Legend:

- ★ — Key slide
- Question… — Key feedback asked
- Data — Model input
- Consultation feedback — Consultation feedback still to take into account

Global Calculator

Iron & Steel Workshop

Products & Manufacturing of the Global Calculator

Workshop of April 24th 2014 (version of July 17th)

Brussels

Department of Energy & Climate Change

CLIMACT

World Resources Institute

eit Climate-KIC

Climate Media Factory

Energy R&D International

LSE The London School of Economics and Political Science

Imperial College London

EY Building a better working world

国家发展和改革委员会能源研究所

Preliminary information on this preread

Global Calculator

- This document
  - Supported workshop discussions of April 24th 2014
  - Addresses steel assumptions to refine the model
  - Other materials assumptions are addressed through sector specific consultations which are available through these links (cement, chemicals)
  - There is also a cross-sector analysis here
- The model was subsequently updated however it is still a work in progress as of July 2014. Some non processed expert feedback is noted within the document
- You are more than welcome to share feedback and we will try to include it in future version of the analysis. For this reason, this document will continuously update itself until September 1st
- All this documentation is open source

Agenda

Content

• **Introduction to the Global Calculator**	**9-10h**
• Iron & steel demand prospective	10-11
• Iron & steel manufacturing with lower energy intensity	11h30-13h

Introduction to the Global Calculator

Background

Expert & Literature review

Most introduction material is described in the cross sector document

Global Calculator

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

The cross sectoral document is available here

Introduction to the Global Calculator

Background

Expert & Literature review

The following stakeholders will be provided with an opportunity to review the steel assumptions [1]

Global Calculator

Iron & steel specific

Worldsteel Association
- Clare Broadbent, Eldar Askerov

European Steel Technology Platform
- Jean-Pierre Birat

Eurofer
- Jean Theo Ghenda

Steel Institute VDEh
- Marten Sprecher

Fraunhofer institute
- Marlene Arens

ArcelorMittal
- Jean-Sebastien Thomas, Karl Buttiens

Tata Steel

All sectors (interaction planned later)

Think tanks
- WBCSD
- GIZ

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

NGOs
- Greenpeace
- WWF

Legend
Workshop presence

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

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

Global Calculator

Main sources used for this analysis

Organisation	Source
World Steel Association	• World Steel in Figures 2013 • Steel Statistical year book 2013 • Sustainable steel: Policy and indicators 2013 • Steel's Contribution to a Low Carbon Future • The three Rs of sustainable steel (Reduce, Reuse, Recycle), 2010
Eurofer	• Low Carbon Steel Roadmap 2050 (IEA involved, led by BCG and German Steel Institute)
EU JRC	• Prospective Scenarios on Energy Efficiency and CO2 Emissions in the EU Iron & Steel Industry
UN work	
ULCOS	• Official website
Midrex	• MidrexStats2011-6.7.12
IEA	• 2013 Key world energy statistics • 2012 technology perspectives
Cambridge	• With both eyes open
	• NTNU & Cambrige University (2014 04 10 International Materials Education Symposium)
US Environmental Protection Agency	• Available and emerging technologies for reducing greenhouse gas emissions from the iron and steel industry. North Carolina: US EPA. , 2010
Previous consultations	• Similar roadmaps performed in Belgium and Wallonia

Content

• Introduction to the Global Calculator	9-10h
• **Iron & steel demand prospective**	**10-11**
• Iron & steel manufacturing with lower energy intensity	11h30-13h

