand lever	100%-175% evolution by 2050

SOURCE: (1) Global Calculator team assumptions

1 The IEA ETP 2012 suggests an increase in Iron & Steel production in all scenarios in most regions

Global Calculator

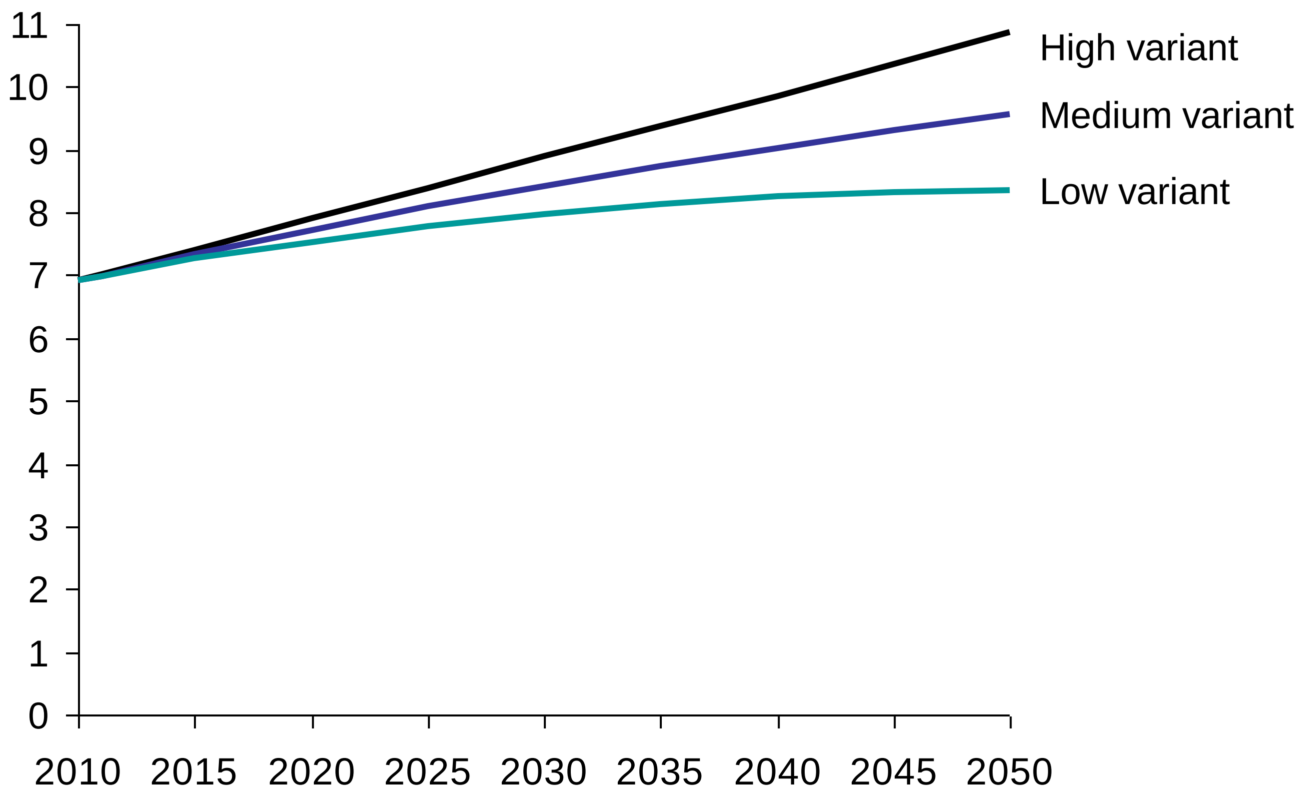
Production evolution per scenario per region for Steel
(Mton)



SOURCE: ETP 2012, IEA

1 By 2050, the world population is expected by the UN to grow by ~20 to ~55%

World population
(billions)



2010-2050 growth
(%)

+57%

+38%

+21%

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

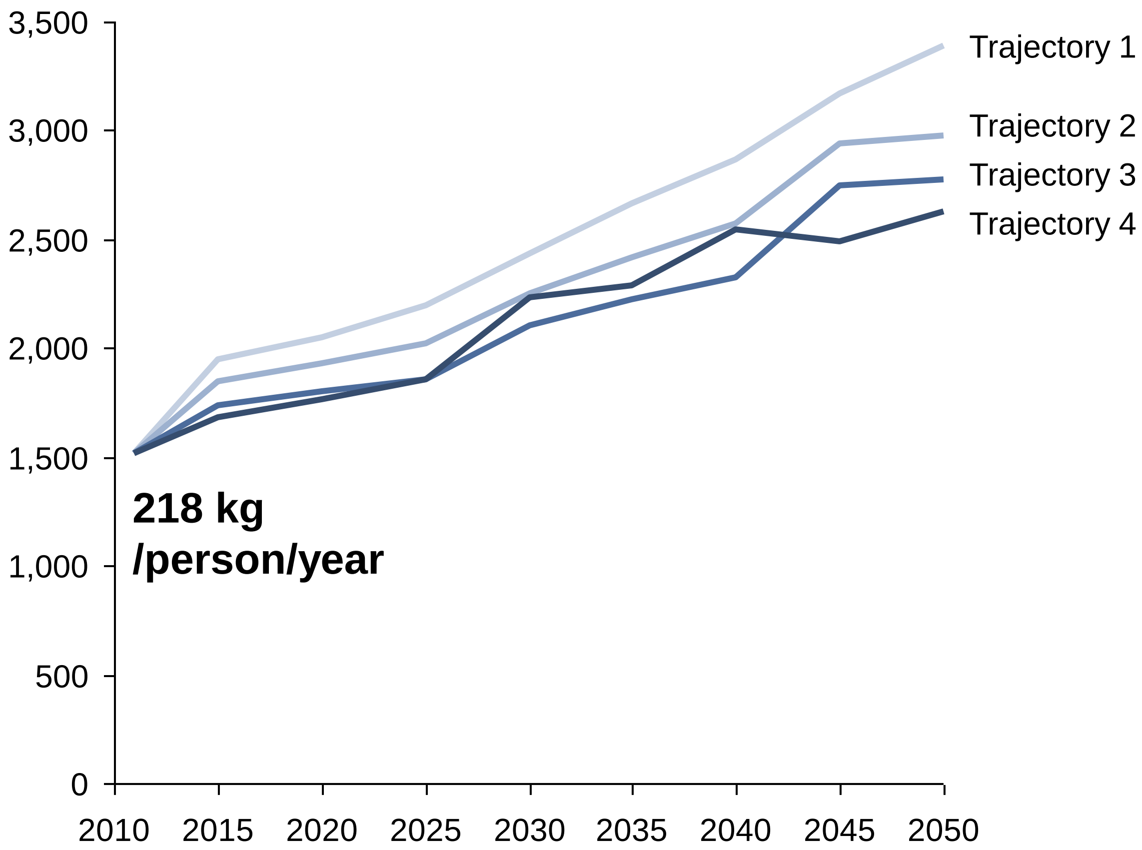
1

Global calculator growth forecasts

Production according to trajectories 1, 2, 3 & 4
(based on sectors demand, before design, switch & recycling)

Global Calculator

Steel production per year per ambition level[1]
(M tons)



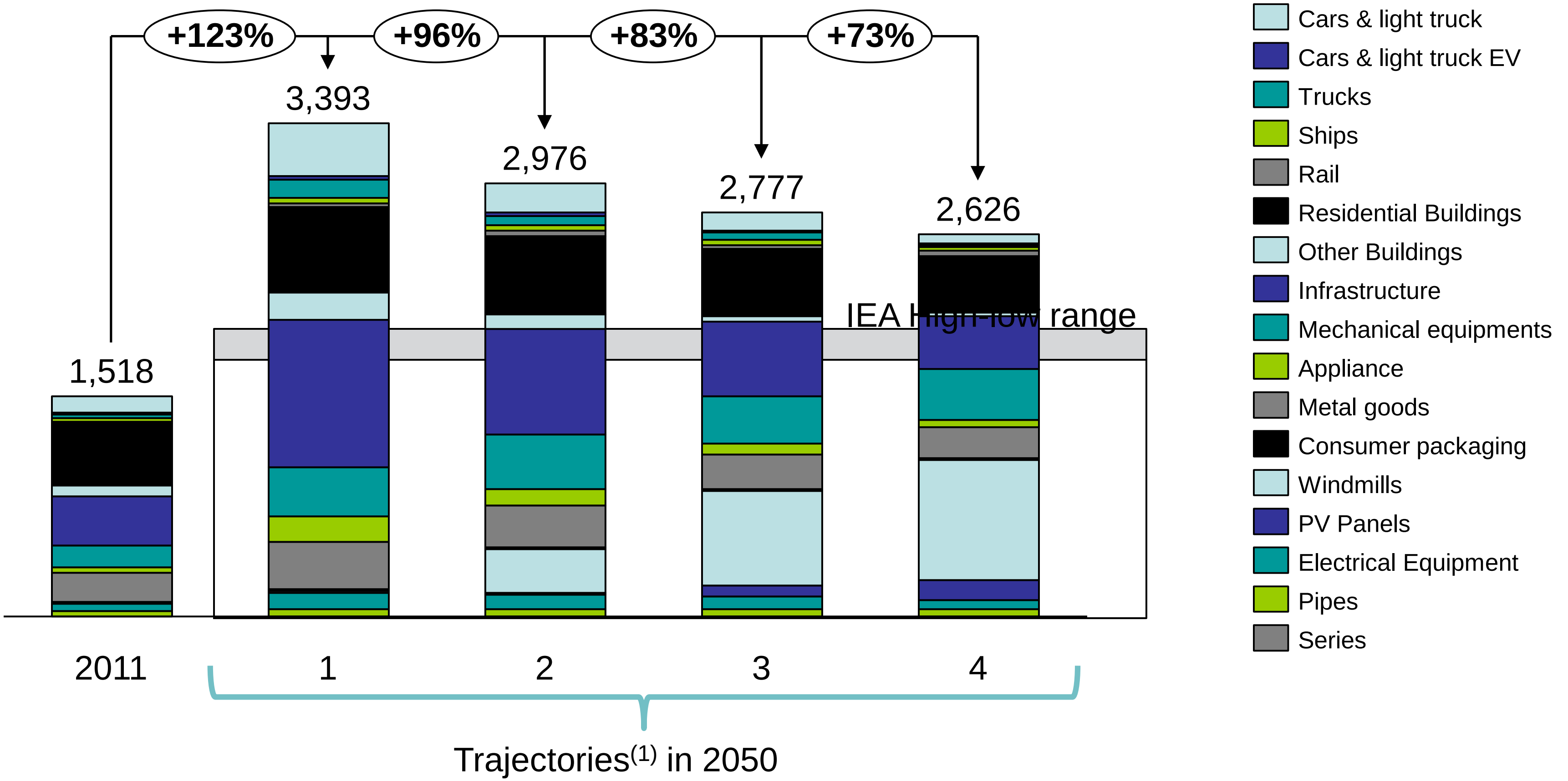
Delta 10-50,%	Implied demand per person
+124%	355 kg /person/year
+96%	316 kg /person/year
+83%	291 kg /person/year
+73%	275 kg /person/year

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

Iron & Steel

Materials demand growth in trajectories 1, 2, 3 & 4 (1)

Annual Steel production per ambition level(1), by product
(M tons)



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

Agenda

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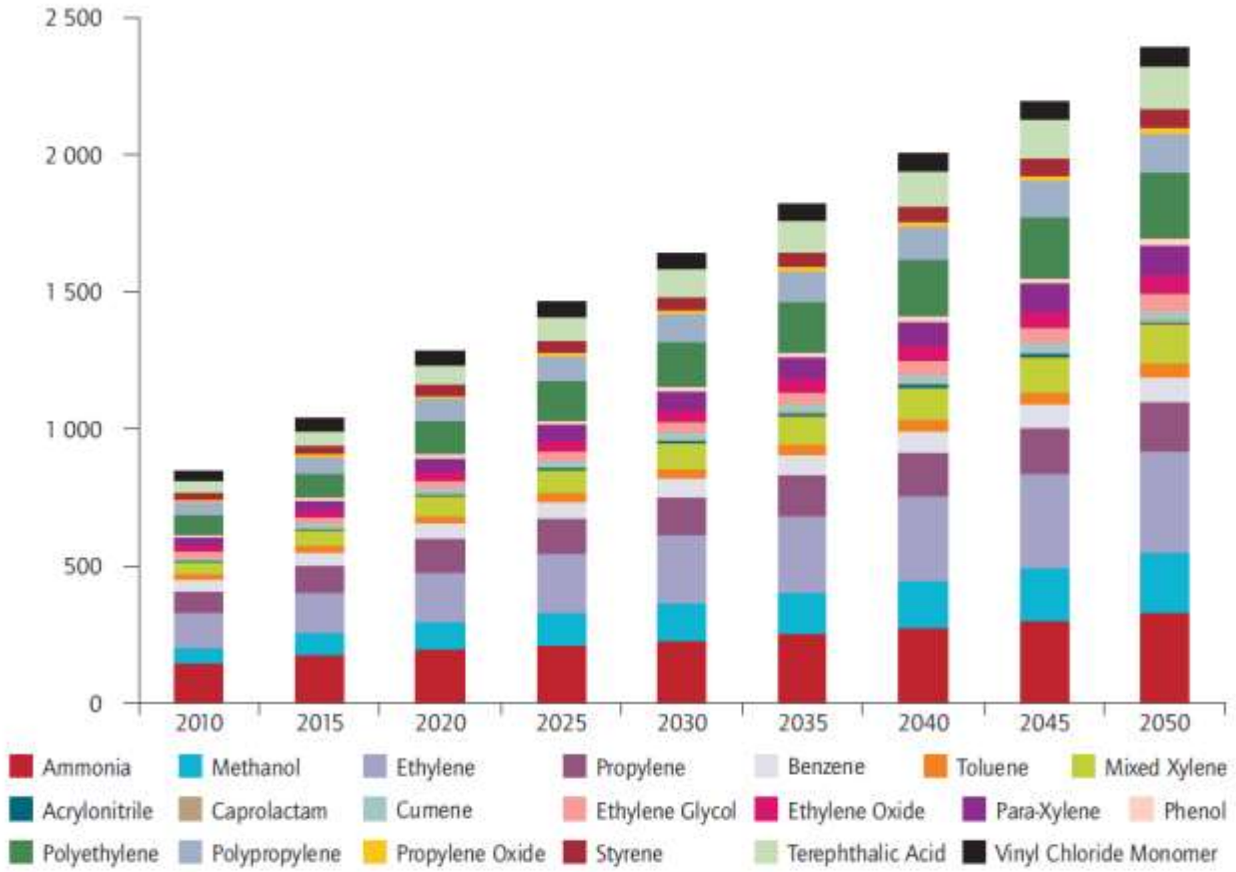
1

Significant growth is expected in production volume of the chemical and petrochemical sector

Global Calculator

Chemical production volumes forecasts
(Mt)



SOURCE: ICCA Catalytic roadmap (data from SRI consulting (IHS)

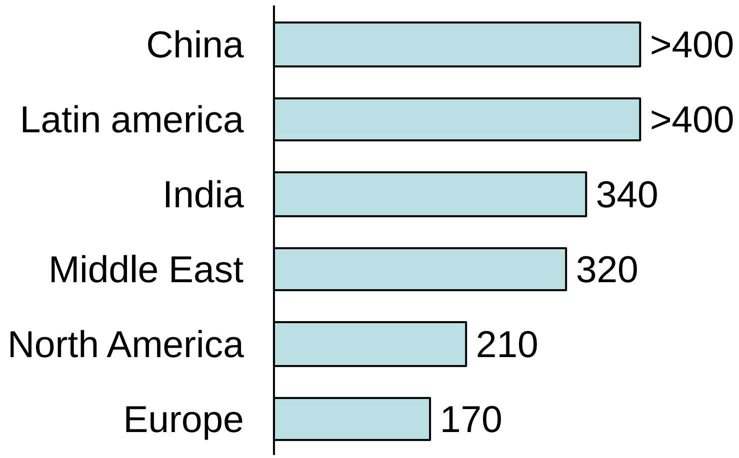
Strong variances are expected between regions (1/2)

Regional variability

- The largest growth in HVC demand is expected to occur in Africa and Middle East. China already biggest chemical producer worldwide
- Demand for chemical products increases sharply in fast-developing countries
- Likely strongest increase in bulk-chemical production outside Europe
- This regional outlook could be positively impacted by shale gas in some locations (e.g. United States Gulf Coast) [2]

Growths per region to 2050

(%)[2]



SOURCE: (1) IEA ETP 2012 (2) ICCA catalytic roadmap

1

Strong variances are expected between regions (2/2)

This is because the competitiveness levels strongly differ

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Level of competitiveness: High | Medium | Low

Region	Conventional economics: Cost position	Conventional economics: Local demand growth[1]	Other crucial factors: Access to skilled labor, skilled labor[2]/ education[3]	Other crucial factors: Business climate, ease of doing business[4]/ corruption[5]	Other crucial factors: Integration/ resilience
EU27	25-50% disadvantage compared to other regions (Low)	1-3% (Medium)	17 / 14 (High)	21 / 12 (Medium)	Overall, highly integrated and mature industry (High)
US	10-40% advantage vs. Europe (High)	2-4% (Medium)	6 / 25 (High)	4 / 19 (High)	Highly integrated and mature industry, new investments ongoing (High)
China	Higher cost than EU for some products, up to 50% lower cost for others (Medium)	>10% (High)	44 / 54 (Medium)	96 / 80 (Low)	Less mature industry, not yet fully optimized (Medium)
Saudi Arabia	Cost advantage (up to >50%) for bulk chemicals (High)	~8% (High)	31 / 39 (Medium)	26 / 63 (Low)	Less mature industry, more narrow range of chemicals produced (Low)

- Investments are required to improve energy efficiency and processes
- Investments will be harder to obtain in regions with a lower competitiveness level

NOTE: Europe represented by Germany in rankings;

1 Calculated as production minus net exports between 2011-2016 using data from IHS Economics;

2 Rank in "Availability of scientists and engineers", World Economic Forum (WEF);

3 Rank in "Quality of the Education System", WEF;

4 Rank in the World Bank's ease of doing business index 2013;

5 Rank in Transparency International's corruption perception index 2013

SOURCE: World Bank Doing Business 2014; HIS Economics; WEF Global Competitiveness Report 2013-2014; Transparency International

Rationale for expected 2050 chemicals demand

Global Calculator

Rationale for assessing future steel production

Population evolution	7 billion people in 2010[3] 8-10 billion people in 2050 [3]
Demand per capita evolution	• HVC: from 44 kg/capita in 2010 to 87-105 kg/capita in 2050 [1] • Ammonia: from 24 kg/capita in 2010 to 28-32 kg/capita in 2050 [1] • Methanol: from 8 kg/capita in 2010 to 22-27 kg/capita in 2050 [1] • Other chemicals: are assumed to follow the trend of HVC
Regional changes	• The largest growth in HVC demand is expected to occur in Africa and Middle East • European growth is expected to be much more modest • Shale gas could have a strong positive impact on US demand
Market segment changes	No major shift between transport, infrastructure and buildings is expected But plastics expected to replace other materials in each of these sectors

In conclusion	• IEA ETP 2012 forecast:
	  • 635-872 M tons HVC in 2050
	  • 268-310 M tons Ammonia in 2050
	  • 213-254 M tons Methanol in 2050

SOURCE: (1) IEA ETP 2012 (2) With both eyes open

1

Rationale for expected 2050 chemicals demand (2/2)

Global Calculator

Technologies & Products	Evolution driven by	Assumptions (if by product demand)
Packaging	Product demand lever	80-110% evolution by 2050
Consumer products	Product demand lever	80-110% evolution by 2050
Cars & light trucks	Transport model	/
Windmill (blades in carbon fibre)	Estimate from the supply sector	/
PV	Estimate from the supply sector	/
Buildings	Building model	/
Fertilizers	Land model	/

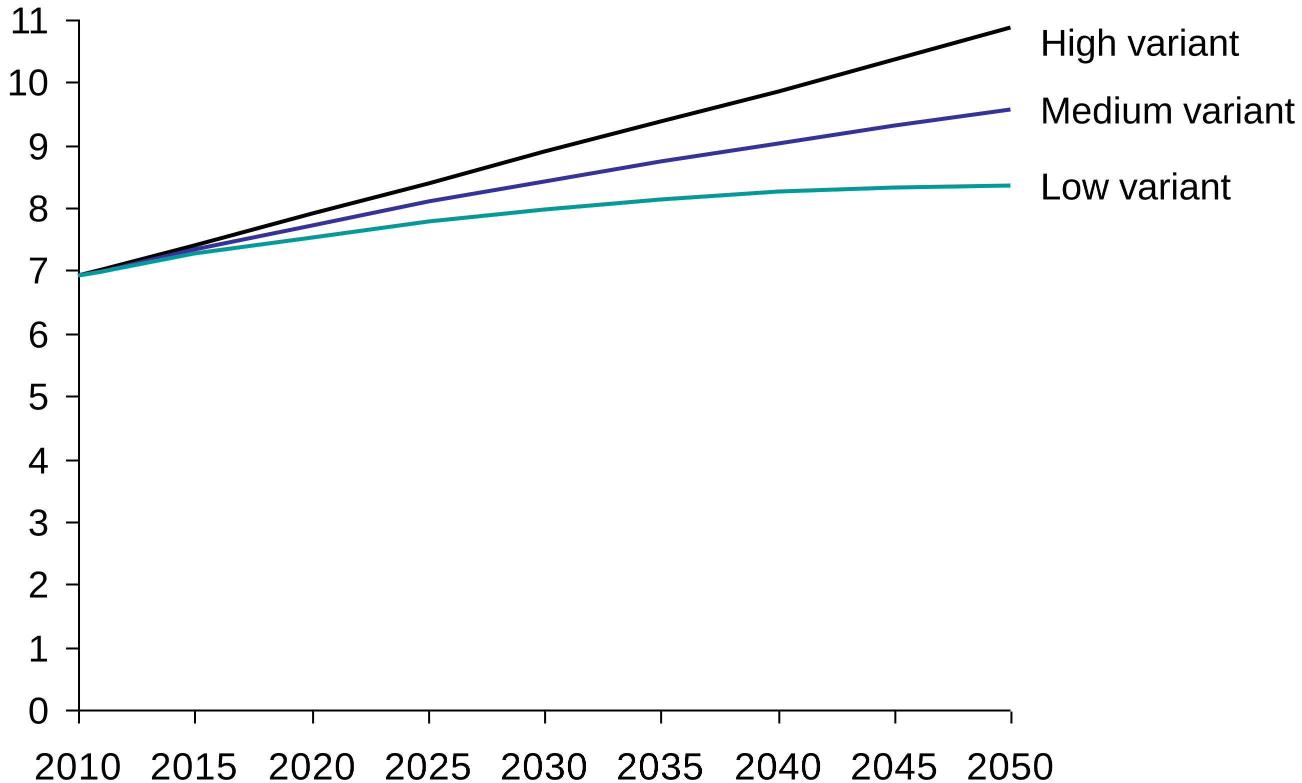
SOURCE: (1) Global Calculator team assumptions

1

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

Global Calculator

World population
(billions)



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+38%

+21%

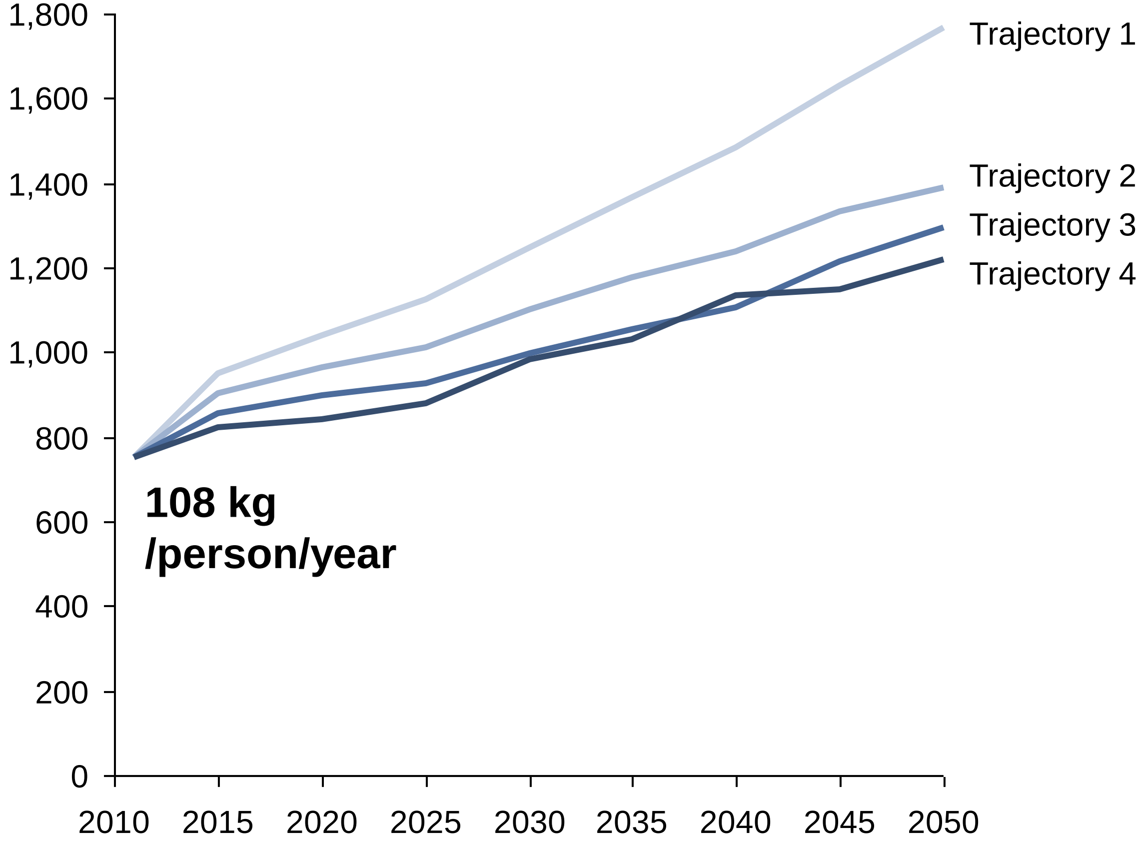
SOURCE: http://esa.un.org/unpd/wpp/unpp/panel_population.htm 2012 revision

1

Global calculator growth forecasts

Production according to trajectories 1, 2, 3 & 4
(based on sectors demand, before design, switch & recycling)

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



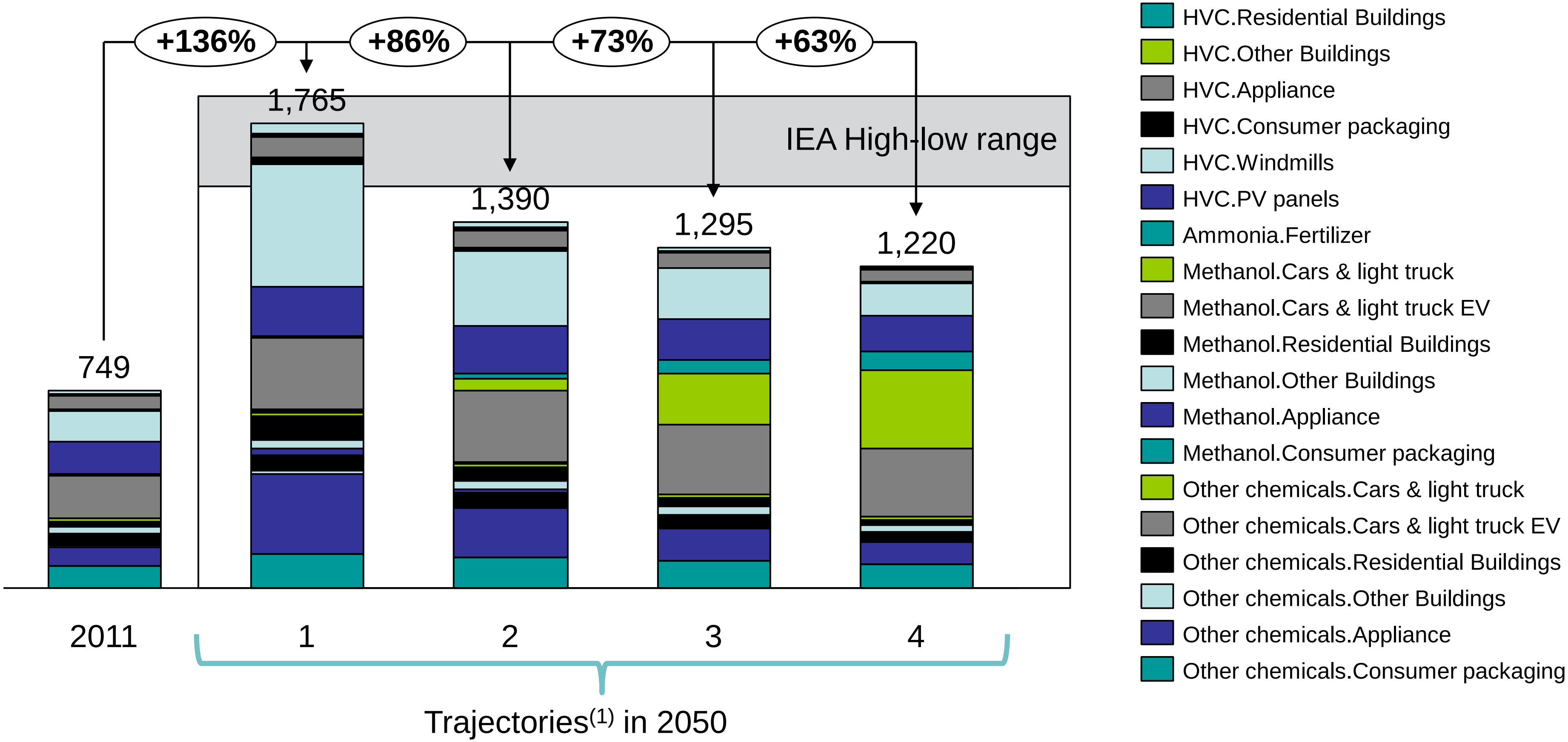
Delta 10-50,%	Implied demand per person
+136%	185 kg /person/year
+86%	146 kg /person/year
+73%	136 kg /person/year
+63%	128 kg /person/year

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

Chemicals

Materials demand growth in trajectories 1, 2, 3 & 4 (1)

Annual Chemical production per ambition level(1), by product
(M tons)



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

Agenda

Global Calculator

2050 evolution of materials and emissions

Materials demand evolution

- Cross sector demand
- Cross sector material switch
- Steel
- Chemicals
- **Aluminium**
- Cement
- Paper & Timber

Reduction potential on the manufacturing processes

- Resulting emissions
- Discussion on ambition levels across sectors
- Discussion on CCS
- Steel
- Chemicals
- Aluminium
- Cement
- Paper, Timber & Other

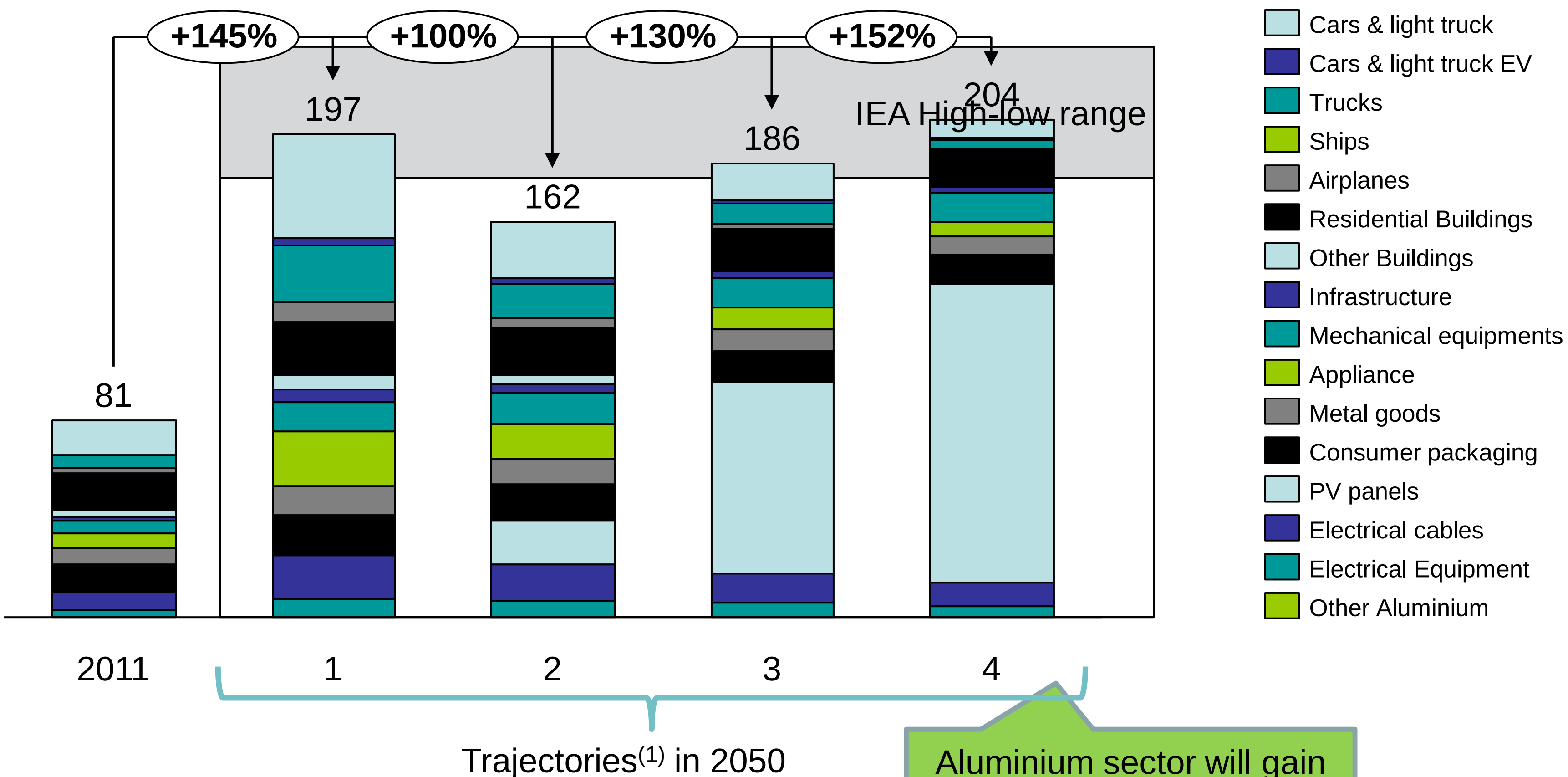
Figures of July 2014

Aluminium

Materials demand growth in trajectories 1, 2, 3 & 4 (1)

Global Calculator

Annual Aluminium production per ambition level(1), by product
(M tons)



Aluminium sector will gain from product switch

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

Agenda

Global Calculator

2050 evolution of materials and emissions

Materials demand evolution

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- Steel
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Reduction potential on the manufacturing processes

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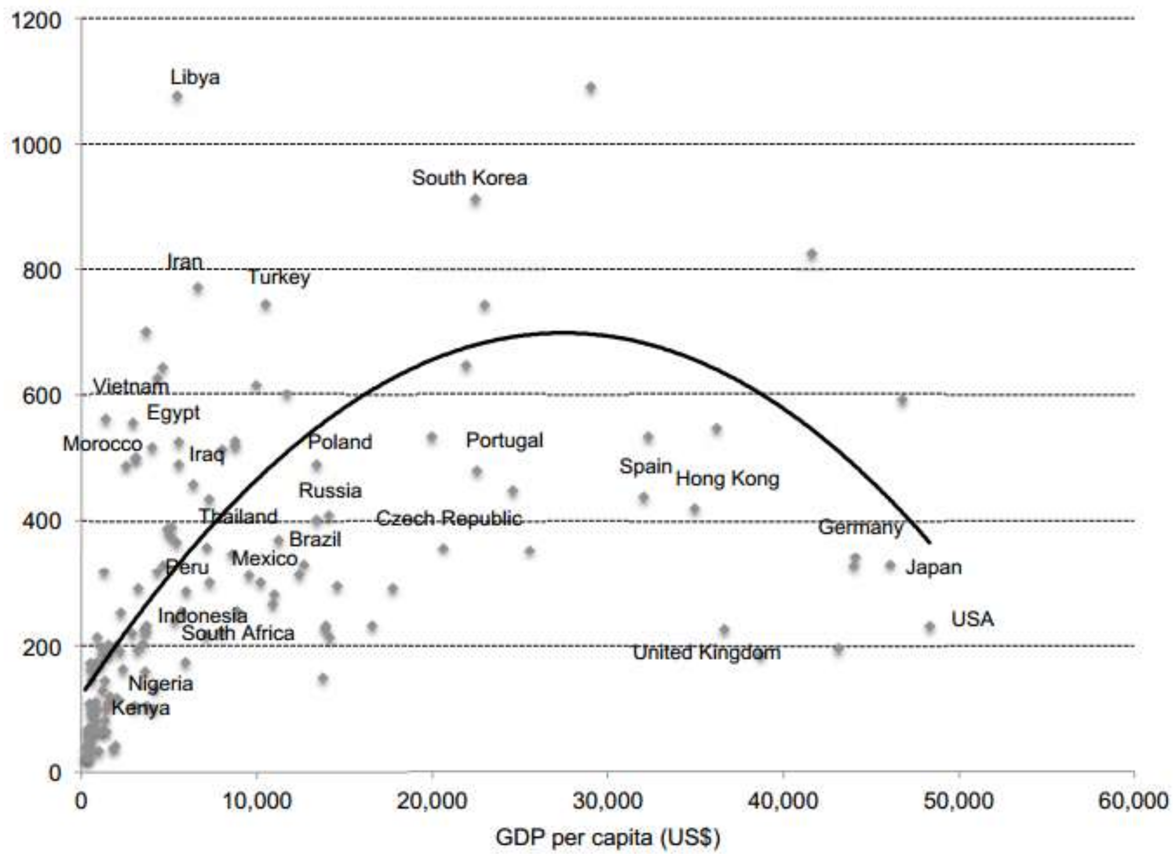
1 As income/person increases, cement demand increases and then decreases

Global Calculator

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

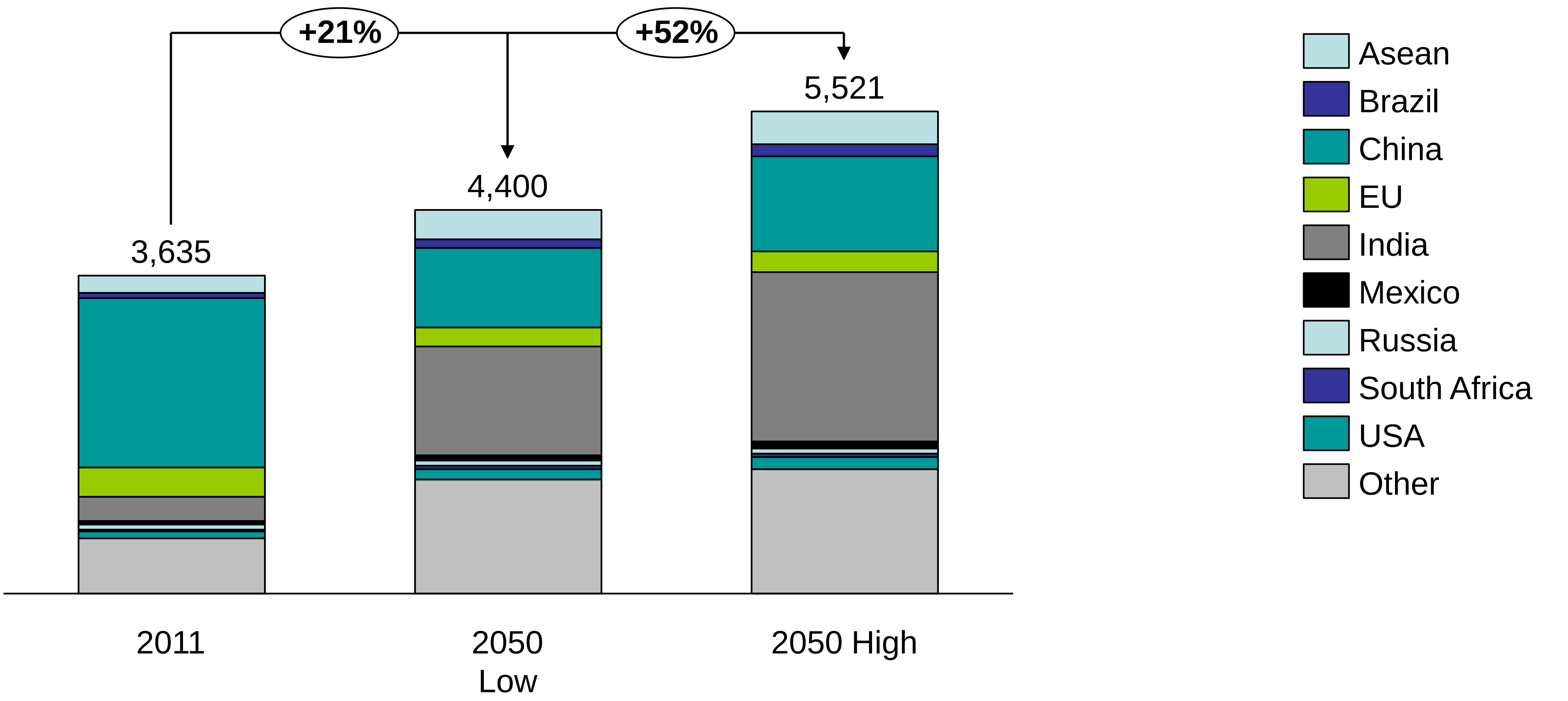
Driver	Rationale	Correlation
Demography	Per capita consumption is ~450kg	Direct correlation
Income	Increase with GDP growth up to ~$20k/person, but then declines, when demand for new buildings and infrastructure has been satisfied	Difficult correlation, as evolution should be modelled per region
New 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

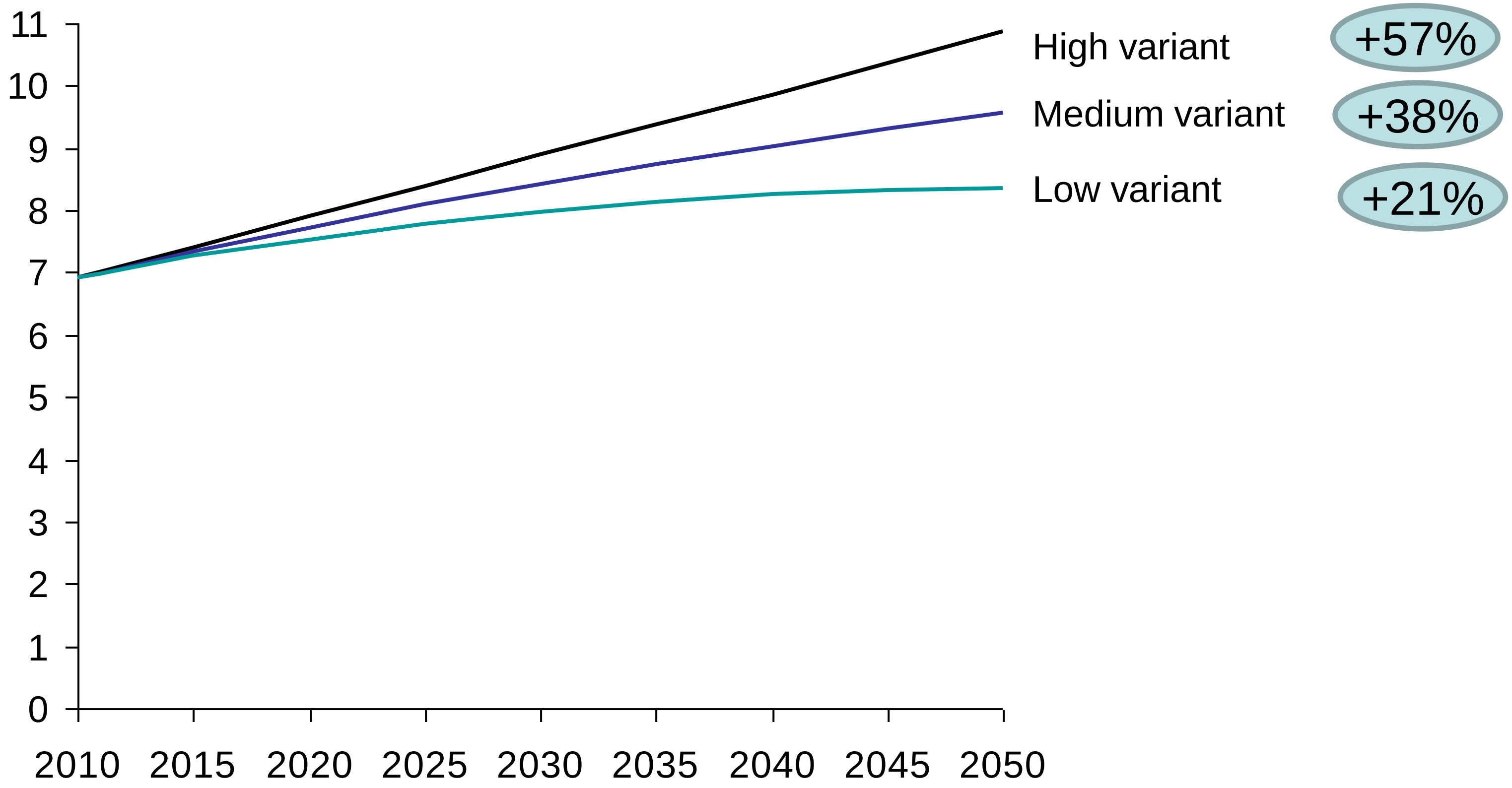
1

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

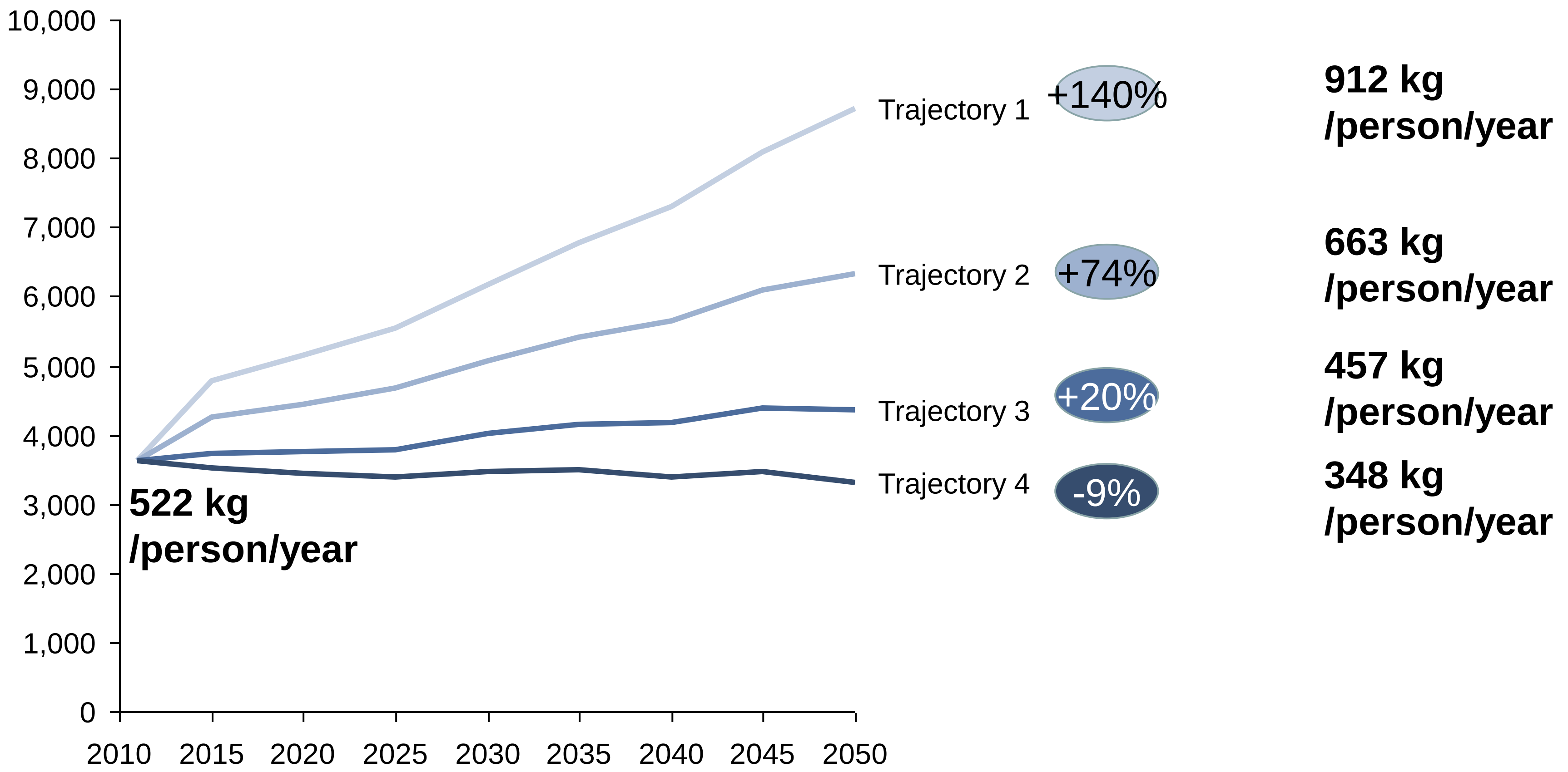
1 Model growth forecasts

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

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

Delta 10-50,%

Implied demand per person



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

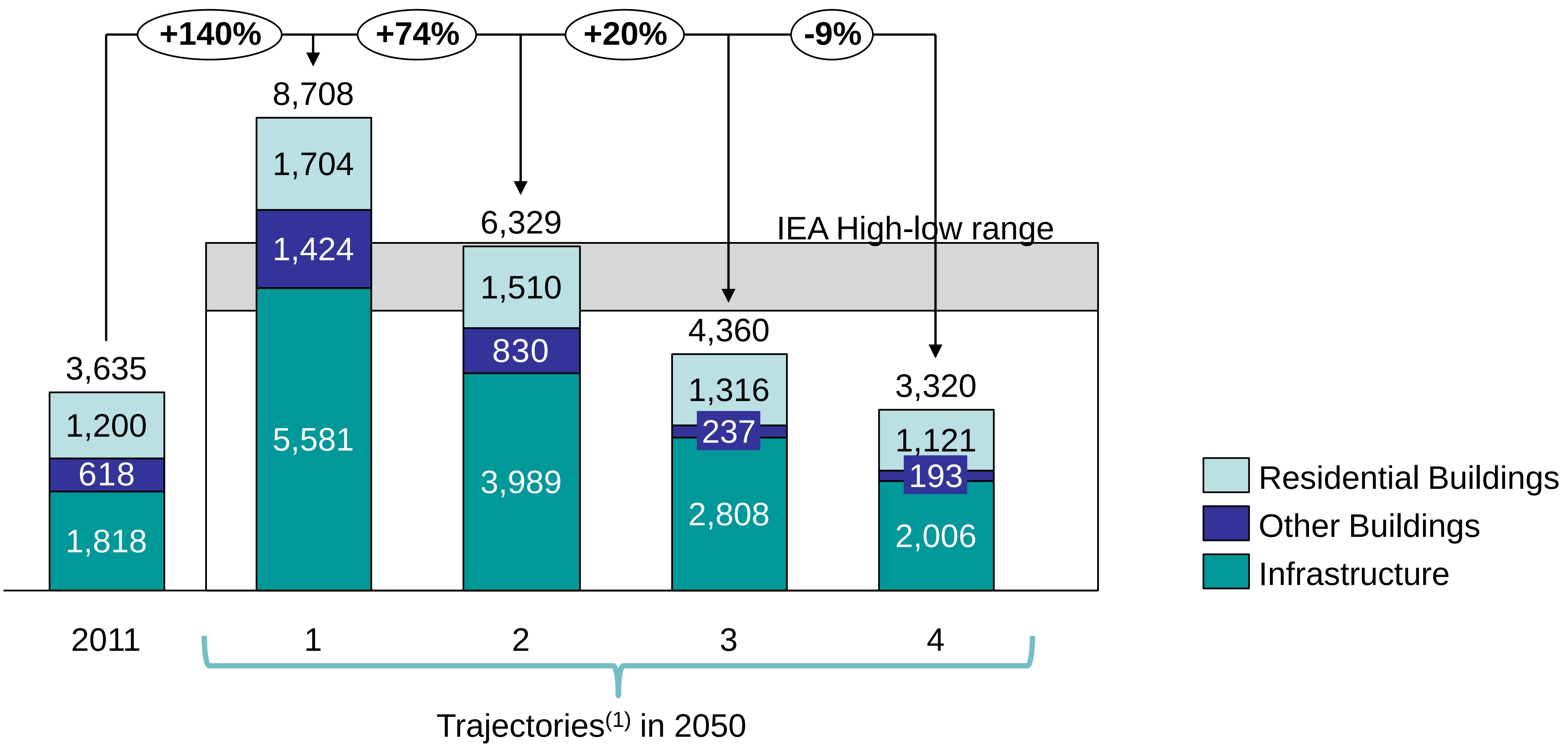
Figures of July 2014

Global Calculator

Cement

Materials demand growth in trajectories 1, 2, 3 & 4 (1)