Steel demand perspectives

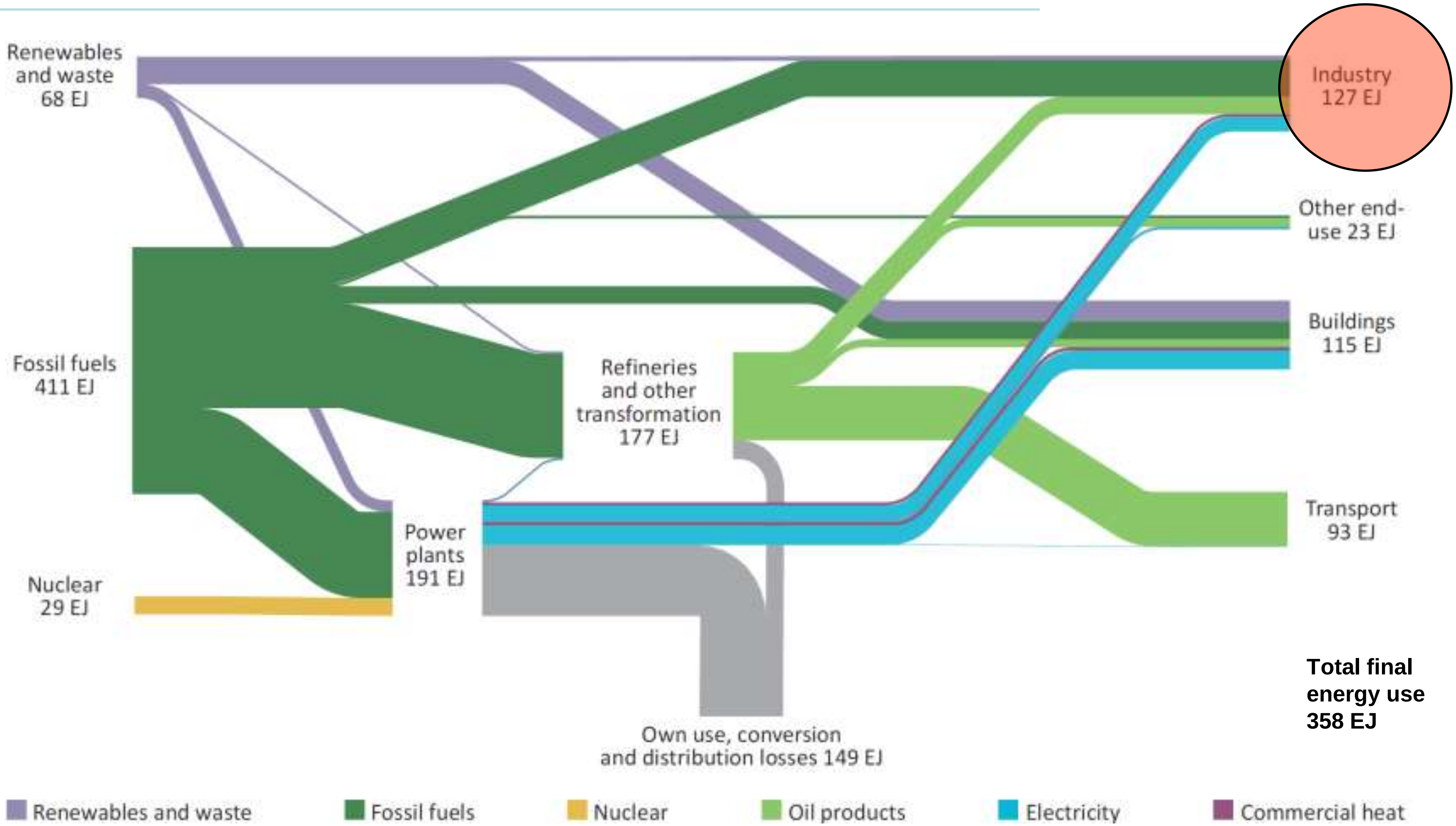
Current situation

Steel demand drivers

Resulting steel demand at constant technology

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

Energy Sankey in 2009, (EJ)



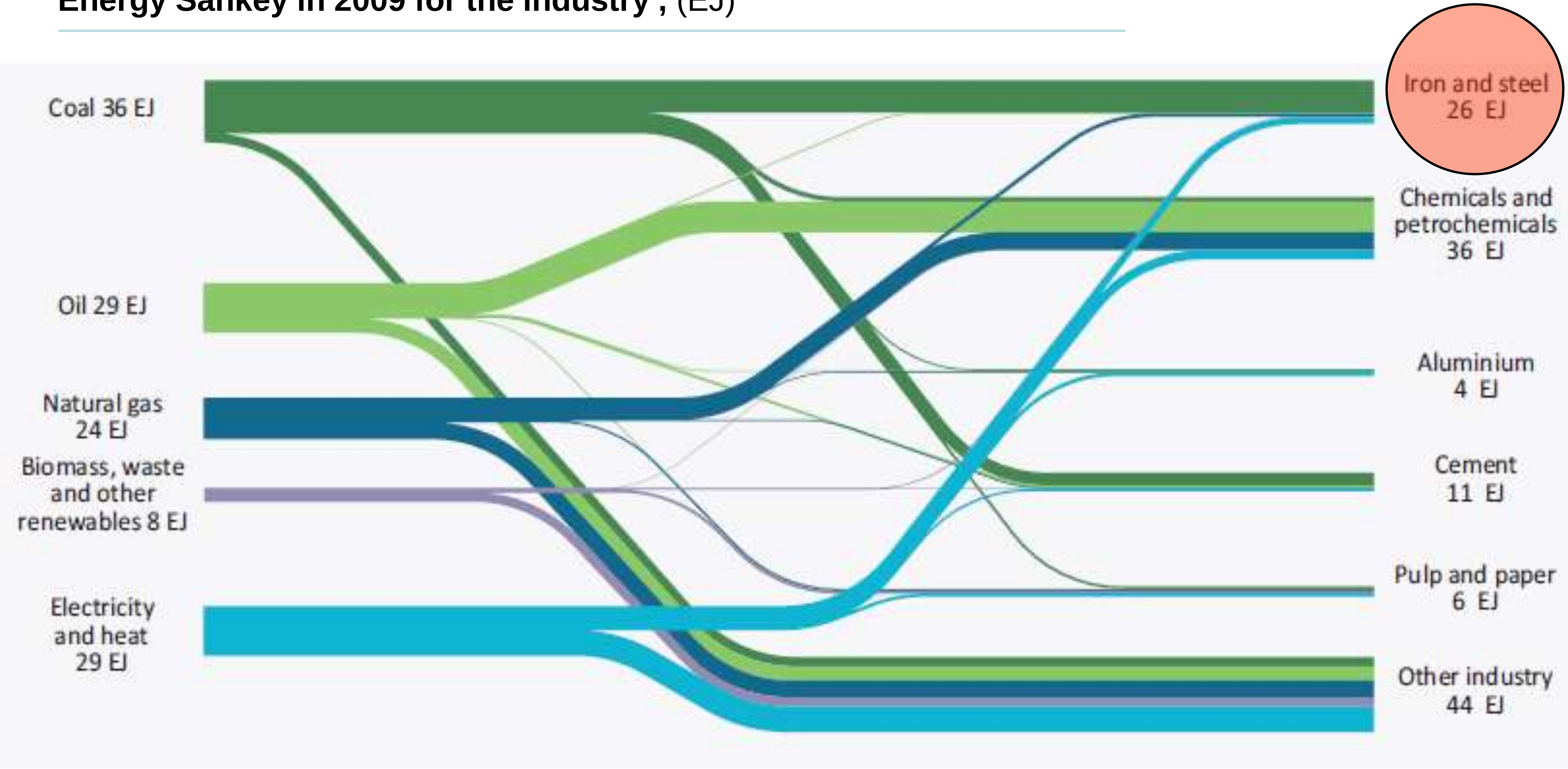
SOURCE: ETP 2012, IEA

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

Steel currently represents ~20% of the industry energy use, and mainly relies on coal

Global Calculator

Energy Sankey in 2009 for the industry , (EJ)