Annual Cement production per ambition level(1), by product
(M tons)



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

Agenda

Global Calculator

2050 evolution of materials and emissions

Materials demand evolution

- Cross sector demand
- Cross sector material switch
- Steel
- Chemicals
- Aluminium
- Cement
- **Paper & Timber**

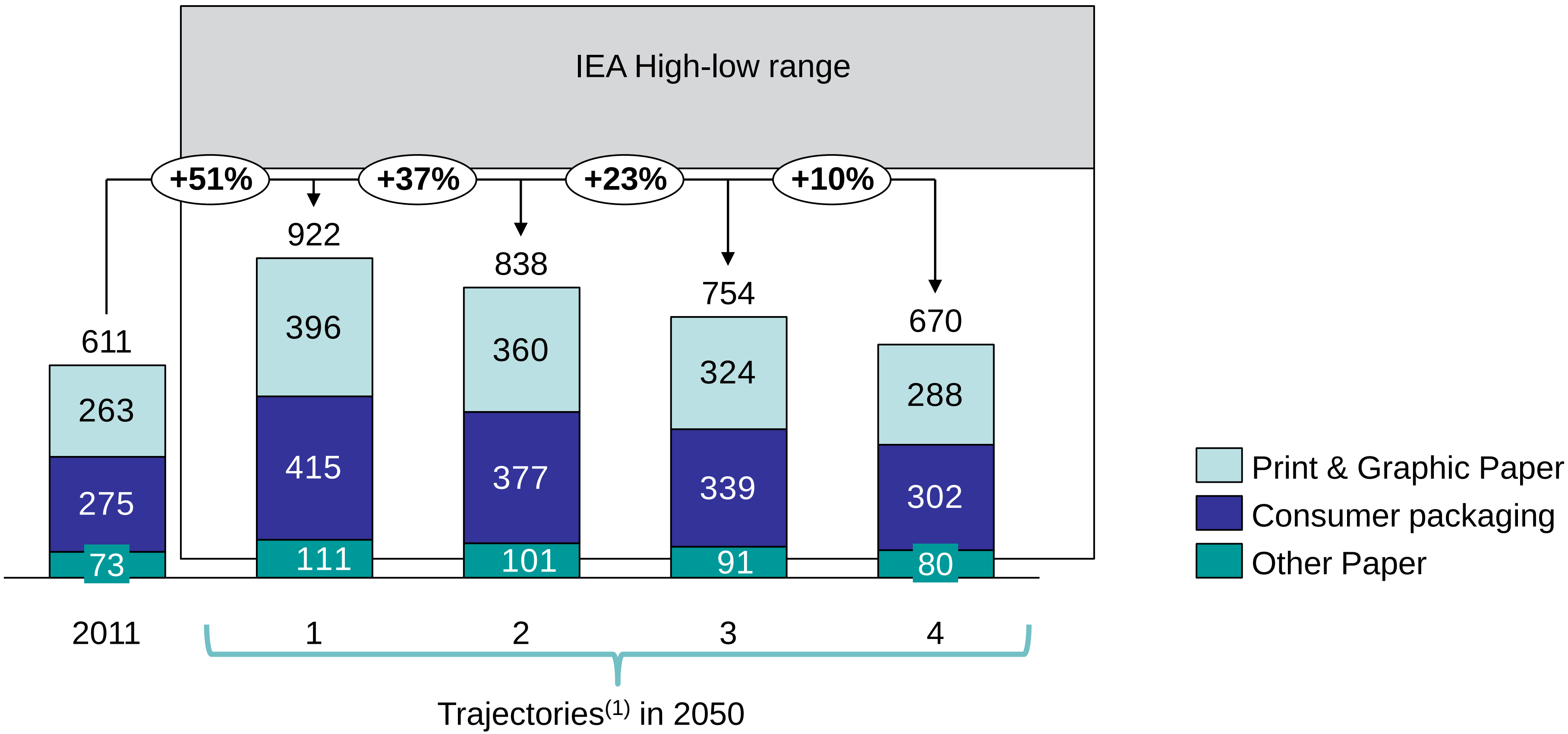
Reduction potential on the manufacturing processes

- Resulting emissions
- Discussion on ambition levels across sectors
- Discussion on CCS
- Steel
- Chemicals
- Aluminium
- Cement
- Paper, Timber & Other

Paper

Materials demand growth in trajectories 1, 2, 3 & 4 (1)

Annual Paper production per ambition level[(1)], by product
(M tons)

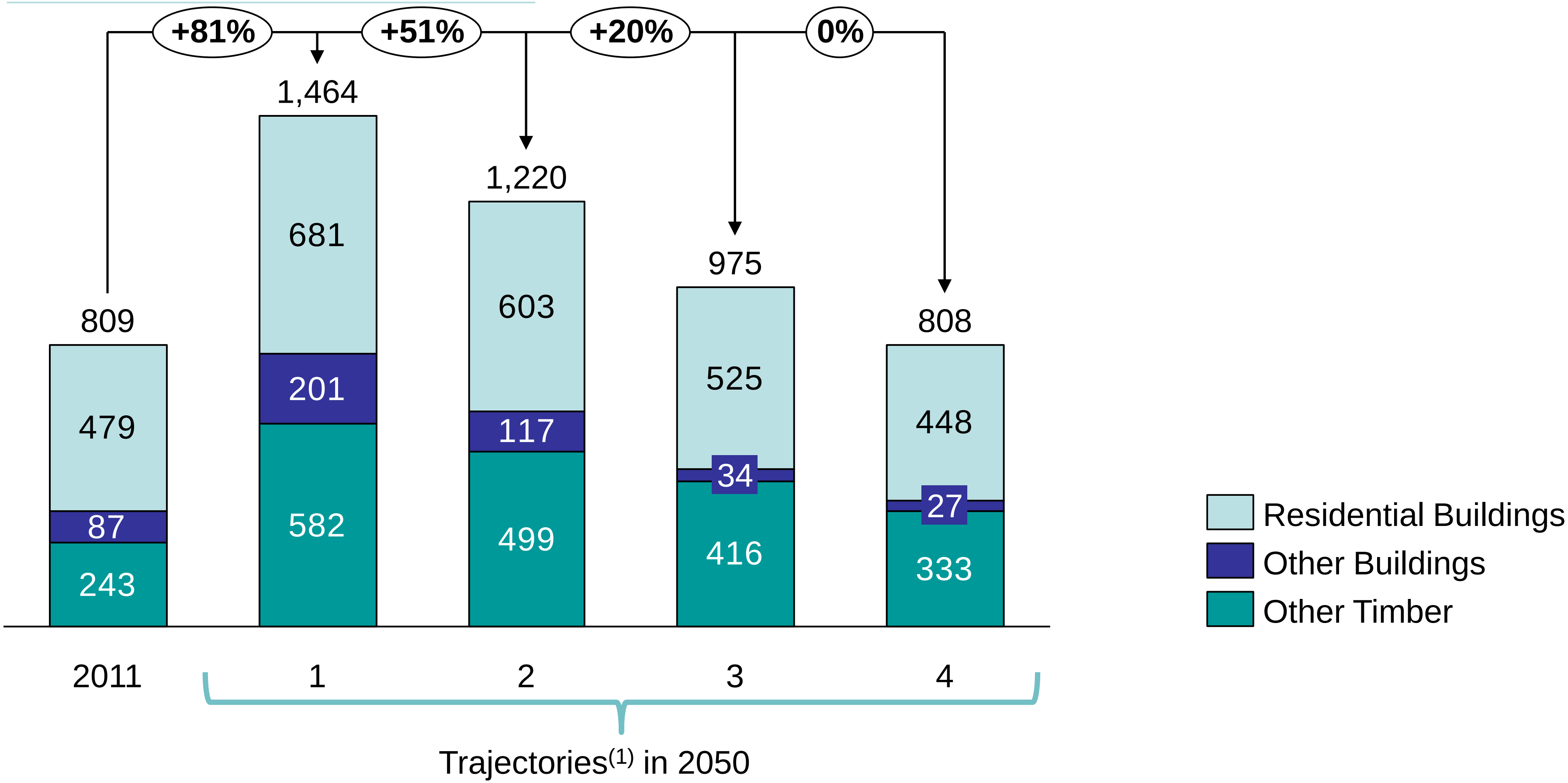


NOTE: (1) The population follows the average UN projection in all four trajectories
SOURCE: IEA ETP 2012, Global calculator model

Timber

Materials demand growth in trajectories 1, 2, 3 & 4 (1)

Annual Timber production per ambition level(1), by product
(M tons)



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

Agenda

Global Calculator

2050 evolution of materials and emissions

Materials demand evolution

- Cross sector demand
- Cross sector material switch
- Steel
- Chemicals
- Aluminium
- Cement
- Paper & Timber

Reduction potential on the manufacturing processes

- Resulting emissions
- Discussion on ambition levels across sectors
- Discussion on CCS
- Steel
- Chemicals
- Aluminium
- Cement
- Paper, Timber & Other

Agenda

Global Calculator

2050 evolution of materials and emissions

Materials demand evolution

- Cross sector demand
- Cross sector material switch
- Steel
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Reduction potential on the manufacturing processes

- **Resulting emissions**
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- Paper, Timber & Other

For the materials production, ~50 actions are being considered

Global Calculator

List of actions & levers assessed

Industry groups		Design	Switch	Recycle	Process improvements	Alternative fuels	Energy efficiency	CCS
Steel		• Product Design • High strength steel	• Switch to alu, fibres & timber	• Product recycling • % scrap based (for each various technologies exist)	• Carbon materials reduction • Portion of Classic BOF /Top gas recycling & Hisarna/ oxygen/EAF DRI/EAF scrap • Smelt reduction, Hydrogen, Electrolysis	• Coke to gas injection • Coal PCI to biomass	• Material efficiency • Energy efficiency (EE) • CHP	• CCS
Chemicals	All	• Product design		• Product recycling • Material recycling	• Process intensification • Catalyst optimization	• Oil to gas	• Clustering & integration	• CCS
	HVC		• Switch from steel, alu, cement	• Green chemistry	• Included in energy efficiency		• EE	• CCS
	Ammonia			• Fertilizers composition	• Included in energy efficiency		• EE	• CCS
	Methanol						• EE	• CCS
	Other			• Green chemistry	• Included in energy efficiency • Selective catalytic reduction	• Hydrogen production by electrolysis • Natural gas or biomass	• EE • Switch Mercury to membrane	• CCS
Aluminium		• Product design	• Switch to fibres	• Product recycling • Material recycling	• Included in energy efficiency	• Gas injection	• EE	• CCS
Cement		• Product design	• Switch to Timber & Plastics	• Composed/metallurgical cement	• Dry process	• Coal & oil to Waste & biomass	• EE • CHP /heat recovery	• CCS
Pulp & paper		• /	• /	• More recycled paper • Other cellulose sources • Bio-refineries	• Black liquor gasification • Drying innovation	• Coal & oil to gas • Coal & oil to biomass	• EE • CHP	• CCS
Timber		• Product design	• Switch from steel &cement	• /	• /	• /	• /	• /

SOURCE: Climact

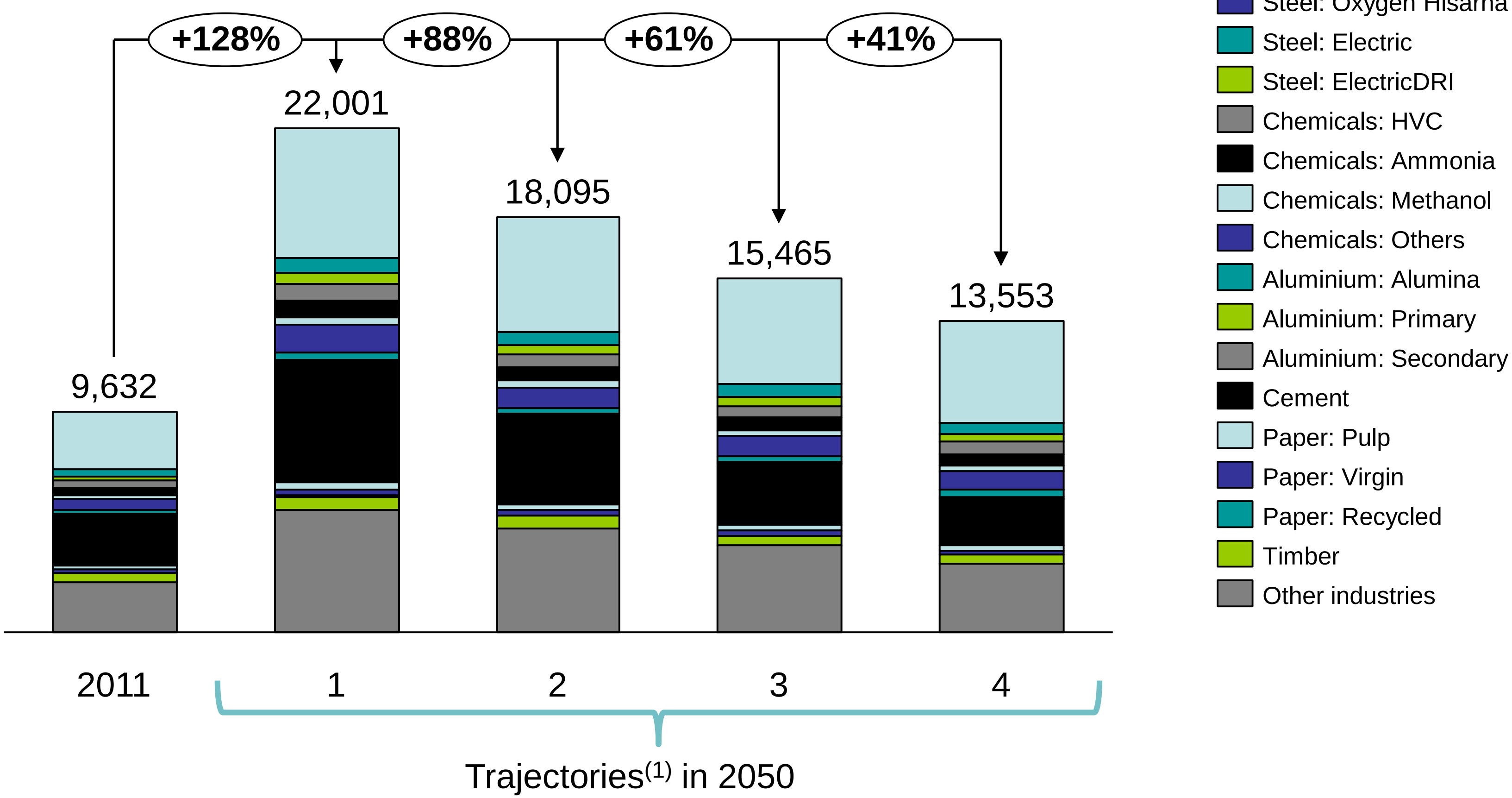
Figures of July 2014

Global Calculator

Total

GHG Emissions in trajectories 1, 2, 3 & 4

Total GHG emissions per year, by technology
(M tons $CO_2e^{(2)}$)



NOTE: (1) The population follows the average UN projection in all four trajectories
(2)Assuming biomass emits, not including electricity related emissions

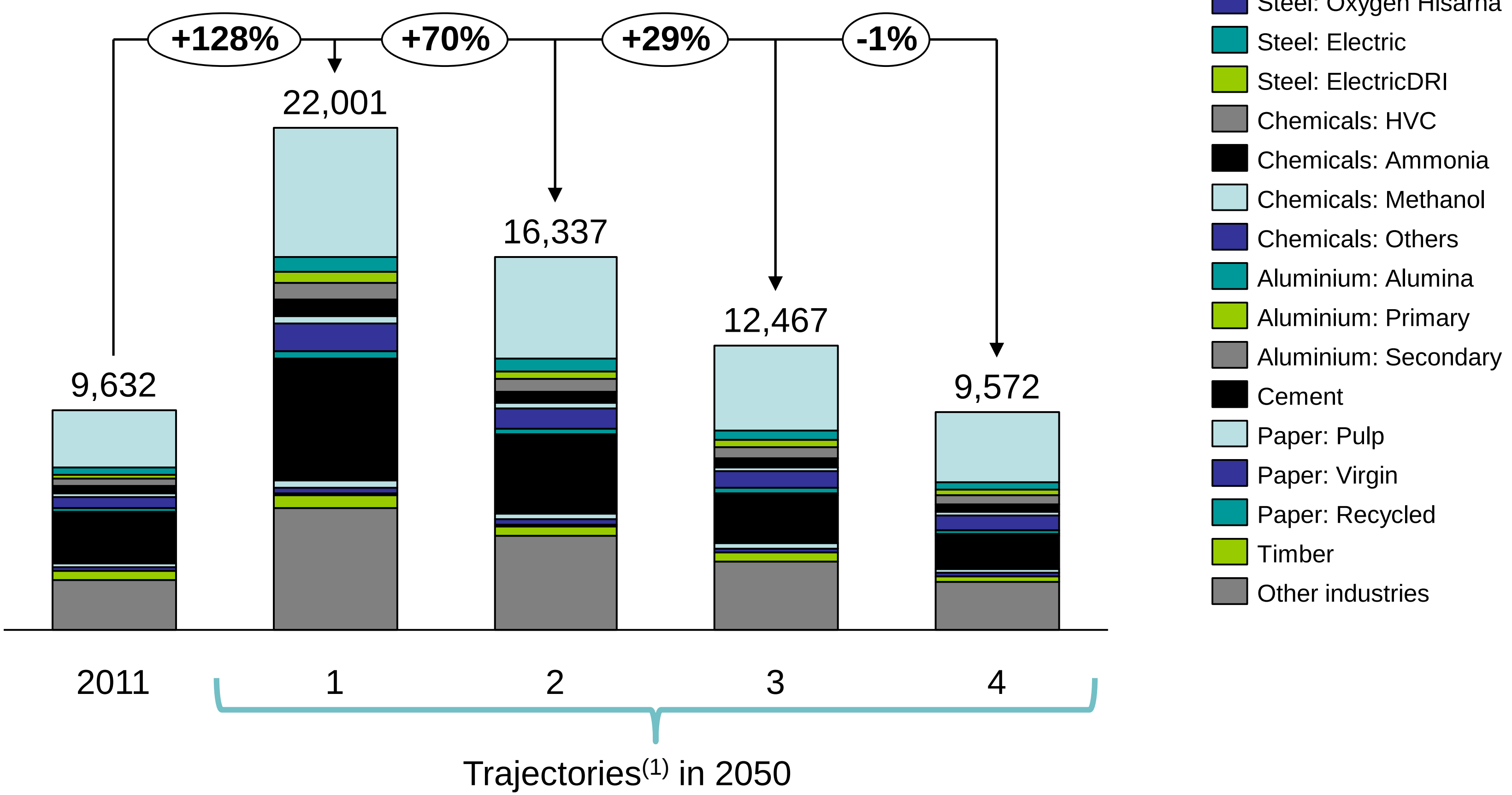
SOURCE: IEA ETP 2012, Global calculator model

Total
GHG Emissions in trajectories 1, 2, 3 & 4

Figures of July 2014

Global Calculator

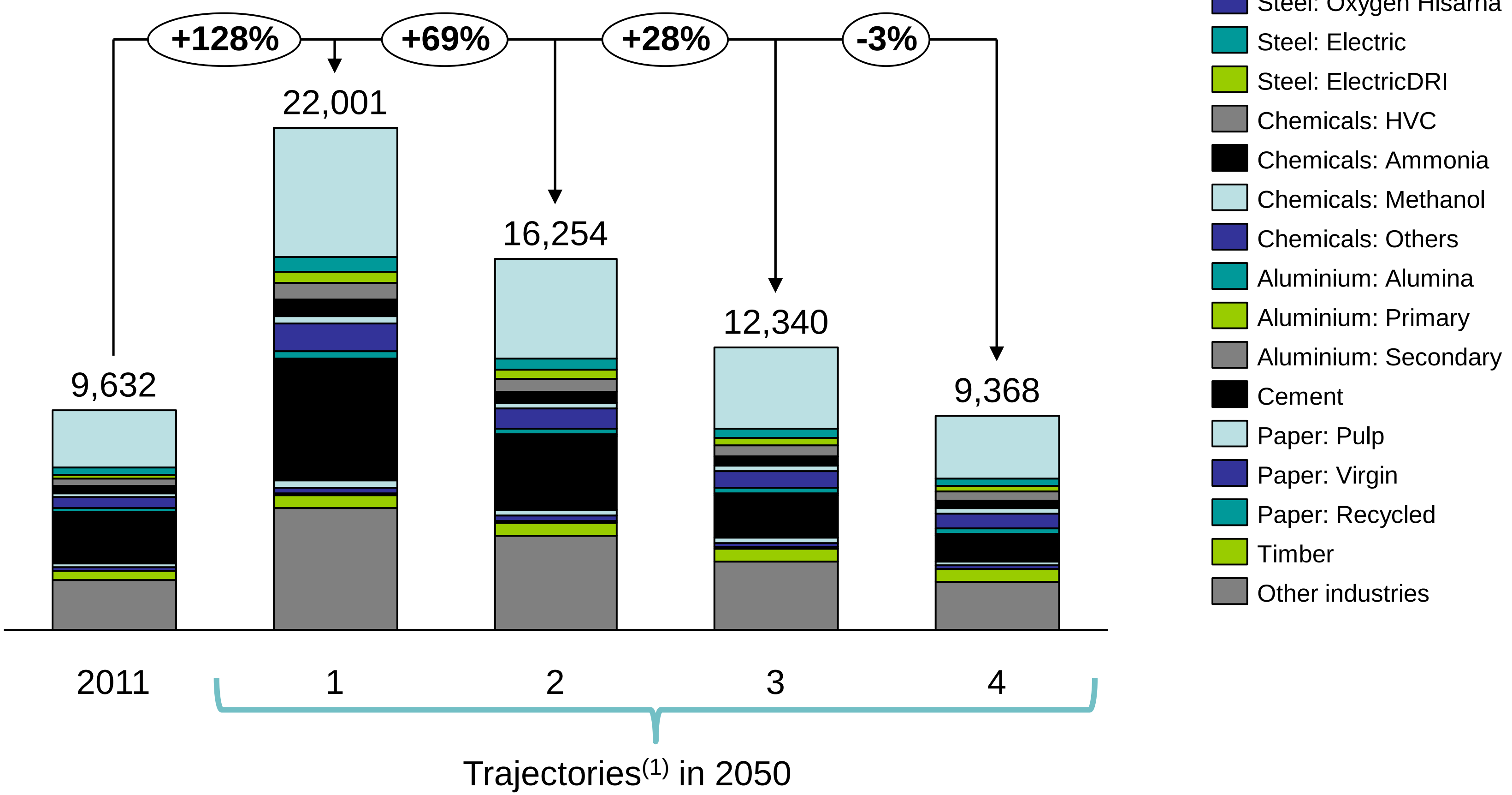
Total GHG emissions per year, by technology
(M tons CO_2e)



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

Total
GHG Emissions in trajectories 1, 2, 3 & 4

Total GHG emissions per year, by technology
(M tons CO_2e)



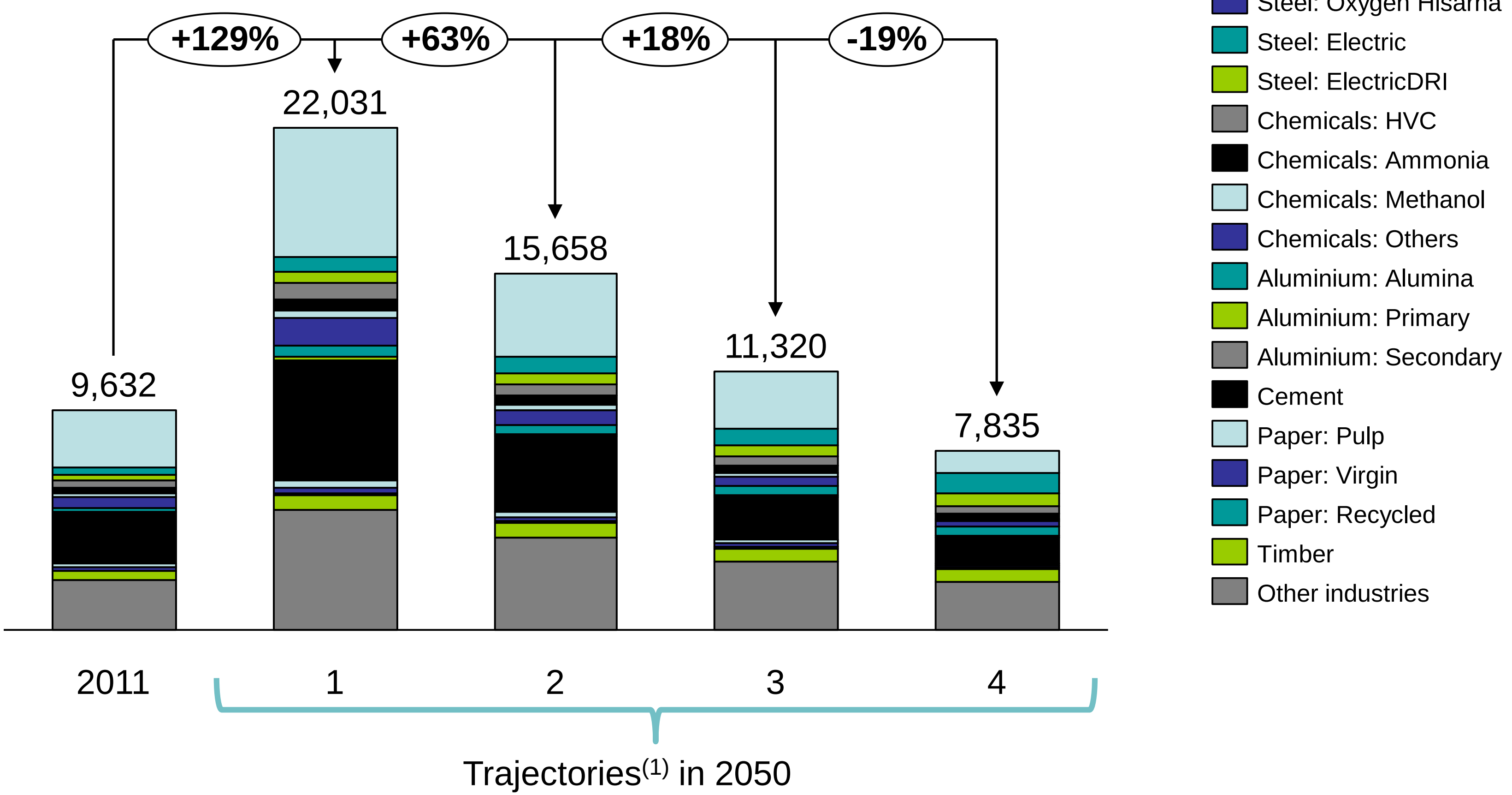
NOTE: (1) The population follows the average UN projection in all four trajectories
(2)Assuming biomass emits, not including electricity related emissions
SOURCE: IEA ETP 2012, Global calculator model

Figures of July 2014

Global Calculator

Total
GHG Emissions in trajectories 1, 2, 3 & 4

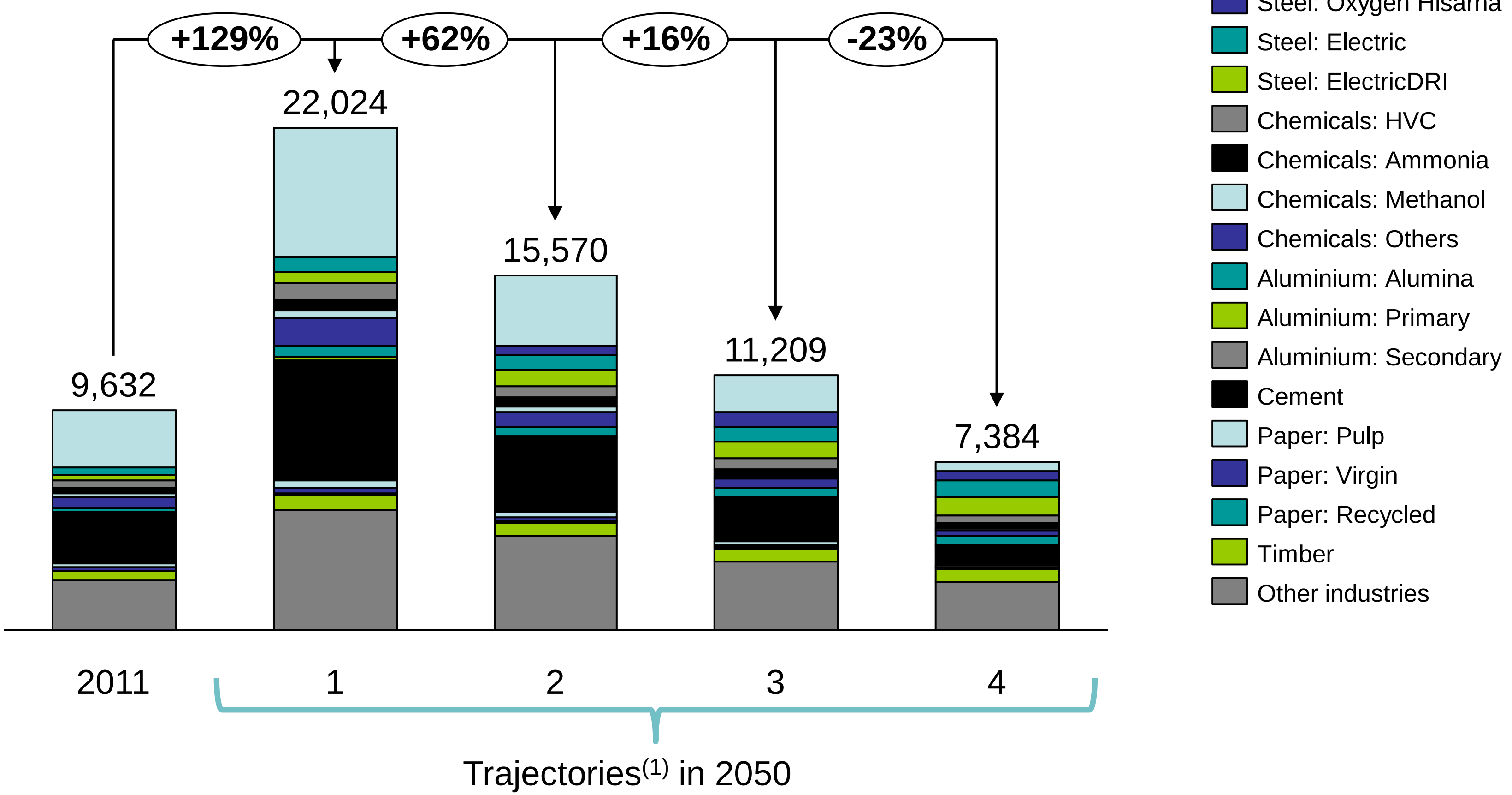
Total GHG emissions per year, by technology
(M tons CO_2e)



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

Total
GHG Emissions in trajectories 1, 2, 3 & 4

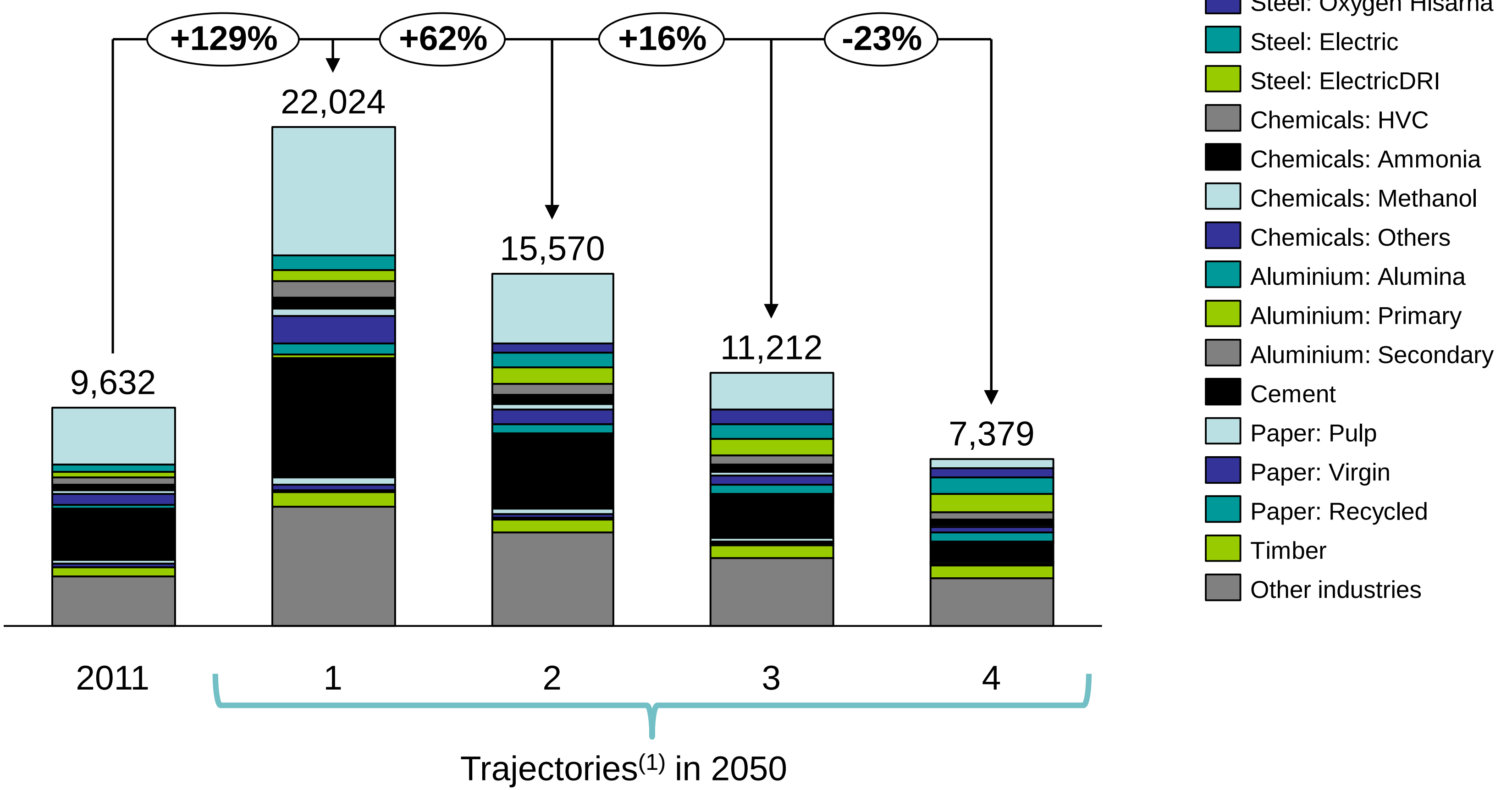
Total GHG emissions per year, by technology
(M tons CO_2e)



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

Total
GHG Emissions in trajectories 1, 2, 3 & 4

Total GHG emissions per year, by technology
(M tons CO_2e)



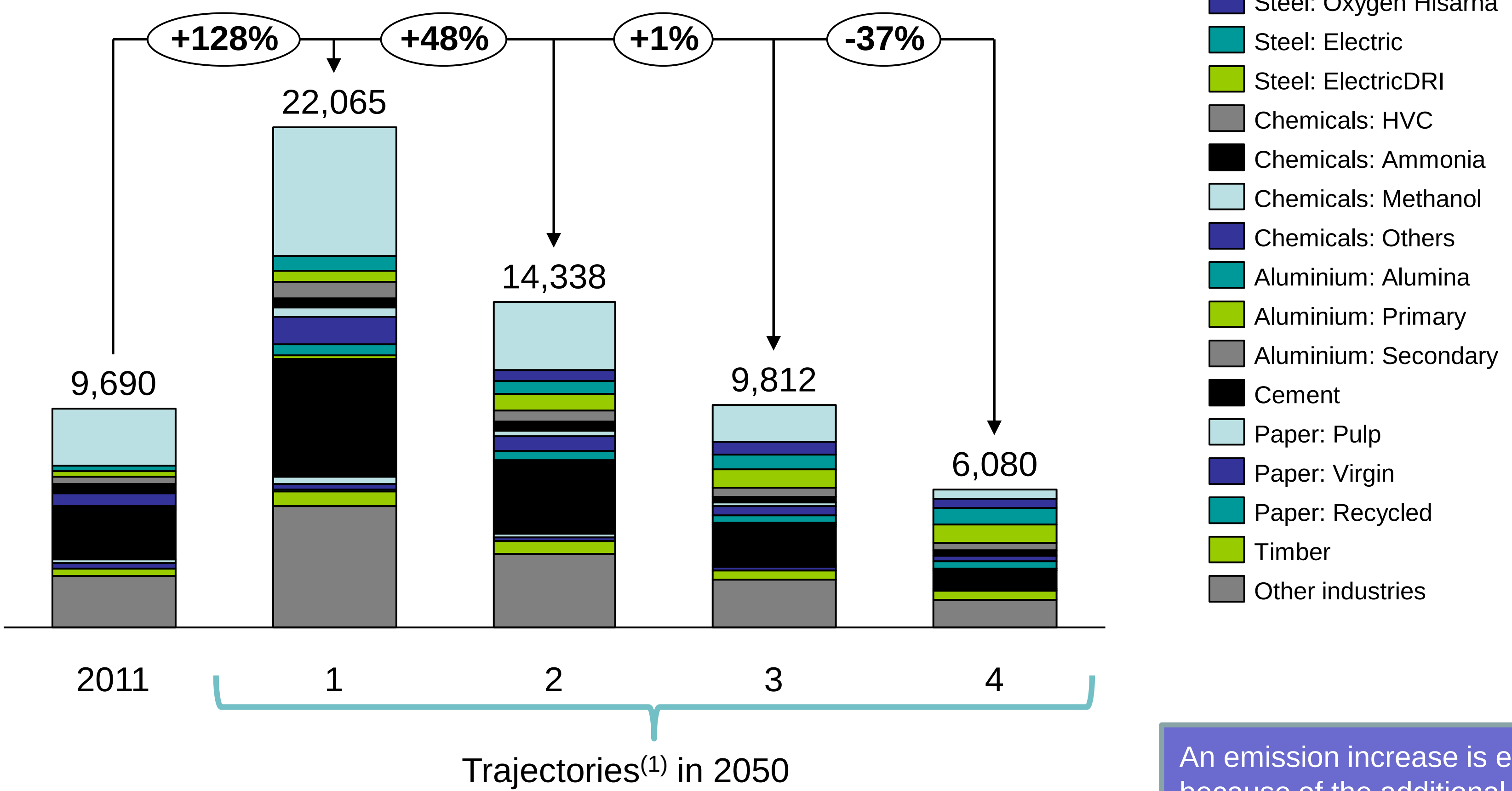
NOTE: (1) The population follows the average UN projection in all four trajectories
(2)Assuming biomass emits, not including electricity related emissions
SOURCE: IEA ETP 2012, Global calculator model

Biomass impact outweighs other fuel switches

Total

GHG Emissions in trajectories 1, 2, 3 & 4

Total GHG emissions per year, by technology
(M tons CO_2e)

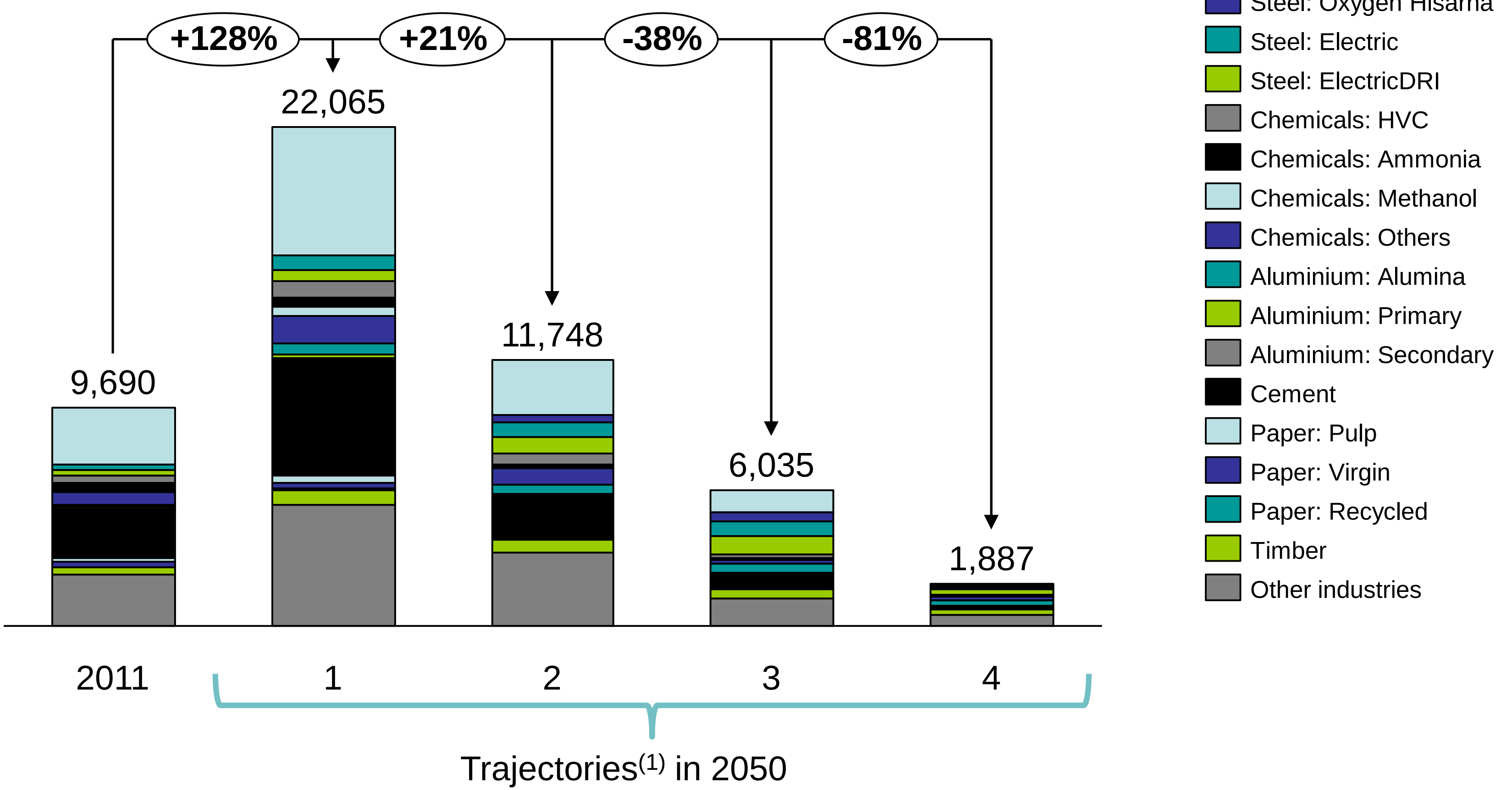


An emission increase is expected here because of the additional gas consumption in chemicals and paper for the CHPs (while electricity emissions are not accounted for in this slide)

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

Total
GHG Emissions in trajectories 1, 2, 3 & 4

Total GHG emissions per year, by technology
(M tons CO_2e)



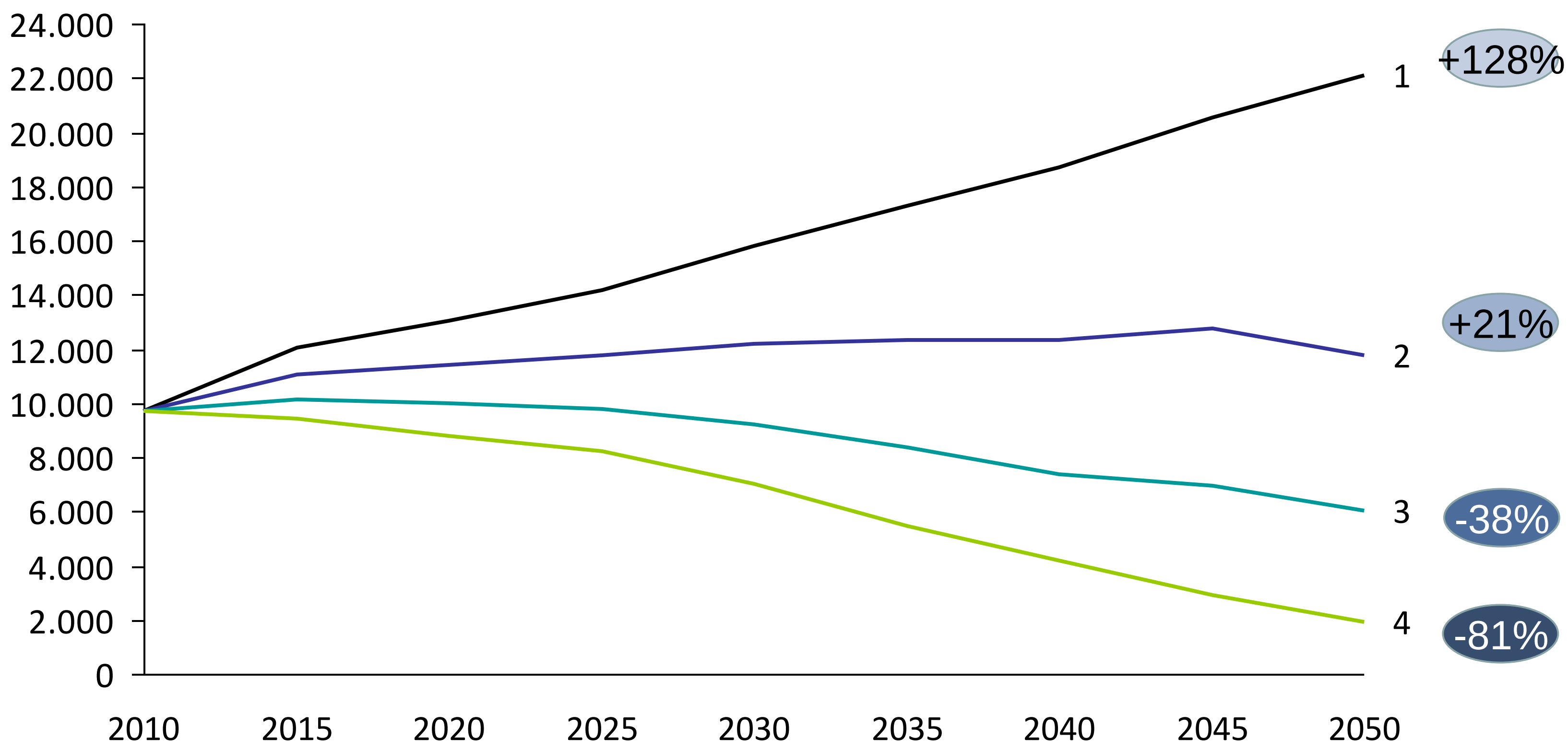
NOTE: (1) The population follows the average UN projection in all four trajectories
(2)Assuming biomass emits, not including electricity related emissions
SOURCE: IEA ETP 2012, Global calculator model

Figures of July 2014

Global Calculator

Total
GHG Emissions evolutions in trajectories 1, 2, 3 & 4

Total GHG emissions for different lever ambition levels
($MtonCO_2e$)

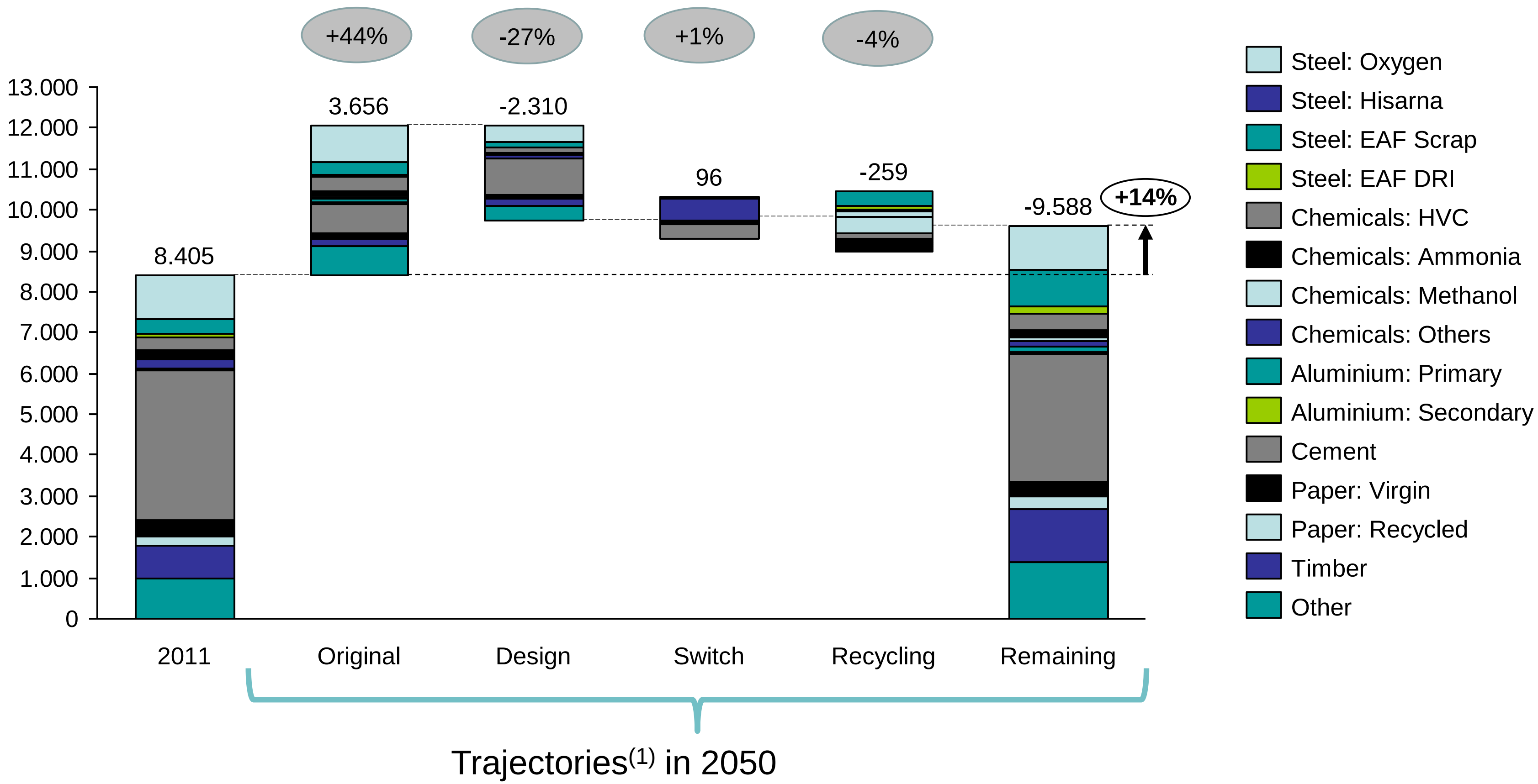


NOTE: (1) The population follows the average UN projection in all four trajectories
(2)Assuming biomass emits, not including electricity related emissions
SOURCE: IEA ETP 2012, Global calculator model

Reduction potential

Details for ambition level 3 (then detailed per industry)

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

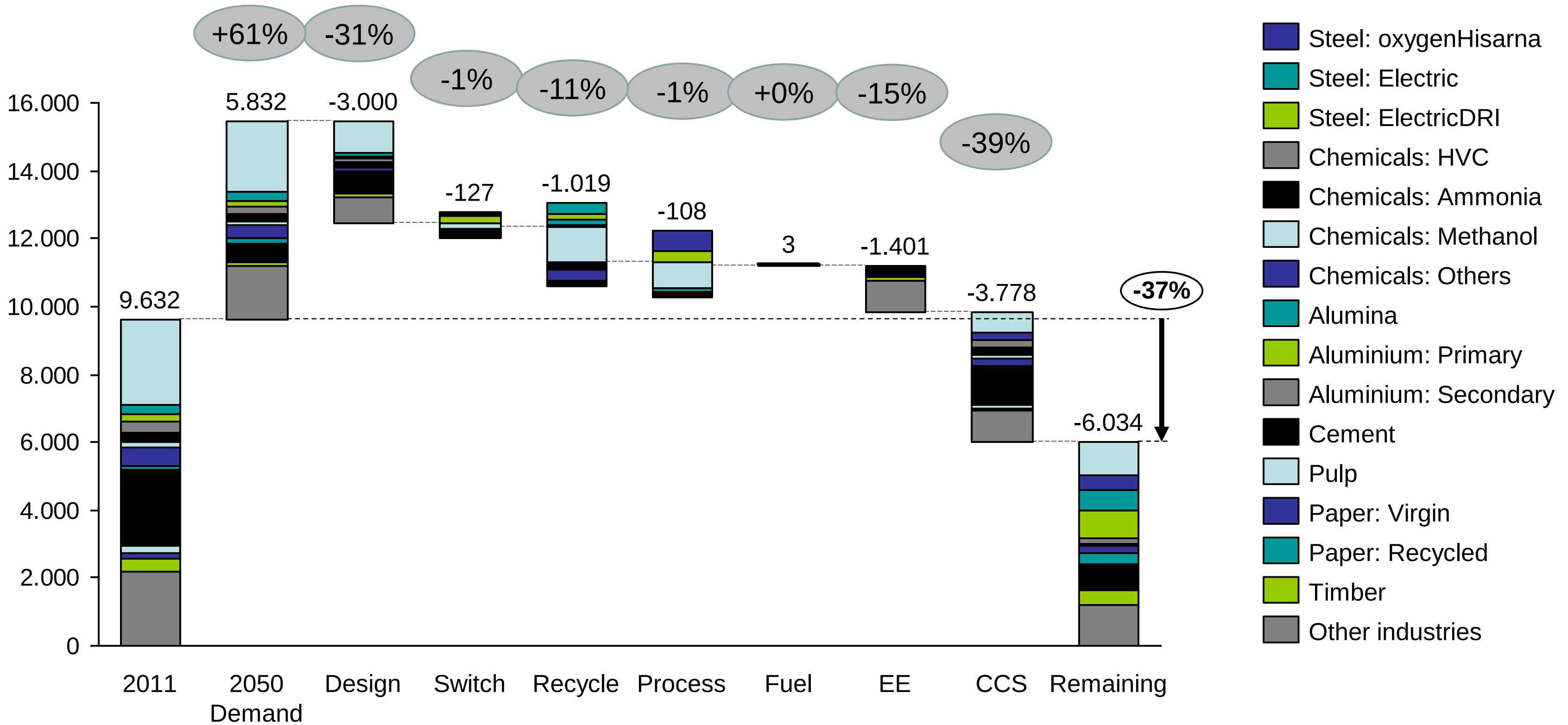


NOTE: (1) The population follows the average UN projection in all four trajectories
(2)Assuming biomass emits, not including electricity related emissions
SOURCE: IEA ETP 2012, Global calculator model

Reduction potential

Details for ambition level 3 [1] (then detailed per industry)

Total 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

Agenda

Global Calculator

2050 evolution of materials and emissions

Materials demand evolution

- Cross sector demand
- Cross sector material switch
- Steel
- Chemicals
- Aluminium
- Cement
- Paper & Timber

Reduction potential on the manufacturing processes

- Resulting emissions
- **Discussion on ambition levels across sectors**
- Discussion on CCS
- Steel
- Chemicals
- Aluminium
- Cement
- Paper, Timber & Other

Total
GHG Emissions in trajectories 3

Total emissions, along each step (by materials)
(M tons CO_2e, (% evolution vs 2011))

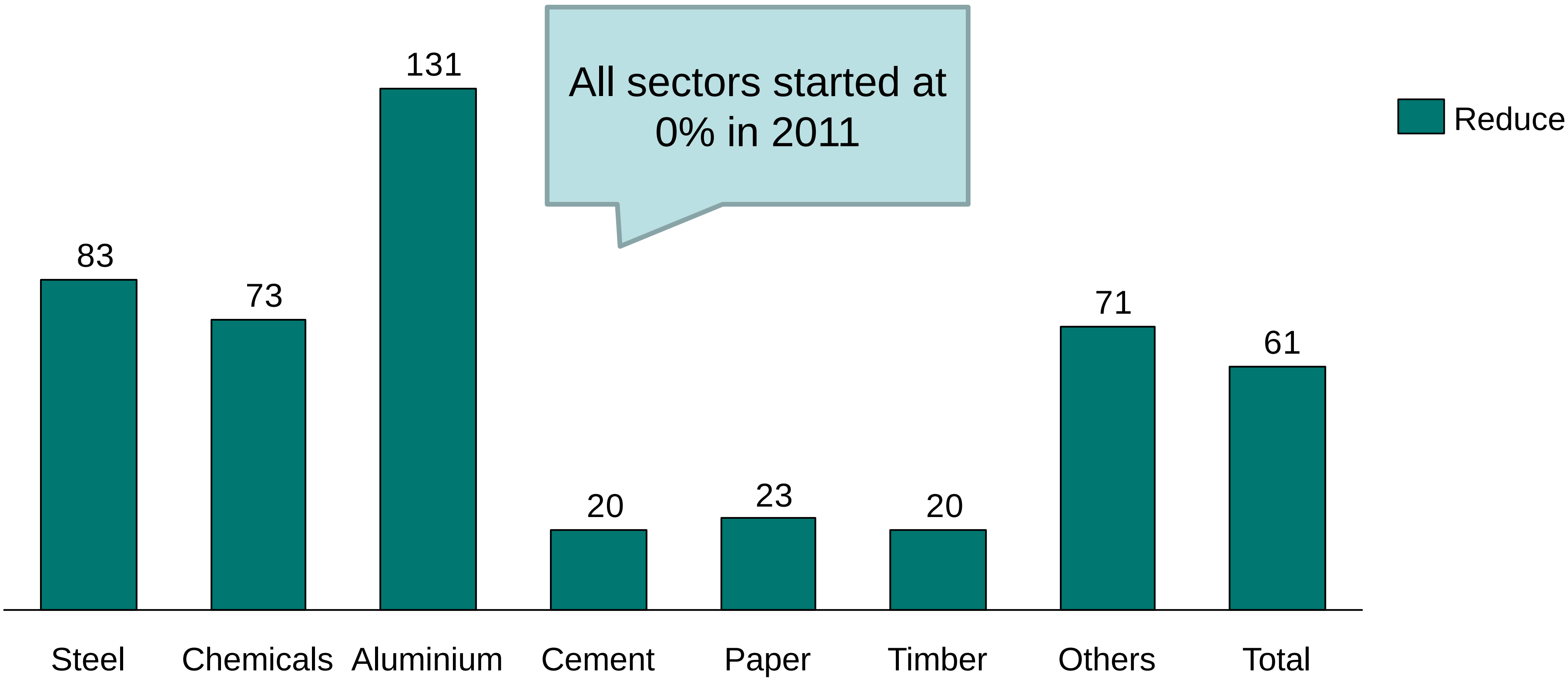
Material	2011	2050							
		Demand	Design	Switch	Recycling	Process	Fuel	EE	CCS
Steel	3.039	5558 (83%)	4447 (46%)	4227 (39%)	3690 (21%)	3718 (22%)	3715 (22%)	3642 (20%)	2842 (-6%)
Chemicals & petrochemicals	1.286	2223 (73%)	1824 (42%)	1880 (46%)	1315 (2%)	1275 (-1%)	1269 (-1%)	1225 (-5%)	466 (-64%)
Aluminium	150	347 (131%)	278 (85%)	311 (107%)	481 (220%)	470 (213%)	470 (213%)	449 (199%)	385 (156%)
Cement	2.206	2646 (20%)	2117 (-4%)	1899 (-14%)	1899 (-14%)	1844 (-16%)	1855 (-16%)	1746 (-21%)	633 (-71%)
Pulp & Paper	393	485 (23%)	436 (11%)	436 (11%)	349 (-11%)	316 (-20%)	316 (-19%)	238 (-39%)	86 (-78%)
Timber	348	419 (20%)	335 (-4%)	557 (60%)	557 (60%)	557 (60%)	557 (60%)	417 (20%)	417 (20%)
Other industries	2.210	3787 (71%)	3030 (37%)	3030 (37%)	3030 (37%)	3030 (37%)	3032 (37%)	2095 (-5%)	1205 (-45%)
Total	9.632	15465 (61%)	12466 (29%)	12339 (28%)	11320 (18%)	11210 (16%)	11214 (16%)	9812 (2%)	6034 (-37%)

Knowing the different sector characteristics, do these reductions seem balanced across sectors ?