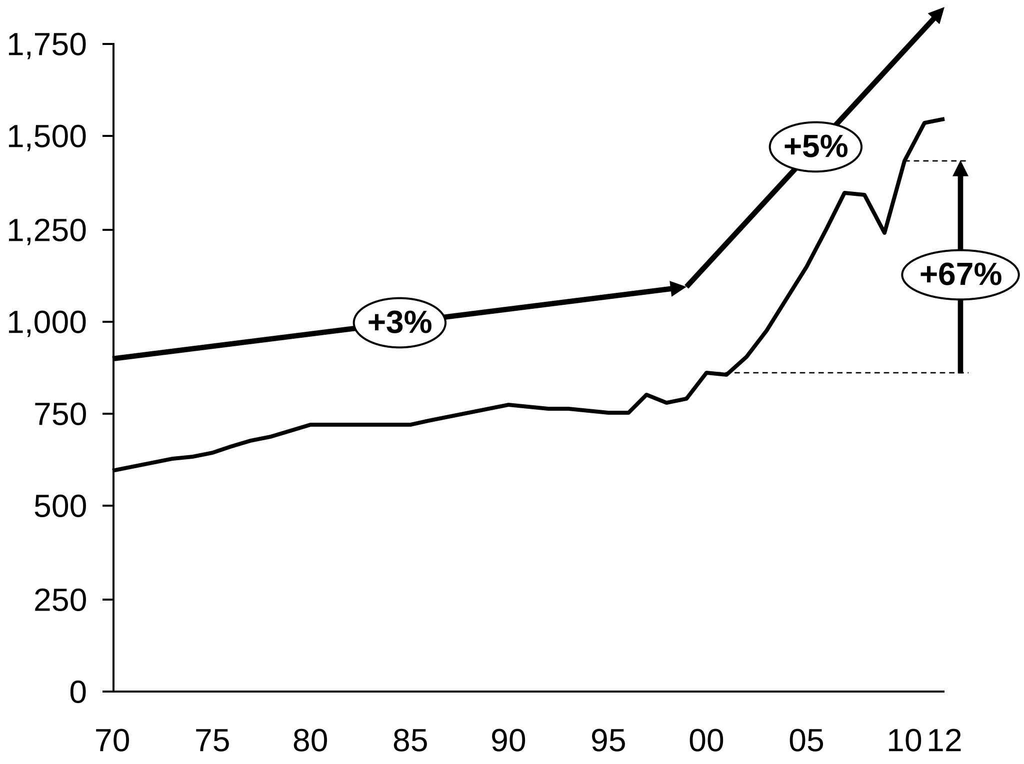
SOURCE: ETP 2012, IEA

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

Historic steel demand evolution

Global Calculator

World crude steel production
(M tons)



- Production stayed nearly constant between 1975 and 2000, it grew 67% between 2000 and 2010
- World crude steel production fell between 2007 & 2009 mostly in OECD economies, where production sank by 25% (1)
- Led by China and India, steel production in Asia continued to climb, although at a slower place (1)