Let's decompose this slide step by step

Total
GHG Emissions in trajectories 3(1)

Change in GHG emissions(2) vs 2011 after this lever
(% vs 2011)



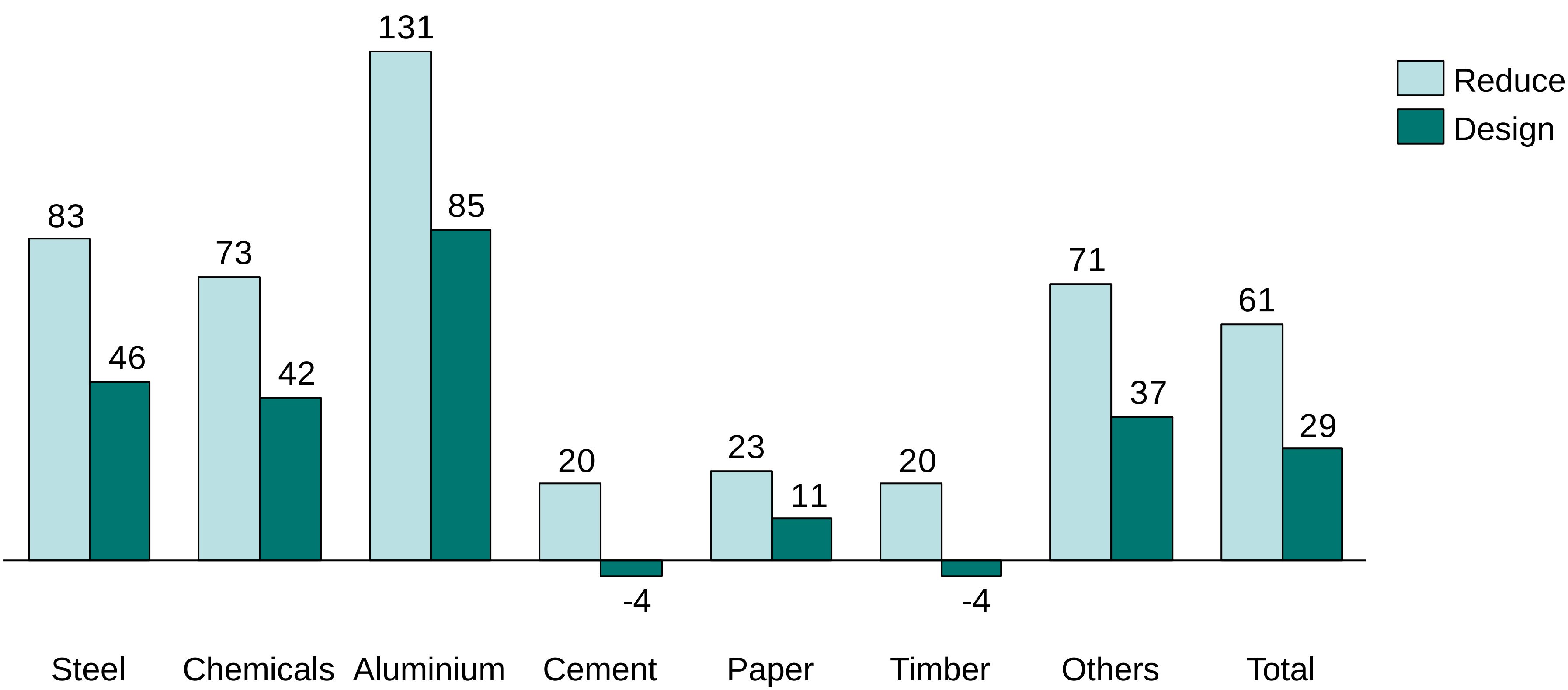
NOTE: (1) The population follows the average UN projection in all four trajectories
(2)Assuming biomass emits, not including electricity related emissions
SOURCE: IEA ETP 2012, Global calculator model

Total

GHG Emissions in trajectories 3[1]

Global Calculator

Change in GHG emissions[2] vs 2011 after this lever
(% vs 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

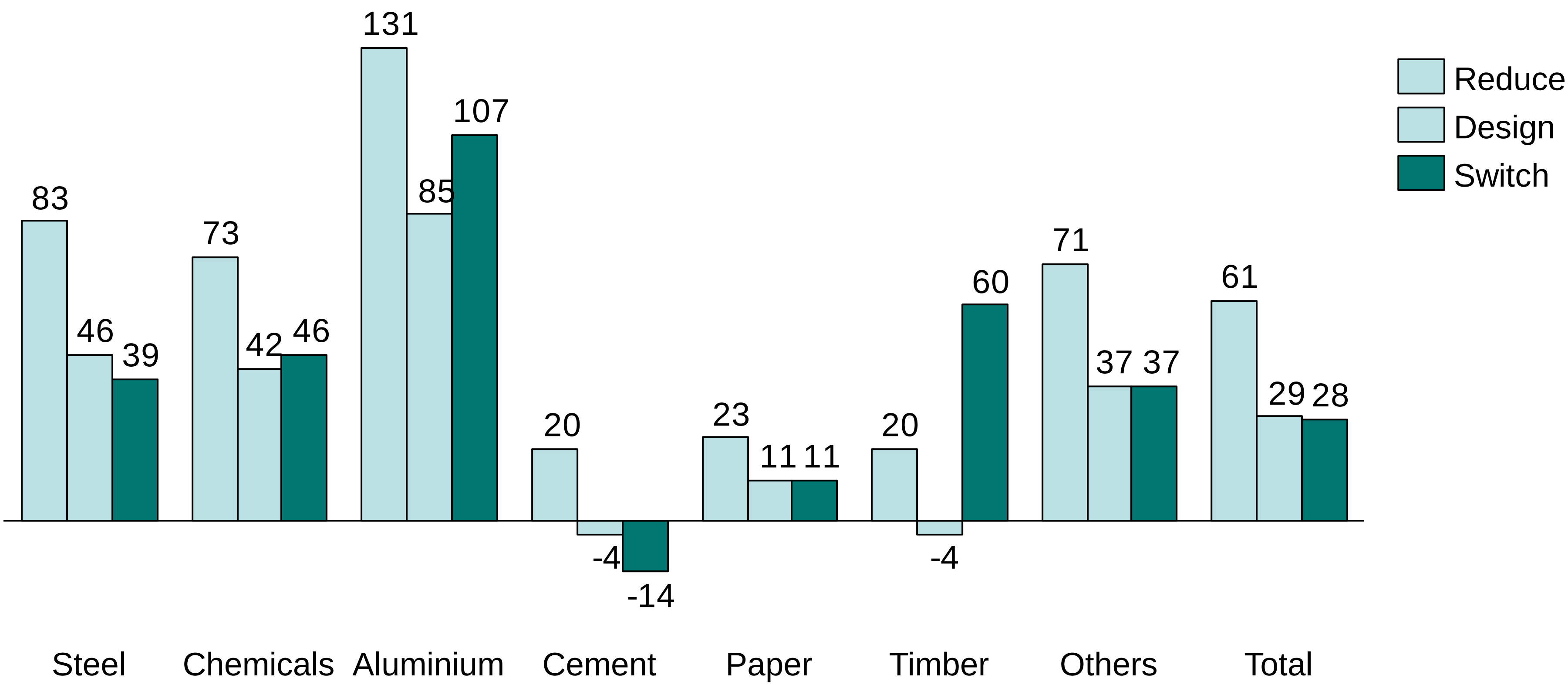
Reduce | Design | Switch | Recycle | Process | Fuel Switch | Energy efficiency | CCS

Figures of July 2014

Global Calculator

Total
GHG Emissions in trajectories 3[1]

Change in GHG emissions[2] vs 2011 after this lever
(% vs 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

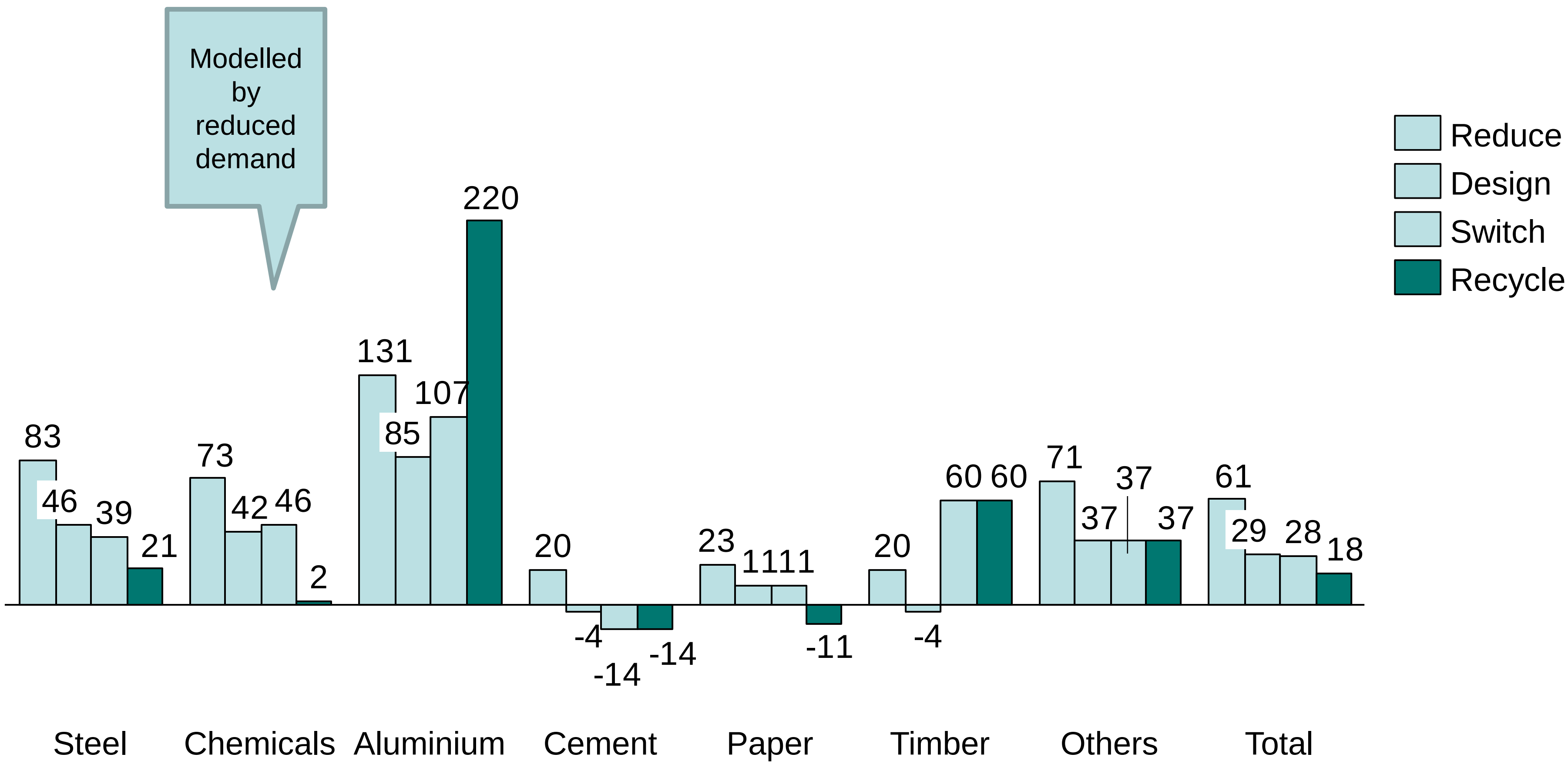
The fact carbon fibres emit more is currently not modelled

Figures of July 2014

Total
GHG Emissions in trajectories 3(1)

Global Calculator

Change in GHG emissions(2) vs 2011 after this lever
(% vs 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

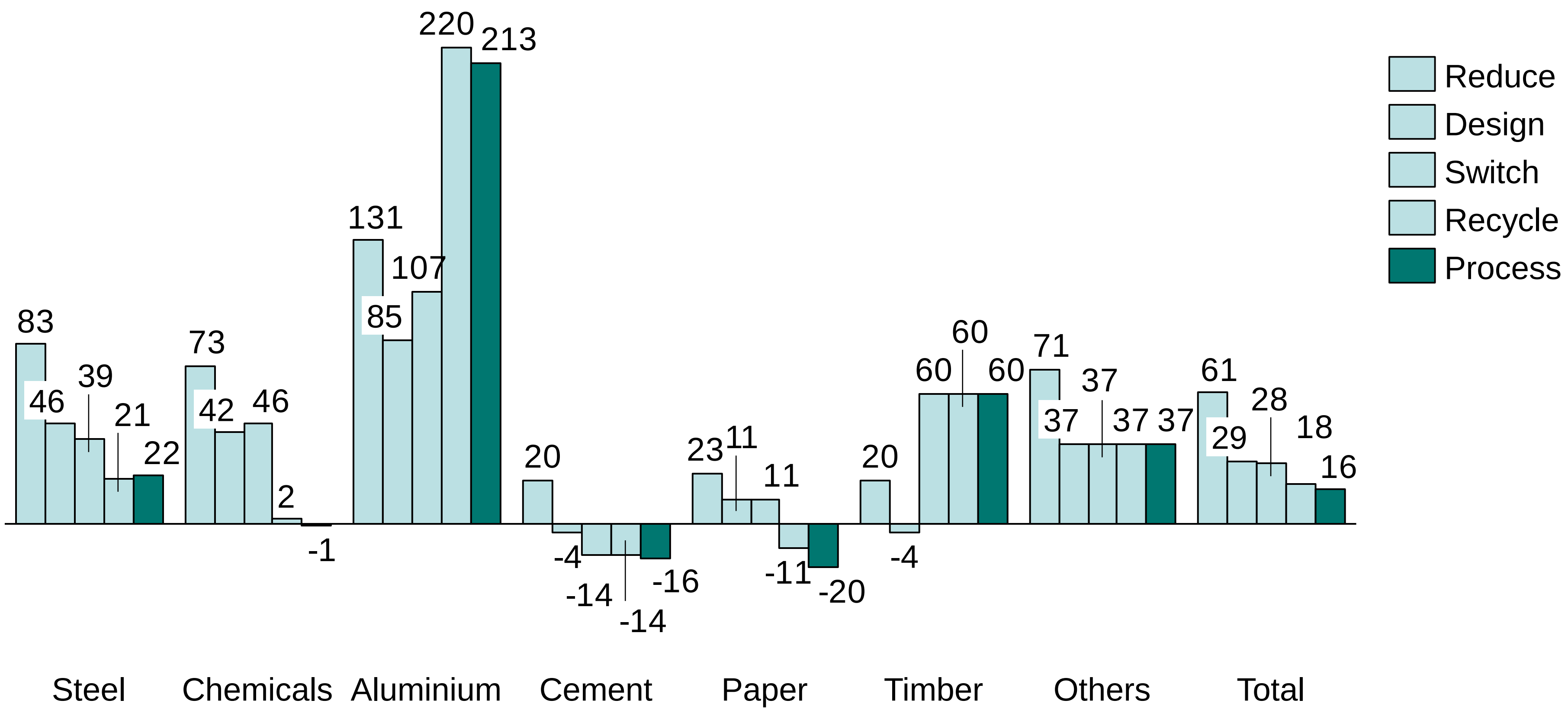
Aluminium recyling assumptions modified in the model after this slide was performed

Figures of July 2014

Global Calculator

Total
GHG Emissions in trajectories 3[1]

Change in GHG emissions[2] vs 2011 after this lever
(% vs 2011)



NOTE: (1) The population follows the average UN projection in all four trajectories
(2)Assuming biomass emits, not including electricity related emissions

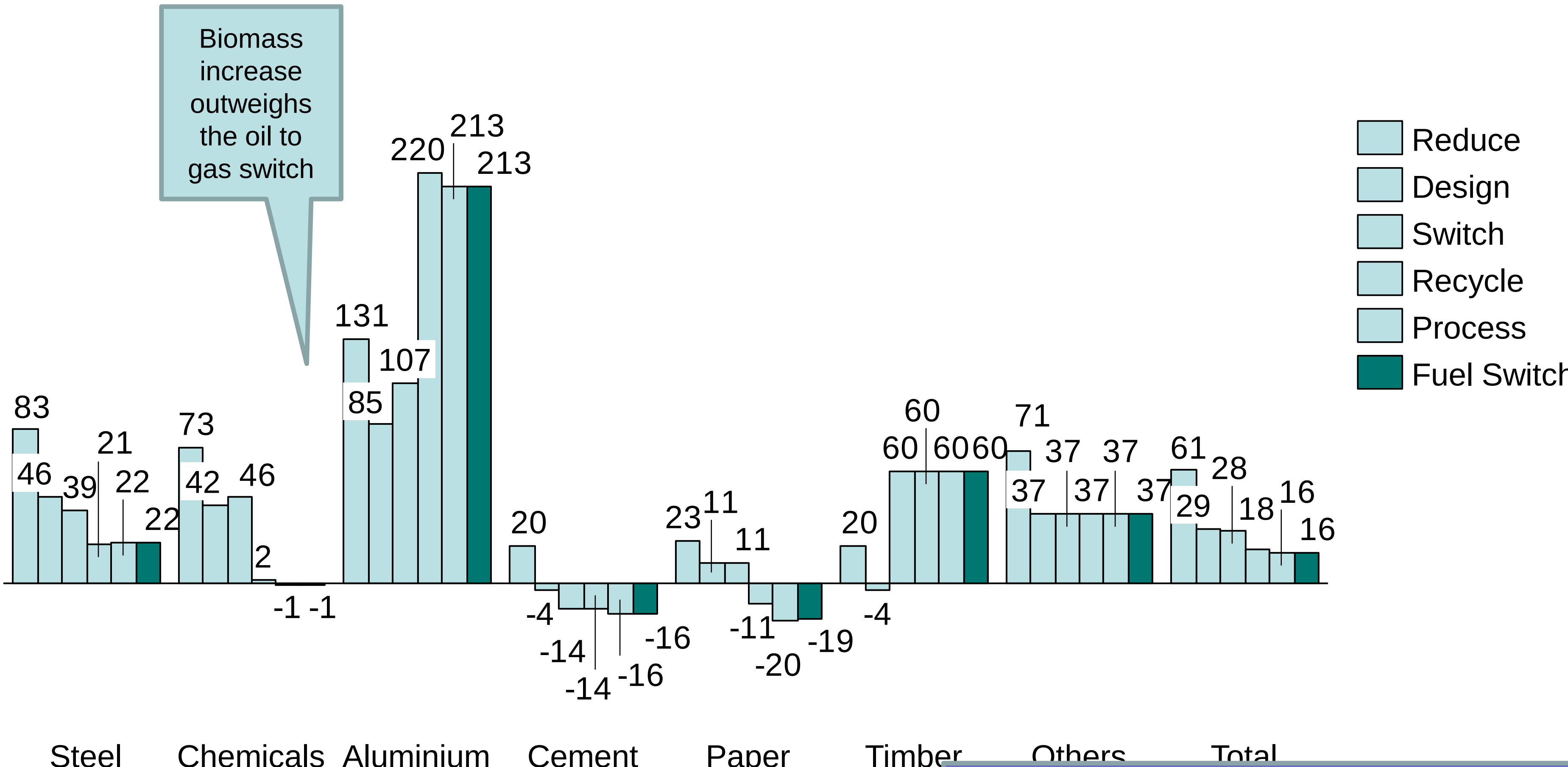
SOURCE: IEA ETP 2012, Global calculator model

Figures of July 2014

Total
GHG Emissions in trajectories 3 (1)

Global Calculator

Change in GHG emissions (2) vs 2011 after this lever
(% vs 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

Biomass is modelled as fossil hydrocarbons at this stage, it is then removed at the end

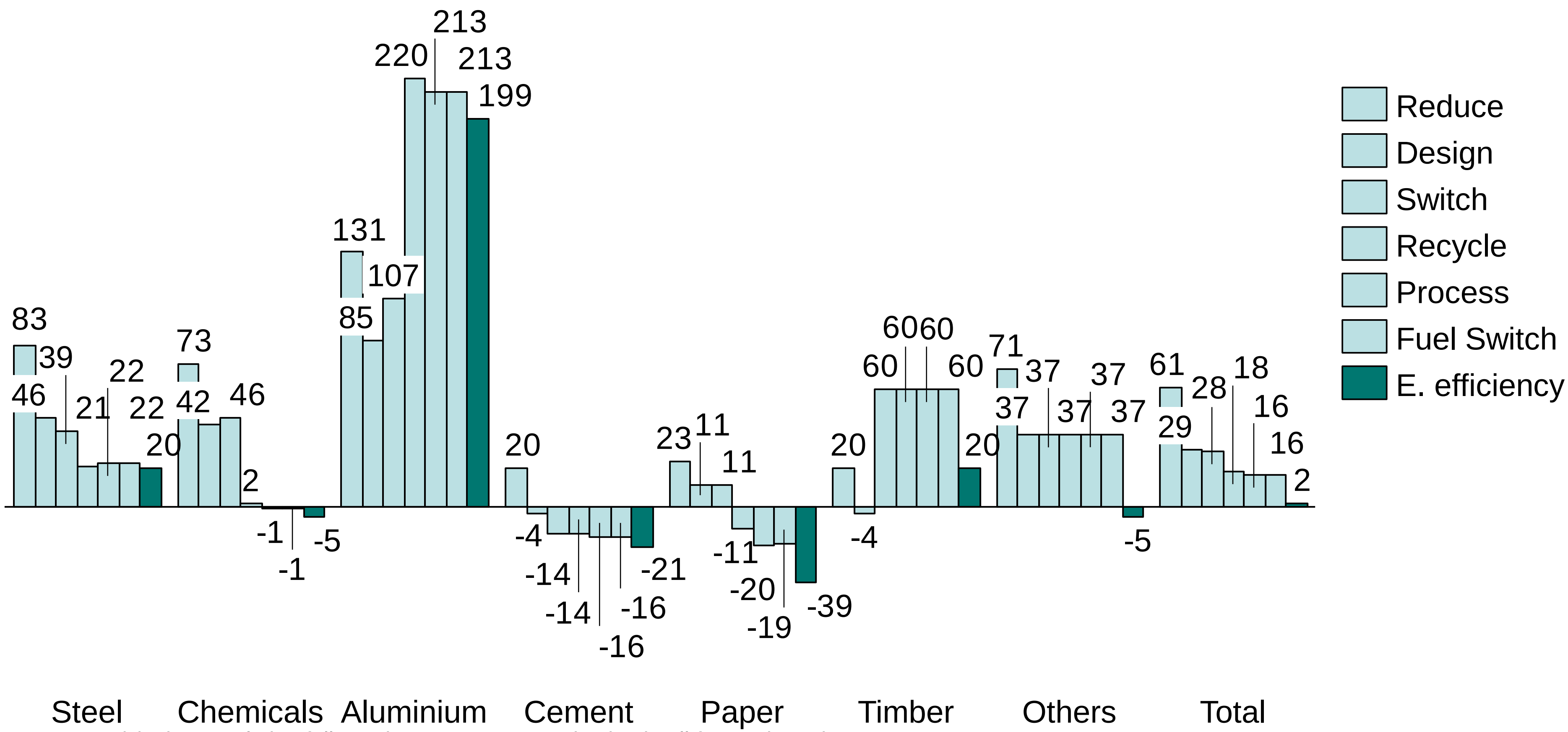
Figures of July 2014

Total

GHG Emissions in trajectories 3(1)

Global Calculator

Change in GHG emissions(2) vs 2011 after this lever
(% vs 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

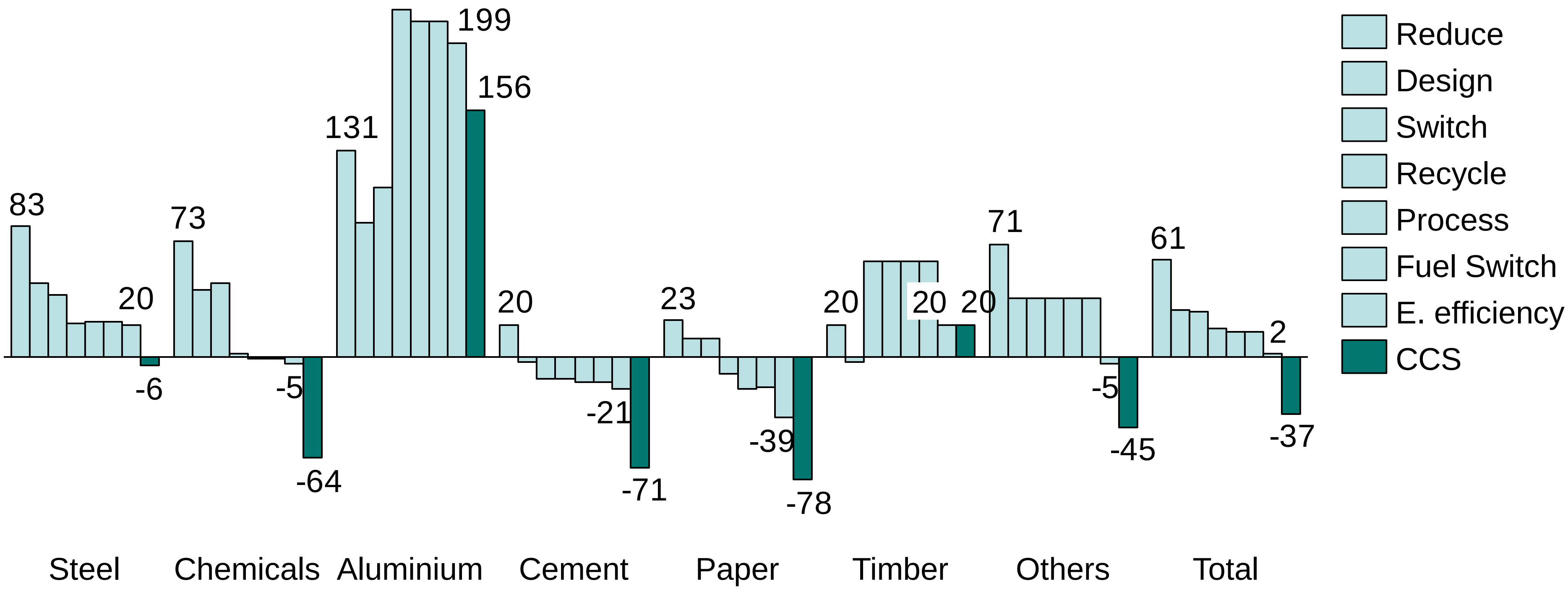
Figures of July 2014

Global Calculator

Total

GHG Emissions in trajectories 3(1)

Change in GHG emissions(2) vs 2011 after this lever
(% vs 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

Total

GHG Emissions in trajectories 3

BACKUP

Total emissions, along each step (by technology)
(M tons CO_2e, (% evolution vs 2011))

Material	Technology	2011	2050							
			Demand	Design	Switch	Recycling	Process	Fuel	EE	CCS
Steel	Oxygen	2.529	4626 (83%)	3701 (46%)	3518 (39%)	2477 (-2%)	1674 (-34%)	1670 (-34%)	1598 (-37%)	1022 (-60%)
	Oxygen Hisarna	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Electric	300	548 (83%)	438 (46%)	417 (39%)	714 (138%)	625 (109%)	625 (109%)	625 (109%)	625 (109%)
	Electric DRI	210	384 (83%)	307 (46%)	292 (39%)	499 (138%)	794 (278%)	794 (278%)	794 (278%)	794 (278%)
Chemicals & petrochemicals	HVC	324	559 (73%)	459 (42%)	473 (46%)	441 (36%)	420 (30%)	413 (28%)	396 (22%)	198 (-39%)
	Ammonia	286	495 (73%)	406 (42%)	419 (46%)	318 (11%)	318 (11%)	319 (11%)	296 (3%)	44 (-84%)
	Methanol	158	273 (73%)	224 (42%)	231 (46%)	130 (-18%)	130 (-18%)	130 (-18%)	121 (-23%)	18 (-89%)
	Others	518	895 (73%)	735 (42%)	757 (46%)	426 (-18%)	406 (-22%)	406 (-22%)	412 (-21%)	206 (-60%)
Aluminium	Alumina	106	245 (131%)	196 (85%)	219 (107%)	365 (245%)	365 (245%)	365 (245%)	349 (229%)	349 (229%)
	Primary	30	70 (131%)	56 (85%)	62 (107%)	104 (245%)	95 (214%)	95 (214%)	91 (200%)	33 (9%)
	Secondary	14	33 (131%)	26 (85%)	29 (107%)	11 (-20%)	10 (-27%)	10 (-27%)	10 (-31%)	4 (-75%)
Cement	Cement	2.206	2646 (20%)	2117 (-4%)	1899 (-14%)	1899 (-14%)	1844 (-16%)	1855 (-16%)	1746 (-21%)	633 (-71%)
Pulp & Paper	Pulp	194	240 (23%)	216 (11%)	216 (11%)	163 (-16%)	148 (-24%)	148 (-24%)	109 (-44%)	40 (-80%)
	Virgin	176	217 (23%)	195 (11%)	195 (11%)	148 (-16%)	134 (-24%)	134 (-24%)	101 (-42%)	37 (-79%)
	Recycled	23	28 (23%)	26 (11%)	26 (11%)	38 (63%)	34 (49%)	34 (49%)	27 (19%)	10 (-57%)
Timber	Timber	348	419 (20%)	335 (-4%)	557 (60%)	557 (60%)	557 (60%)	557 (60%)	417 (20%)	417 (20%)
Other industries	Other industries	2.210	3787 (71%)	3030 (37%)	3030 (37%)	3030 (37%)	3030 (37%)	3032 (37%)	2095 (-5%)	1205 (-45%)
Total	Total	9.632	15465 (61%)	12466 (29%)	12339 (28%)	11320 (18%)	11210 (16%)	11214 (16%)	9812 (2%)	6034 (-37%)

Knowing the different sector characteristics, do these reductions seem balanced across sectors ?

Agenda

Global Calculator

2050 evolution of materials and emissions

Materials demand evolution

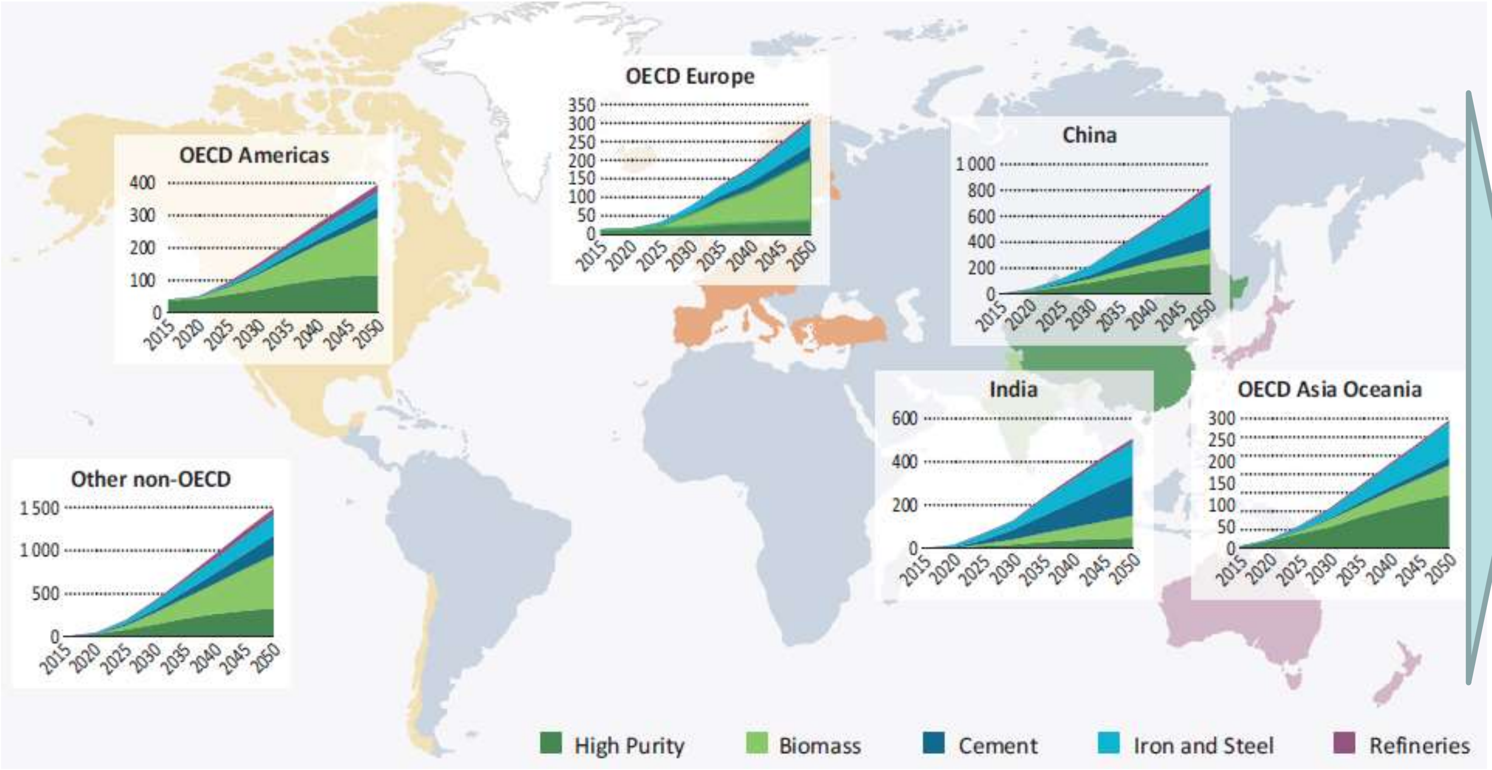
- Cross sector demand
- Cross sector material switch
- Steel
- Chemicals
- Aluminium
- Cement
- Paper & Timber

Reduction potential on the manufacturing processes

- Resulting emissions
- Discussion on ambition levels across sectors
- **Discussion on CCS**
- Steel
- Chemicals
- Aluminium
- Cement
- Paper, Timber & Other

Carbon Capture & Storage
Projections by region

Capture rate
($MtCO_2$/year)



Blue scenario leads to a 4 Gt reduction in 2050, while total additional costs add up to 3 trillion USD by 2050

SOURCE: IEA ETP 2012, IEA UNIDO 2011

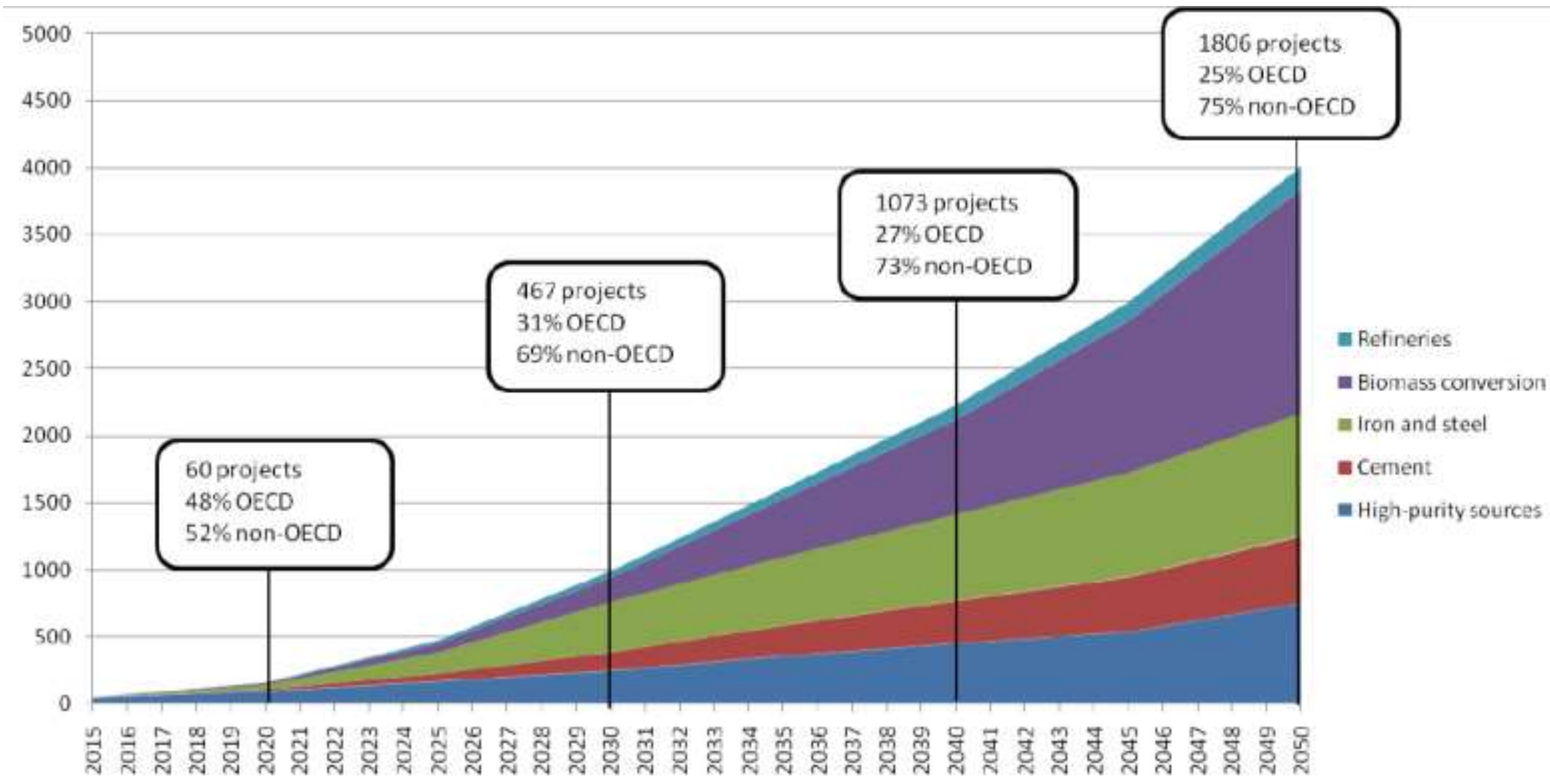
Carbon Capture & Storage

Blue roadmap goes from 60 projects in 2020 to 1800 in 2050

Global Calculator

Capture rate

($MtCO_2$ captured/year)



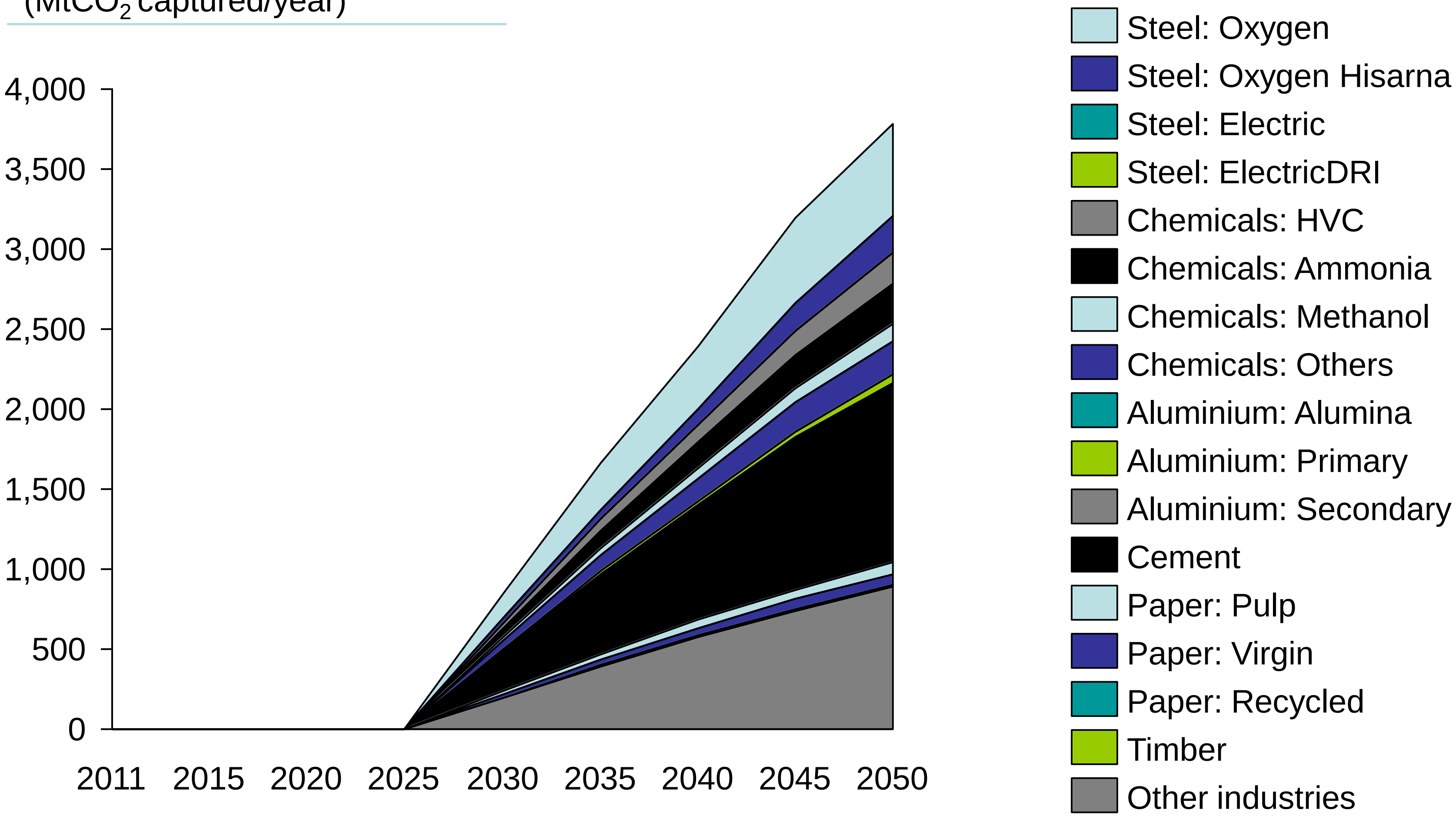
Figures of July 2014

Carbon Capture & Storage

Industry ambition 3 leads to a similar capture rate

Global Calculator

Capture rate
($MtCO_2$ captured/year)

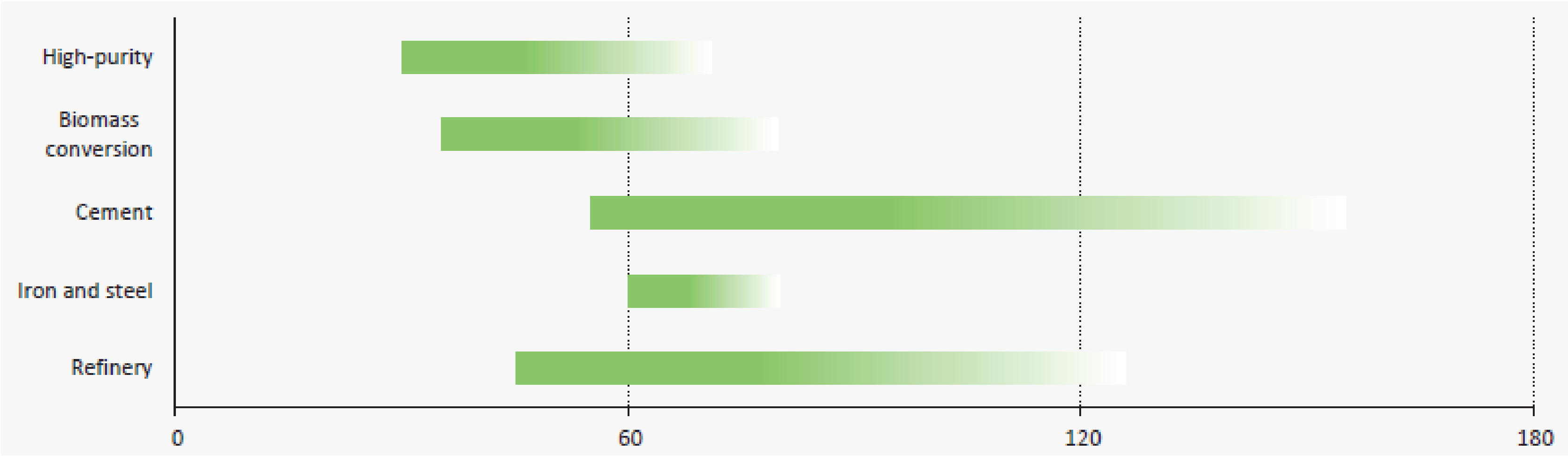


NOTE: Biomass is considered as fossil fuel & electricity emissions are not counted in this view
SOURCE: Global Calculator model,

Carbon Capture & Storage
Cost per industry

Global Calculator

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



In addition, an electricity consumption of 0,33 TWh/MtCO_2e captured is modelled

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

Carbon Capture & Storage
What this would imply per sector

Global Calculator

Sector implications for a blue scenario equivalent

Iron & Steel	• Improve the economics of capture techniques in the iron & steel sector • Equip 75% of new production with CCS by 2030 in OECD (50% in non OECD)
Chemicals (High Purity)	• Compile inventory of opportunities & assess costs • Perform demonstration projects involving hydrogen, ammonia & ethylene processes
Aluminium	• Assumed similar to steel (relatively)
Cement	• Improve the economics of capture techniques under flue gas conditions which are typical for the cement sector • Perform full scale plant between 2015 & 2020
Paper	• Assumed similar to Biomass sector objectives (relatively) • R&D on biomass gaseification processes • Realise full scale plants by 2020
Timber	• Assumed similar to paper