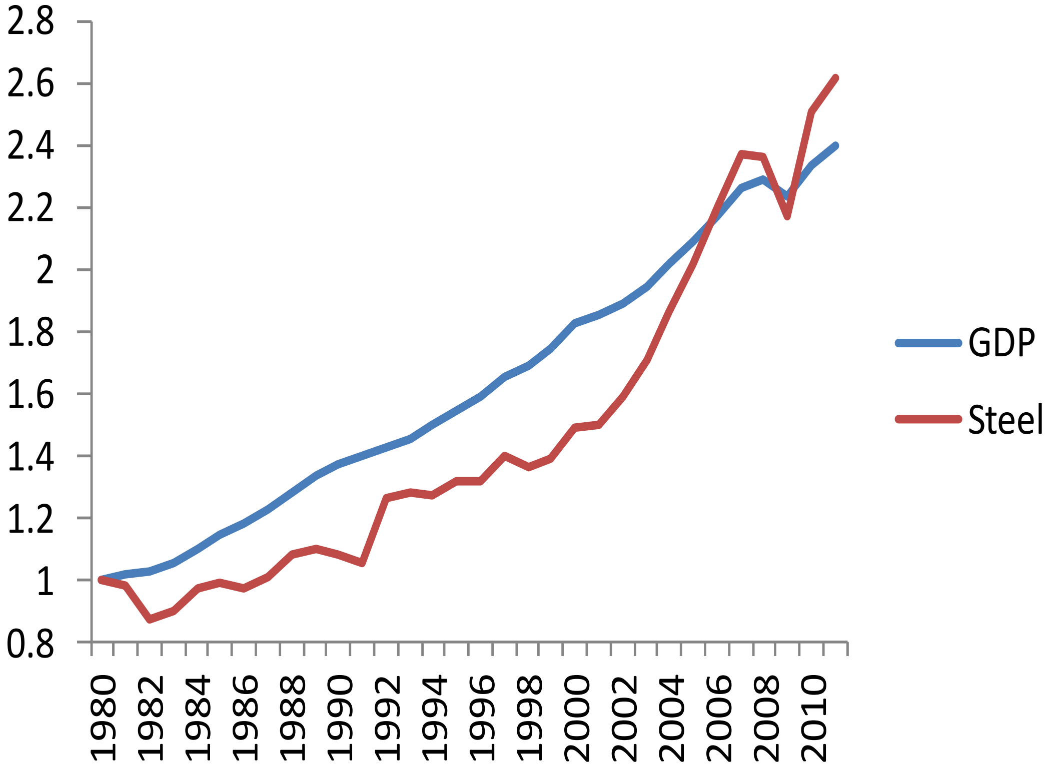
SOURCE : (1) World steel 2011, through IEA ETP 2012

At global level, steel production is correlated to GDP

Global Calculator

World steel production and world GDP evolution
(units production, GDP indexed on 1980 steel production level)

BACKUP



- Historical correlation between steel production and GDP suggest a long term 1-1 relationship
- Global demand growth is driven by emerging markets

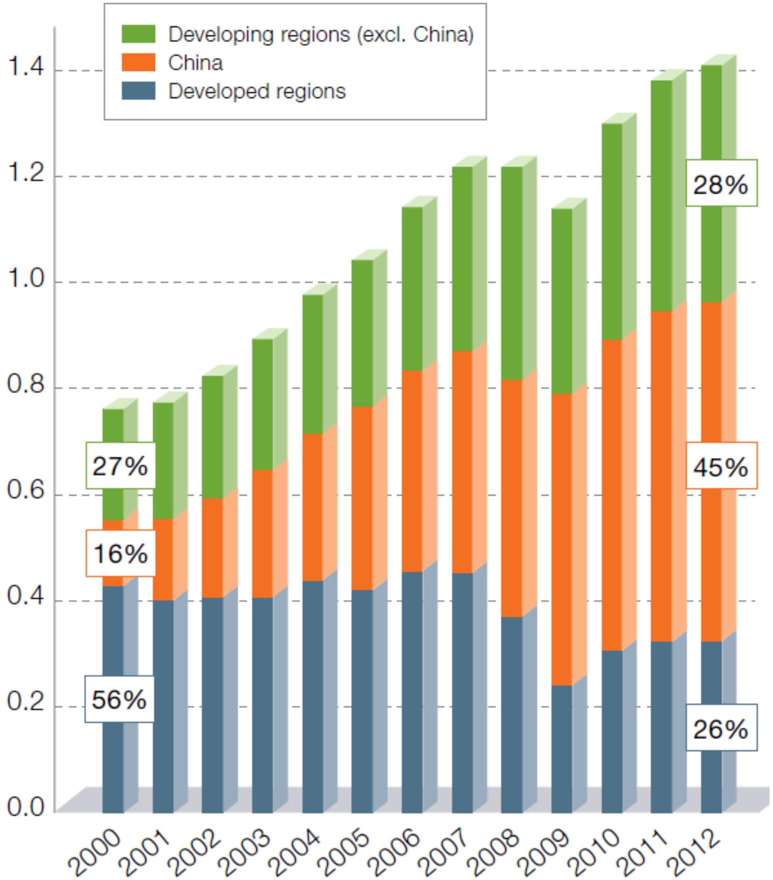
SOURCE : World steel association and World Bank