SOURCE: IEA UNIDO 2011

Agenda

Global Calculator

2050 evolution of materials and emissions

Materials demand evolution

- Cross sector demand
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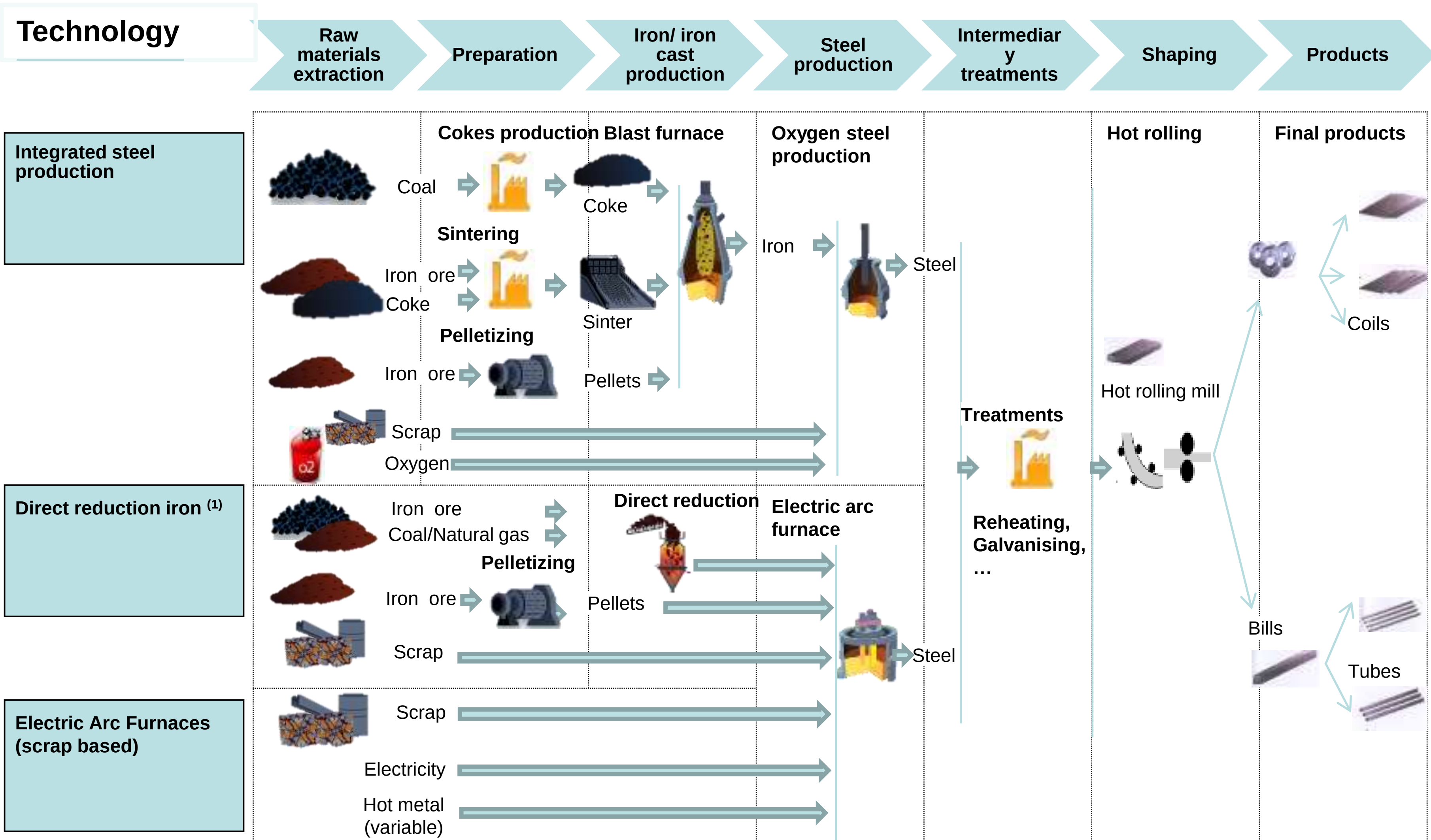
- Chemicals
- Aluminium
- Cement
- Paper & Timber

Reduction potential on the manufacturing processes

- Resulting emissions
- Discussion on ambition levels across sectors
- Discussion on CCS
- **Steel**
- Chemicals
- Aluminium
- Cement
- Paper, Timber & Other

3 technologies are currently used to make most of the steel

Global Calculator

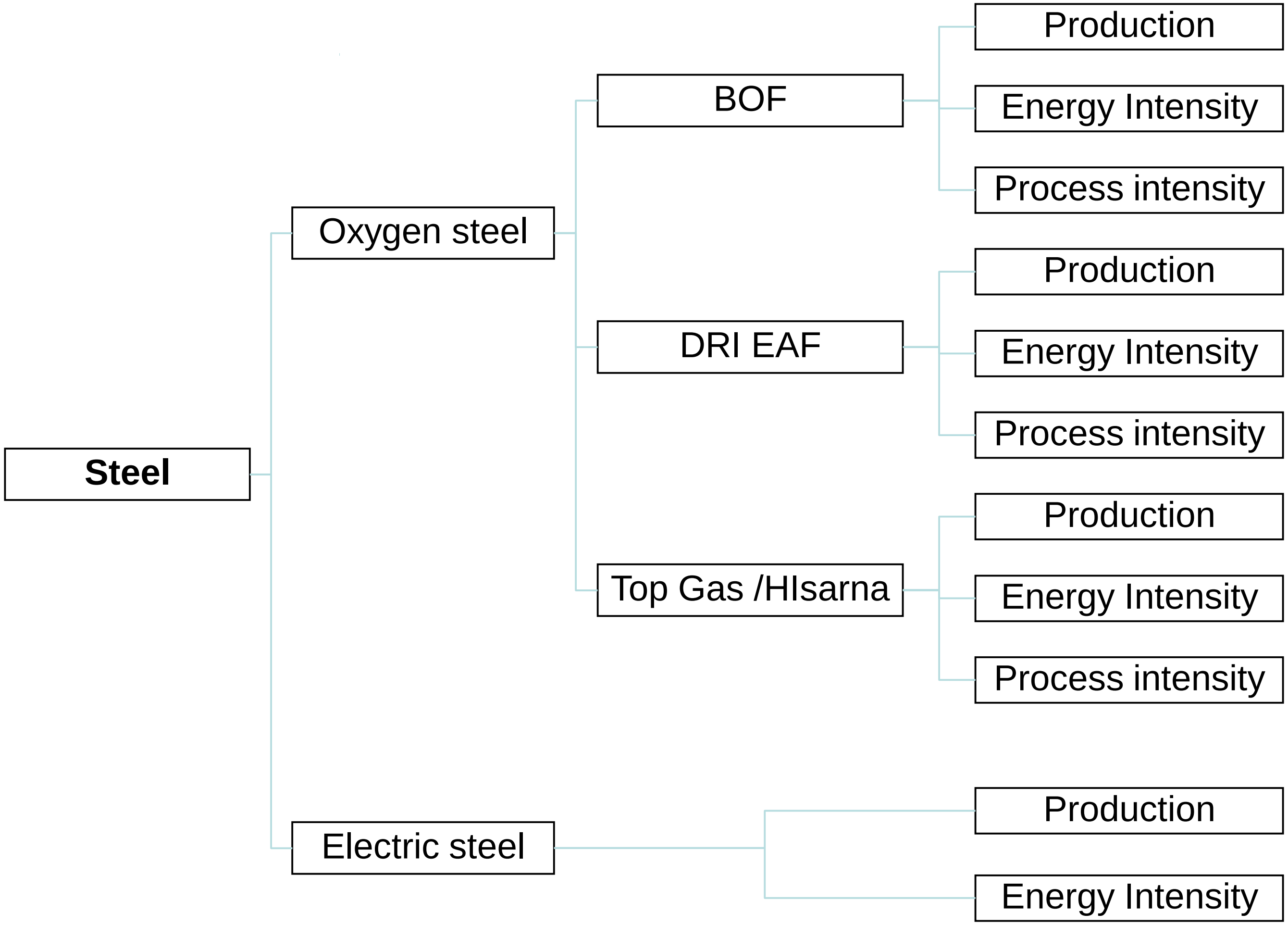


NOTE: (1) DRI is illustrated here with the Electric arc furnaces. It can also be performed with Blast furnaces

SOURCE: GSV, World Steel, Climact

Steel emissions are being modelled

Steel emission tree



SOURCES: Climact

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

Global Calculator

List of actions & levers assessed

Design	Switch	Recycling
• Changing product and material specifications to answer the same needs with less materials	• Change materials to enable a low carbon product (over the product lifetime)	• Recycle the product or the material
Smarter design with similar steel grades	In vehicles : To aluminium & to plastics	Product recycling
Increase proportion of high strength steel	In buildings/Infr. :T o green plastics & to timber	Material recycling: Electric arc furnace

SOURCE: Climact

2

Design: Smarter design & high strength steel increase

Better designs & new steel grades can lower the mass required to fulfil specifications

Smarter design

- Smarter design can enable to reduce the materials demand (including steel)
- Examples include:
  - Lighter vehicles
  - Buildings with less redundancies

High strength steel

- At world level, estimates mention the use of high strength steel to be :
  - Globally at around 20% with a potential of 50%
  - In the automotive industry above 50% already

High strength steel characteristics

Requires less steel

- High strength steel (also called « Hard steel » or « High processability steels ») can be substituted to normal steel but requiring 30% less steel to meet the same standards (e.g. to enable the end product to be as solid)
- For automotive manufacturers, the use of Advanced and Ultra High-Strength steels (AHSS and UHSS), allow to reduce mass of the vehicles by 17% to 25% while maintaining safety standards[(2)]
- At global level, this is modelled by a reduction in steel production. At local level, we would assume the installations which would invest in the technology would continue to produce at full capacity.

Impact on the steel production

- Producing higher strength steel does not produce significantly more CO_2e emissions per ton of steel produced. It is estimated that treatments like reheating and galvanizing could increase consumption by 2-5% (with an unknown upside) [(1,3)]
- High strength steel tends to depend more on the primary steel. But this is not exclusive; high strength steel can be made from the secondary steel [(3)]

NOTE :Producing higher strength steel does not affect the industry profitability because even if less is required, it is also sold with a higher margin per ton

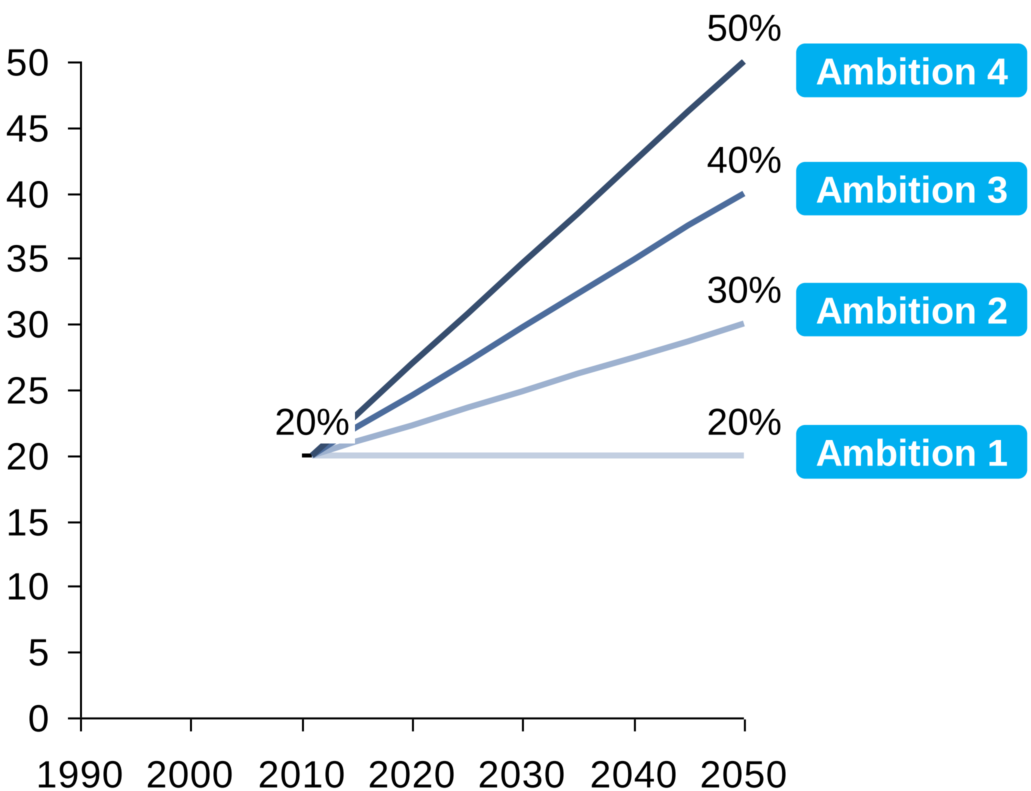
SOURCE: (1) Arcelor, (2) WorldSteel fact sheet the 3Rs (Reduce, Reuse, Recycle), based
A) on ULSAB research (WorldAutoSteel), carmakers' own body structure designs
B) 'Determination of Weight Elasticity of Fuel Economy for Conventional ICE Vehicles, Hybrid Vehicles and Fuel Cell Vehicles', fka, June 2007
Climact, interview expert in the context of Belgium Low Carbon 2050, (3) Global Calculator steel consultations

Figures of July 2014

Global Calculator

2 Design: Smarter design & high strength steel increase
Proposed lever ambitions

Share of high strength steel
(%)



- High strength steel is modelled requiring 30% less steel
- Upside on smart design and downside on additional specific consumption of high strength steel not modelled and assumed to balance one another

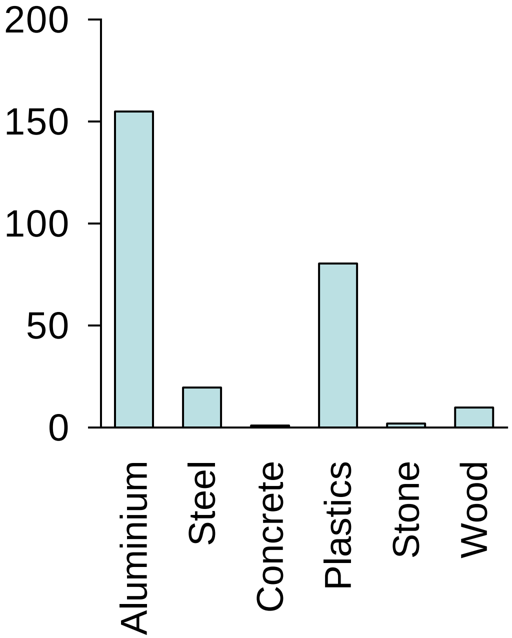
Lever cost (2) €/t crude steel	
Input (fuel & material)	-x
Other opex	0
Capex	+x

NOTE:(2) Assuming the additional capex is balanced by the input reduction
SOURCE: Climact national consultations

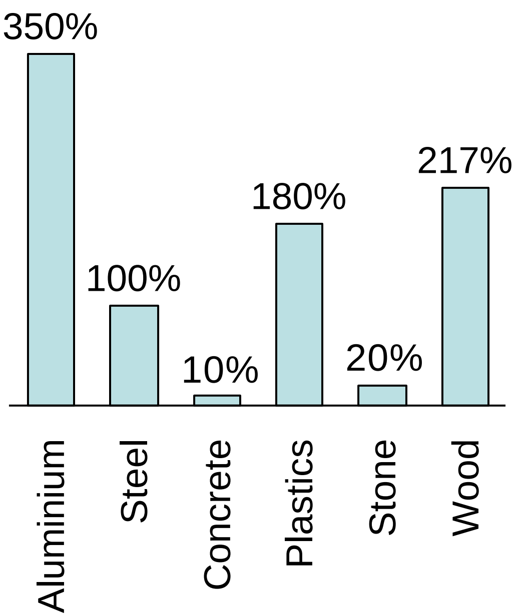
Material switch

Steel is a relatively cheap material

Embodied energy
(Gj/t)



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



- Compared to other metals, steel has lower embodies energy and costs
- Concrete and stone are not substitutes as they are weak in tension
- Aluminium does not score well but enables lighter products

Embodied energy to convert the material in useful form

Relative cost per tonne to convert the materials in useful form

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

Steel can be substituted to enable less CO_2 emissions along product life cycles

Global Calculator

Materials which can replace /be replaced by steel

	Characteristics		Steel replacement assumption	
	Advantages	**Weaknesses**	**Vehicles (8%)**	**Buildings/ Infrastructure (38%)**
Aluminium	Density	Less strong, less recyclable Higher cost & embodied energy	Up to 20% steel can be replaced by aluminium	Not applicable
Concrete	Steel compatibility (rebar), Low cost & embodied energy, no corrosion	Weak in tension Non recyclable	Not applicable	Would be modelled by smart design
Plastics **(Composite materials, glass/ carbon fibres reinforced epoxies)**	Density, Strength per density (of some plastic types)	Lower recyclability Less reparable (e.g. carbon fibre cars) Higher embodied energy Difficult manufacturing	Up to 20% steel can be replaced by carbon fibre (HVC)	Not applicable
Stone & Masonry	Lower embodied emissions	Must be reinforced with mortar (from cement) Cannot be reinforced or moulded into shapes	Not applicable	Not applicable
Timber	Strength and stiffness per density [(1)]	Less durable, requires protection against fire and rot, less stable Lower, uniformity	Not applicable	Up to 20% steel can be replaced by timber in buildings

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

Figures of July 2014

Global Calculator

2 Material switch
Proposed lever ambitions

Level 1	Level 2	Level 3	Level 4
Minimum effort (following current regulation)	**Moderate effort** easily reached according to most experts	**Significant effort** requiring cultural change and/or important financial investments	**Maximum effort** to reach results close to technical and physical constraints
• **Vehicles:** 0% switch • **Buildings:** 0% switch	• **Vehicles:** 5% substitution by aluminium, 5% by plastics • **Buildings/Infra:** 5% substitution by timber	• **Vehicles:** 10% substitution by aluminium, 10% by plastics • **Buildings/Infra:** 10% substitution by timber	• **Vehicles:** 20% substitution by aluminium, 20% by plastics • **Buildings/Infra:** 20% substitution by timber

Lever cost (€/t steel)	
Steel➔ Aluminium	0
Steel ➔ Timber	0
Steel➔ Plastics	0

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

Reusing the products

The steel product reusing lever is not modelled

Rationale on reusing the products

- When using steel based products, both the products (cars, appliances, etc.) and the materials (scrap steel) can be reused
- The products reusing lever is currently not modelled, this is due to lack of data, and perception this lever has a lower impact

Illustrations on Products

- In North America approximately 33% of the straight railway track sections purchased comes from used rail that is disassembled at redevelopment sites (1)

SOURCE: (1) Worldsteel factsheet on the 3Rs (Reduce, Reuse, Recycle)

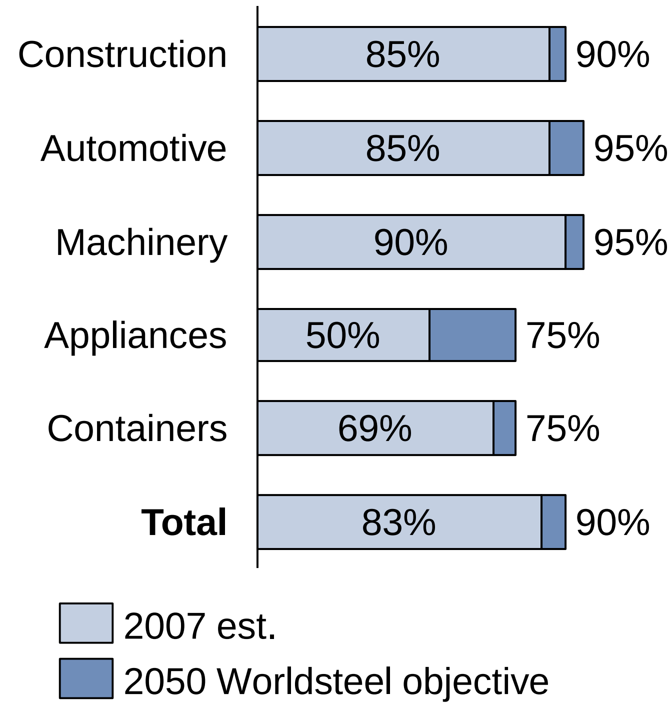
Materials recycling : Scrap based steel

Up to 90% of steel could come from be recycled streams by 2050

Rationale on steel recycling

- Steel is the world's most recycled material [3]
- We are still a long way from collecting all our discarded metals for recycling
  - Steel reinforcement bars in sub surface concrete (e.g. foundations and tunnels) are currently not extracted at end of life [2]
  - Deep sea line pipes are not removed at the end of their lives
- 100-150$/ton scrap is required in order to have economically viable recovery of scrap (high scrap prices will drive up the scrap collection price) [4]
- Maximum recycling rates for steel might be at 90%[1]

Worldsteel recycling rate targets [3]
(2007 est. and 2050 objectives, %)



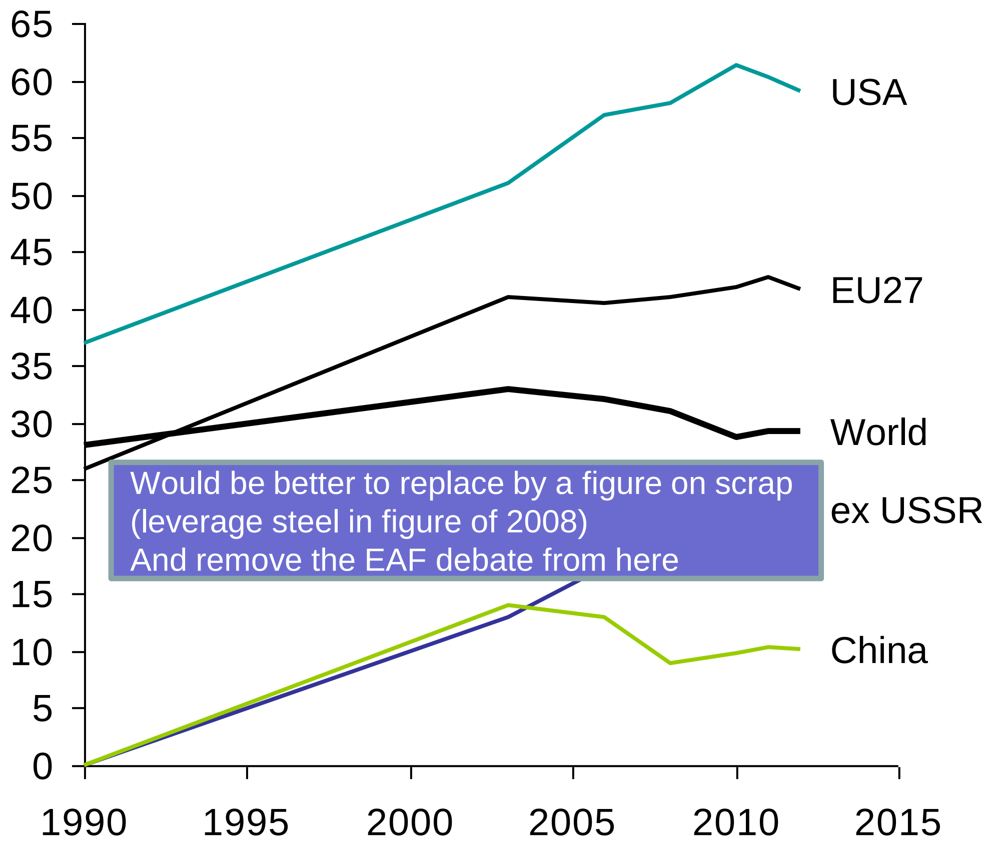
SOURCE: (1) Professor Robert Ayres (INSEAD) (2) (with both eyes open) (3) Worldsteel fact sheet, the 3 Rs(Reduce, Reuse, Recycle) (4) Global Calculator consultations

2

Materials recycling: Scrap based steel

Recycled steel is at~30% well below the 80%, this is because of a) the limited availability and b) the time lag

Historic evolution of the Electric steel production in the total crude steel production (%) [1]



- Steel Production and therefore reserves are increasing worldwide[2]
- The steel stock should, by some estimates, become self sufficient in one century
- World reduction is explained by growth in developing countries
- Historically, the proportion of electric steel has increased in developed geographic areas; as countries develop, they produce more metal scrap
- Fast growing countries favour oxygen steel production (as the availability of scrap is not sufficient to meet the rapidly growing production)
- There is a large increasing amount of steel embedded in products that are still in use and have not reached the end of their lifespan. Steel can remain more than 50 years in the lifecycle which creates a lag between production increase and available scrap metal increase [3]

NOTES: (1) the EAF includes the both 100% scrap based EAF as well as EAF that uses DRI and/or hot metal in addition to scrap
(3) Length is function of the sector. 50 years is typically applicable in the buildings sector, automotive and consumer goods sector typically have shorter life times

SOURCE: IISI, (1)Worldsteel in figures, Eurostat, Groupement de la Sidérurgie, (2) McKinsey

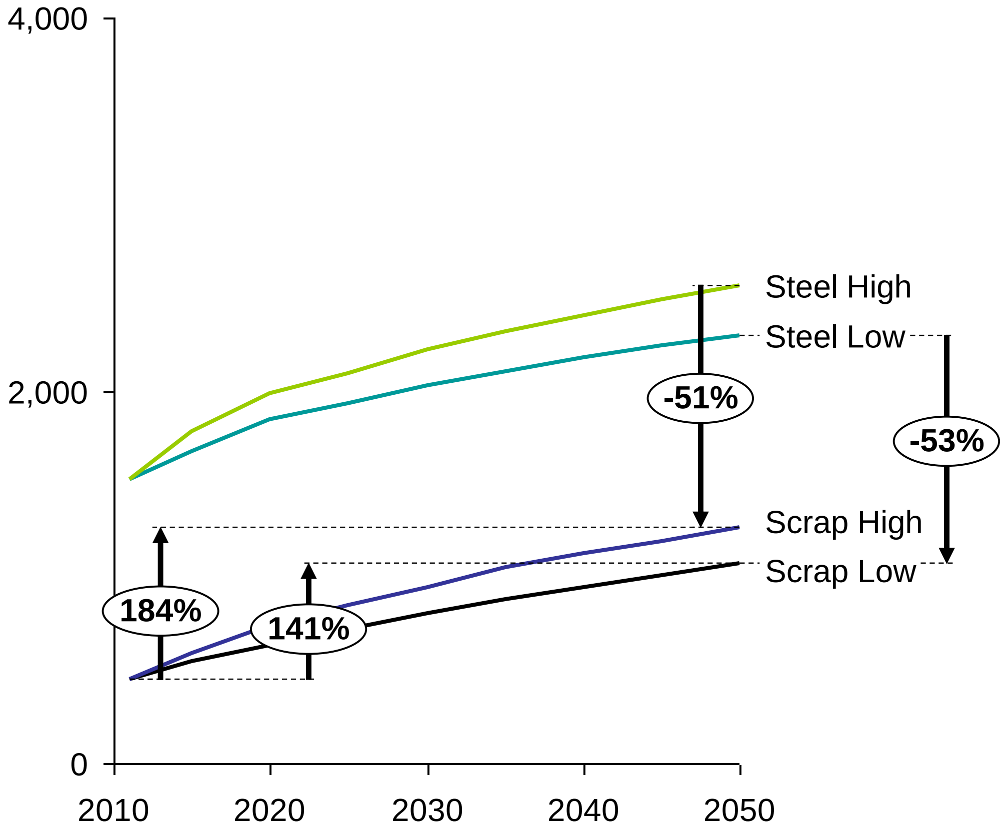
2

Materials recycling: Scrap based steel

Scrap availability is limited

IEA estimates on the availability of scrap in the 2-4-6DS scenarios
(Mt)

IEA Confidential data until September



- Steel scrap is expected to increase by 140-180%
- In future versions of the model, the scrap availability will be fixed directly in the model
- Worldsteel forecasts 40% recycled steel in 2050. 50% supply from scrap is a reasonable scenario, but dependent on many factors (e.g. economics for energy, raw materials and scrap prices and cost and overall demand region or country by country etc.)(2)
- Higher scrap estimates (up to 75%), assuming 25% additional by including industrial scrap (3)
- Scrap availability rate could go much higher by 2100 (3)

SOURCE: IEA ETP 2012, (2) Worldsteel, (3) With Both Eyes open

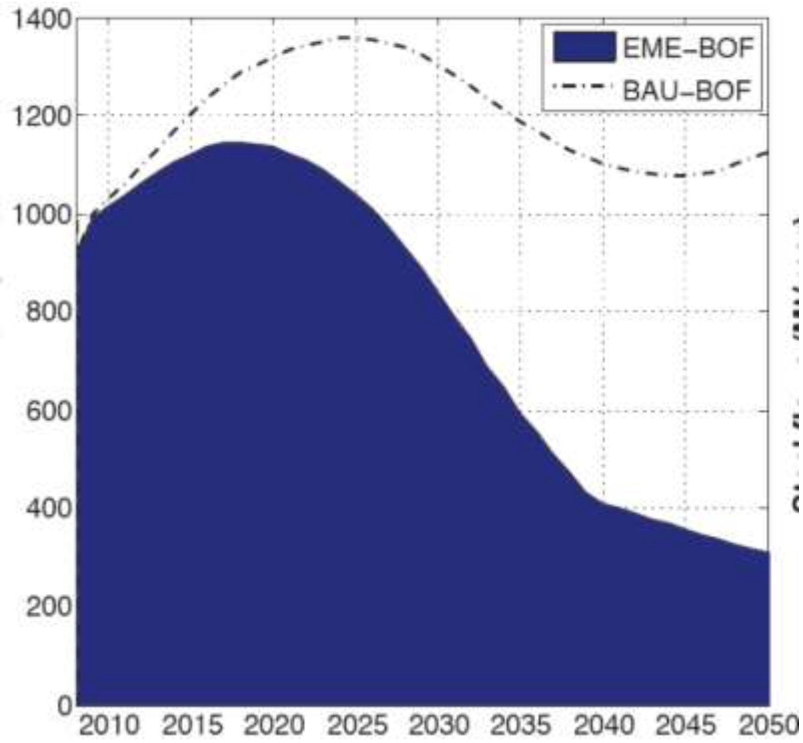
2

Materials recycling: Scrap based steel

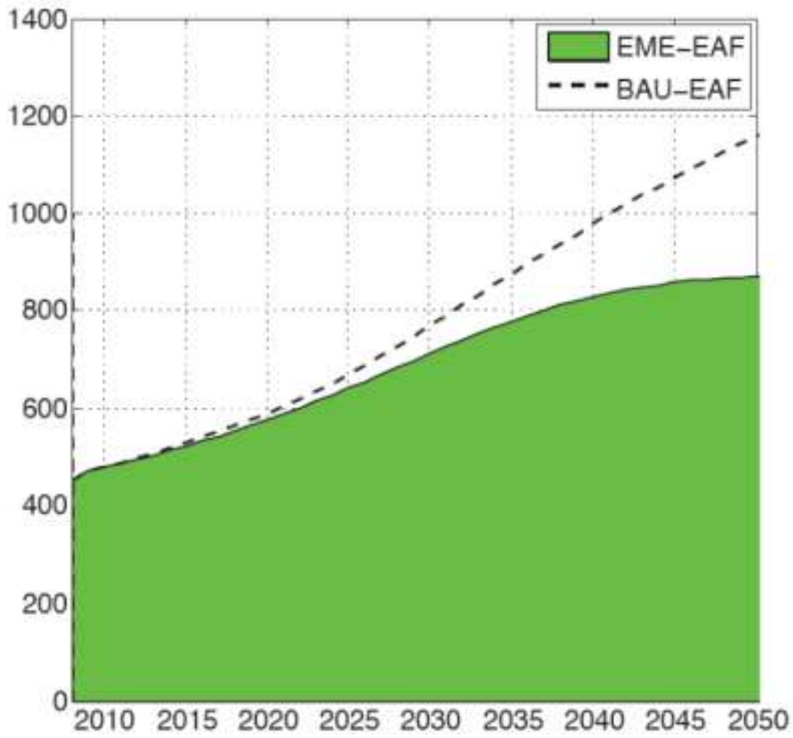
In lower demand scenario, NTNU & Cambridge scenarios forecast earlier market saturation and higher scrap%

Global Calculator

Primary steel flows (from ore)
(Mt/year)



Secondary steel making (from scrap)
(Mt/year)



SOURCE: NTNU & Cambrige University (2014 04 10 International Materials Education Symposium)

Materials recycling: Scrap based steel

Transition to EAF has impacts in terms of product quality and price

EAF increase implications

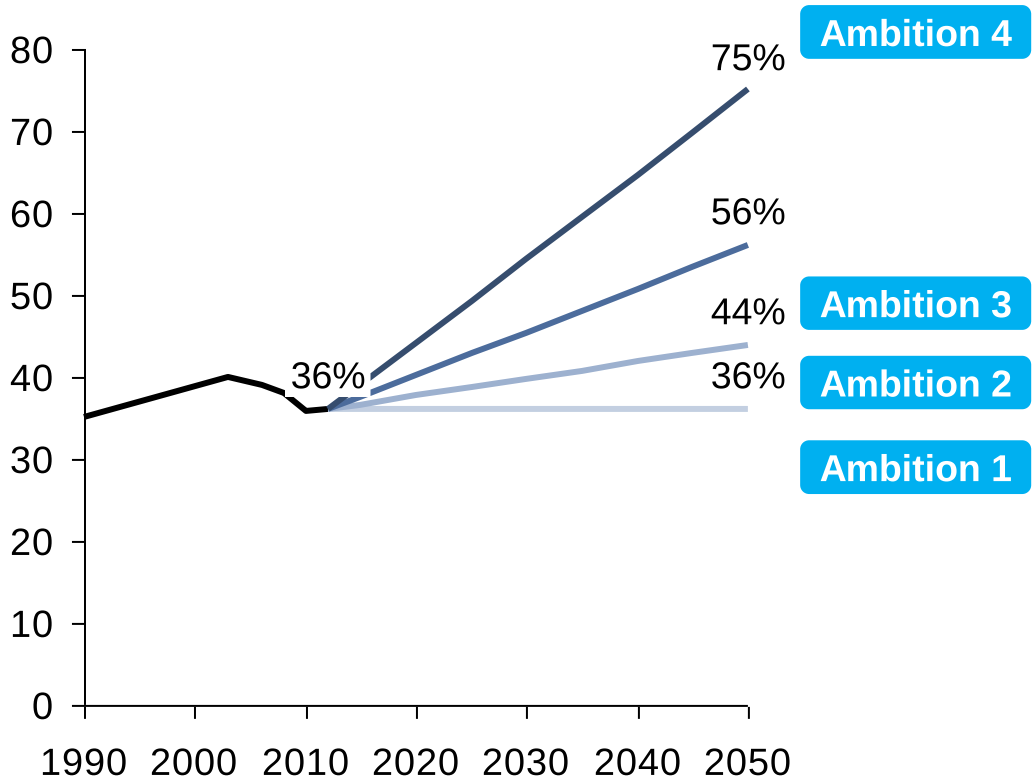
- The cost /ton of EAF steel is higher [1,3,4] because of the energy consumption [6]
- EAF enables to produce the steel for all applications[7]. However, BOF production produces higher quality steel for some applications (e.g. automotive sector) [3]
- High EAF scenarios require higher quality Scrap metals collection
- The reduction of BOF has a negative impact on other industries (e.g. cement uses blast furnaces slag to produce composed/metallurgic cements which emit less CO_2 [2])
- In a world with overcapacity, EAF ovens offer more flexibility to be turned on or off

SOURCES: (1) Wallonia Steel consultation (2) Wallonia cement consultation, (3) GSV, (4) Ulcos, (5) McKinsey , (6) Duferco, (7) Worldsteel

2 Materials recycling: Scrap based steel

Proposed lever ambitions

Scrap steel production in the total crude steel production (%)



Ambitions reflect the 2050 scrap availability

This is different from the proportion of EAF

SOURCE: (1) Total production is kept constant but we assume this production is shifted to Electric Arc furnaces

(2) Eurofer 2013, A Steel Roadmap for a Low Carbon Europe 2050

Carbon intensity of material production

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

List of actions & levers assessed

Process improvement

- Towards fuels which emit less CO_2

  - Reduction of carboniferous materials
  - Portion of Classic /Top gas recycling & Hisarna in oxygen
  - Portion of DRI /scrap in EAF
  - Smelt reduction potential(1)
  - Electrolysis
  - Hydrogen

Fuel substitution

- Modification of processes

  - Coke subsitution by gas injection
  - Coal PCI substitution by biomass

Energy efficiency

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

  - Improvements in current process
  - CHP

End of pipe technologies

- Carbon capture and storage

  - CCS implementation
  - CCU

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

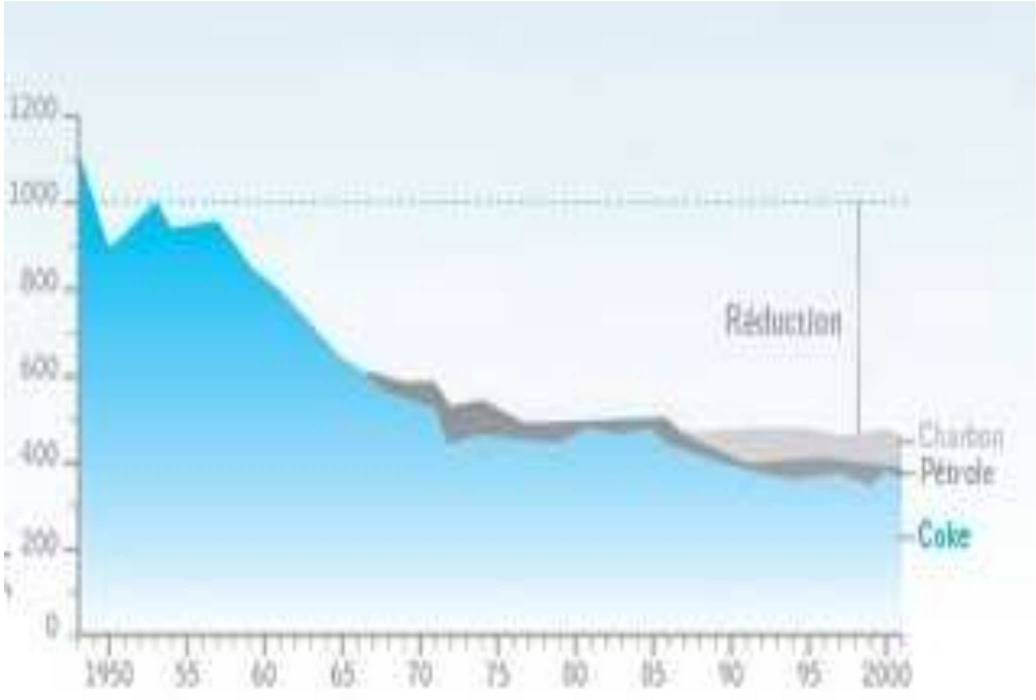
3

Process : Reduction of carboniferous materials

There is limited further potential in reducing the amount of carboniferous materials per ton of steel

Global Calculator

Evolution of carboniferous materials to produce liquid iron cast
(Kg CO_2e/t liquid iron cast)



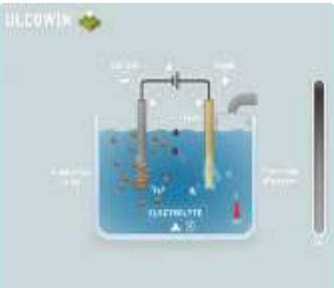
- The amounts of carboniferous materials per ton of steel have been significantly reduced during the last decades
- To date, the blast furnaces in the EU15 use today an average of 0,49 kg of carboniferous materials per kg of liquid iron cast produced(1), or 115kg of input materials for 100kg of steel (2)

It is considered this lever has no additional potential

SOURCE: (1)ULCOS VDEh Germany, (2) WorldSteel Fact sheet, the 3Rs (reduce, reuse, recycle), Steel consultation Belgium Low Carbon 2050

3 ULCOS is performing prototypes to assess the feasibility of four technologies

Global Calculator

				
Technology	**Top gas recycling (+ Carbon capture)**	**ULCORED + EAF (+ Carbon Capture)**	**HIsarna smelter (+ Carbon capture)**	**Ulcowin – Electrolysis**
Process	• Recycling CO (reducing agent) from blast furnace waste gas • Reduces coke and coal requirements • Cokes and sinter production unchanged	• Direct reduction process • Uses natural gas as reducing agent • No coke required	• Combines all the heat processes in one • Direct use of ore and coal : 20 % reduction of CO2 – 80 % with CC • Significant coal savings - partial substitution by biomass, natural gas, or H2 • Substantial reduction of other emissions	
Maturity	• Laboratory: done • Pilot: done • Demonstrator: tbc • Deployment: > 2020 onwards	• Laboratory: done • Pilot: 2013 • Demonstrator: 2020 • Deployment: > 2030 • Other direct reduction (MIDREX is industrial)	• Laboratory: done • Pilot: 2011-2013TATA steel IJmuiden • Demonstrator: 2020 • Deployment: > 2030 • Other smelters (FINEX and COREX are industrial)	• Laboratory: ongoing • Pilot: 2020 • Demonstrator: 2030 • Deployment: > 2040 • Experimental (current pilots work at ~5kg capacity per day)

3 Process changes

For each ambition level, a combination of the various technologies is proposed

Technology applicability along the different ambitions
(% of total steel production, (allocation available of scrap))

Ambition	Oxygen steel			Electric steel		Electrolysis	Proportion of scrap in steel production
	Classic	Top Gas Recyling (HIsarna, not ULCORED)	Hydrogen based reduction	DRI EAF	EAF (Scrap)		
1	✓ 70% (7,7% scrap)	✓ 0% (-scrap)	✓ -	✓ 5% (3,3% scrap)	✓ 25% (25% scrap)	-	(36%)
2	✓ 61% (8,5% scrap)	✓ 2% (0,1% scrap)	✓ -	✓ 6% (4,2% scrap)	✓ 31% (31% scrap)	-	(44%)
3	✓ 48% (9,8% scrap)	✓ 5% (0,5% scrap)	✓ -	✓ 8% (5,2% scrap)	✓ 40% (40% scrap)	-	(56%)
4	✓ 25% (10,0%scrap)	✓ 10% (3% scrap)	✓ -	✓ 10% (7% scrap)	✓ 55% (55% scrap)	-	(75%)

NOTES: Assumption all scrap is used
This lever should be used jointly with the scrap availability lever, specific consumption of the various routes is tailored, assuming 100% scrap based to be 3 times less energy intensive.
To limit economic damage, classic oxygen plants are not all decommissions by 2050, and some are converted to Top gas.
Steel overcapacity context will be adverse to change and investments
SOURCE: Global Calculator consultation & analysis

3 Process changes
For each process route, costs are applied

Blast Oxygen furnace cost assumptions (1)		
€/t crude steel	Retrofit	New
Input	117,36	117,36
Other opex	371,64	371,64
Capex	171	441

Scrap based EAF cost assumptions (2) €/t crude steel	
Input (fuel & material)	58,68
Other opex	430,32
Capex	184

DRI based EAF cost assumptions (2) €/t crude steel	
Input (fuel & material)	74,36
Other opex	497,64
Capex	414

SOURCE: (1) Eurofer Steel Roadmap towards a low carbon economy 2050 (2013)
NOTES (2) Excluding decommissioning costs

Process changes
Top gas/HIsarna, Electric steel and Electrolysis condition the applicability of the other levers

Global Calculator

Lever applicability along the main technical options

Type of lever	Improvement Lever	Oxygen steel			Electric steel		Electrolysis
		Classic	Top Gas Recyling (HIsarna, not ULCORED)	Hydrogen based reduction	EAF (Scrap)	DRI EAF	
Product mix	Increase in higher strength steel	✓	✓	✓	✓	✓	✓
Process improvement	Reduction of carboniferous materials (non-fuel related)	/ (Sidmar close to limits)	✓ (already included)	/	/	✓ (already included)	✓ (reduction TBC)
	Smelt reduction	/	(redundant with Ulcored /HIsarna)	/	/	/	/
Alternative fuels	Coal substitution by gas injection	✓	/	/	/	/	/
	Coal substitution by biomass	✓	/	/	/	/	/
Energy efficiency	Reduce mechanical and thermal losses	✓	/	/	/	/	/
	CHP potential	/	/	/	/	/	/
End of pipe	Carbon capture & storage	✓ (less likely)	✓	/	/	✓	/

Insights applicable along Process improvements, fuel substitution and energy efficiency

- The recent rapid expansion of crude steel production and the resulting additional capacity positively affected the energy efficiency of the industry [(1)]
- Additional capacity has reduced the average age of the capital stock, and the new plants tend to be more energy efficient, although not all have introduced BATs
- In several countries, existing furnaces have been retrofitted with energy efficient equipment, and energy efficiency policies have led to the early closure of inefficient plants
- The sector still has the technical potential to further reduce energy consumption by approximately 20% [(2)]
- There is a multitude of process improvements such as the Near net shape casting which can still be implemented

Source: (1) World Steel, 2011, (2) IEA ETP 2012

Process improvements: Penetration of DRI EAF

Proposed lever ambitions

Comments on EAF DRI technology

- With the data used, EAF DRI has a specific consumption close to 4 times the Scrap EAF and close to the BOF
- It is to note that some sources mention that DRI enables a 20% energy consumption reduction vs BOF(1)
- DRI based EAF production is expected to gain share in total crude steel production
- Assumption DRI will be used in the future unless we don't have any more fracking
- In level 4, this will be 0% (no scrap left)

SOURCE: (1) Eurofer Steel Roadmap towards a low carbon economy 2050 (2013)
NOTES (2) Excluding decommissioning costs

3

Process improvements: Top-gas recirculation/HIsarna

Proposed lever ambitions

Comments on Top-gas and HIsarna technology

- Retrofits enable a 20%[(1)] consumption reduction
- Greenfield full HIsarna implementation are modelled, these enable a 35% consumption reduction[(3)]
- Carbon capture is modelled by the CCS lever (not here)

NOTES

(1) Eurofer Steel Roadmap towards a low carbon economy 2050 (2013)
(2) Assuming the additional capex,is balanced by the input reduction
(3) Belgian consultation

3

Process improvements: Hydrogen based reduction

Proposed lever ambitions

Level 1	Level 2	Level 3	Level 4
Minimum effort (following current regulation)	**Moderate effort** easily reached according to most experts	**Significant effort** requiring cultural change and/or important financial investments	**Maximum effort** to reach results close to technical and physical constraints
• 0%	• 0%	• 0%	• 0%

This technology is considered a far away technology breakthrough and we therefore do not include it, even in level 4 ambition

SOURCE: Steel consultation Wallonia Low Carbon 2050

Figures of July 2014

3

Process improvements: Electrolysis
Proposed lever ambitions

Global Calculator

Level 1	Level 2	Level 3	Level 4
Minimum effort (following current regulation)	**Moderate effort** easily reached according to most experts	**Significant effort** requiring cultural change and/or important financial investments	**Maximum effort** to reach results close to technical and physical constraints
• **0%**	• **0%**	• **0%**	• **0%**

This technology is considered a far away breakthrough (current pilots work at ~5kg capacity per day[(1)]) and we therefore still do not include it in level 4 ambition

SOURCE: Steel consultation Wallonia Low Carbon 2050

3

Fuel substitution : Coke substitution by Gas injection
Proposed lever ambitions

Global Calculator

Level 1	Level 2	Level 3	Level 4
Minimum effort (following current regulation)	**Moderate effort** easily reached according to most experts	**Significant effort** requiring cultural change and/or important financial investments	**Maximum effort** to reach results close to technical and physical constraints
• **0% coke replaced by gas in non-Hisarna oxygen**	• **2% coke replaced by gas in non-Hisarna oxygen**	• **3% coke replaced by gas in non-Hisarna oxygen**	• **5% coke replaced by gas in non-Hisarna oxygen**

Lever cost
€/t crude steel

Input (fuel & material)	Cost of fuels
Other opex	0
Capex	0

SOURCE: Steel consultation Wallonia Low Carbon 2050

3 Fuel substitution : Coal substitution by biomass
Proposed lever ambitions

Level 1	Level 2	Level 3	Level 4
Minimum effort (following current regulation)	**Moderate effort** easily reached according to most experts	**Significant effort** requiring cultural change and/or important financial investments	**Maximum effort** to reach results close to technical and physical constraints
• **/**	• **Substitution of 15% coal PCI by biomass in non Hisarna oxygen**	• **idem level 2**	• **idem level 2**

This technology has limited impact after HIsarna

Lever cost €/t crude steel	
Input (fuel & material)	Cost of fuels
Other opex	0
Capex	0

SOURCE: SERPECCC study

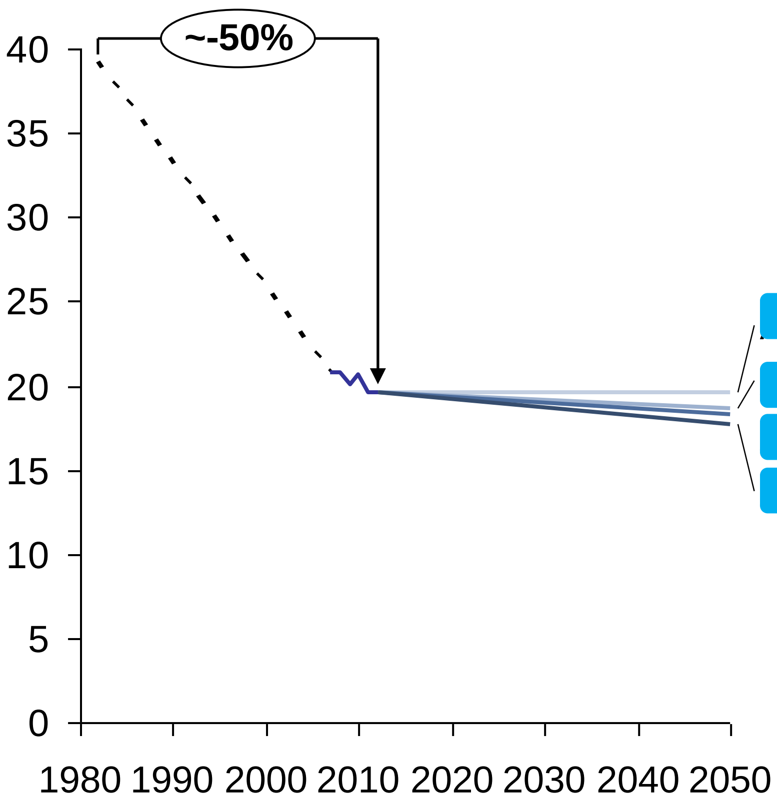
Global Calculator

3

Energy (and material) efficiency

Energy efficiency has drastically improved over the last 30 years, leaving limited improvement on existing technology

Energy intensity (1) (2)
(GJ/ton crude steel)



- With strong historical improvement in energy efficiency, we assume limited further improvement (with same technologies)
- There is ~25% scrap through the chain which can be reused (this is accounted through additional scrap availability in level 4 and not here)
- Downstream processes also reveal significant improvement potential; In the EU, through downstream improvements, total energy efficiency could be improved by 5% (4)
- However, replacing all existing plants by BaT will enable a certain reduction
- Efficiency improvements are only applied on non-Hisarna BOF

Lever cost (3) €/t crude steel

Input (fuel & material)	-x
Other opex	0
Capex (Assuming 5 years payback on energy savings)	127 +x

SOURCE: (1) Worldsteel sustainable steel policy & indicators 2013
(2) Worldsteel: Steel's contribution to a low carbon future
(4) Global Calculator consultation
NOTE: (3) Assuming the additional capex is balanced by the input reduction

Global Calculator

3 Energy efficiency : CHP potential

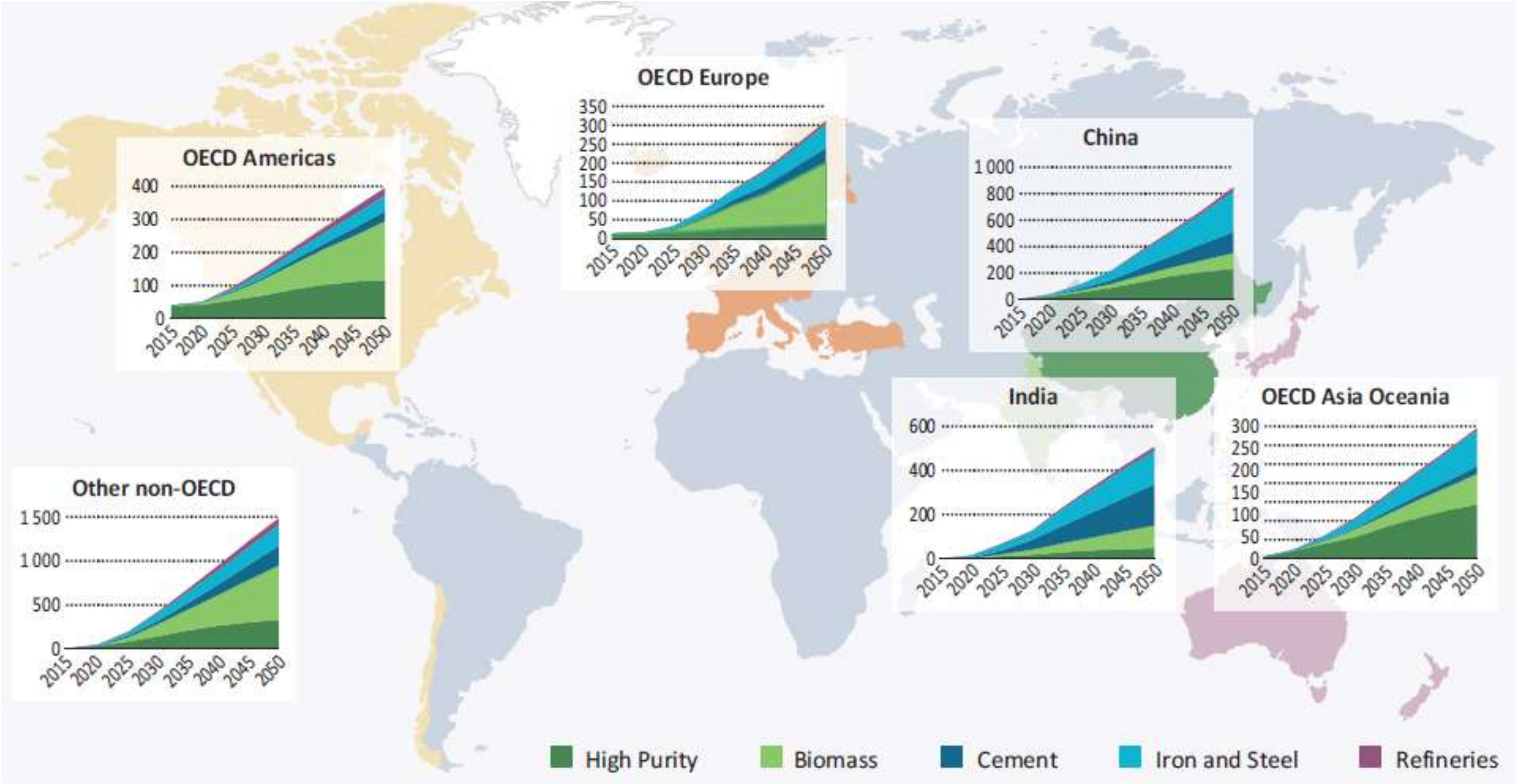
Proposed lever ambitions

Level 1	Level 2	Level 3	Level 4
Minimum effort (following current regulation)	**Moderate effort** easily reached according to most experts	**Significant effort** requiring cultural change and/or important financial investments	**Maximum effort** to reach results close to technical and physical constraints
• **No additional potential**	• **No additional potential**	• **No additional potential**	• **No additional potential**