China is now using close to half of the world steel

Global Calculator

Evolution of world apparent steel use per region[2]
(billion tons finished steel products)

BACKUP



- 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]
- The five most important producers (China, Japan, the United States, Russia and India) accounted for over 65% of total global crude steel production in 2010[1]

NOTE : (3) Such as Latin America, Asia, Africa and the Indian sub-continent
SOURCE : (1) IEA ETP 2012 (2) Worldsteel : steel's contribution to a low carbon future

Steel demand perspectives

Current situation

Steel demand drivers

Resulting steel demand at constant technology

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

Global Calculator

Value chain

Illustrations

Resources

Rare materials | Iron ore | Sand

Materials analysis

Uranium | Fossil hydro-carbons | Biomass

Energy analysis

Materials

Steel | Cement | Aluminium | Chemicals | Pulp & paper

Products

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

1

Steel offers unique combination of characteristics: Toughness, Thermal expansion, Corrosion resistance, Electrical resistance, Ductility, and Availability

Steel materials characteristics (including various alloys and treatments)

Solid	Steel is often used to make strong stiff (non-flexible) structures It is tough and crack don't appear easily (vs ceramics) It can also be used to make cables (only resistant in traction)
Stable	Low thermal expansion (similar to cement)
Durable	High melting temperature and can be protected from corrosion
Ductile/ Recyclable	Steel can be made to change shape without cracking. Through melting, steel can theoretically be recycled an infinite number of times
Affordable/ Available	Steel is relatively cheap, and there are large reserves of iron ore. It tends to be more expensive than some other durable materials (e.g. cement and timber)
Conductor	Can be used to conduct heat and electricity (less than several other metals such as aluminium or copper)

Half the construction steel is for rebar with cement, the 2 materials complement each other (cement protects from corrosion and steel is strong in traction)

SOURCE: with both eyes open

Iron & steel demand driving products

Global Calculator

Steel driving products
(2011)

Steel

1518 Mt steel
2991 M tCO_2e
1,97 tCO_2e/t steel

Transport	13%: 194 Mt steel	**Cars & light trucks**	8%: 123 Mt steel
		Trucks	2%: 28 Mt steel
		Ships	2%: 23 Mt steel
		Rail	1%: 20 Mt steel
Industrial equipment	16%: 246 Mt steel	**Electrical equipment**	3%: 46 Mt steel
		Mechanical equipment	10%: 153 Mt steel
Construction	55%: 832 Mt steel	**Infrastructure**	22%: 332 Mt steel
		Residential Buildings	28%: 422 Mt steel
		Other Buildings	5%: 77 Mt steel
Metal products	16%: 247 Mt steel	**Metal goods**	13%: 193 Mt steel
		Consumer packaging	1%: 11 Mt steel
		Domestic appliances	3%: 43 Mt steel
Energy	0,6%: 10Mt steel	**Windmills**	0,4%: 6 Mt steel
		PV Panels	0,02%: 0,3 Mt steel
		Pipes	3%: 40 Mt steel

NOTES: (1)There are other products, these have been diluted amongst the existing categories
(2) Half the "Construction" steel is used for rebar with cement

SOURCES: With both eyes open, Copyright 2012 UIT Cambridge Ltd, adapted by Climact to 2011 figures

1

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

Global Calculator

Technologies & Products		Amounts (units, 2011)	Intensity (t steel/product)	Annual Steel production (M tons, 2011)[2]
Transport	Cars & light truck	113 (M Vehicles)	1100 kg/vehicle	123
	Trucks	5,7 (M Vehicles)	4900 kg/vehicle	28
	Ships	1 (k units)	20 000	23
	Rail	5 (k units)	4000	20
Buildings	Buildings Residential	3 930 (km^2 [4])	107 kg/m^2 [1]	422
	Buildings Others	830 (km^2 [4])	93 kg/m^2 [1]	77
	Infrastructure	1750 (km^2 [4])	187 kg/m^2	332
	Mechanic al equipment	160 (M tons)	0,97	153
	Appliance	253 (M tons)	0,17	43
Consumer goods	Metal goods	257 (M tons)	0,75	193
	Consumer packaging	530 (M tons)	0,02kg/kg packaging	11
Energy	Windmills	17,500 2MW turbines	350 tons/2MW turbine[3]	6,1
	PV panels	160 M m^2	2kg $/m^2$	0,320
	Electrical equipment	61,1 (M tons)	0,75	46
	CCS + oil pipes	100 000 km	0,4 ton/m	40
Other	Other Steel	~0M (tons)	1	~0