No potential remains after all energy efficiency measures have been implemented

NOTE: (1) Includes the behavioural, the energy audits

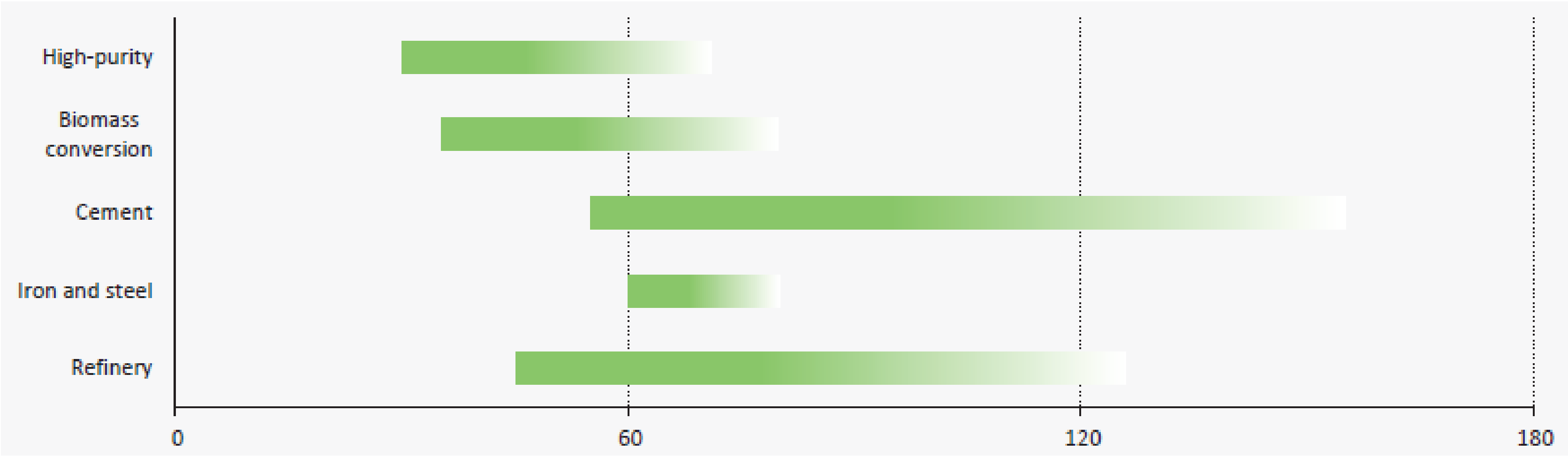
Capture rate
($MtCO_2$/year)



SOURCE: IEA ETP 2012

Cost per industry as per the IEA ETP 2012

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



In addition, an electricity consumption of 0,33 TWh/MtCO_2e captured is modelled

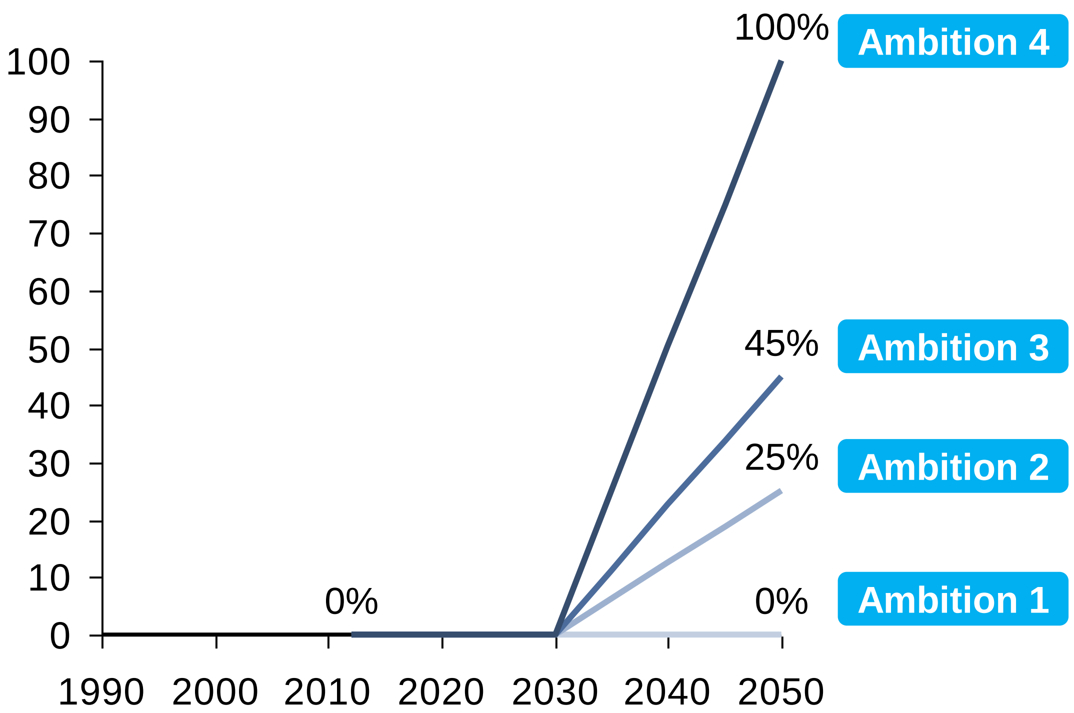
NOTE: The range of costs shown here reflect the regional average costs of applying CCS in each sector, and, therefore, the overall cost of abatement in a sector will be affected by the assumed level of CCS uptake in each sector (IEA, 2009 and IEA and UNIDO 2011). These costs include the cost of capture, 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

Penetration of CCS
(% of plants equipped)



- Several pilots available but industrial scale not rolled out before 2030
- Could be cheaper than top-gas recycling to reduce emissions (2)
- Ambition 3 aligned to ETP 2012 ambition of 40-45% plants
- 80% capture rate (1)
- Only applied on oxygen steel & DRI in levels 1,2,3 & 4
- The specificities of CCS in the steel sector (e.g. energy consumption) should be refined in a later version of the model

Lever cost (2)

Input (fuel & material)	0,33 TWh Elec/Mt captured
Other opex	$20 USD/ton captured
Capex	$40 USD/ton captured

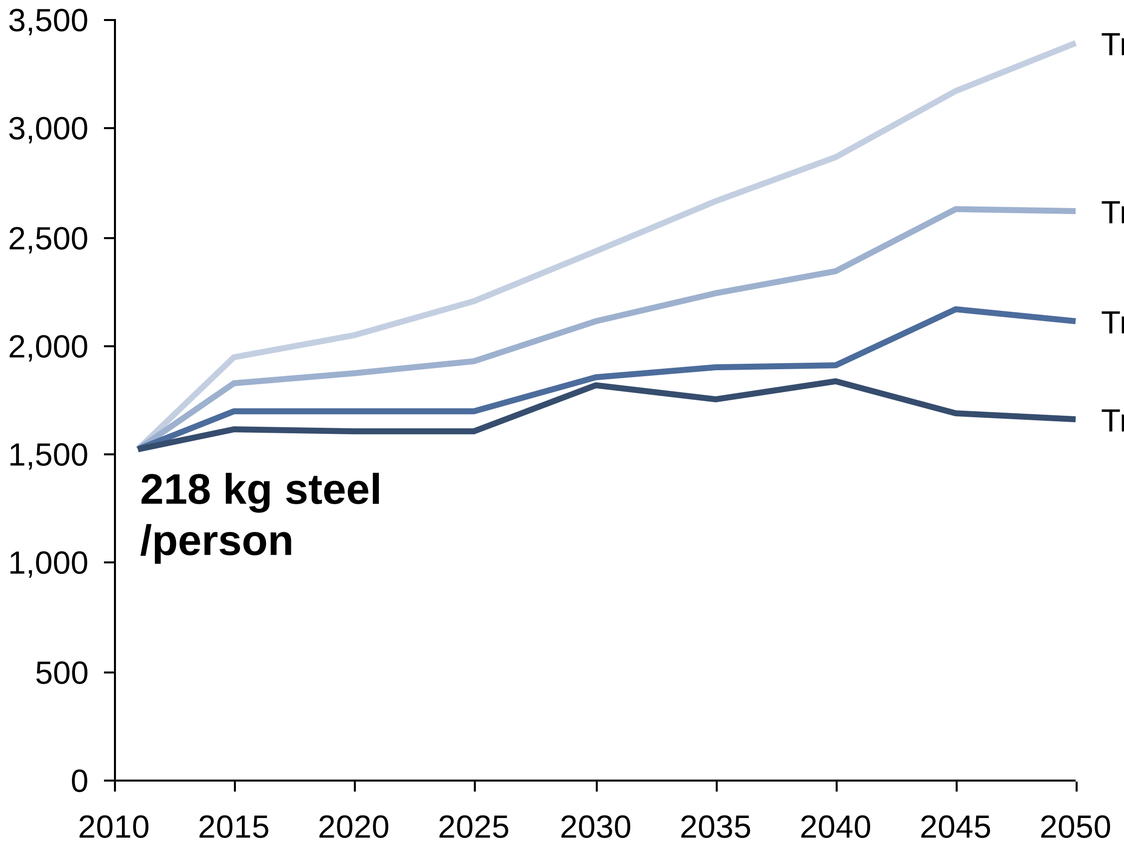
SOURCE: (1) Eurofer Steel Roadmap towards a low carbon economy 2050 (2013), on HIsarna and Ulcored technologies
(2) (Carpenter, 2012, through ETP 2012).

Model growth forecasts

Production according to trajectories 1, 2 and 3 (after design, switch & recycling)

Global Calculator

Steel production per year per ambition [1,2]
(M tons)



	Delta 10-50,%	Implied demand per person
Trajectory 1	+124%	355 kg steel /person
Trajectory 2	+72%	273 kg steel /person
Trajectory 3	+39%	221 kg steel /person
Trajectory 4	+9%	174 kg steel /person

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 aluminium and plastics sectors)

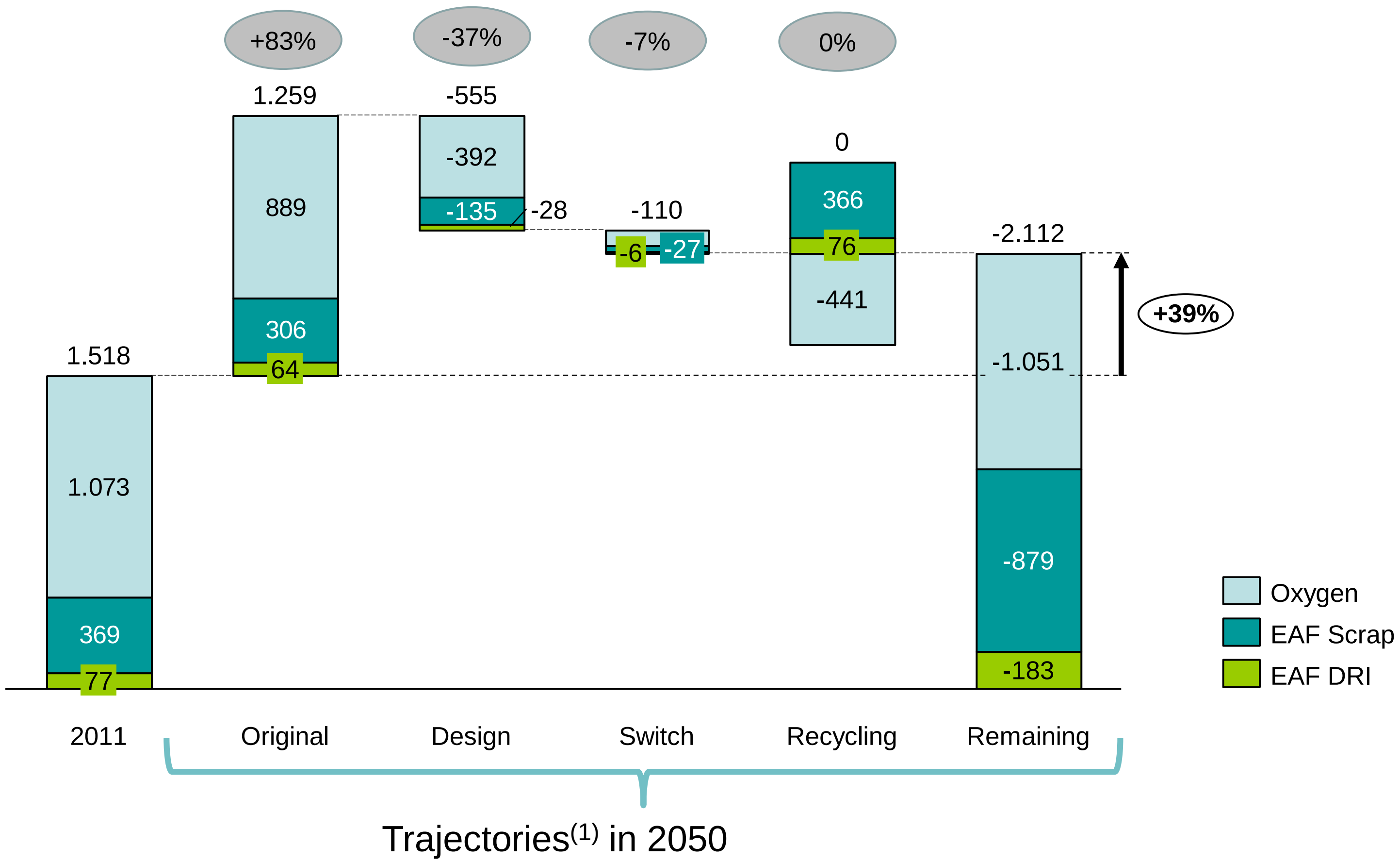
SOURCE: IEA ETP 2012, Global calculator model

Reduction potential

Details for ambition level 3[(1)]

Steel 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

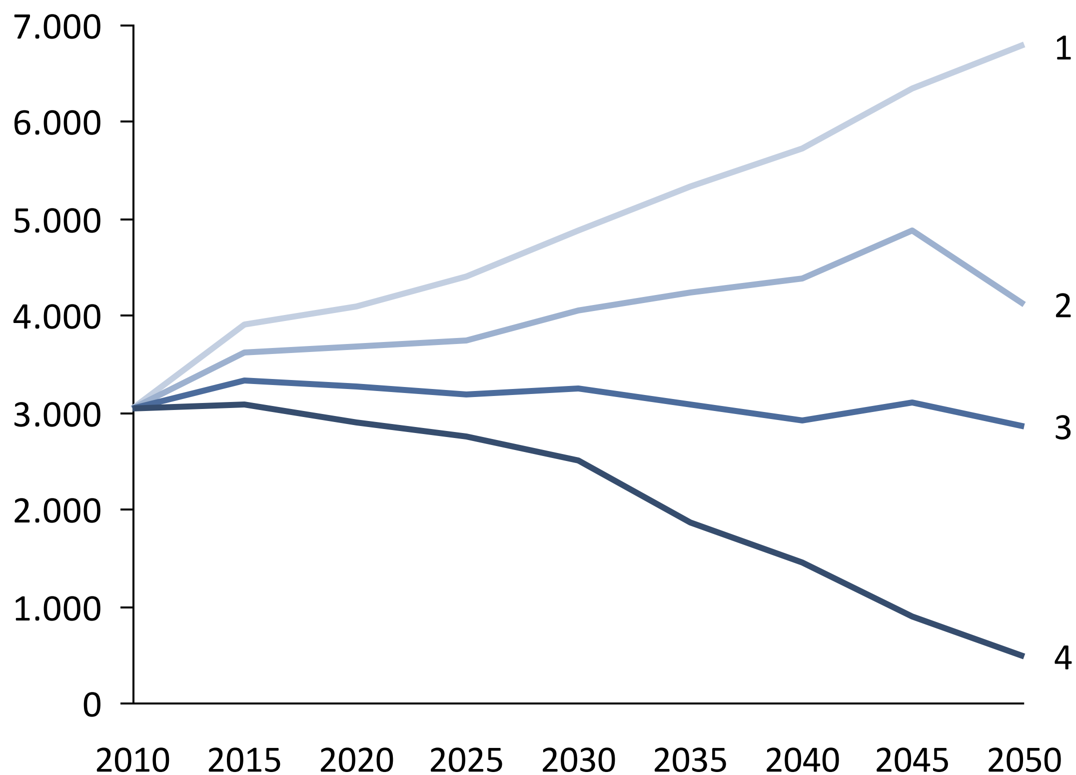
Figures of July 2014

Global Calculator

Reduction potential

Emissions according to different trajectories

GHG emissions for different ambition levels [1,2,3]
($MtonCO_2e$)



	Delta 10-50,%	**Specific emissions**
1	+123%	**2,0 tCO_2e /tsteel**
2	+35%	**1,6 tCO_2e /tsteel**
3	-6%	**1,3 tCO_2e /tsteel**
4	-84%	**0,3 tCO_2e /tsteel**

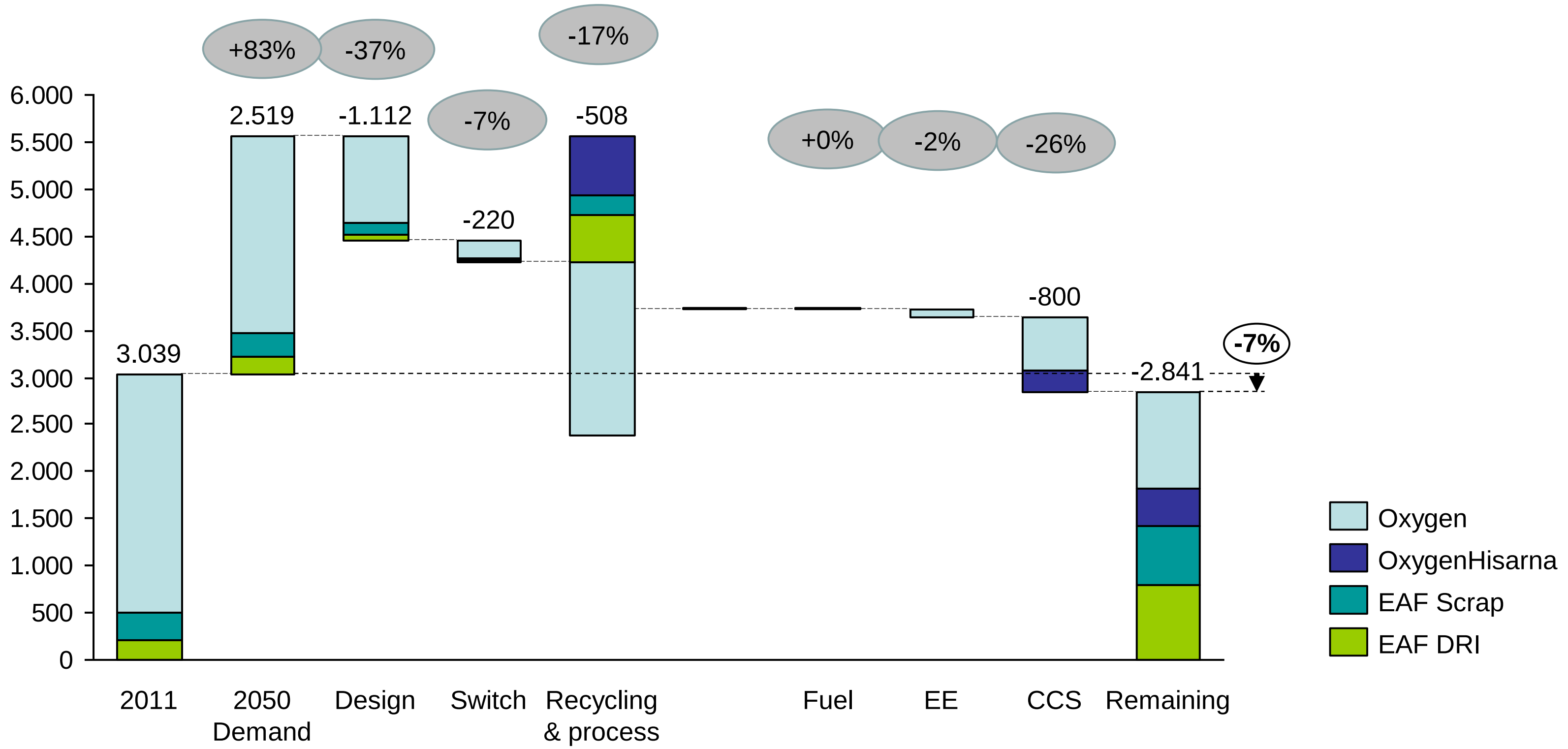
NOTE: (1) The population follows the average UN projection in all four trajectories
(2) Excluding biomass related reductions & electricity related emissions
(3) Other sectors are impacted by these transitions (e.g. additional emissions are created in the aluminium and plastics sectors)

SOURCE: IEA ETP 2012, Global calculator model

Reduction potential

Details for ambition level 3 (1)

Steel 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

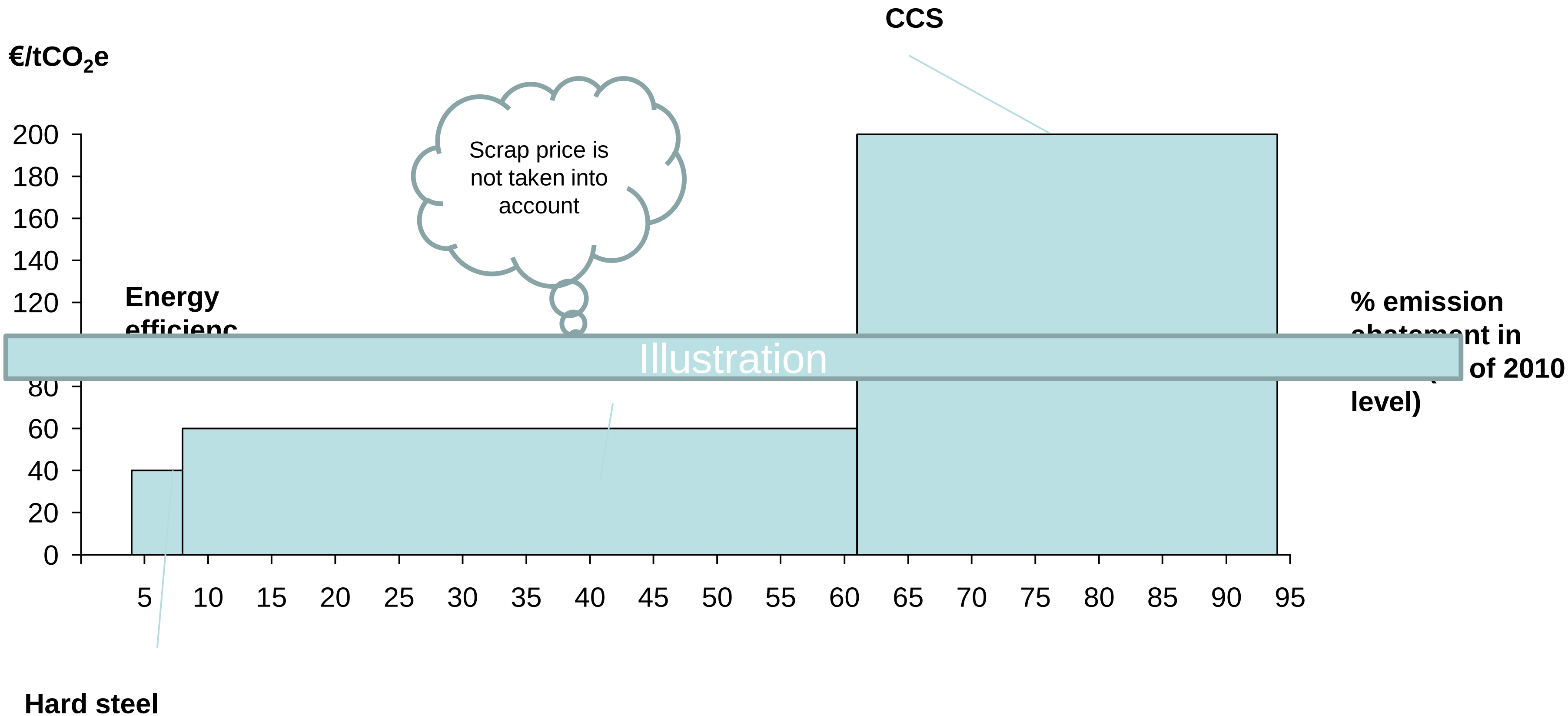
Illustration

Cost

Marginal cost and abatement potential for different levers under trajectory 2 with ambition level 4

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

€/tCO_2e, % emission abatement in 2050 (% of 2010 level)



NOTE: Hypothesis of cost neutral energy efficiency measures , cost of biomass generic across all sectors

SOURCE: Global calculator model

Agenda

Global Calculator

2050 evolution of materials and emissions

Materials demand evolution

- Cross sector demand
- Cross sector material switch
- Steel
- Chemicals
- Aluminium
- Cement
- Paper & Timber

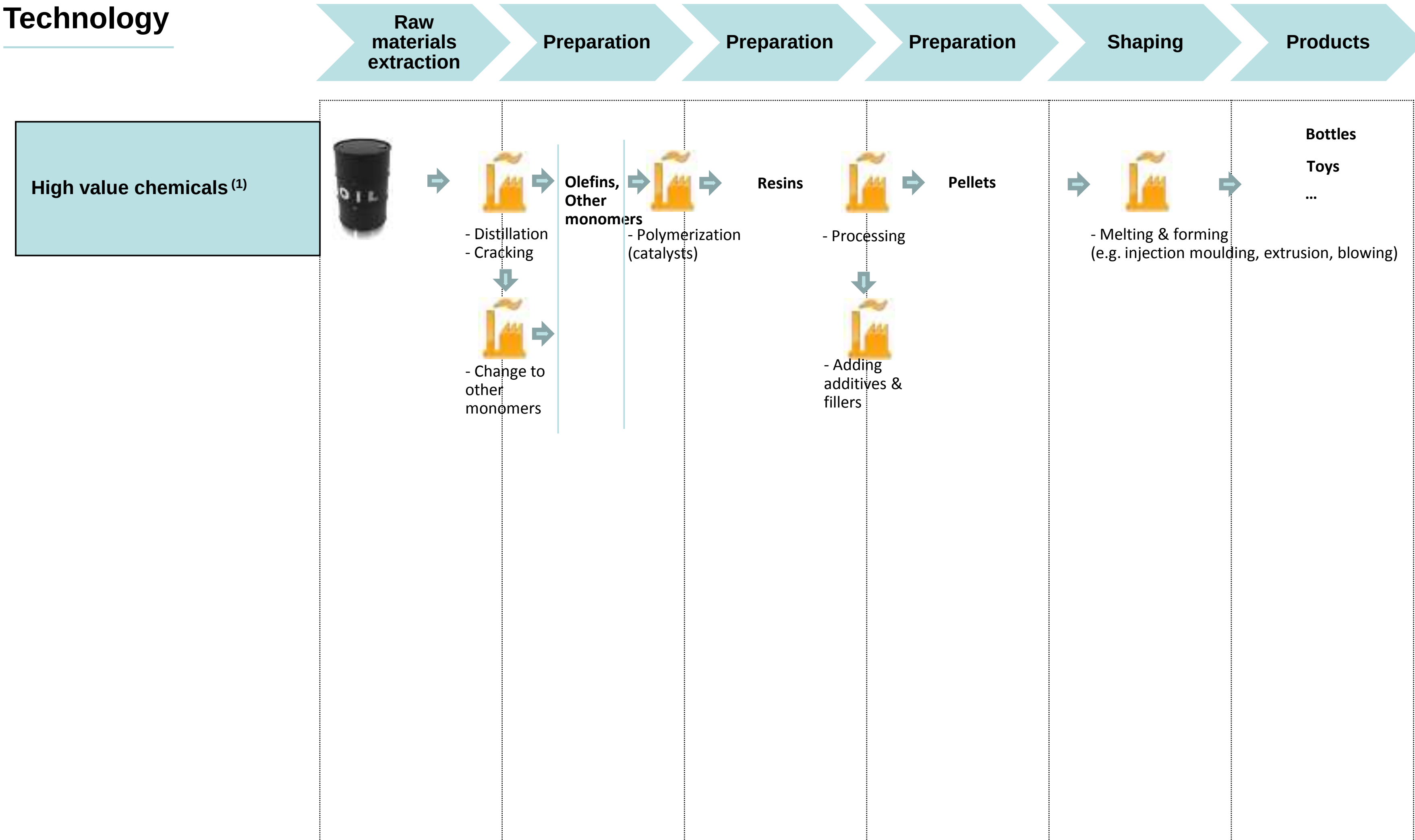
Reduction potential on the manufacturing processes

- Resulting emissions
- Discussion on ambition levels across sectors
- Discussion on CCS
- Steel
- **Chemicals**
- Aluminium
- Cement
- Paper, Timber & Other

130 different industrial processes are used to manufacture the largest 18 volume chemicals, however 4 chemicals families are being assessed

Global Calculator

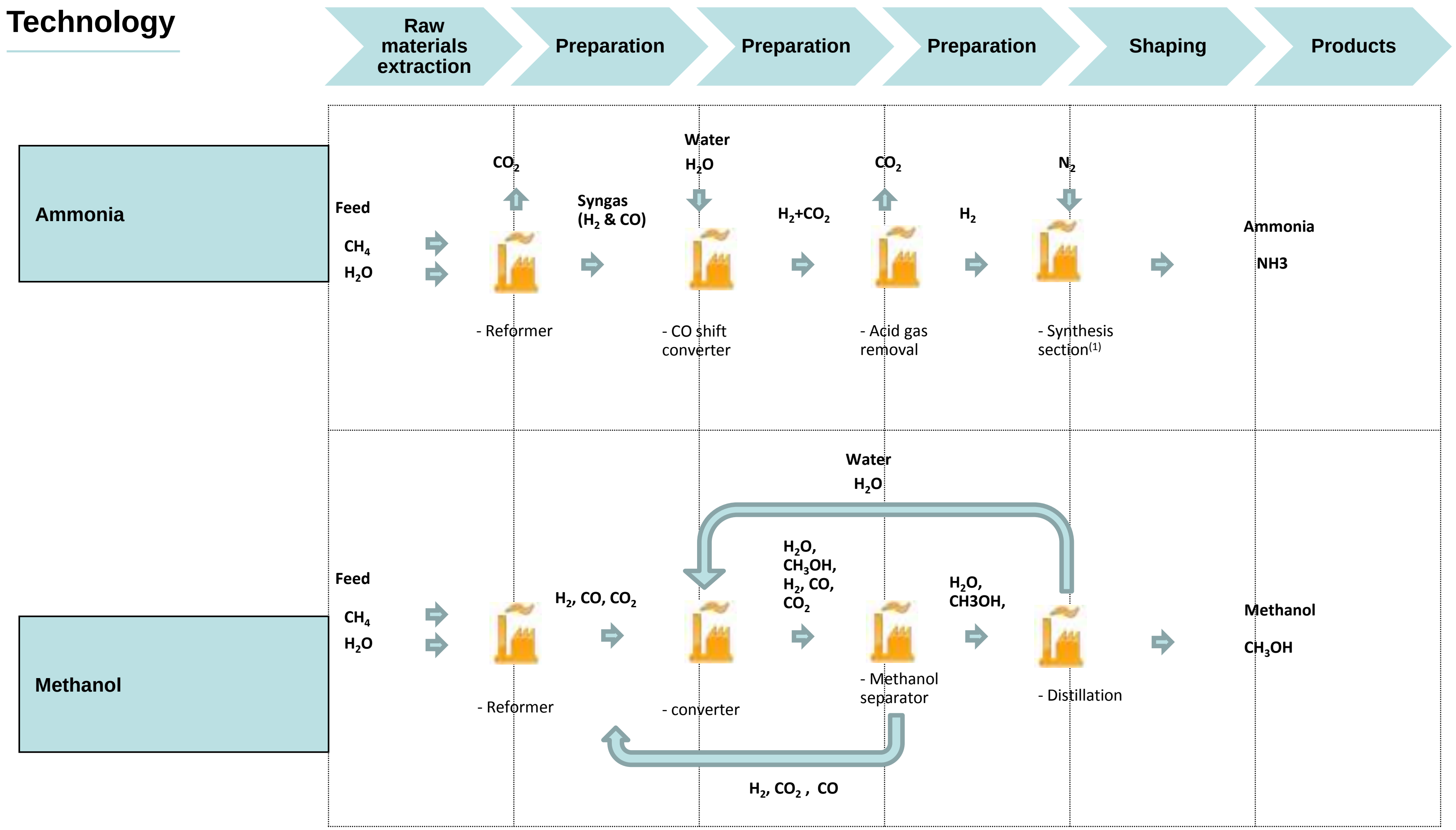
Technology



NOTE: (1)Ethylene, Propylene, BTX aromatics(benzene, toluene and mixed xylenes)
SOURCE: Climact

4 chemicals families are being assessed

Global Calculator

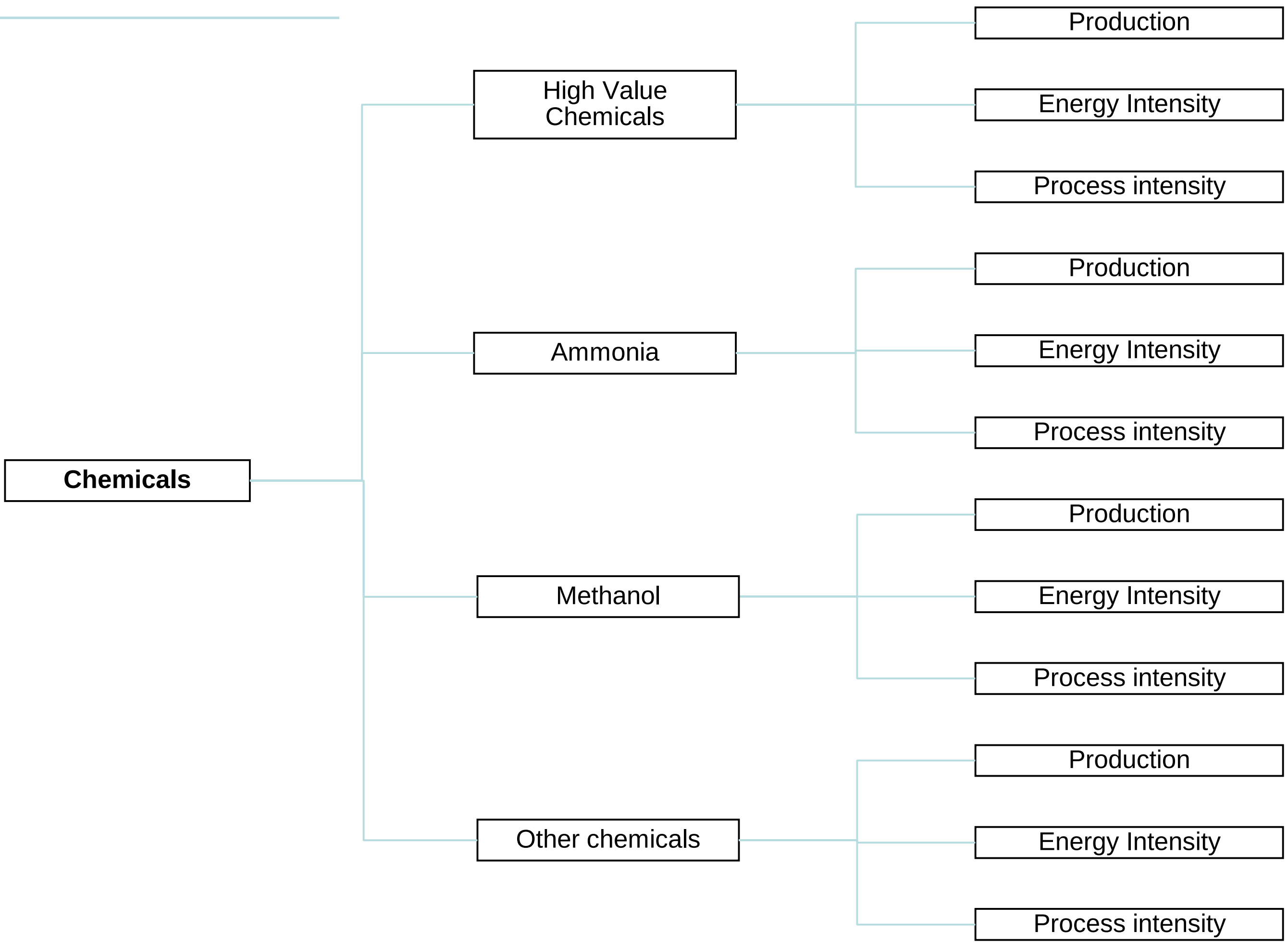


NOTE: Haber-Bosch process
SOURCE: ICCA Catalytic roadmap

Chemicals emissions are being modelled

Global Calculator

Chemicals emission tree



SOURCES: Climact

Structure of the levers

The following levers are applied sequentially

Order and applicability of levers per chemical family

Lever	HVC	Ammonia	Methanol	Other
Material switch	✓	✓	✓	✓
Green plastics	✓	/	/	/
Products recycling	✓	/	/	/
Materials recycling	✓	/	/	/
Improved design	✓	/	/	/
Process changes	✓ Catalytic naphta cracking	✓ Hydrogen production	✓ Hydrogen production	/
Fuel switches	✓	✓	✓	✓
Energy efficiency	✓	✓	✓	✓
CCS	✓	✓	✓	✓

2

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 bio-based plastics
& to timber

Recycling

- Recycle the product or the material

Product recycling

Material recycling

Bio-based plastics

CCU discussion

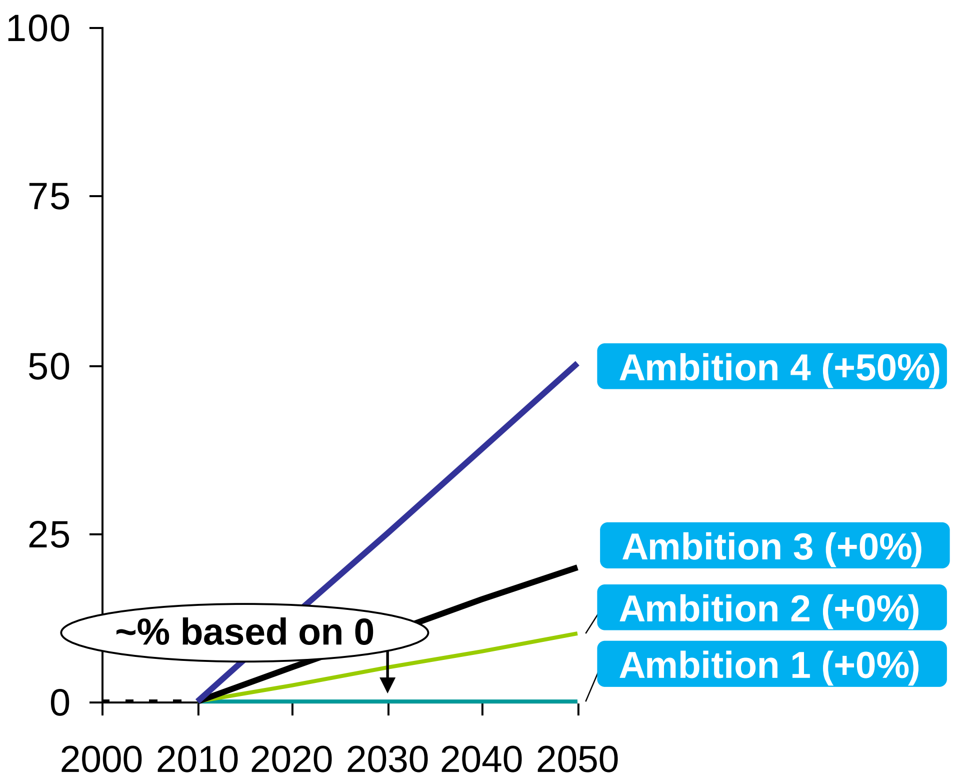
SOURCE: Climact

2

Product mix: Improved design

Chemicals recycling rates are much lower than in other industries

Reduced material demand through improved design (%)



SOURCE: (1) With both eyes open

Rationale

- Improved composites and polymers will have significantly better properties
- Production of plastics leads to limited yield loss (some moulding enable no loss at all)

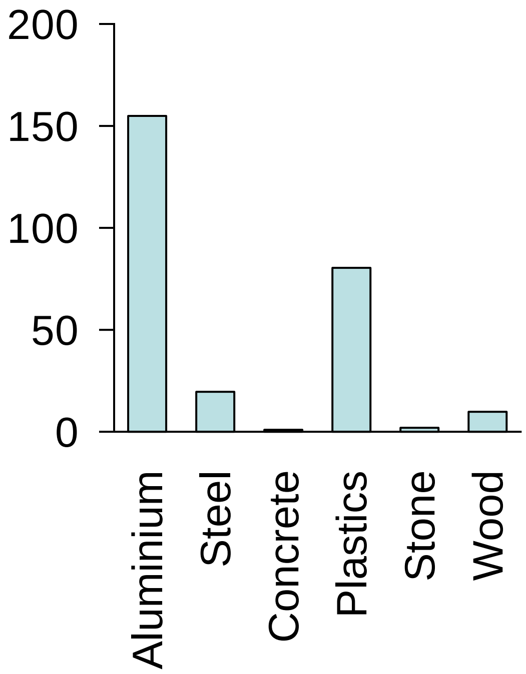
In a later version of the model, Plastics Europe should be contacted to review these assumptions

2 Product mix: Material switch

Steel is a relatively cheap material

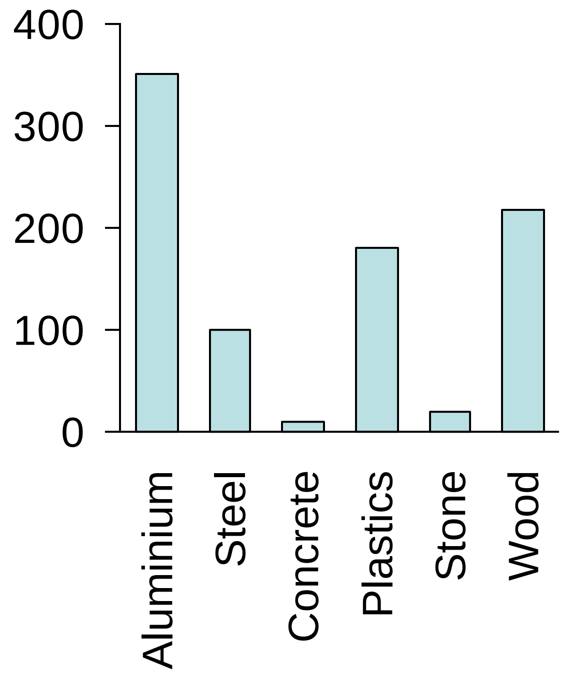
Global Calculator

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

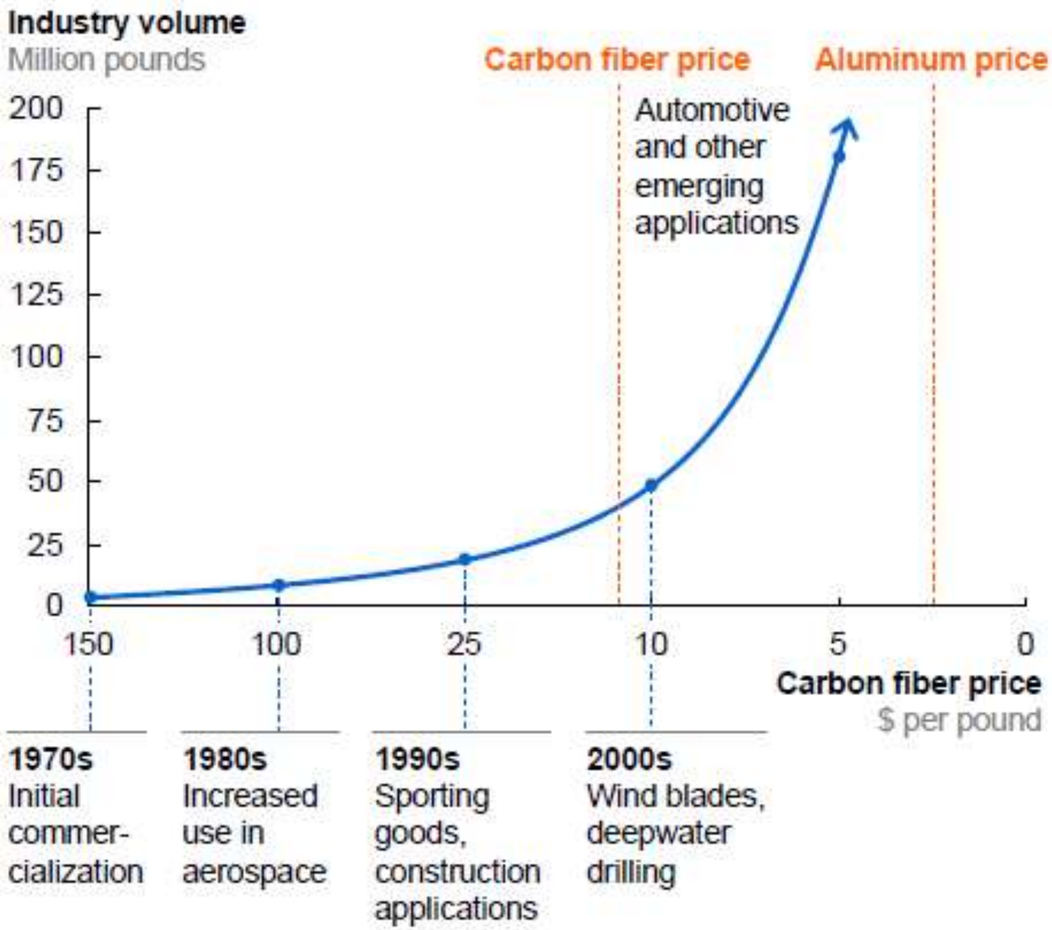
- Compared to other materials, plastics have relatively high embedded energy and useful costs
- If plastics substitutes other materials, it will be for its ease of mouldability or characteristics during product life

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

2 Large scale adoption of carbon fibre is hindered by high costs

Global Calculator

Carbon fibre market evolution
(Million pounds)



Penetration barriers

- High cost relative to aluminum is main barrier to adoption
- Penetration in high-end industries will continue, given relative price inelasticity
- Industries also face large sunk cost upon switching to carbon fiber, given change of technology required

SOURCE: Deutsche Bank; expert interviews; Zoltek; McKinsey Global Institute analysis

Chemicals

Chemicals can substitute other materials if they enable emissions during the whole product life cycle

In a later version of the calculator, include feedback from:

- Plastics Europe
- Car manufacturers

Materials which can replace /be replaced by chemicals

	Characteristics		Chemicals replacement assumption			
	Advantages	**Weaknesses**	**HVC**	**Ammonia**	**Methanol**	**Other**
Aluminium	Recyclability Lower cost & embodied energy	Density	Not modelled	Not modelled	Not modelled	Not modelled
Steel	Recyclability Lower cost & embodied energy	Density Corrosion	Substitutes steel in vehicles & buildings /infrastructure (3)	Not modelled	Not modelled	Not modelled
Concrete	"Recyclability", Low cost & embodied energy, no corrosion	Weak in tension	Insulation materials substitutes cement in buildings/infrastructure (1)	Not modelled	Not modelled	Not modelled
Stone & Masonry	Lower embodied emissions	Must be reinforced with mortar. Cannot be reinforced or moulded	Not modelled	Not modelled	Not modelled	Not modelled
Biomass (Timber /paper)	high strength and stiffness per density (1)	Less durable, sensitive to fire and rot, less stable	Not modelled (1)	Not modelled (1)	Not modelled (1)	Not modelled (1)

NOTES: (1) Development of mega cities increases demand for noise and heat insulation products. Performance will take a larger role (e.g. to gain space)
(2) Green chemistry is modelled in another lever
(3) 15% of plastics in cars today. With trend towards EV, there will be more emphasis on the need for light weight materials

Figures of July 2014

2 Product mix : Material switch
Proposed lever ambitions

Level 1	Level 2	Level 3	Level 4
Minimum effort (following current regulation)	**Moderate effort** easily reached according to most experts	**Significant effort** requiring cultural change and/or important financial investments	**Maximum effort** to reach results close to technical and physical constraints

• **Vehicles:** 0% switch
• **Buildings:** 0% switch
	• **Vehicles**
	  • 5% steel ➔ plastics
	• **Buildings/Infra:**
	  • 5% cement ➔ green plastics
		• **Vehicles**
		  • 10% steel ➔ plastics
		• **Buildings/Infra:**
		  • 10% cement ➔ green plastics
			• **Vehicles**
			  • 20% steel ➔ plastics
			• **Buildings/Infra:**
			  • 20% cement ➔ green plastics

Lever cost (€/t chemicals)	
Steel➔ Plastics	0
Concrete➔Plastics	0

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

Product mix: Bio-based plastics (1/4)

The “bio” can be in one of two dimensions

Global Calculator

Share of green plastics
(%) [1]

	Plastic is Non bio- degradable	Plastic is Bio-degradable
From renewable materials	**Biopolymers** • e.g. BioPE (PP/PET), biosourced PA, PTT	**Biopolymers** • e.g. PLA, PHA, • Amidons
From fossil materials	**Conventionnal polymers** • Nearly all conventional plastics • e.g. PE, PP, PET	**Biopolymers** • e.g. PBAT, PBS, PCL

Addressed by bio-based plastics lever (renewable materials row)

Addressed by recycling lever (non bio-degradable column)

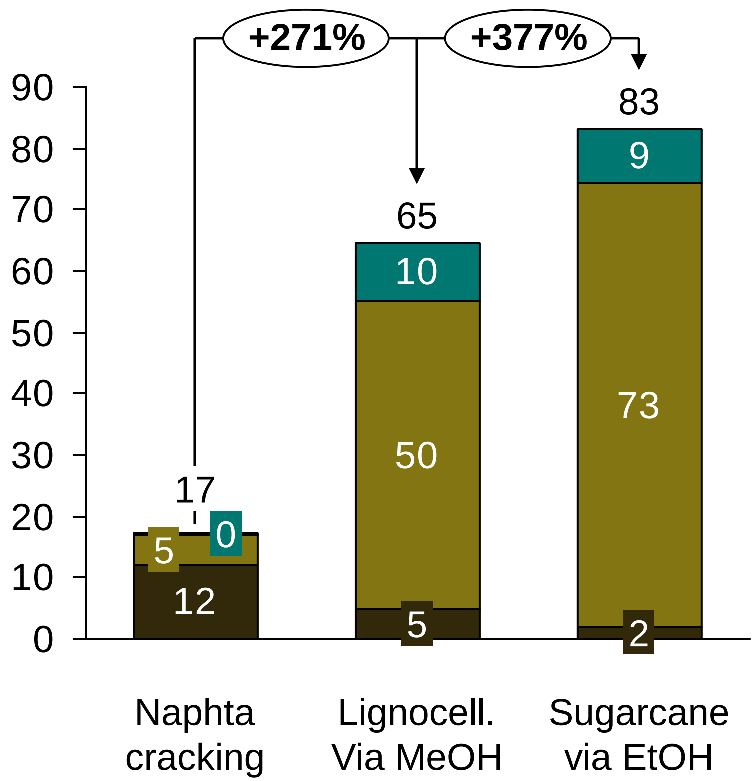
Not modelled; considered a small part of the total

NOTES: Biomass availability is constrained, and enters in competition with biomass use for food, other products and energy.
The Global calculator illustrates the impacts of using biomass
Some estimates lead to 10% of biomass in feedstock, (these figures include a wider scope e.g. biofuels and waste from slaughter houses)
SOURCE: (1) Fost+ environmental impact of biopackaging

Product mix: Green plastics (2/4)

Using biomass feedstock can be significantly more energy intensive than the established fossil-based routes

Energy use for biomass versus fossil routes to HVC
(GJ/t HVC)



- The previous slides notes the competition for biomass. Likewise, there is competition for fossil fuels (between energy and product applications)
- This model does not look at the subsidies dimension, it is worth noting however that there are currently no subsidies planned for sequestring CO_2 in products (e.g. ETS only looks at emissions)

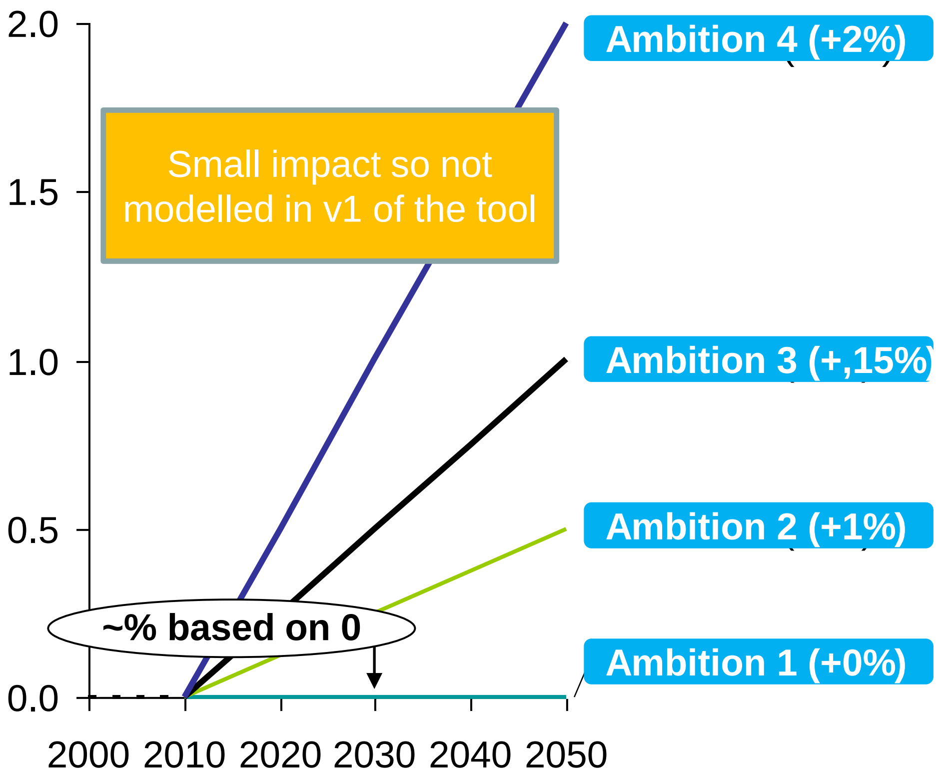
NOTE EtOH= Ethanol
SOURCE: (1) DECHEMA

2

Product mix: Green plastics (3/4)

Only a small proportion of plastics can be made from biomass

Share of green plastics within HVC
(%)



Rationale on green plastics rates

- Several monomers, such as the ethylene olefins, can be produced from plants (e.g. sugar cane)(2)
- More generally the feedstock can be made from biomass
- Bioplastics also tend to be more biodegradable than oil based plastics (but all 4 combinations are possible)
- Overall, the energy consumption of the relevant biomass routes is 3.5 to 5 times that of the fossil route (2) . We assume it requires no more fossil energy
- Catalysis process changes (lever addressed later) facilitate the inclusion of biomass feedstock

Lever cost (€/t chemicals)	
Specific consumption	*4

NOTE: (2) The largest commercial activity currently takes place in Brazil, where the Brazilian petrochemical company Braskem operates the first industrial-scale sugarcane-based ethanol plant (200 kt/yr capacity) for subsequent polyethylene production.

SOURCE: (1) With both eyes open (2) ICCA

2

Product mix: Green plastics (4/4)

Caveat on modelling

CCU was not modelled at significant scale in this version of the tool

- For higher rates of Carbon Capture & Usage (CCU), the development of a hydrogen supplychain was required
- Hydrogen supply chain has since been modelled in industry in the second version of the calculator

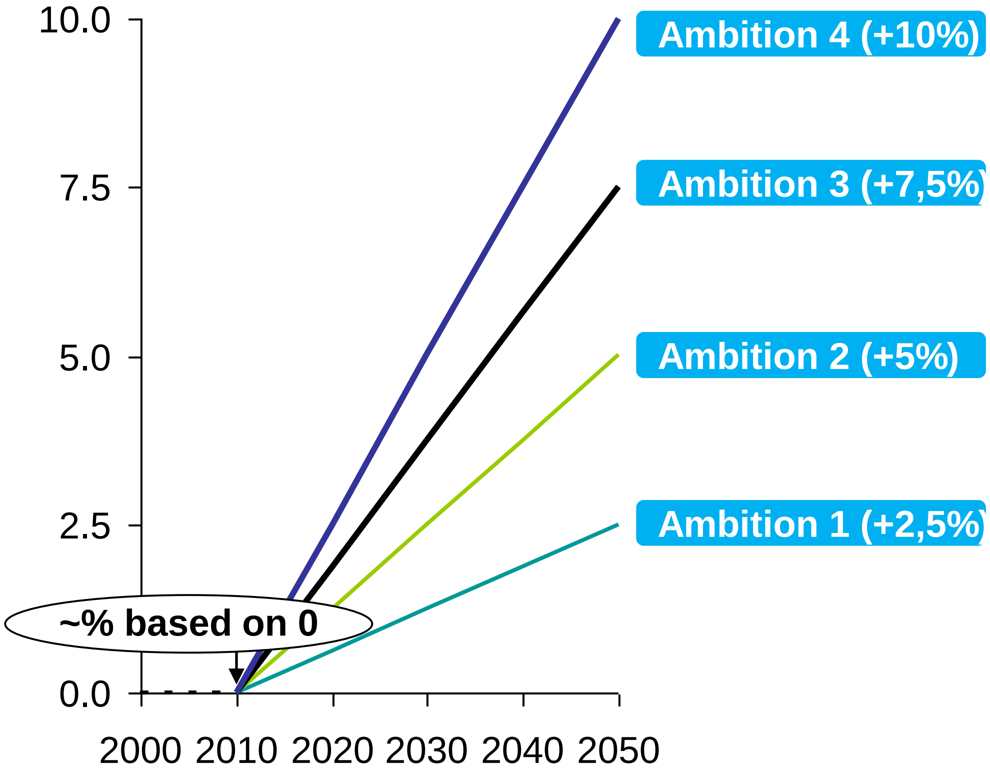
Figures of July 2014

2 Product mix: Products recycling

The chemicals product recycling lever is assessed

In a future version of the model, consult Plastics europe to assess how much plastics is recycled today

Recycling share
(%)



Rationale on product recycling

Design will evolve to make products more recyclable
Product recycling is difficult because of the large amount of different plastic applications, and the cheap price of plastics
2 application areas are identified:

- Packaging in the UK
  - ~20kg packaging /person/year is in the end consumer waste
  - ~30kg packaging /person/year is for moving goods from factory to factory or shops
  - There is a potential to further recycle packaging products, especially the reuse of industrial packaging
- Construction
  - Pipes could be dismantled and reused
  - Car components could be reused

Lever cost
(€/t chemicals)

0 (also generates value)

NOTE: (1) Only applied to non biodegradable plastics

2

Product mix: Materials recycling
Chemicals recycling rates are much lower than in other industries

Global Calculator

Rationale on plastics recycling rates

- Low plastics value and higher recycling complexity make plastic recycling less attractive
- Higher complexity comes from :
  - the higher variability of plastic manufacturing processes and additives (to change colours & properties) & fillers (cheaper materials which increase strength & hardness)
  - The fact plastics are harder to isolate from other waste streams (e.g. it is weakly magnetic)
  - Only thermoplastics can be recycled (not the thermosets) (2)

Solutions

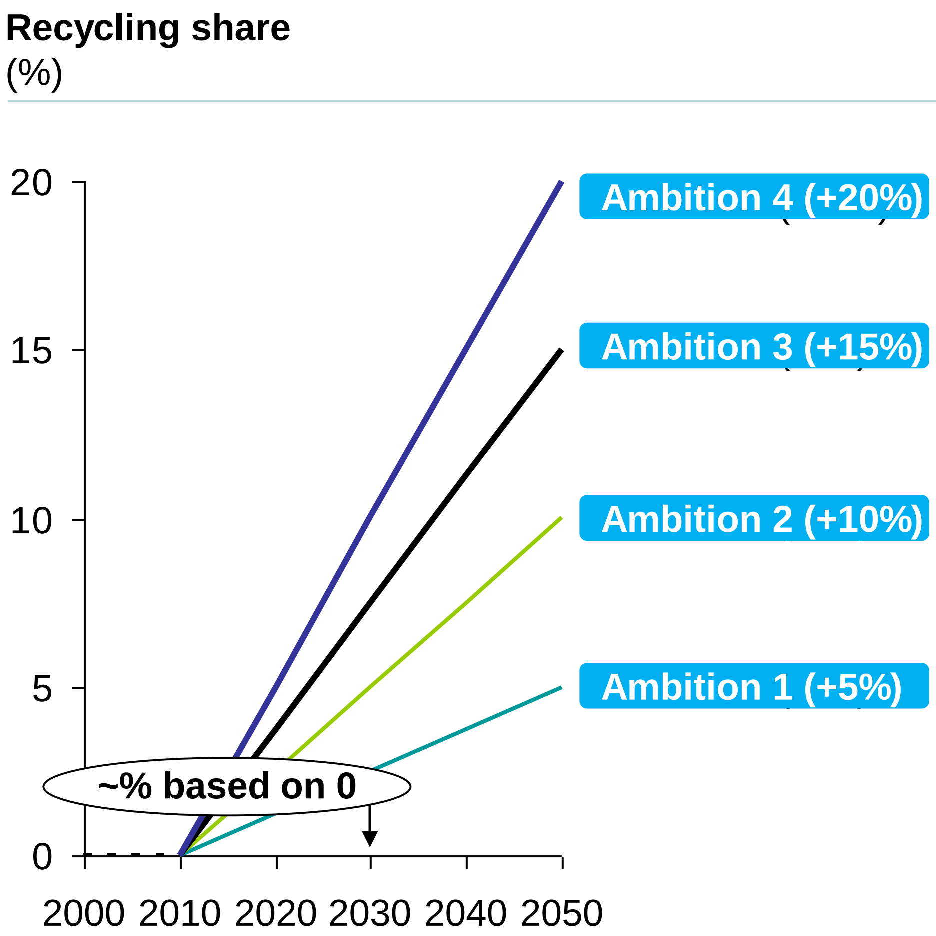
- Production scraps can easily be recycled (not much improvement potential is expected here)
- Improved separation of plastics waste streams from municipal waste (difficult because diverse)
- Improved sorting of plastics waste stream (difficult because similar density and optical properties)
- There are 4 levels of recycling :
  - Primary recycling: material is directly re-extruded
  - Secondary recycling: plastics is ground in small chips, washed, dried & converted in resins (lower quality)
  - Tertiary recycling: plastics are broken down chemically to produce new feedstock (e.g. by pyrolysis)
  - Quaternary recycling: recovery of energy through incineration (this is addressed in the supply/waste analysis, not in manufacturing)

NOTE: (2) There are 2 families of plastics A) Thermoplastics which represent most of the plastics. These can be melted and reformed several times. B) Thermosets, which represent a smaller portion of the plastics. These change irreversibly on being heated, mixed, irradiated, and cannot be recycled (e.g. glass & carbon fibers)
SOURCE: (1) With both eyes open

2

Product mix: Materials recycling

A higher proportion of plastics can be made from these 4 recycling levels



Simplifying assumption: applyied to all chemicals, even though ammonia fertilizers will not have recycling potential

Lever cost (€/t chemicals)
0 (also generates value)

SOURCE: (1) With both eyes open

3

Carbon intensity of material production

The chemical sector has significantly improved historically but major improvements are still available

Global Calculator

Historical improvements

The sector has recently strongly improved it’s energy efficiency

For example, in the US, energy intensity of the chemical sector improved by 39% and GHG emissions intensity was reduced by 10% between 1994 and 2007 [1]

Remaining improvement levers

Various levers are available:

- Better heat integration
- Catalyst tweaks
- State- of-the-art equipment
- Better catalysts
- Separations
- …

SOURCE: (1)ICCA catalytic roadmap

Carbon intensity of material production

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

List of actions & levers assessed

Process improvement

- Towards fuels which emit less CO_2

Various

Fuel substitution

- Modification of processes

Biomass

Waste

Energy efficiency

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

Insulation

CHP/ heat recovery

Various

End of pipe technologies

- Carbon capture and storage

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

Several process improvements could entirely change the energy consumption structure

Global Calculator

Process improvement examples

High value chemicals	• Olefin production via catalytic cracking of naphtha and via methanol, moving away from steam cracking	Could deliver energy savings of 10% to 20% [2]
	• Olefin production via methanol	Not modelled, we simplify assuming all HVC switch to the catalytic process
	• Propylene Oxide (PO)production via the hydrogen peroxide propylene oxide (HPPO) process	Could deliver energy savings of 10-12% [1], but is not modelled cfr supra
Ammonia	• Hydrogen based production of ammonia	+26 GJ/ t ammonia (NH3) Vector switch to 100% electricity
Methanol	• Hydrogen based production of methanol	+15,7 GJ/ t methanol (NH3) Vector switch to 100% electricity
Other chemicals	• Improved hydrogen generation for steam methane reformers • Synthesis of aromatics from lignin, ethanol or methane • Direct synthesis of hydrogen peroxide from hydrogen and oxygen • Direct epoxidation of propylene with oxygen	

SOURCE: (1)ICCA Catalytic roadmap (2) Ren, Patel and Blok, 2006

3

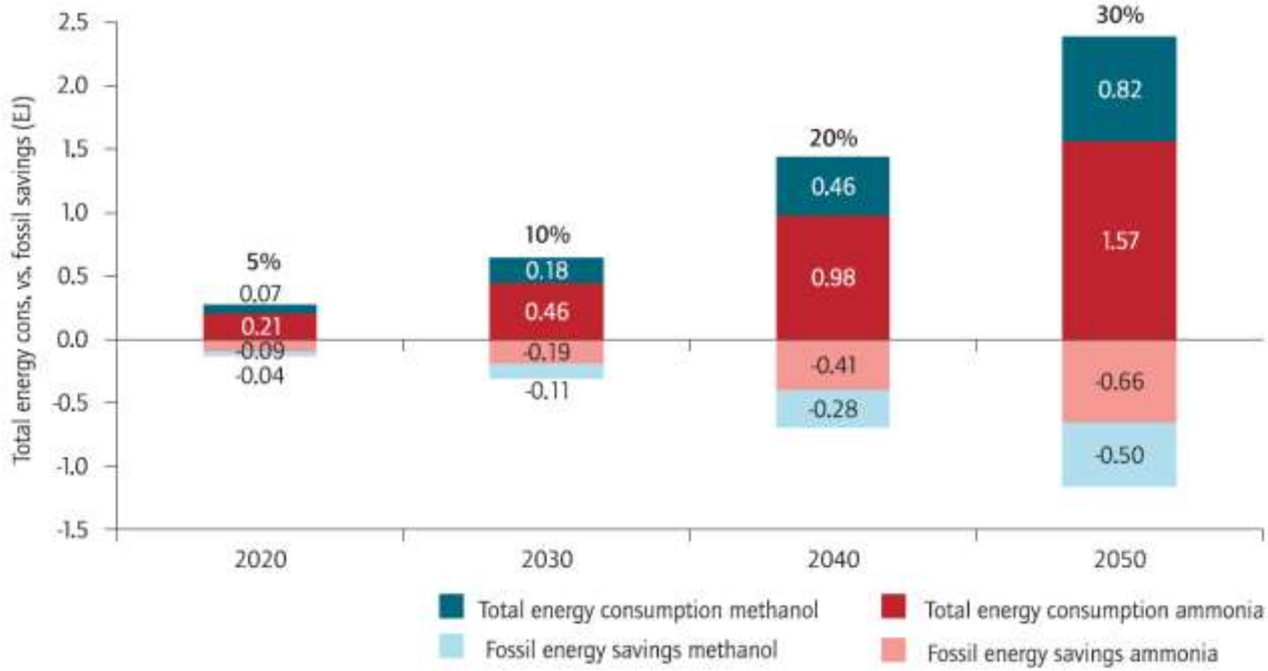
Process improvements

Production of hydrogen from renewables currently uses a lot of energy

Global Calculator

Additional energy demand versus fossil energy savings for replacement of current ammonia and methanol processes by hydrogen-based routes

(% implementation of hydrogen route)



- Ammonia synthesis based on hydrogen from renewable energy sources requires roughly 26 GJ/ t ammonia (NH_3) more energy
  (and we assume a vector switch to electricity)
- For methanol (MeOH) from hydrogen and coal, an additional 15.7 GJ/tMeOH are required compared to the gas steam reforming route and additional 5.6 GJ/tMeOH compared to the coal partial oxidation route
  (and we assume a vector switch to electricity)

SOURCE: (1) DECHEMA, ICCA catalytic roadmap

3 Process improvements

Production of hydrogen from renewables currently uses a lot of energy

Chosen ambition levers

	Process description	Level 1	Level 2	Level 3	Level 4	Modelling
High value chemicals	• Olefin production via naphtha catalytic cracking	0%	-5%	-10%	-20%	Reduction of specific consumption [1]
	• Olefin production via methanol	/	/	/	/	
	• Propylene Oxide (PO)production via (HPPO) process	/	/	/	/	Benefits related to the application of HPPO are included in the above reduction
Ammonia	• Hydrogen based production of ammonia	0%	0%	0%	30%	% switch to new technology +26 GJ/ t ammonia (NH3) Vector switch to 100% electricity
		Not modelled in v1 of the tool				
Methanol	• Hydrogen based production of methanol	0%	0%	0%	30%	% switch to new technology +15,7 GJ/ t methanol (NH3) Vector switch to 100% electricity
		Not modelled in v1 of the tool				
Other chemicals	• Improved hydrogen generation for steam methane reformers • Synthesis of aromatics from lignin, ethanol or methane • Direct synthesis of hydrogen peroxide from hydrogen and oxygen • Direct epoxidation of propylene with oxygen	0%	-5%	-10%	-20%	Assuming same evolution as HVC

Lever cost [1]

Input (fuel & material)	Fuel costs
Other opex	0
Capex	0

NOTE: (1) this is not based on coal, that would increase emissions
SOURCE: (1) DECHEMA, ICCA catalytic roadmap

3 Fuel switches

A significant portion of fuels (excl. feedstock) can be switched to biomass

Chosen ambition levers

	Switch description	Level 1	Level 2	Level 3	Level 4	Modelling
High value chemicals	• Solid & liquid to gaseous	0%	10%	20%	30%	Same specific consumption
	• Solid & gaseous hydrocarbons to biomass (2)	0%	5%	10%	20%	Specific consumption of biomass 5% higher
Ammonia	• Solid hydrocarbons to biomass (2)	0%	5%	10%	20%	Specific consumption of biomass 5% higher
Methanol	• Solid hydrocarbons to biomass (2)	0%	5%	10%	20%	Specific consumption of biomass 5% higher
Other chemicals	• Solid hydrocarbons to biomass (2)	0%	5%	10%	20%	Specific consumption of biomass 5% higher

NOTE: (2) Not related to feedstock (addressed in green plastics lever)
SOURCE: (1) Climact

Lever cost [1]

Input (fuel & material)	Fuel costs
Other opex	0
Capex	0

3 CHP

Up to 20% of the sector electricity can be covered by Combined heat and power units

Chosen ambition levers

	Level description	Level 1	Level 2	Level 3	Level 4	Modelling
High value chemicals	• % of the electricity consumption covered by the CHP	5%	10%	15%	20%	• In this 1st version of the tool, it is approximated by x kwh of electricity which can be replaced by x kwh of gas • This covers the autoproducers • This does not cover the large CHP units which are classified as Electricity producers
Ammonia	• % of the electricity consumption covered by the CHP	5%	10%	15%	20%	
Methanol	• % of the electricity consumption covered by the CHP	5%	10%	15%	20%	
Other chemicals	• % of the electricity consumption covered by the CHP	5%	10%	15%	20%	

Lever cost (1)

Input (fuel & material)	Fuel costs
Other opex	0
Capex	0

NOTE: (2) Not related to feedstock (addressed in green plastics lever)
SOURCE: (1) Climact high level assumption

Energy efficiency
Additional energy efficiency is possible after the previous levers

Energy efficiency rationale (in addition to the technology modifications addressed earlier)

High value chemicals	• Could deliver energy savings ~20% in addition to the process change [(2)]
Ammonia	• Applied on the part not switching to hydrogen based production • Stochiometric : 19,8 GJ/t NH_3 BAT 2050 : 24 GJ/t NH_3 [(3)] • Standard technology 39 GJ/t NH_3 - new BAT technology 28 GJ /t NH_3(-30%)[(1)] • Retrofit options for improvements of reformer section and CO_2 removal section • Potential for low pressure (improved catalysts) and improved process control
Methanol	• Applied on the part not switching to hydrogen based production • Assumption same as ammonia
Other chemicals	• Assumption same as HVC

NOTE: Not related to feedstock (addressed in green plastics lever)
SOURCE: (1) Source : SERPEC study
(2)ICCA Catalytic roadmap
(3) Source: VITO analysis

3

Energy efficiency
Some details are available per industry group

Energy efficiency improvements

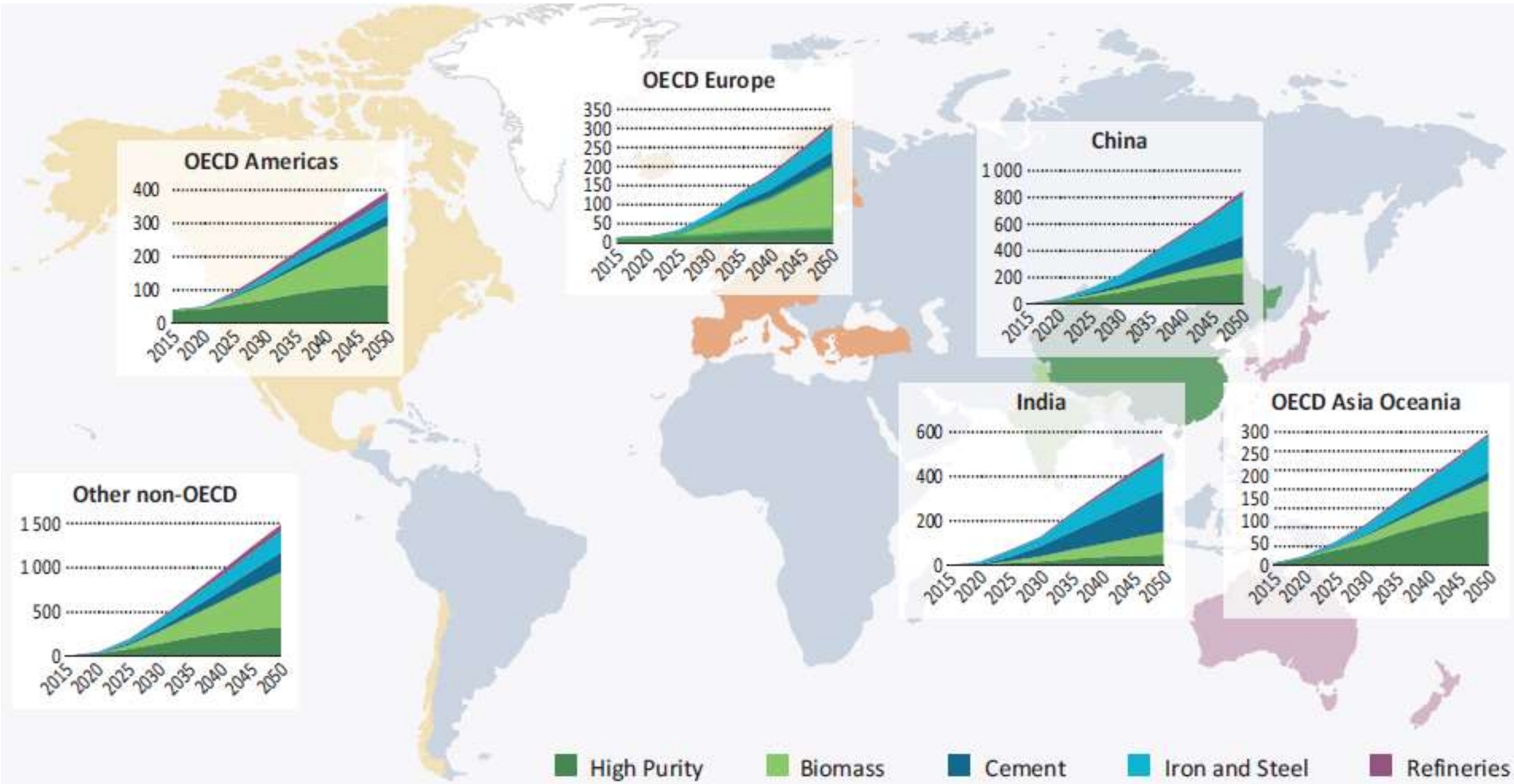
	Description	Level 1	Level 2	Level 3	Level 4	Modelling
High value chemicals	Newer plants &retrofits	0%	-5%	-10%	-20%	Specific consumption reduction
Ammonia	Newer plants &retrofits	0%	-7,5%	-15%	-30%	Specific consumption reduction
Methanol	Newer plants &retrofits	0%	-7,5%	-15%	-30%	Specific consumption reduction
Other chemicals	Newer plants &retrofits	0%	-5%	-10%	-20%	Specific consumption reduction

Lever cost (2)	
Input (fuel & material)	-x
Other opex	0
Capex	+x

SOURCE: (2) Climact assumption

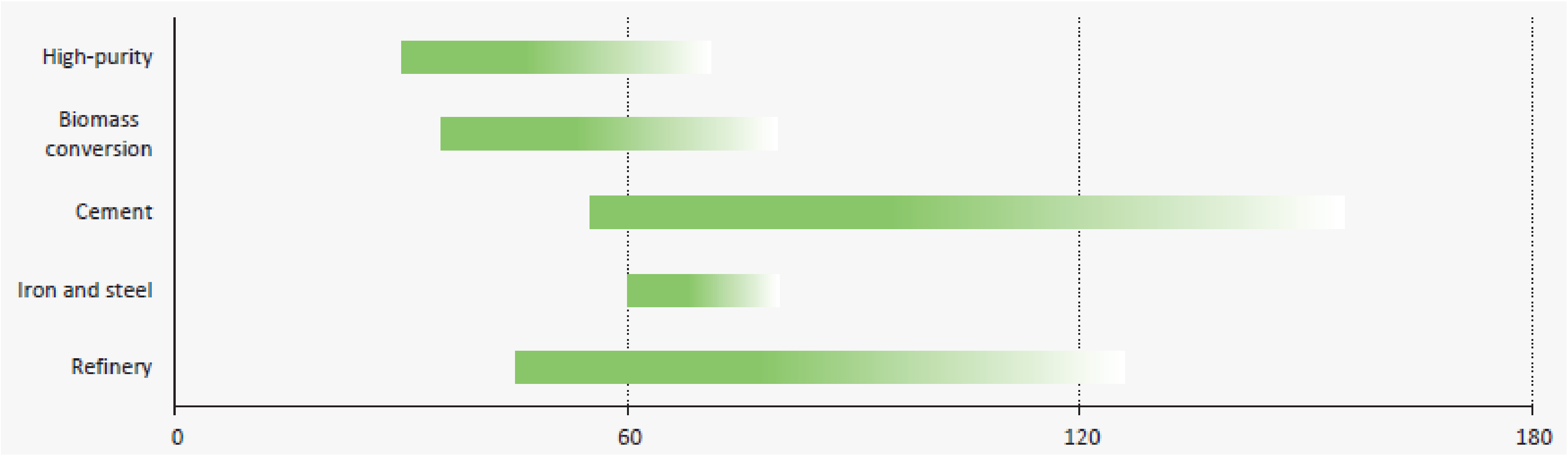
Carbon Capture & Storage
Projections by region

Capture rate
($MtCO_2$/year)



SOURCE: IEA ETP 2012

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



In addition, an electricity consumption of 0,33 $TWh/MtCO_2e$ captured is modelled

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

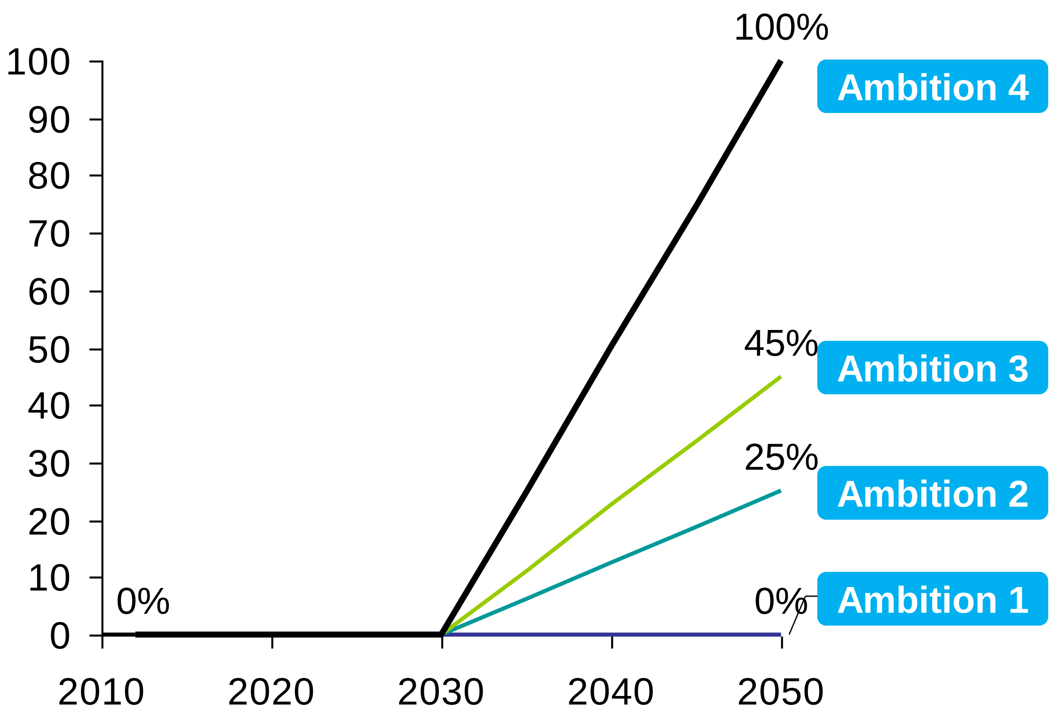
3

Carbon Capture & Storage

Proposed lever ambitions

Global Calculator

Penetration of CCS
(% of plants equipped)



- Large facilities for the production of ammonia, methanol, ethylene oxide, hydrogen and products from coal gasification might have sufficient scale to make CCS financially feasible
- Crackers can also be high-volume sources (1 $MtCO_2$/yr), but their flue gas is more dilute (4% to 7% CO_2, lower concentration than a coal-fired power plant which can be 10% CO_2 to 12% CO_2) and drive up the CO_2 capture costs.
- IEA 2DS suggest a capture of 467$MtCO_2$ for the chemical sector
- 80% capture rate [1]
- The specificities of CCS in the steel sector (e.g. energy consumption) should be refined in a later version of the model

Lever cost [2]

Input (fuel & material)	0,33 TWh Elec/Mt captured
Other opex	$20 USD/ton captured
Capex	$40 USD/ton captured

SOURCE: (1) IEA ETP 2012

Global Calculator

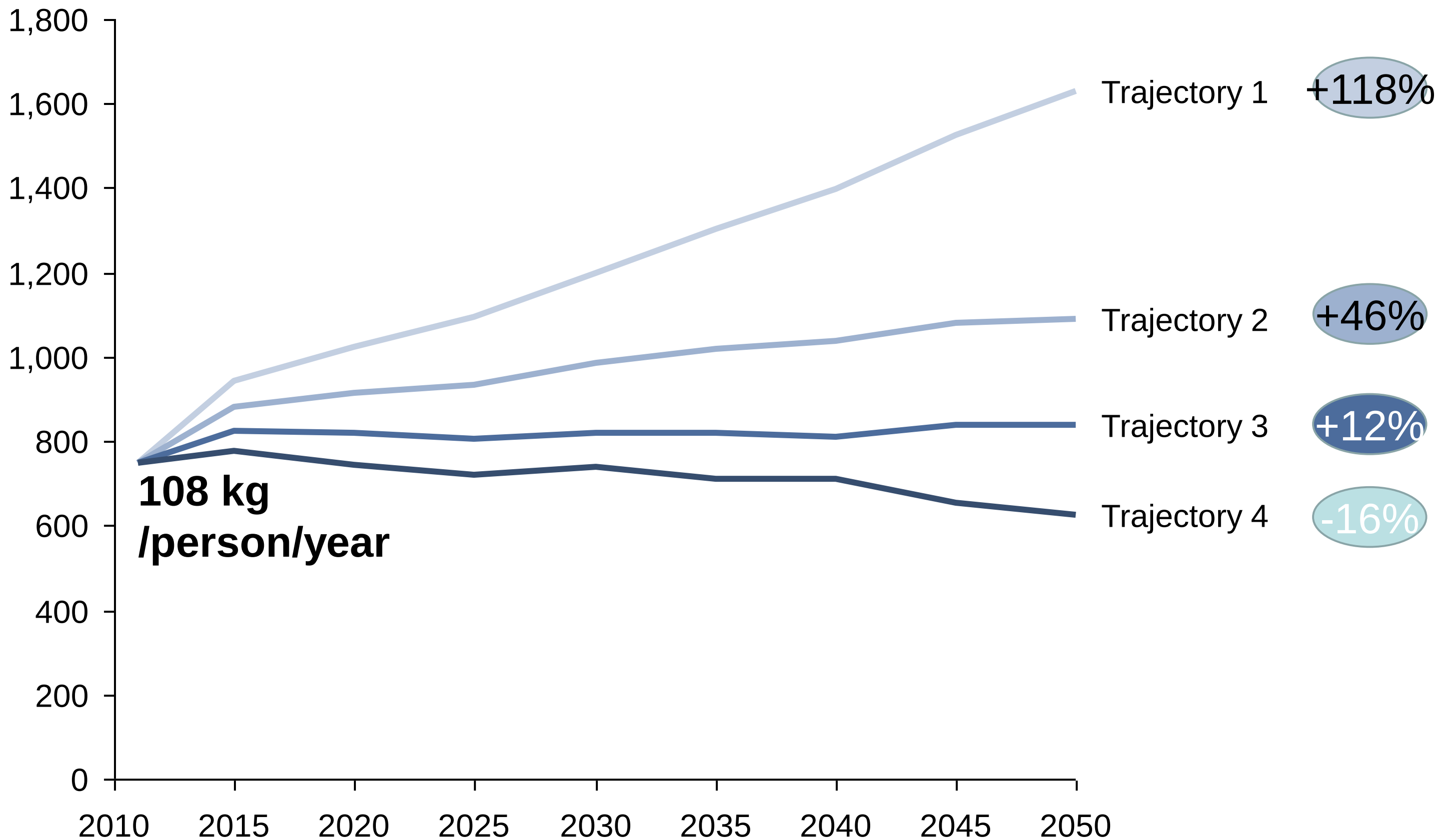
Model growth forecasts

Production according to trajectories 1, 2 and 3 (after design, switch & recycling)

Chemicals production per year for different ambition levels [1,2]
(M tons)

Delta 10-50,%

Implied demand per person



171 kg plastics /person

114 kg plastics /person

88 kg plastics /person

66 kg plastics /person

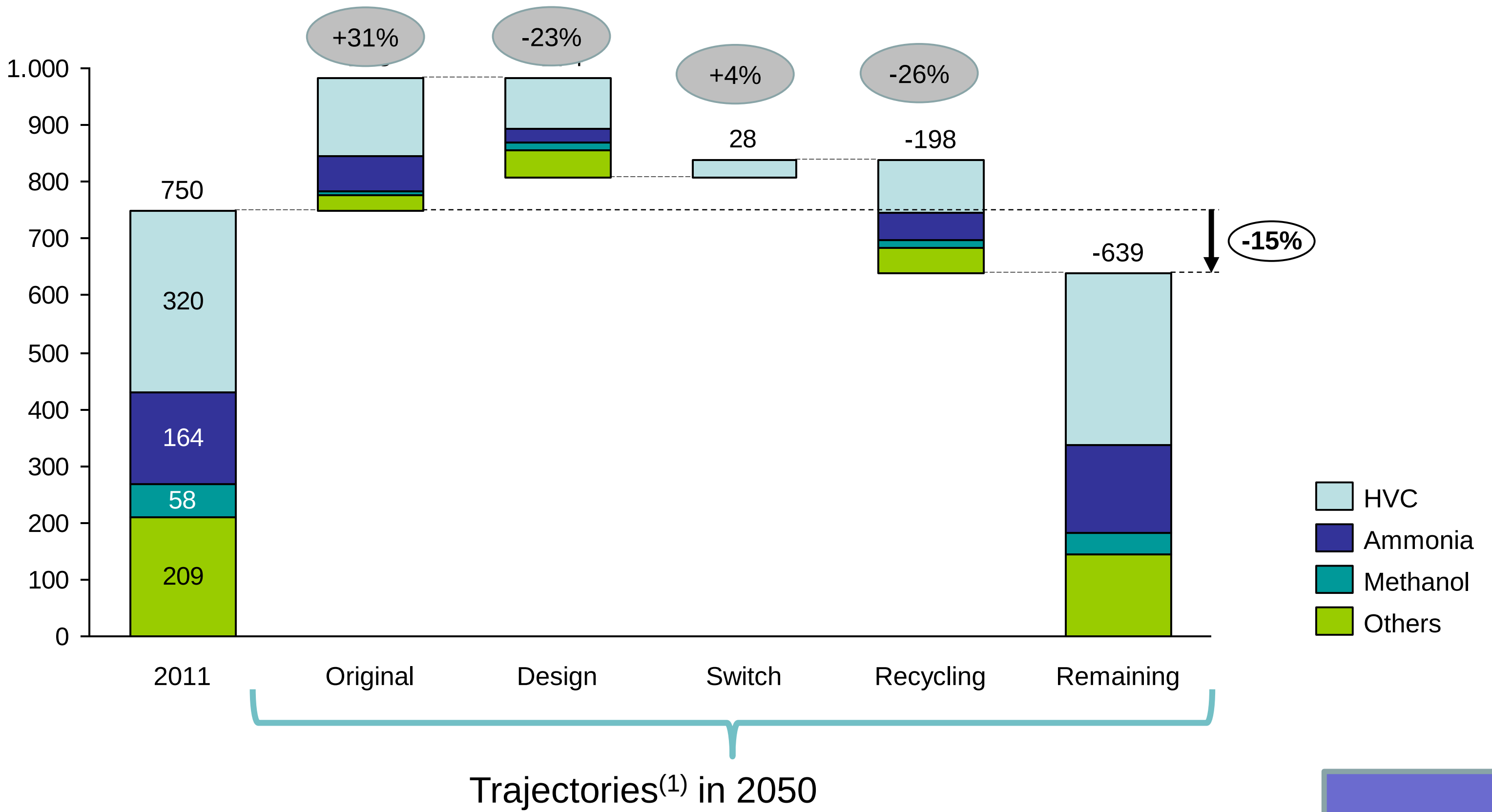
NOTES: (1) The population follows the average UN projection in all four trajectories
(2) Other sectors are impacted by these transitions (e.g. additional productions are created in the timber sector)

SOURCE: IEA ETP 2012, Global calculator model

Global Calculator

Reduction potential
Details for ambition level 3

Chemicals 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

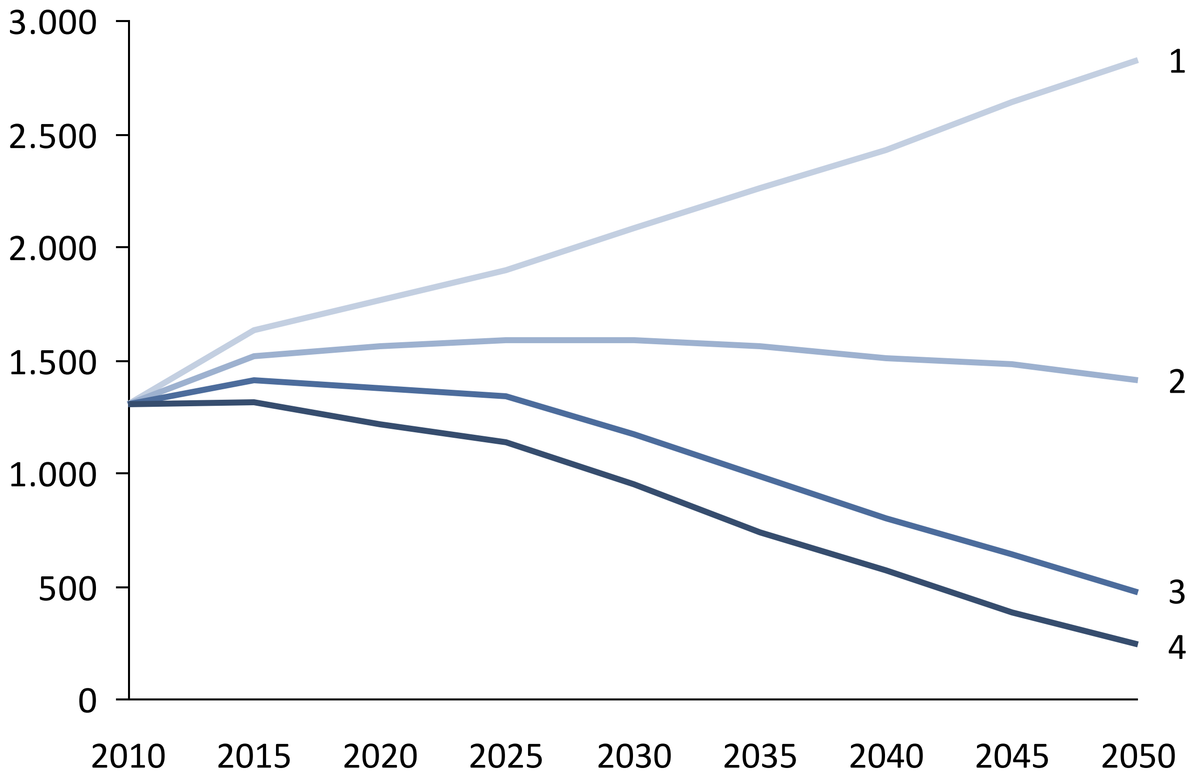
Young modulus applied to chemicals is very high leading to low material increase

Figures of July 2014

Reduction potential

Emissions according to different trajectories

GHG emissions for different ambition levels [1,2,3]
($MtonCO_2e$)



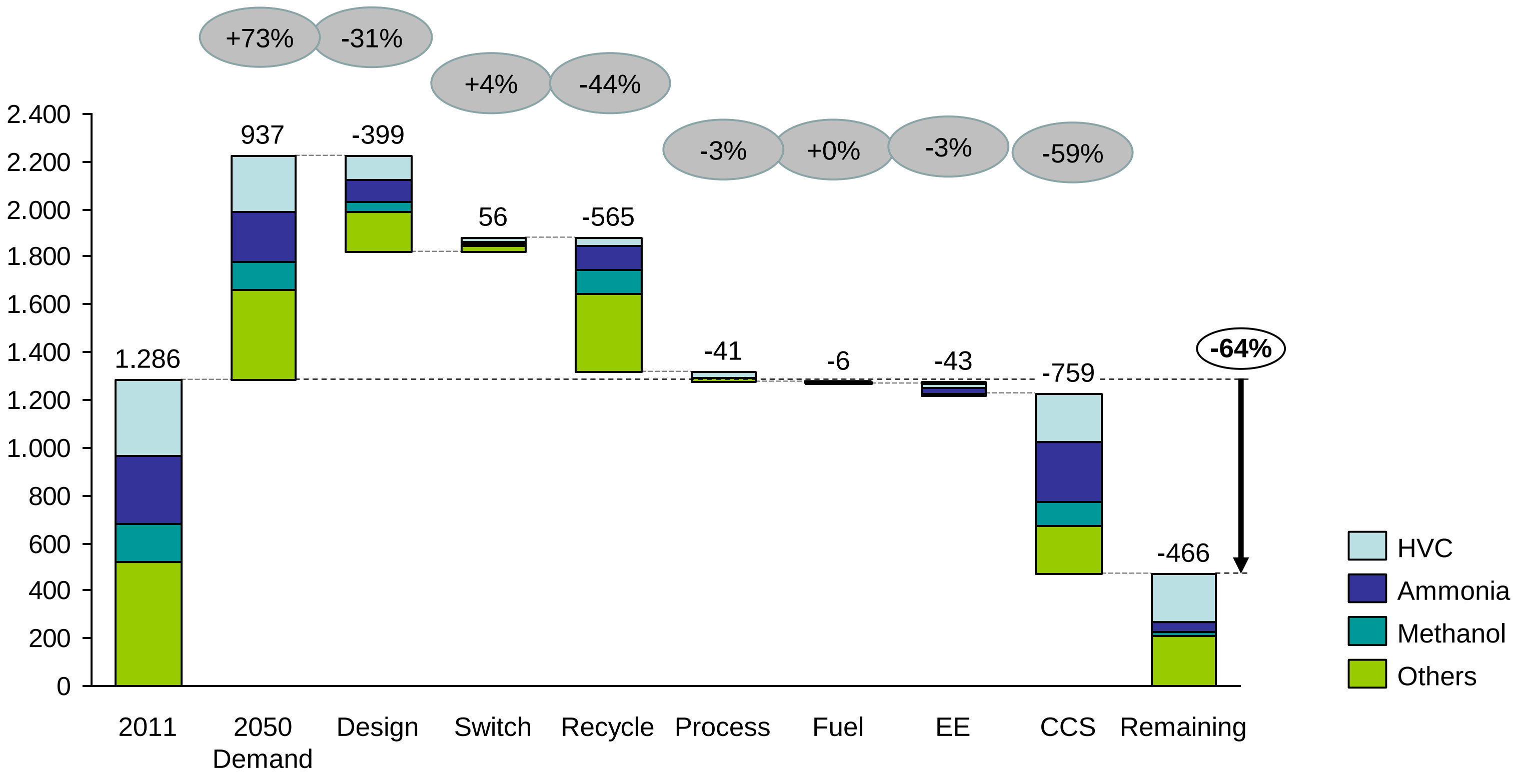
	Delta 10-50,%	Specific emissions
1	+118%	1732 kg /ton plastics
2	+8%	1287 kg /ton plastics
3	-64%	558 kg /ton plastics
4	-86%	381 kg /ton plastics

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. with product switch)

SOURCE: IEA ETP 2012, Global calculator model

Reduction potential
Details for ambition level 3 [1]

Chemicals 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

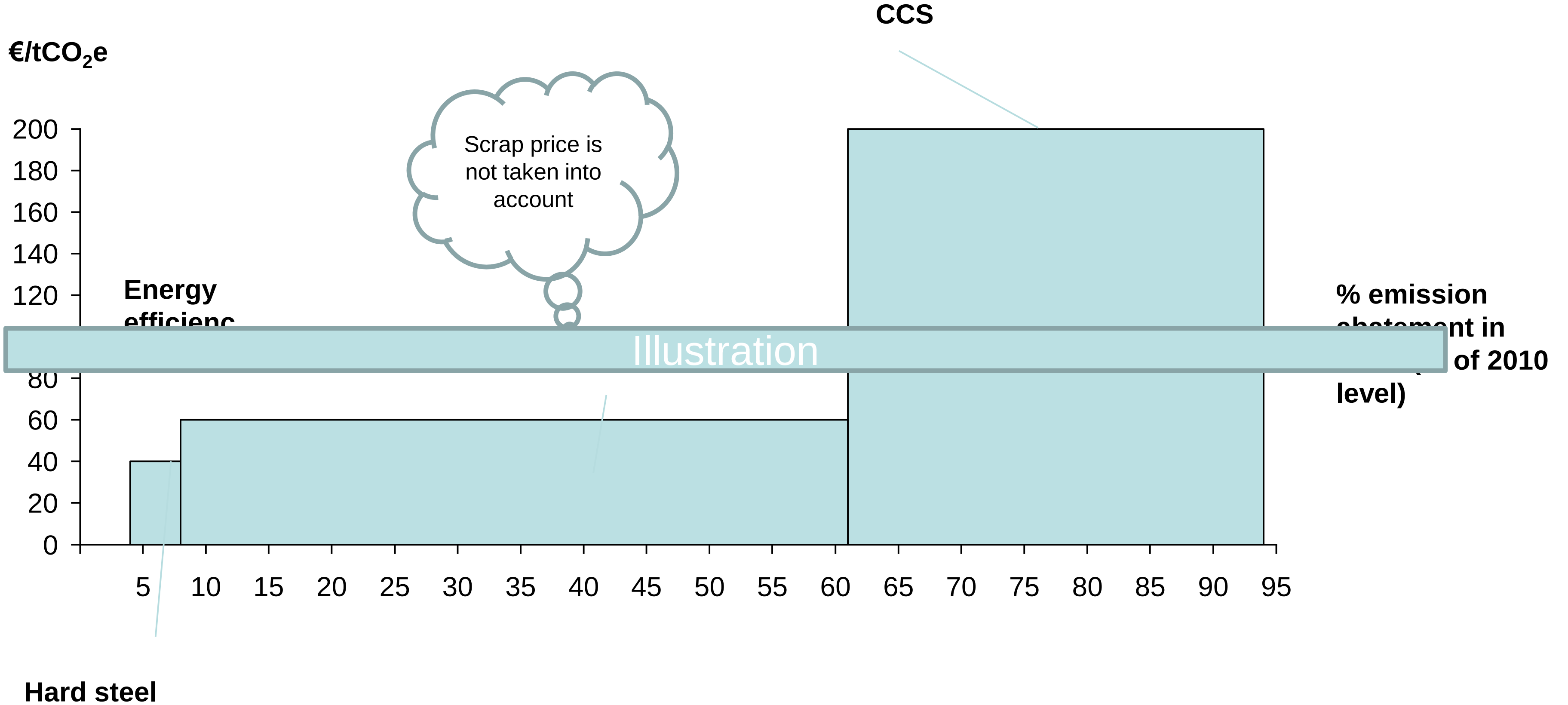
SOURCE: IEA ETP 2012, Global calculator model

Cost

Marginal cost and abatement potential for different levers under trajectory 2 with ambition level 4

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

€/tCO_2e, % emission abatement in 2050 (% of 2010 level)



NOTE: Hypothesis of cost neutral energy efficiency measures , cost of biomass generic across all sectors
SOURCE: IEA ETP 2012, Global calculator model

Global Calculator

2050 evolution of materials and emissions

Materials demand evolution

- Cross sector demand
- Cross sector material switch
- Steel
- Chemicals
- Aluminium
- Cement
- Paper & Timber

Reduction potential on the manufacturing processes

- Resulting emissions
- Discussion on ambition levels across sectors
- Discussion on CCS
- Steel
- Chemicals
- **Aluminium**
- Cement
- Paper, Timber & Other