Model demand drivers

Total 1518 Mton (100%)

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

(4) Of ground surface

SOURCE: (1) Muiris Moynihan thesis obtains 20kg/m² for residential buildings and 100 kg/m² for commercial

(2) With both eyes open (3) Worldsteel Wind energy case study

Steel demand perspectives

Current situation

Steel demand drivers

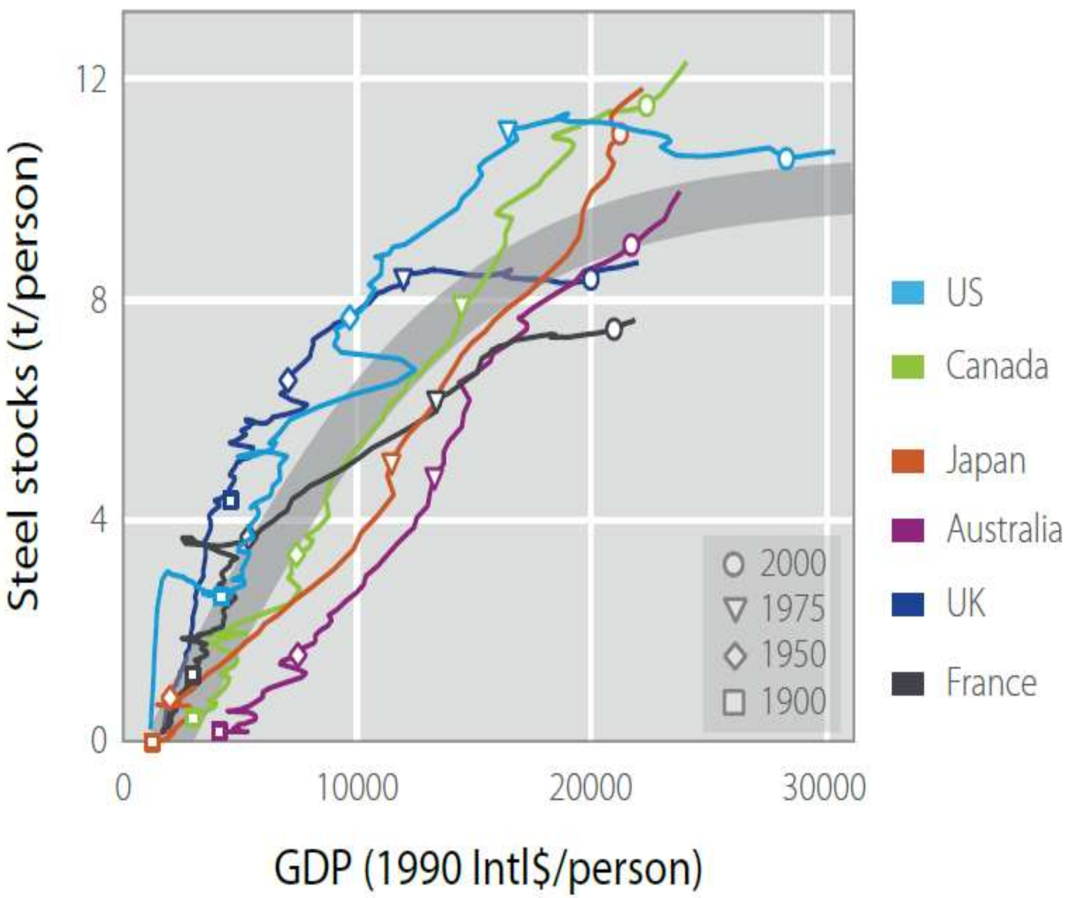
Resulting steel demand at constant technology