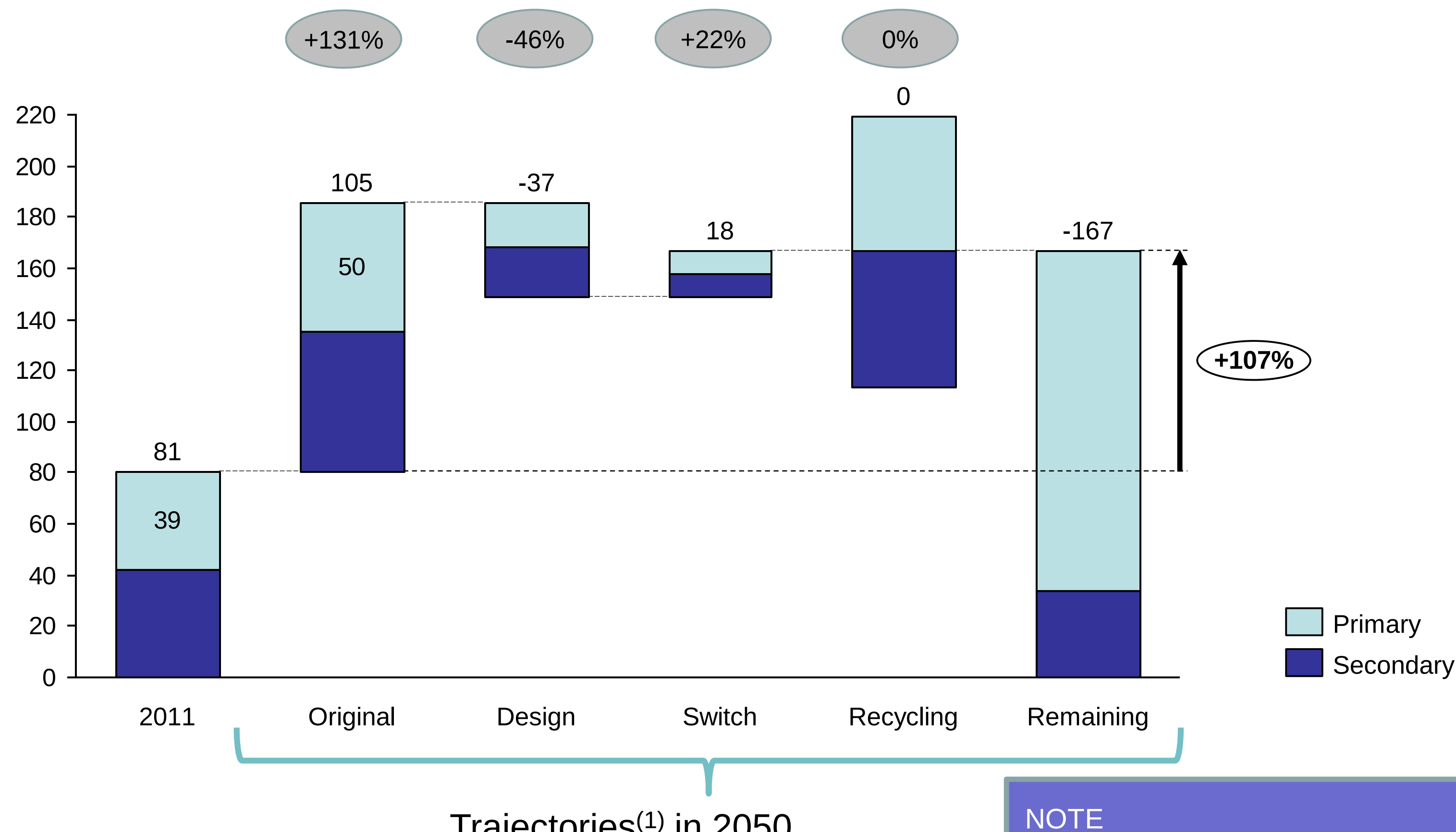
Aluminium assumptions summary

Lever	Ambitions			
	1	2	3	4
Design	0%	-10%	-20%	-30%
Switch to Aluminium from steel	0%	0,5%	1%	2%
Switch to plastics from aluminium (planes)	not modeled	not modeled	not modeled	not modeled
Recycling(% of total)	+10%	+15%	+20%	+25%
Process improvements (as EE)	0%	-5%	-10%	-20%
Fuel switches (coal to biomass in primary alu	0%	2%	3%	5%
CHP	0%	0%	0%	0%
Energy efficiency (additional)	0%	-3%	-5%	-10%
CCS(emissions captured)	0%	43%	64%	85%

NOTE: Because it is used in long term products (alumium locked in buildings & cables) aluminium scrap availability is expected to decrease, limiting the recycling potential
SOURCE: Global Calculator consultations, WorldAluminium

Reduction potential
Details for ambition level 3

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



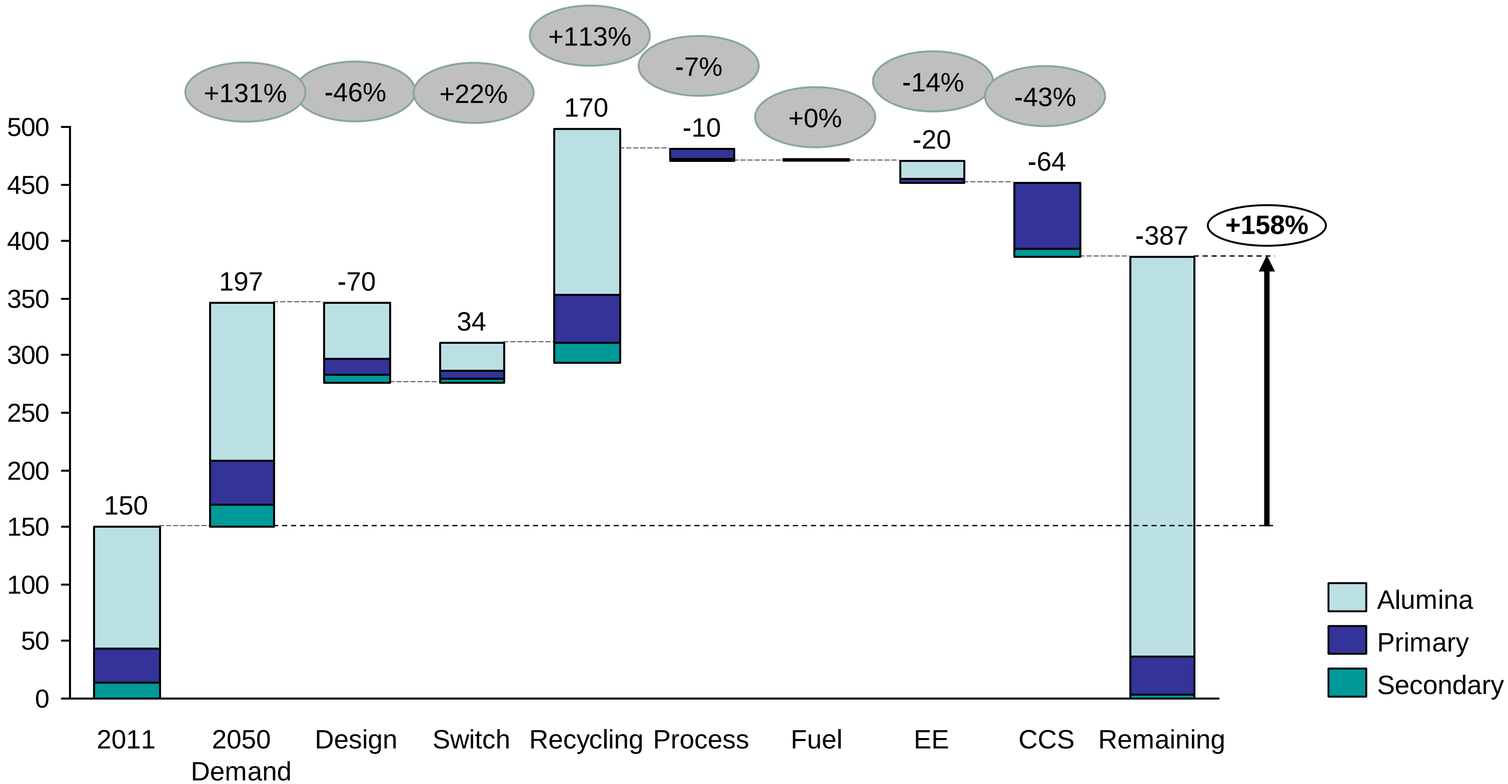
NOTE:
- Because it is used in long term products (aluminium locked in buildings & cables) aluminium recyclability rates are expected to decrease
- Current 30%, Ambition 1: 10%, 2:15% 3: 20%, 4:25%

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

Details for ambition level 3 (1)

Aluminium 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

Agenda

Global Calculator

2050 evolution of materials and emissions

Materials demand evolution

- Cross sector demand
- Cross sector material switch
- Steel
- Chemicals
- Aluminium
- Cement
- Paper & Timber

Reduction potential on the manufacturing processes

- Resulting emissions
- Discussion on ambition levels across sectors
- Discussion on CCS
- Steel
- Chemicals
- Aluminium
- **Cement**
- Paper, Timber & Other

Manufacturing chain definition for each technology

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

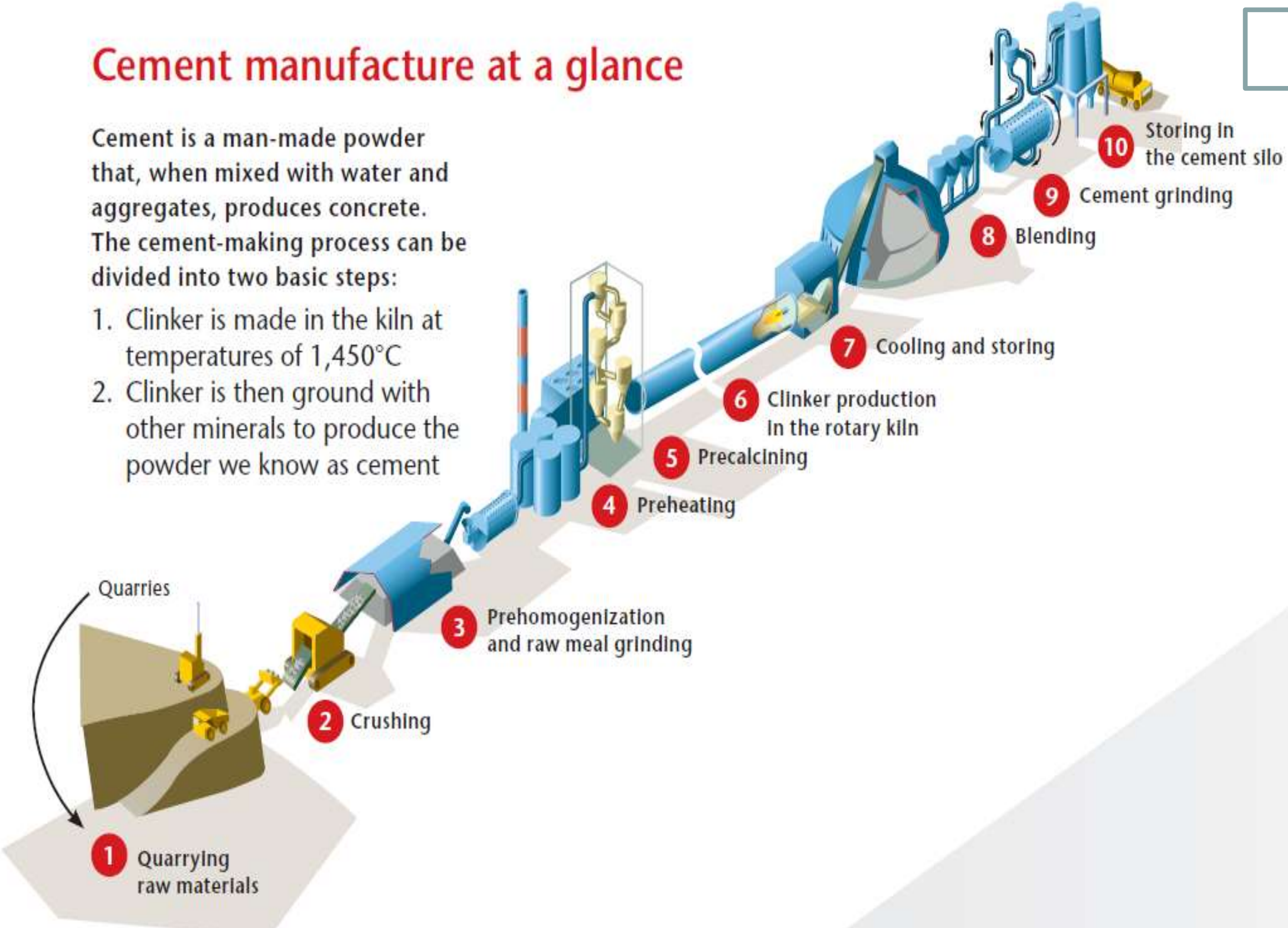
Global Calculator

BACKUP

Cement manufacture at a glance

Cement is a man-made powder that, when mixed with water and aggregates, produces concrete. The cement-making process can be divided into two basic steps:

1. Clinker is made in the kiln at temperatures of 1,450°C
2. Clinker is then ground with other minerals to produce the powder we know as cement

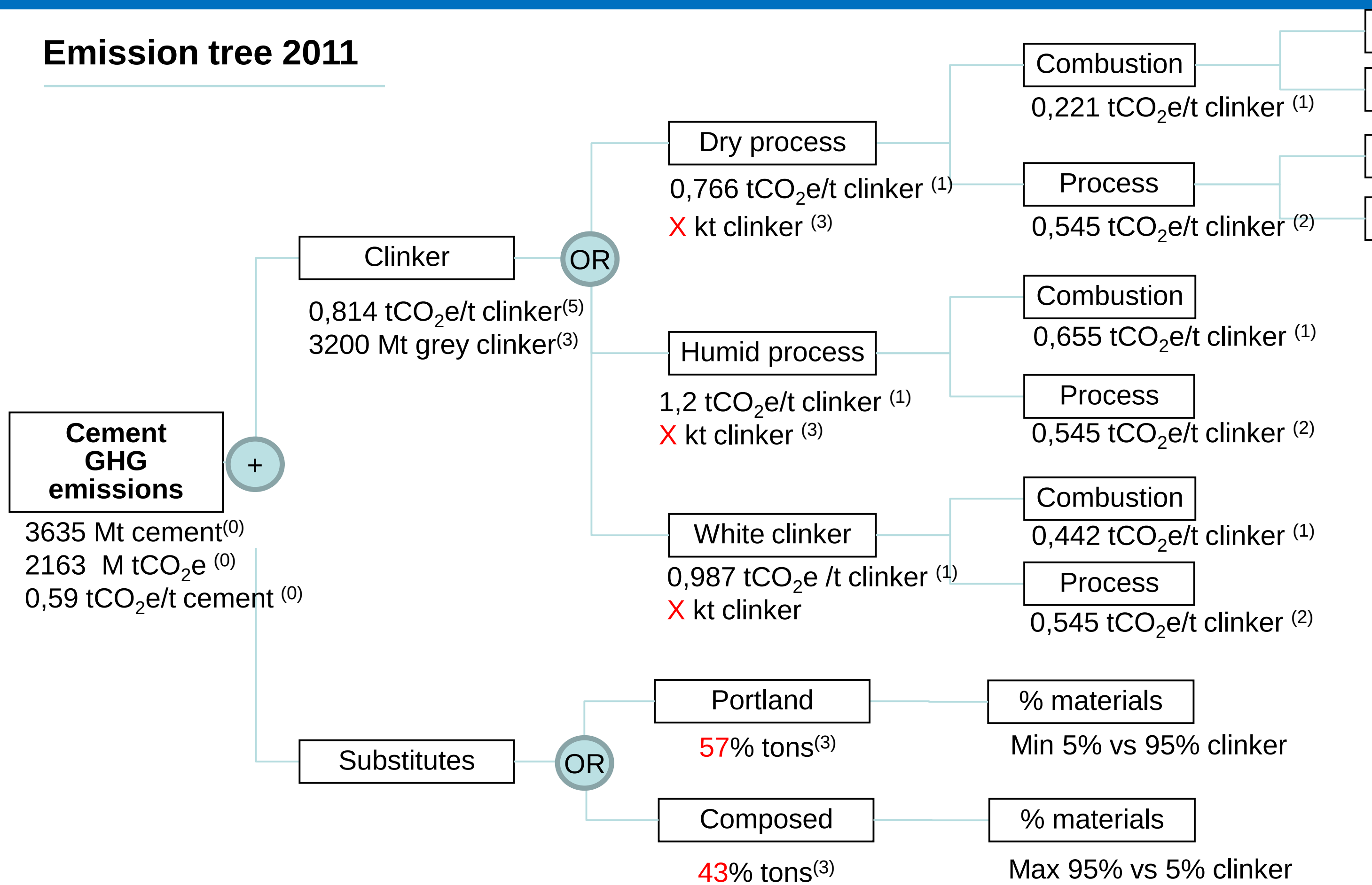


SOURCE: IEA 2009 Cement Technology roadmap

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]

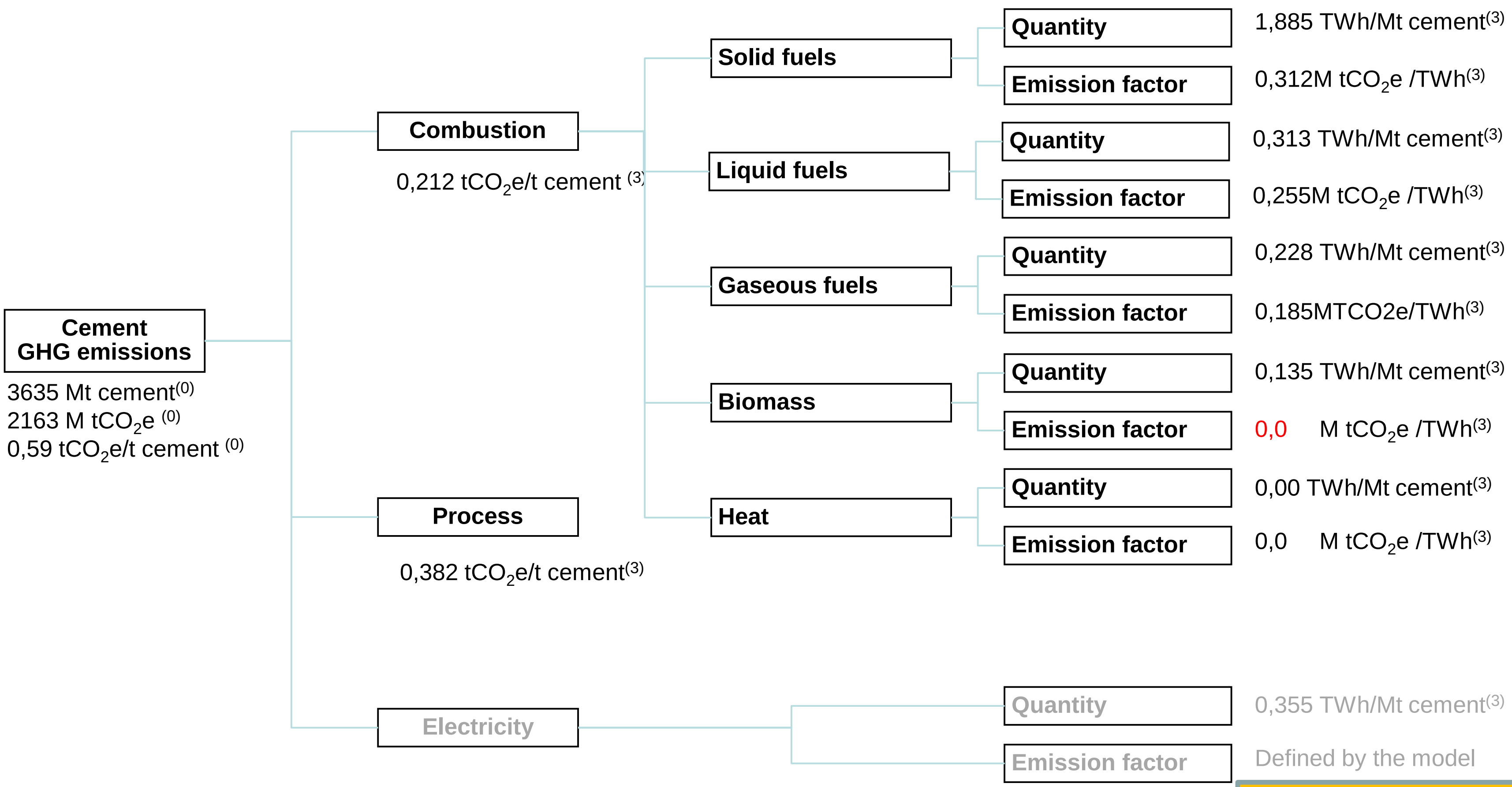
Technology		Total
Production (Mt)		**3635**
Specific Consumption (PJ/MT= GJ/t Cement)	Electricity	**0,35**
	Solid HC	**1,88**
	Liquid HC	**0,31**
	Gaseous HC	**0,23**
	Biomass & Waste	**0,14**
	Heat	**-**
	Total	**2,92**
Specific emissions (tCO2/t cement)	Combustion CO_2e	**0,21**
	Process CO_2	**0,38**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

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

2

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

Global Calculator

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

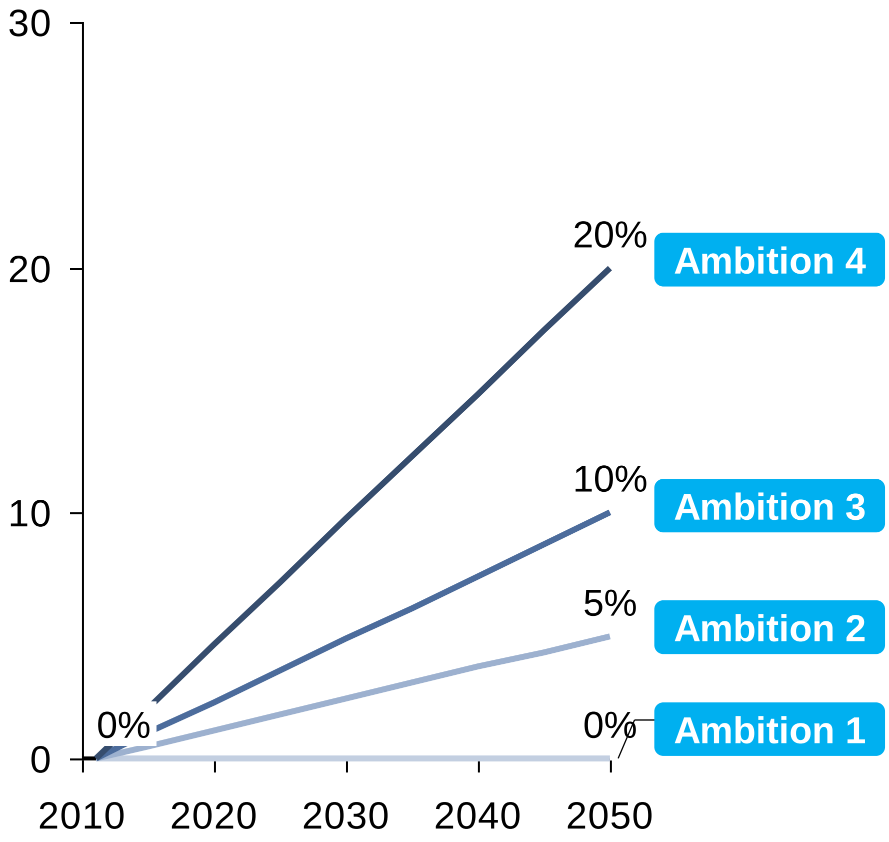
Steel/composed
cement

SOURCE: Climact

2 Smart design

Better specified cement can fulfil the same requirements with lower volumes

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

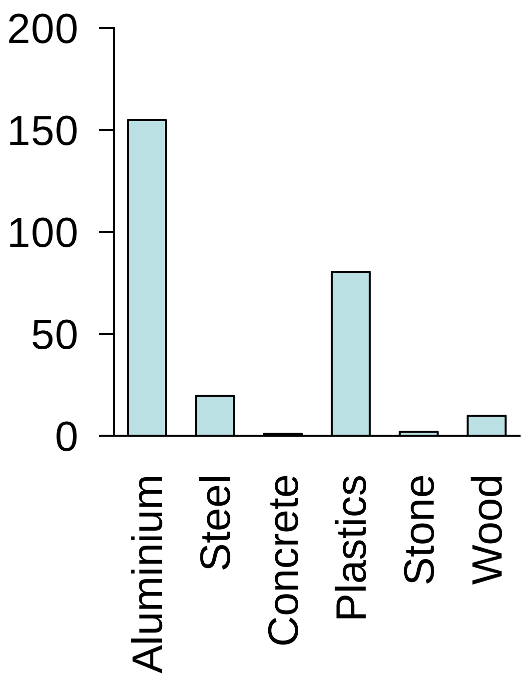
2

Material switch

Cement is one of the cheapest option to build durable constructions

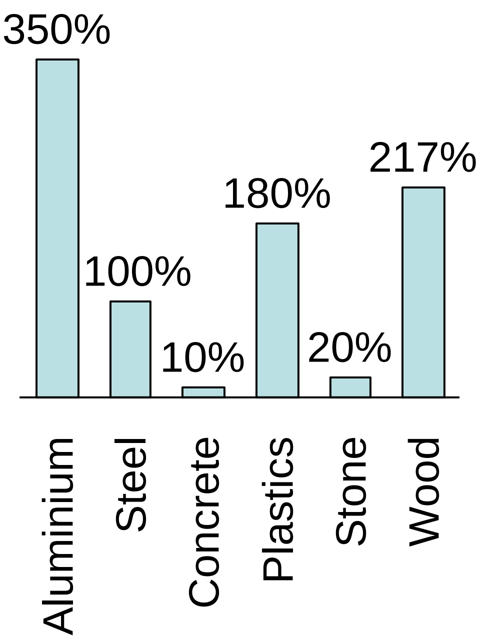
Global Calculator

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.

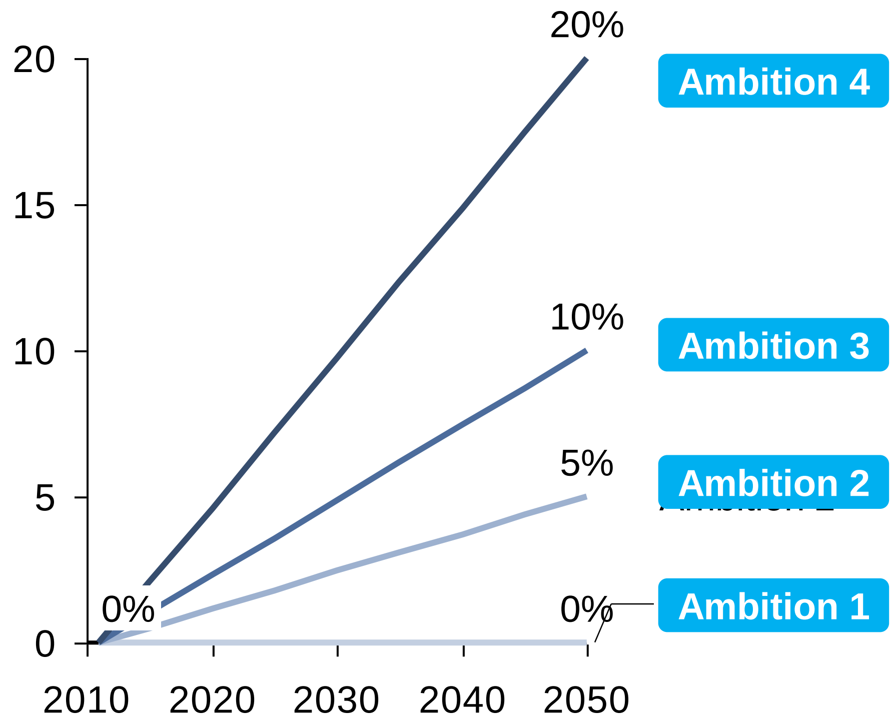
SOURCE: (1) With both eyes open (Orr et Al. (2010), research of efficient concrete shapes

2

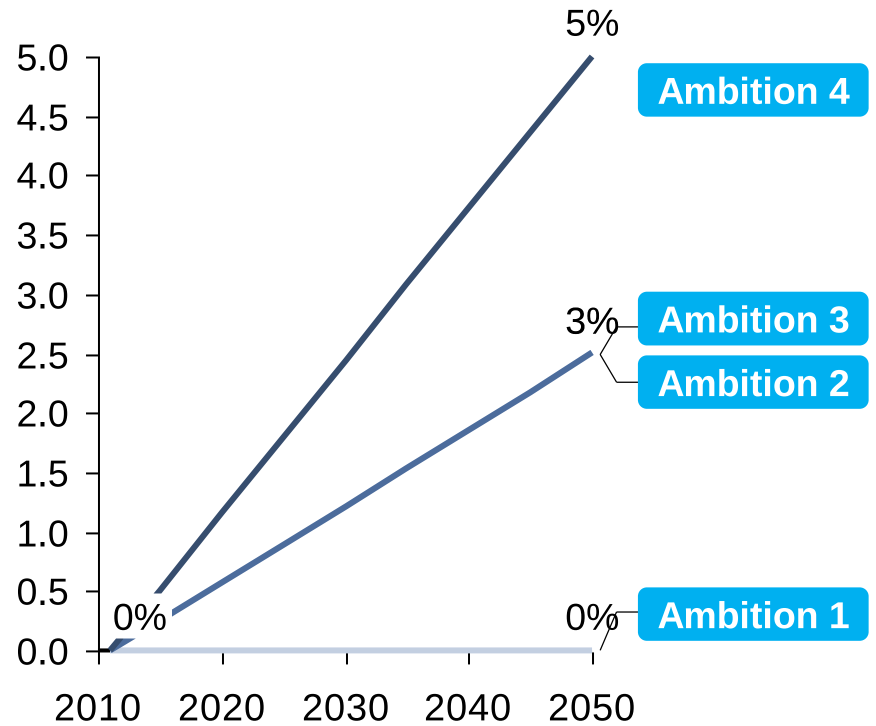
Material switch
Proposed lever ambitions

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

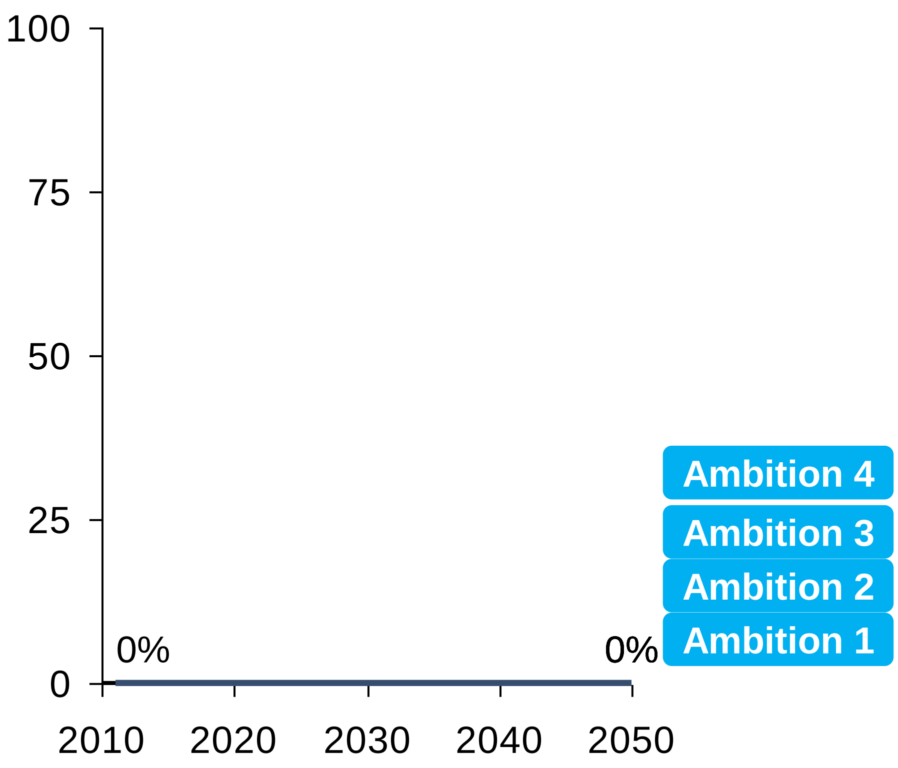
2

Material recycling: Aggregate

Cement is not recycled, but reused as a an aggregate

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

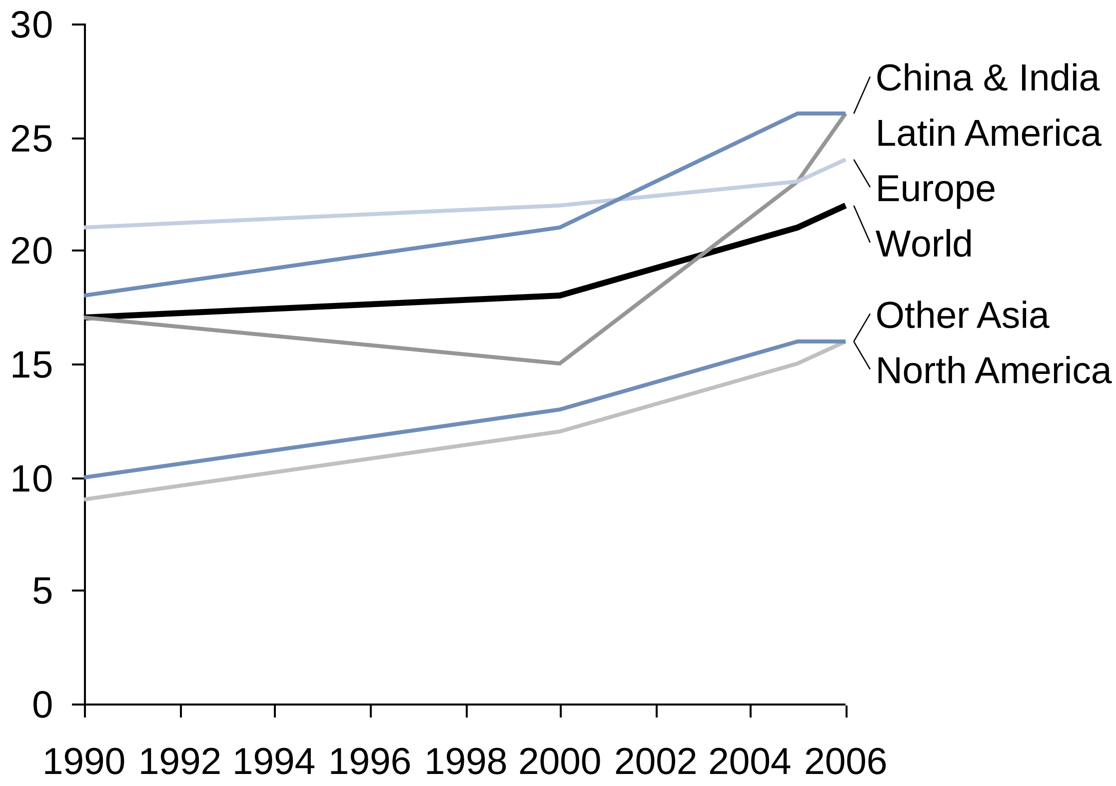
SOURCE: With Both Eyes Open

2

Process improvements: Composed cement

Composed cement market share has increased historically…

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

Process improvements: Composed cement

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

Global Calculator

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

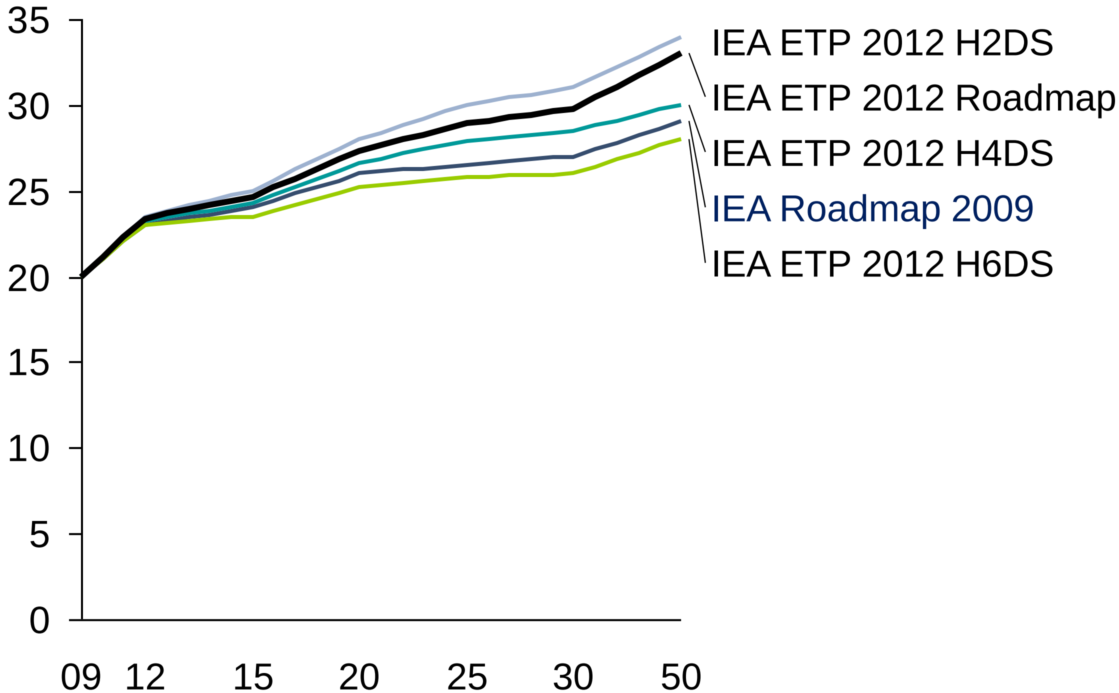
NOTE: Mineral components can be added to the clinker to obtain de cement (flying ashes, blast furnace slag, others), if those are superior to 5%, we get composed cement. Steel cement is a type of composed cement
SOURCE: With Both Eyes Open, IEA Cement roadmap, Carbon war room (WBCSD 2009, Holcim 2009)

Process improvements: Composed cement

IEA scenarios forecast a substitution rate between 28-34%

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)

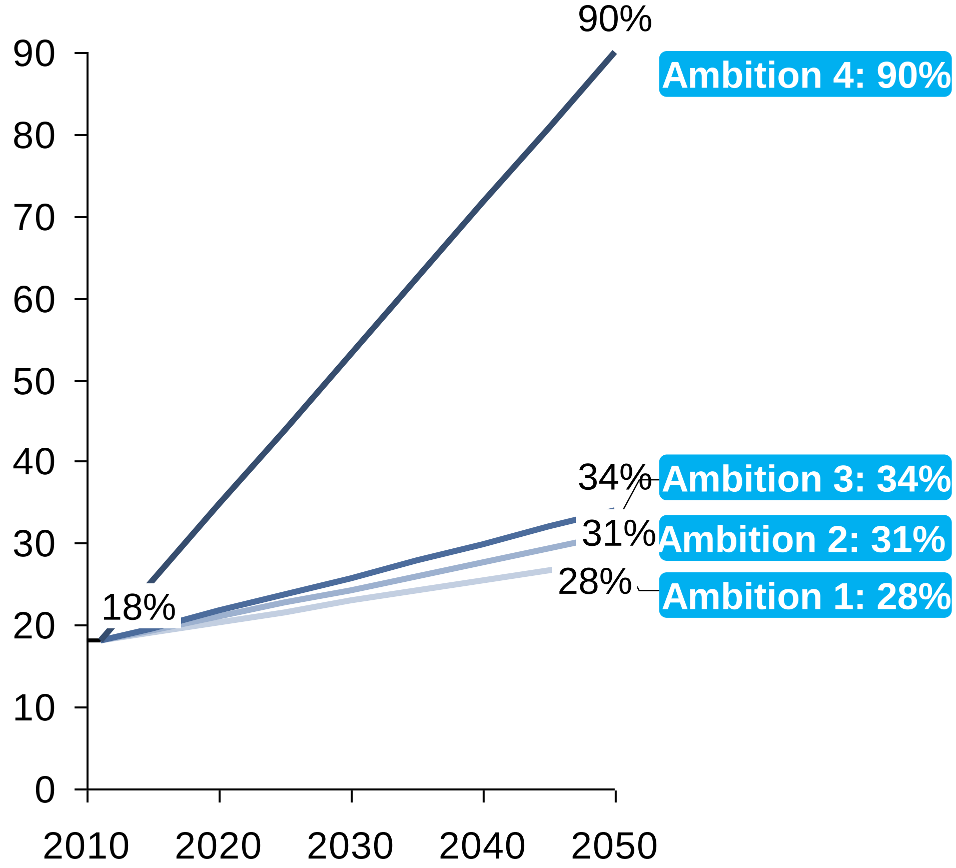
NOTES: Major hypothesis: no emissions are allocated to the steel slag, considering it as a waste from the steel sector
Substitution potential is not applicable to white cement
Intermediary figures are a Climact assumption for 2,4 & 6 DS

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

2 Process improvements: 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

Carbon intensity of material production

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

List of actions & levers assessed

Process improvement

- Towards fuels which emit less CO_2

Dry process

"Green cement"

Fuel substitution

- Modification of processes

Biomass

Waste

Energy efficiency

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

Insulation

Preheating, precalcining

Fluidized bed technology

CHP/ heat recovery

End of pipe technologies

- Carbon capture and storage

CCS implementation

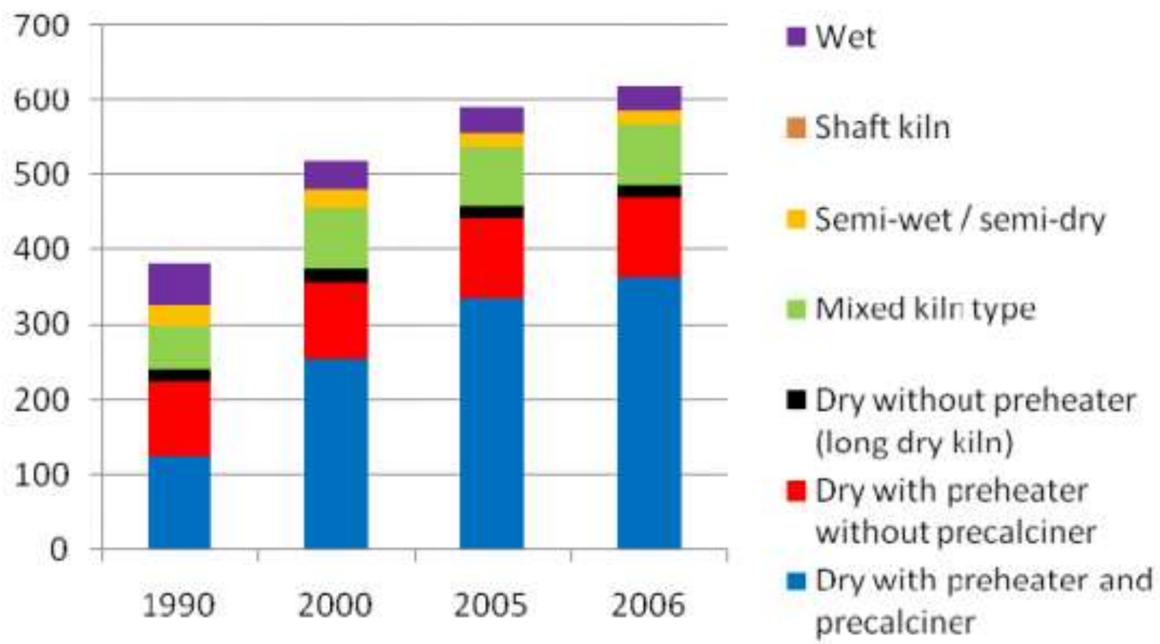
NOTE: Process choice has consequences on applicability of other levers Some combinations are exclusive whilst others can be added in sequential order

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

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

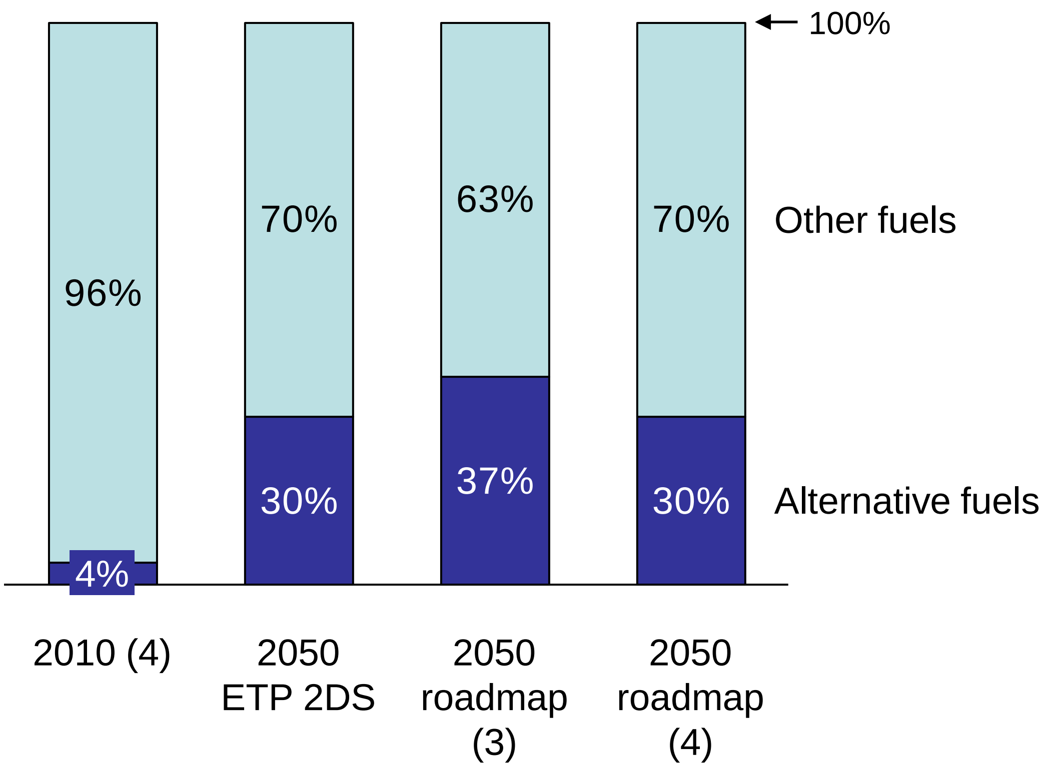
SOURCE: GNR participants to the CSI

3 Alternative fuels

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

Global Calculator

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

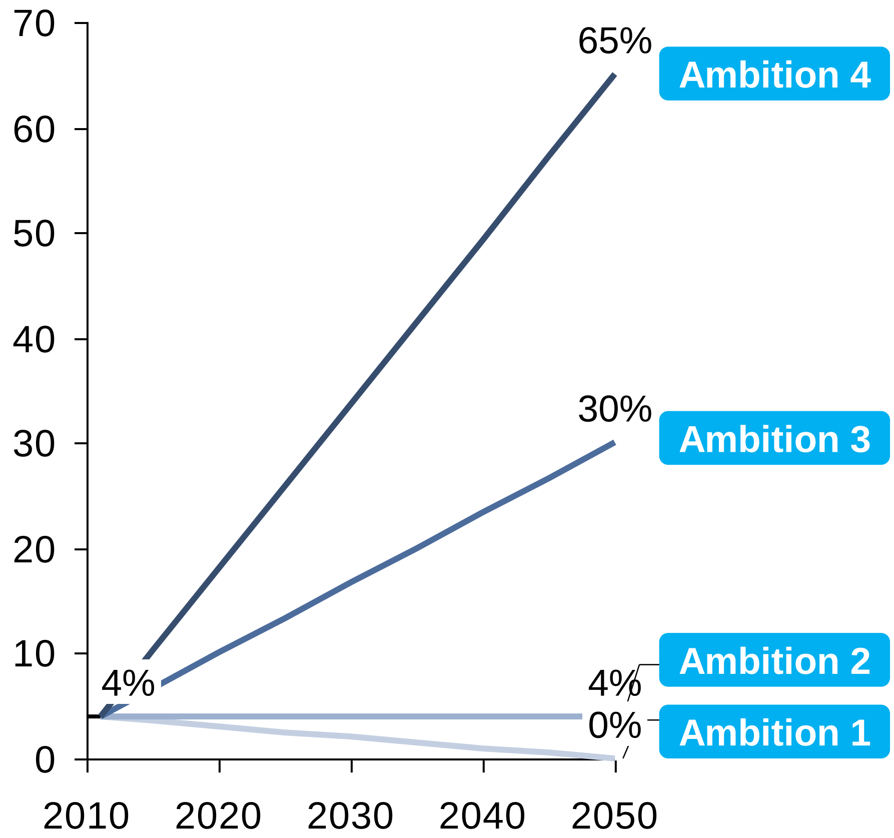
NOTE: We assume biomass & waste combustion emissions at 0 in the first version of the calculator
SOURCE:,(3)IEA Cement Technology RoadMap (4) IEA ETP 2012

Global Calculator

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

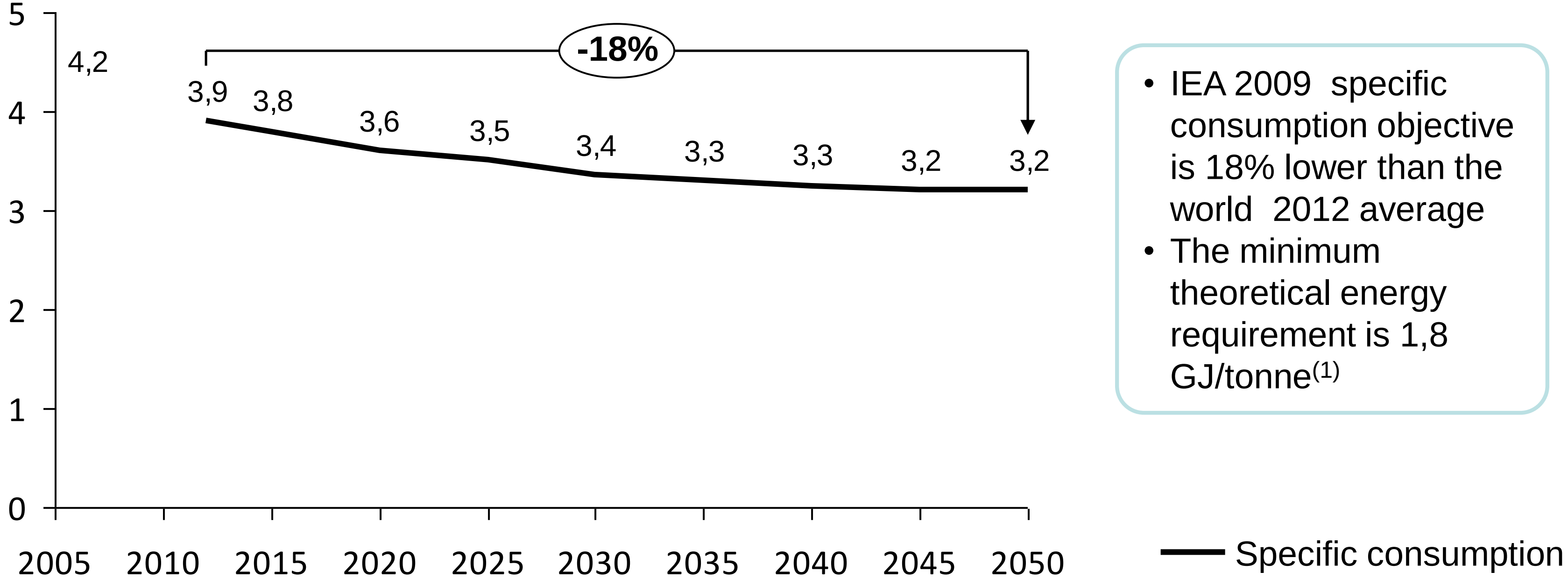
3

Energy efficiency

Clinker energy efficiency can increase by more than 15%

Global Calculator

Specific consumption evolution forecast
(Gj/t clinker)



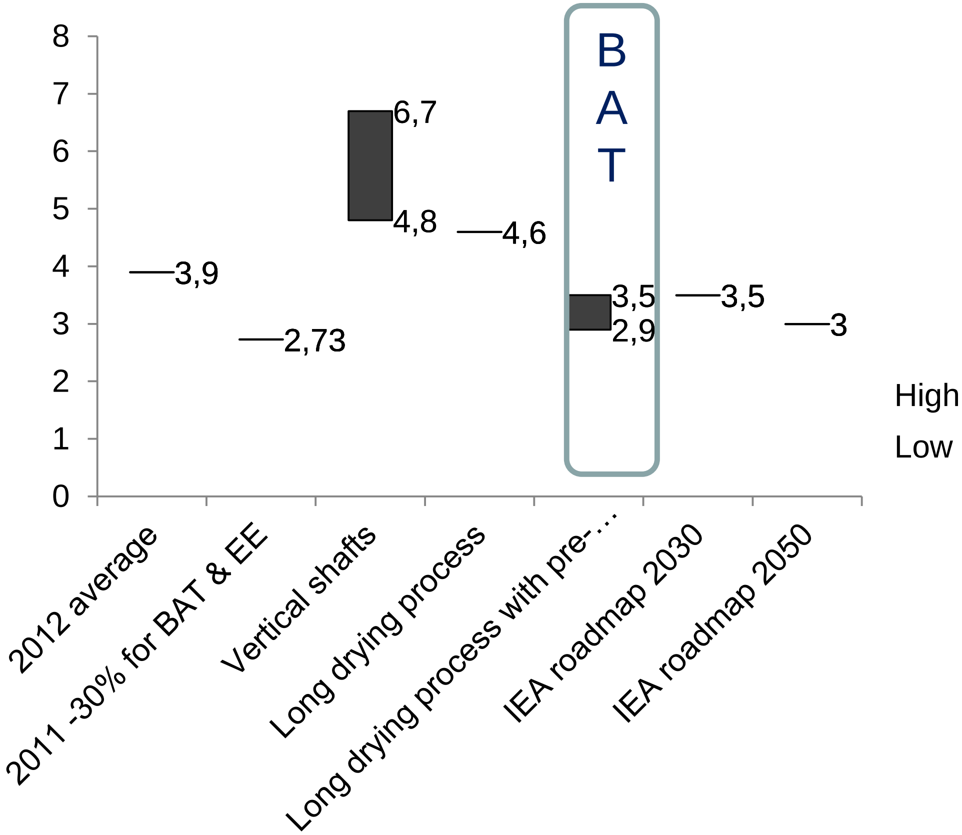
- IEA 2009 specific consumption objective is 18% lower than the world 2012 average
- The minimum theoretical energy requirement is 1,8 GJ/tonne[(1)]

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)



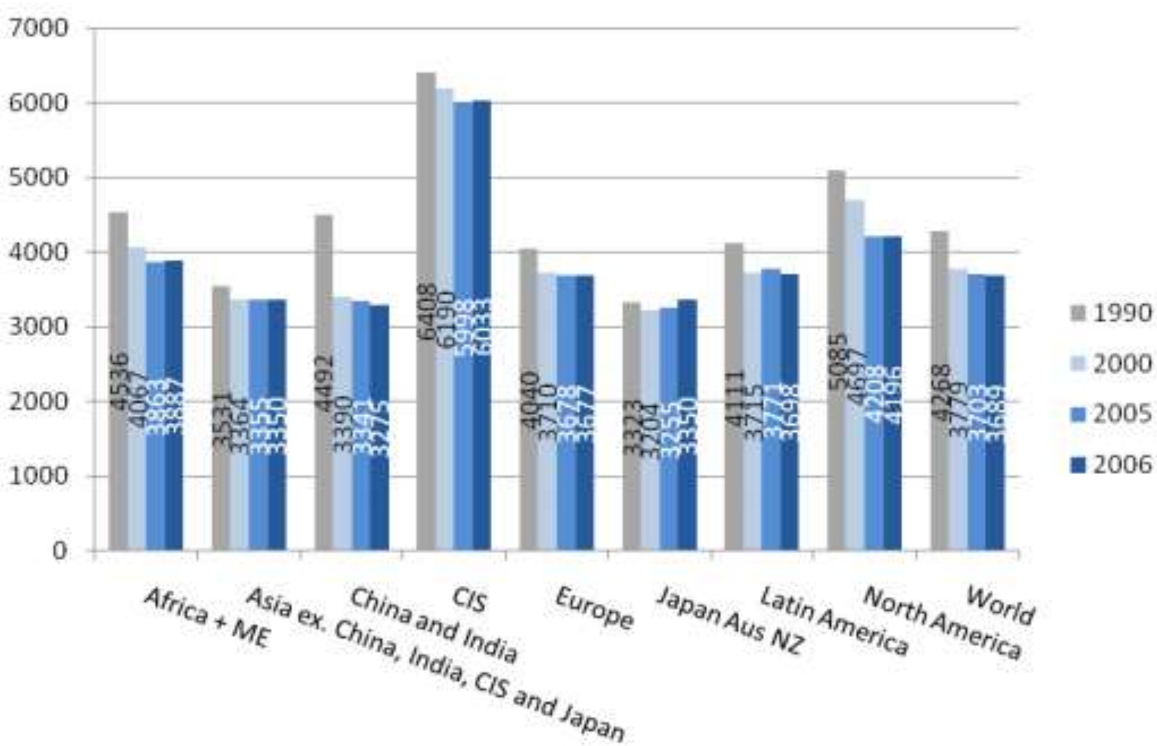
Several factors support the specific consumption reduction:

- 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

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?

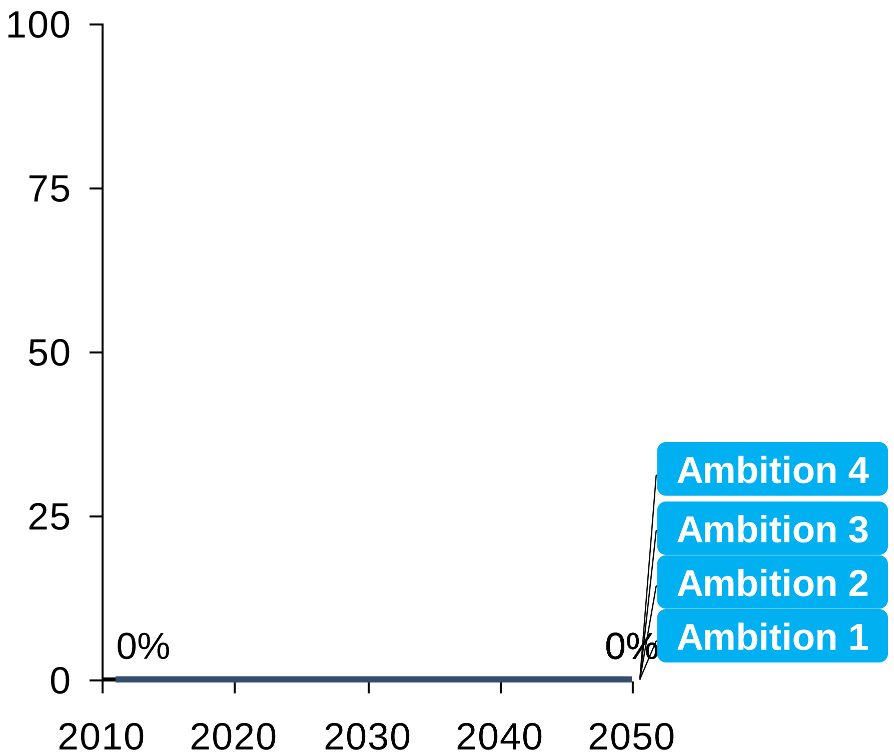
SOURCE: (1) Cement Sustainability initiative (2) with both eyes open (3) ETP

3

Energy efficiency (CHP)
Proposed lever ambitions

Global Calculator

Percentage of electricity production through CHPs (%)



SOURCE: Cement consultation, Climact analysis

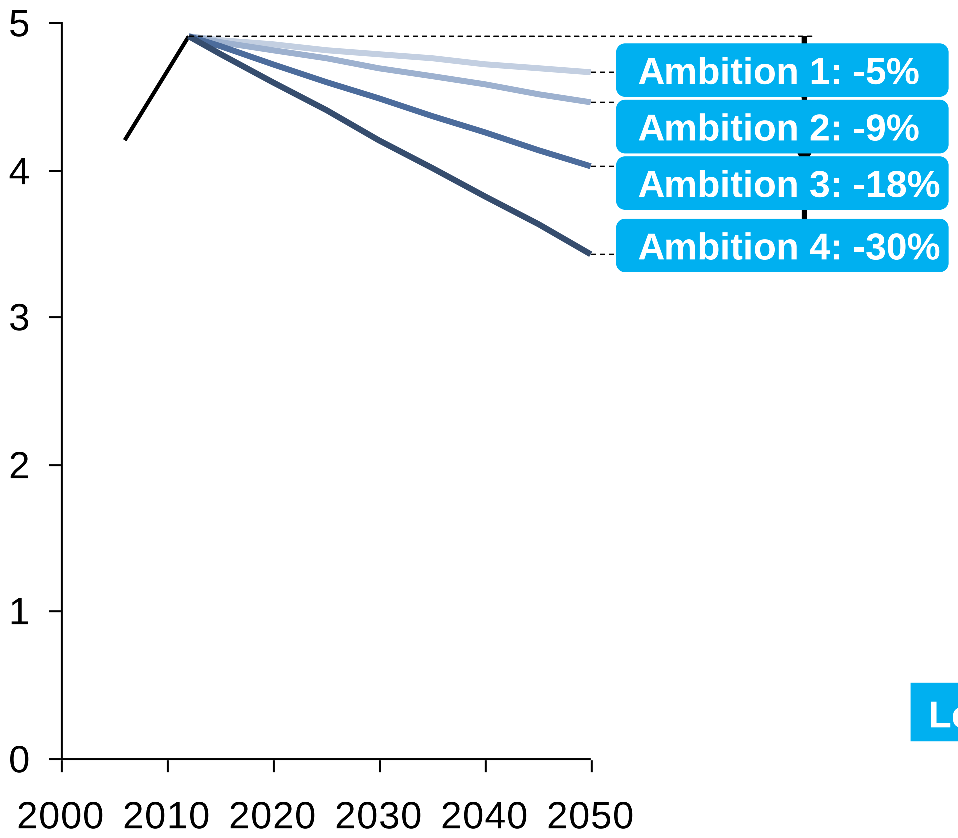
Figures of July 2014

Global Calculator

3

Energy efficiency
Proposed lever ambitions

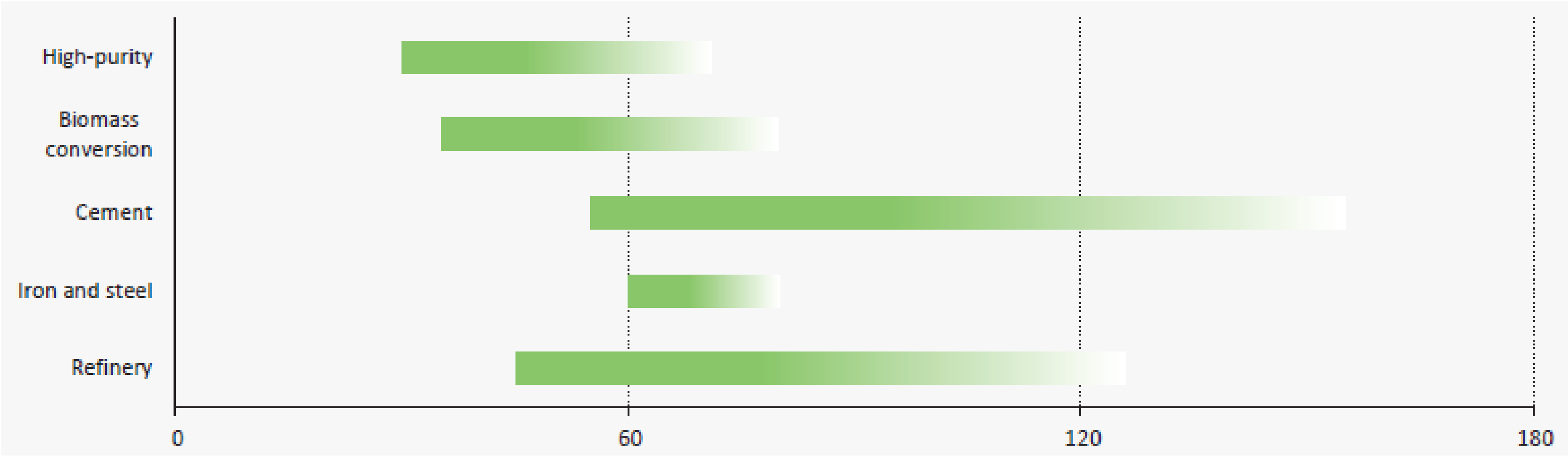
Specific consumption improvements
(Gj/ton clinker, % reduction vs 2010)



Lever cost (3) €/t crude steel	
Input (fuel & material)	-x
Other opex	0
Capex (Assuming 5 years payback on energy savings)	229 +x

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

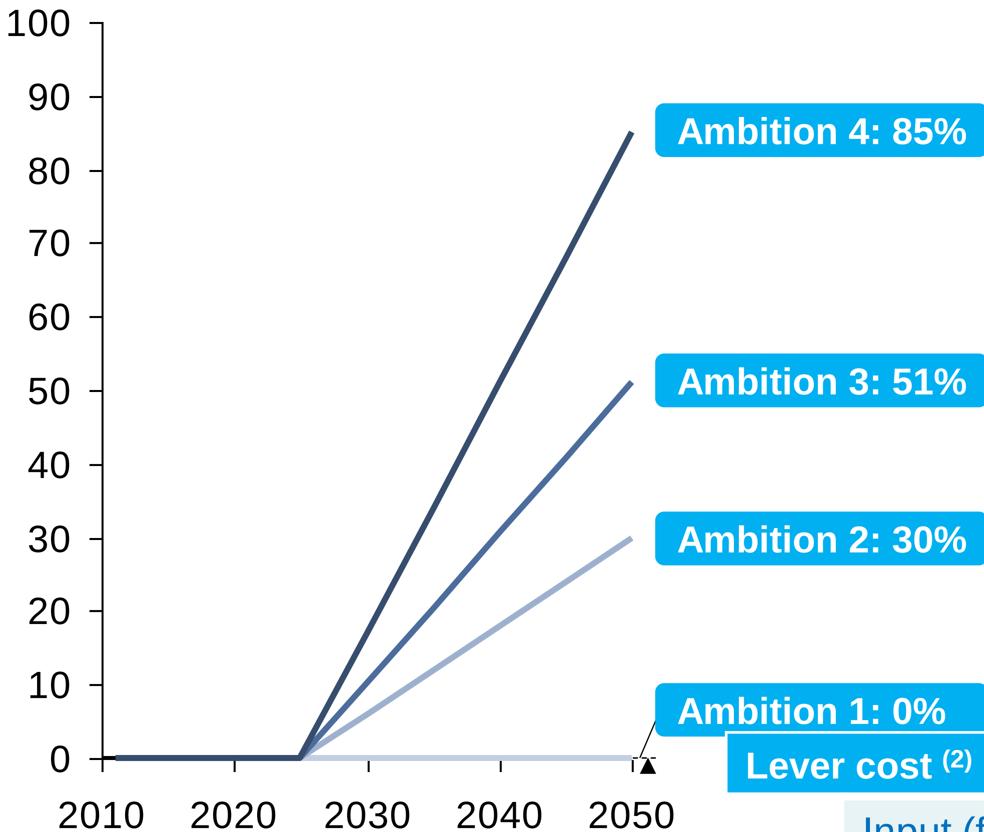
Figures of July 2014

Global Calculator

3 Carbon Capture & Storage

Proposed lever ambitions

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

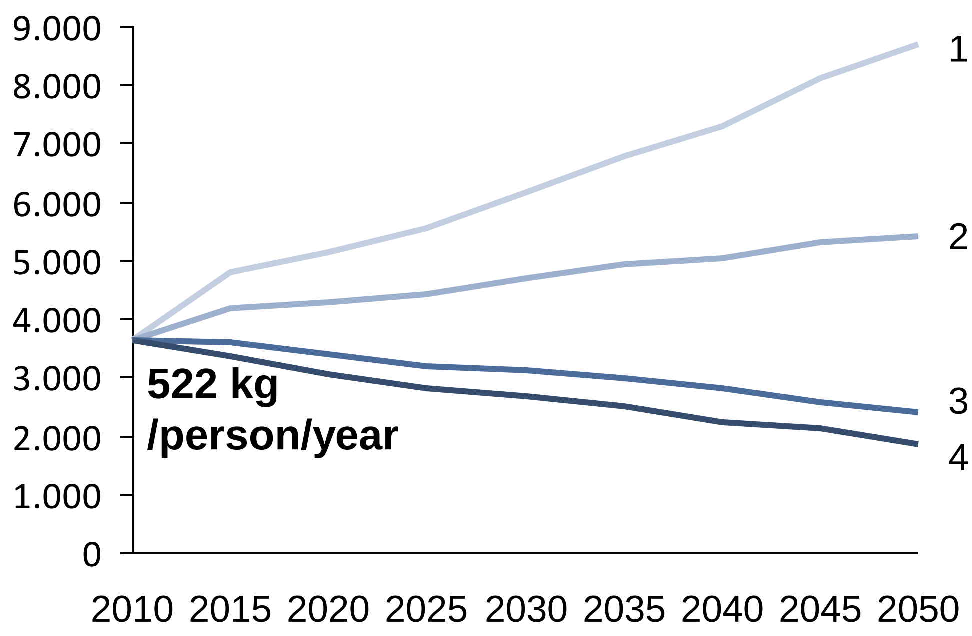
SOURCE: Cement consultation, Climact analysis

Global Calculator

Reduction potential

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

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



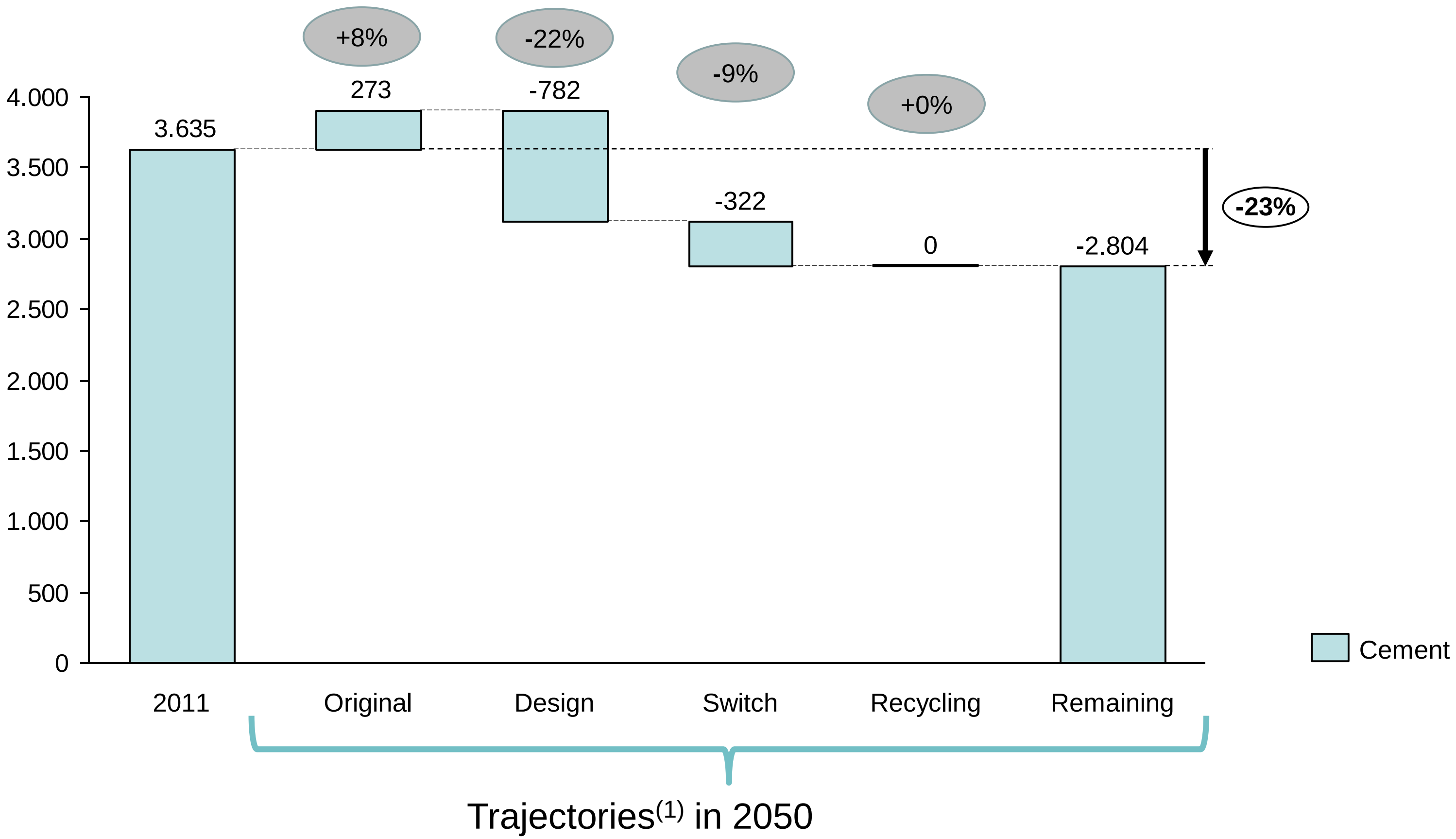
Delta 10-50,%	Implied demand per person
+140%	912 kg /person/year
+49%	565 kg /person/year
-14%	328 kg /person/year
-49%	194 kg /person/year

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

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

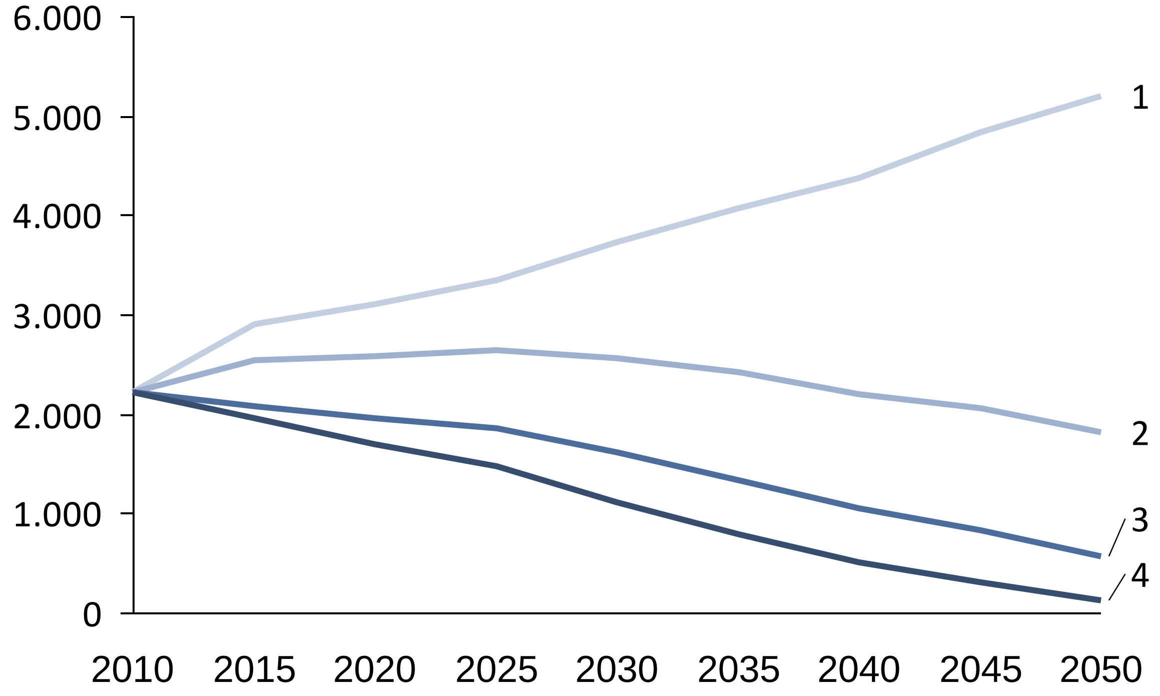


NOTE: (1) The population follows the average UN projection in all four trajectories
(2)Assuming biomass emits, not including electricity related emissions
SOURCE: IEA ETP 2012, Global calculator model

Reduction potential

Emissions according to different trajectories

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



Trajectory	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

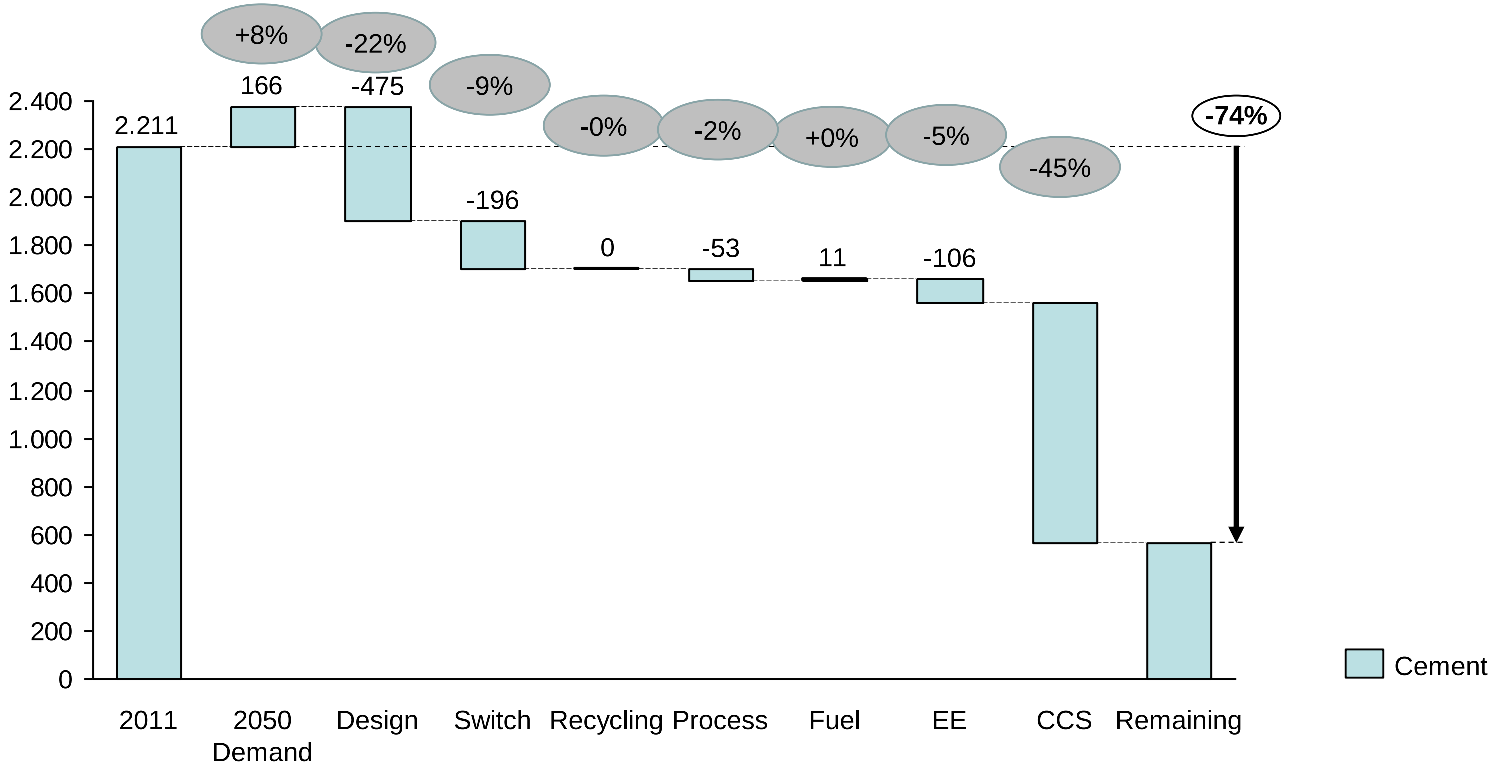
NOTES: (1) The population follows the average UN projection in all four trajectories
(2) Excluding biomass related reductions & electricity related emissions
(3) Other sectors are impacted by these transitions (e.g. additional emissions are created in the timber sector)
SOURCE: IEA ETP 2012, Global calculator model

Global Calculator

Reduction potential

Details for ambition level 3 [1]

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

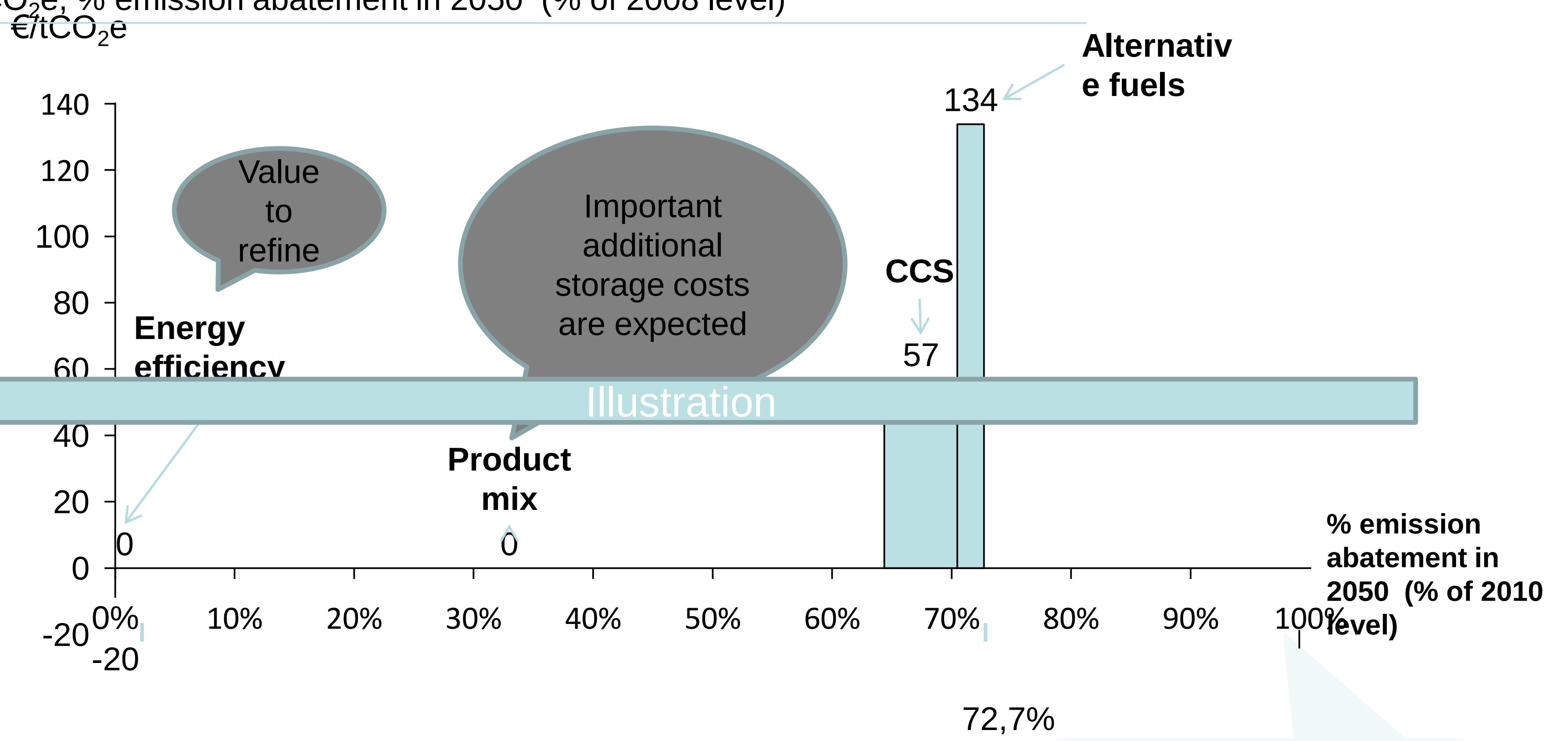
Illustration

Costs

In cement, most of the potential comes from the use of compos... calculator

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

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



To obtain the-99% evolution of ambition 4, add the 2010-2050 21% reduction

NOTE: Including biomass potential
SOURCE: IEA ETP 2012, Global calculator model

Agenda

Global
Calculator

2050 evolution of materials and emissions

Materials demand evolution

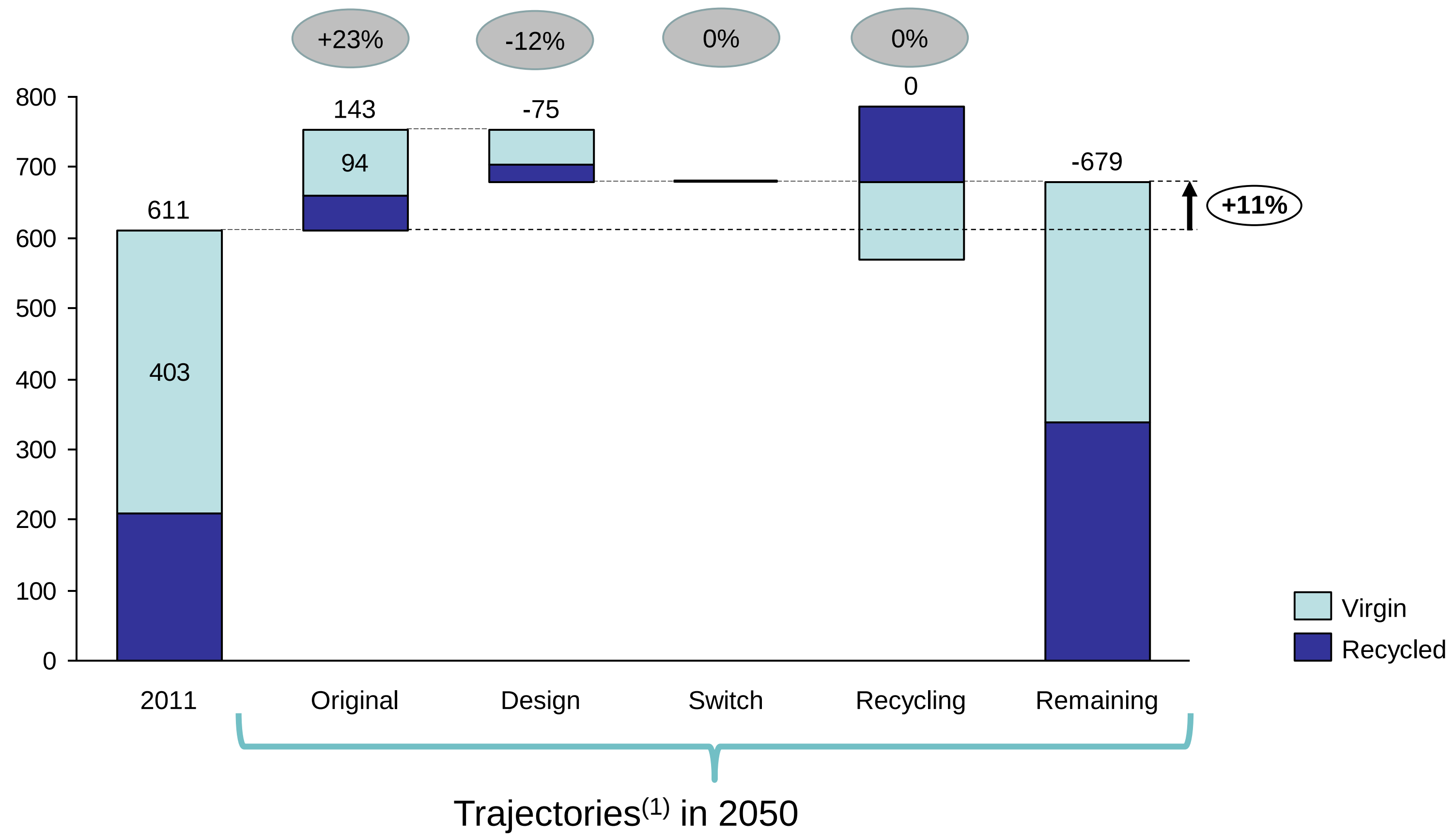
- Cross sector demand
- Cross sector material switch
- Steel
- Chemicals
- Aluminium
- Cement
- Paper & Timber

Reduction potential on the manufacturing processes

- Resulting emissions
- Discussion on ambition levels across sectors
- Discussion on CCS
- Steel
- Chemicals
- Aluminium
- Cement
- **Paper, Timber & Other**

Reduction potential
Details for ambition level 3

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

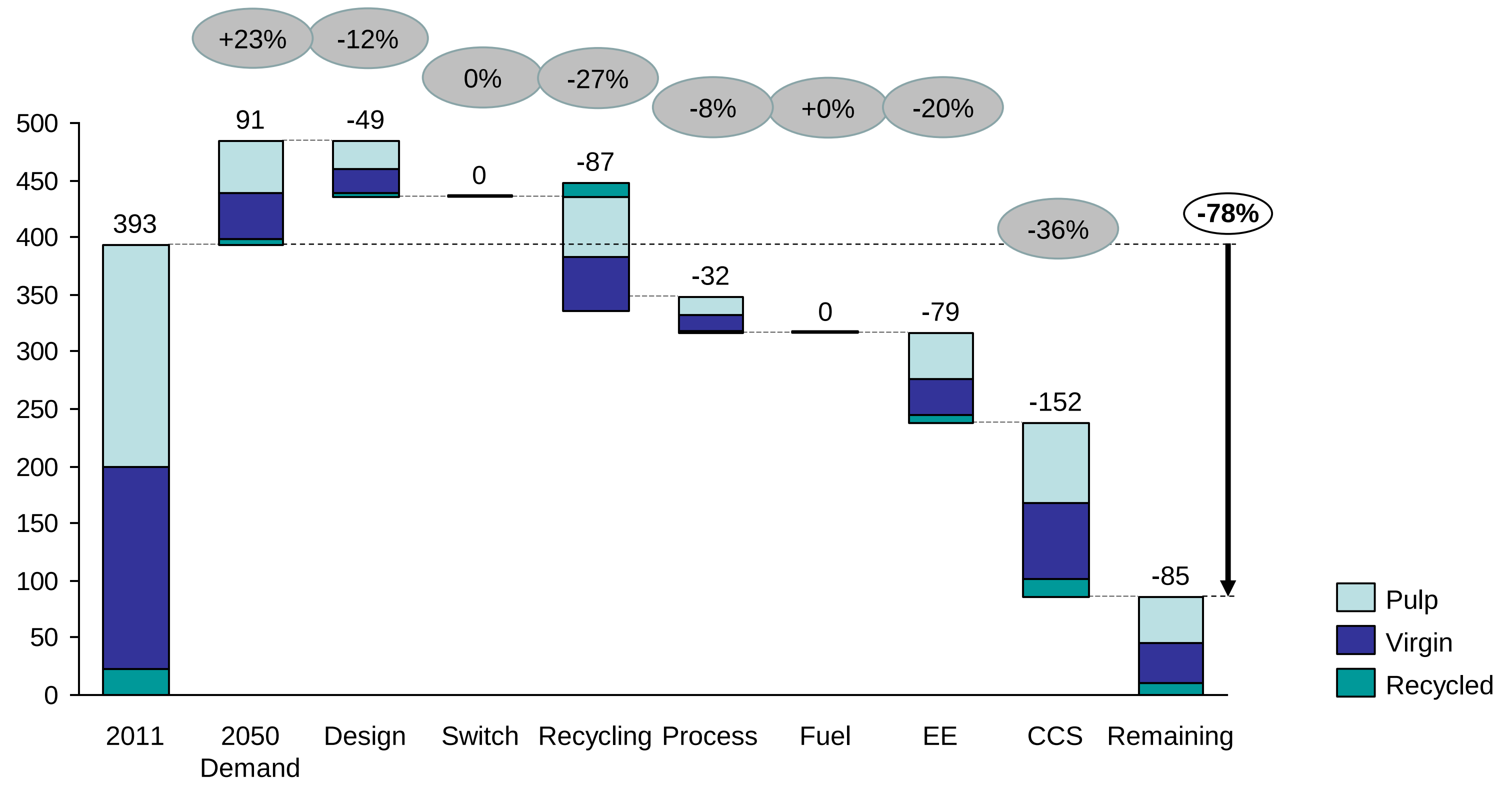


NOTE: (1) The population follows the average UN projection in all four trajectories
(2) Assuming biomass emits, not including electricity related emissions
SOURCE: IEA ETP 2012, Global calculator model

Reduction potential

Details for ambition level 3 (1)

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



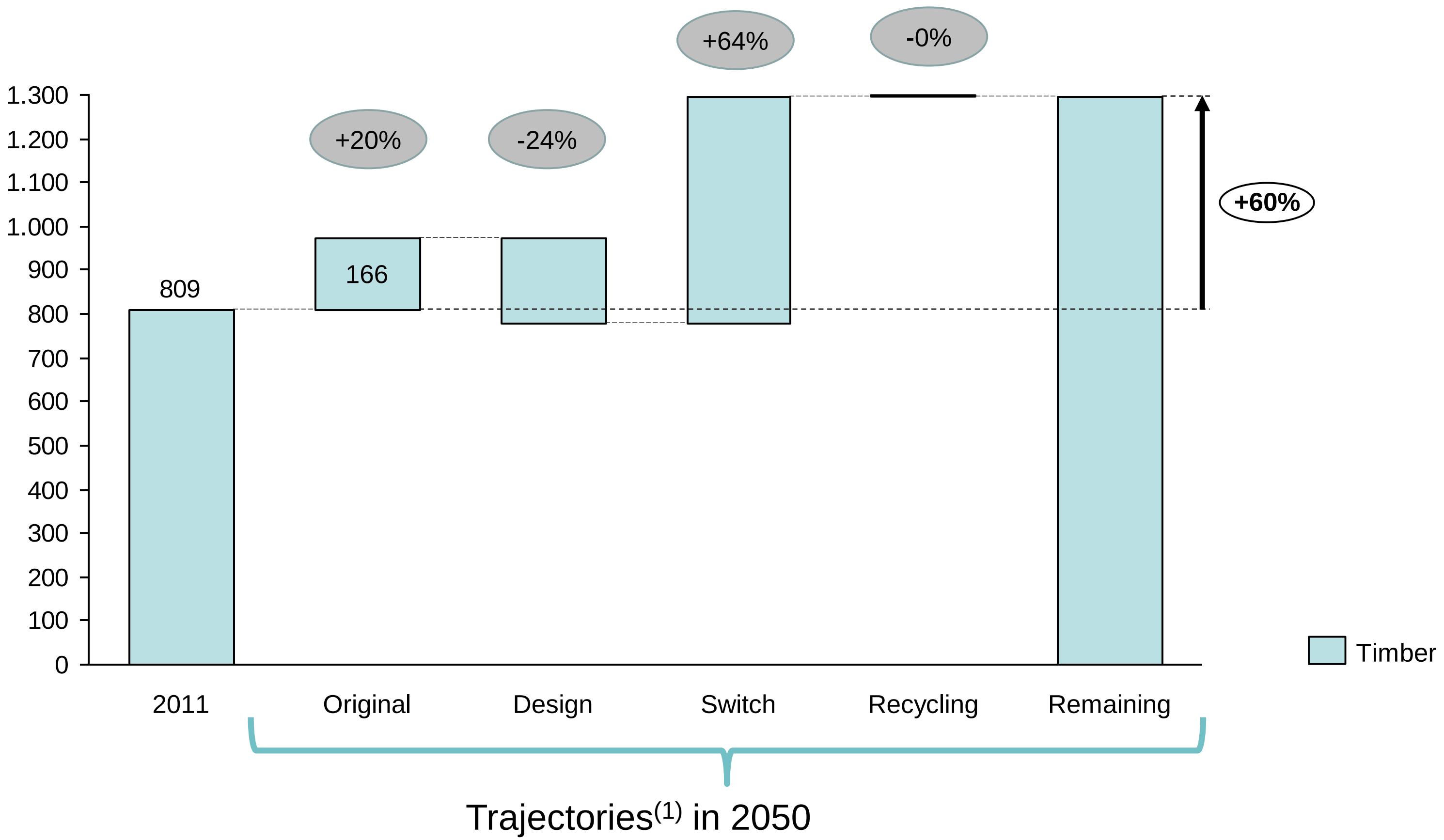
NOTES: (1) The population follows the average UN projection in all four trajectories
(2) Excluding biomass related reductions & electricity related emissions
(3) Other sectors are impacted by these transitions (e.g. additional emissions are created in the aluminium and plastics sectors)
Percentage reductions are calculated vs the 2010 baseline
SOURCE: IEA ETP 2012, Global calculator model

Figures of July 2014

Reduction potential
Details for ambition level 3

Global Calculator

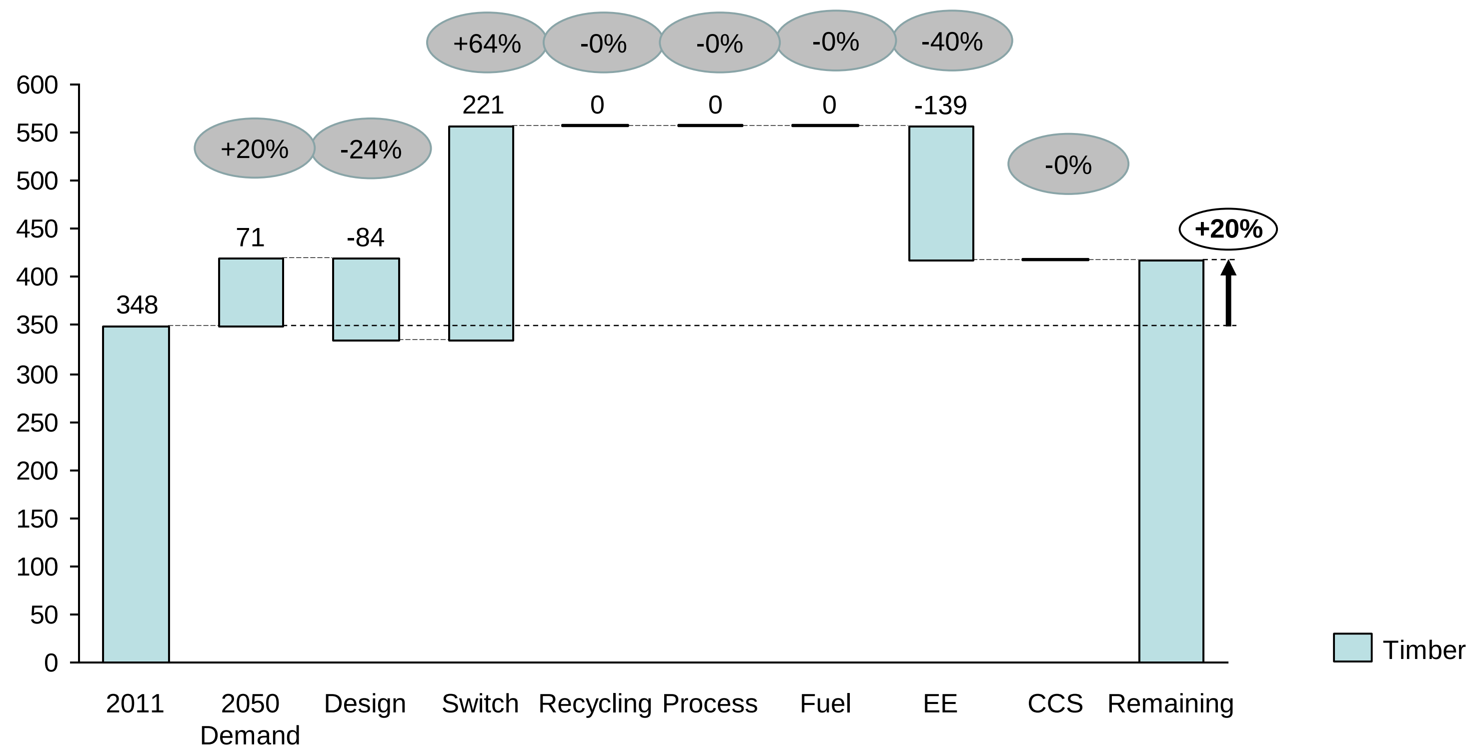
Timber production for ambition level 3
(M tons, % of 2011)



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
Details for ambition level 3 (1)

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



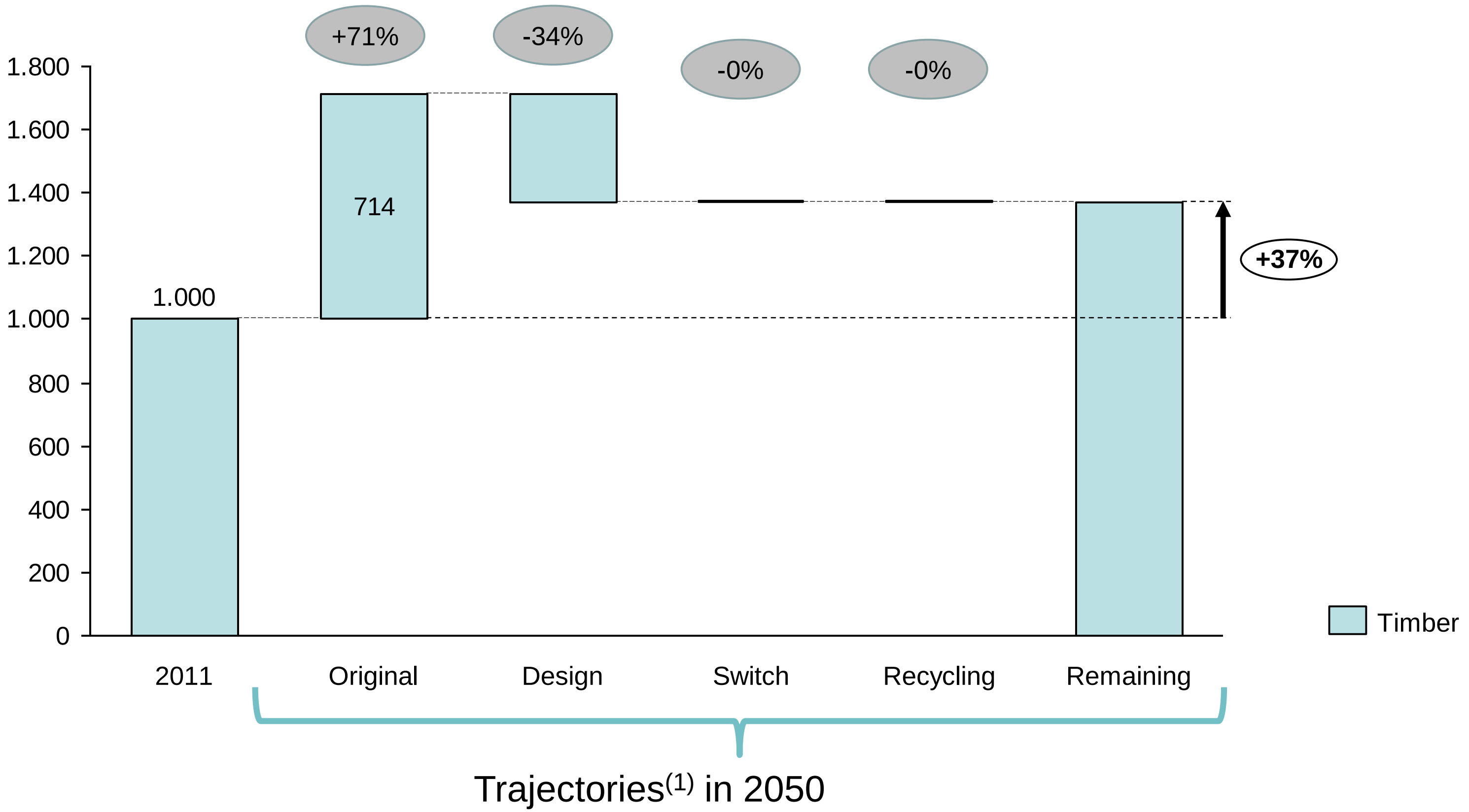
NOTES: (1) The population follows the average UN projection in all four trajectories
(2) Excluding biomass related reductions & electricity related emissions
(3) Other sectors are impacted by these transitions (e.g. additional emissions are created in the aluminium and plastics sectors)
Percentage reductions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

SOURCE: IEA ETP 2012, Global calculator model

Reduction potential
Details for ambition level 3

Global Calculator

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



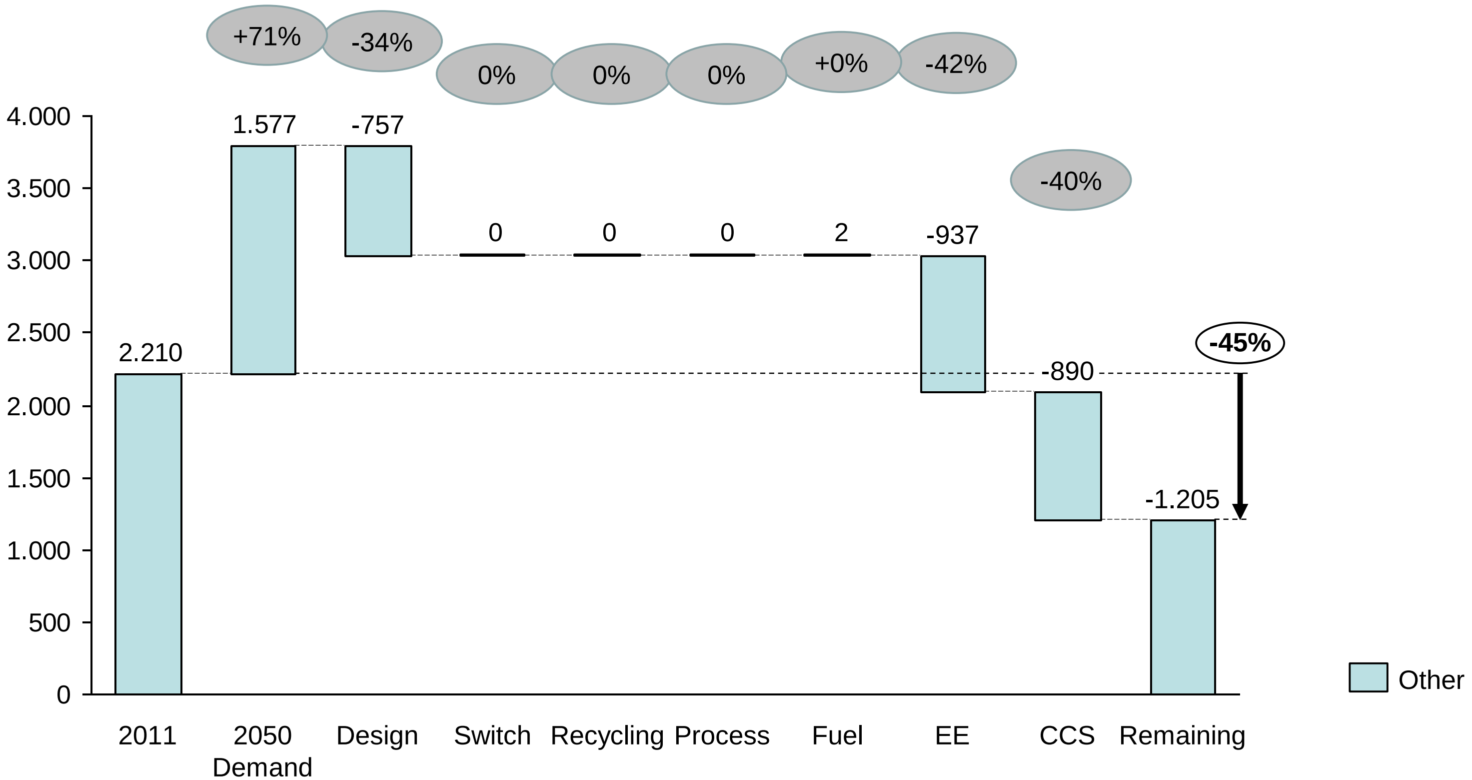
NOTE: (1) The population follows the average UN projection in all four trajectories
(2)Assuming biomass emits, not including electricity related emissions
SOURCE: IEA ETP 2012, Global calculator model

Production of other materials is normalized to 1000 in 2011

Reduction potential

Details for ambition level 3 [(1)]

Other 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

Global Calculator

Thank you.

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