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)

1 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

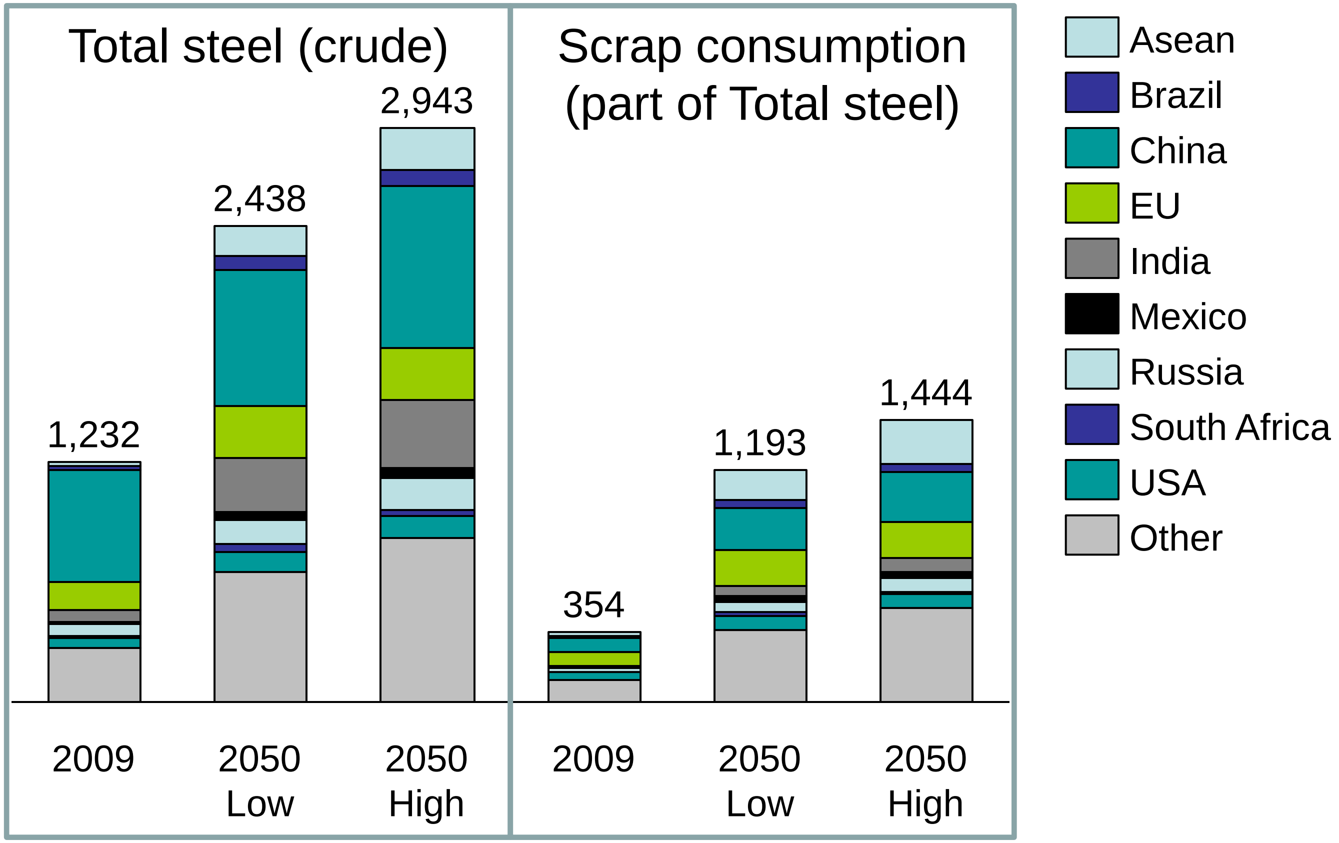
SOURCE: (1) Global Calculator team assumptions

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)



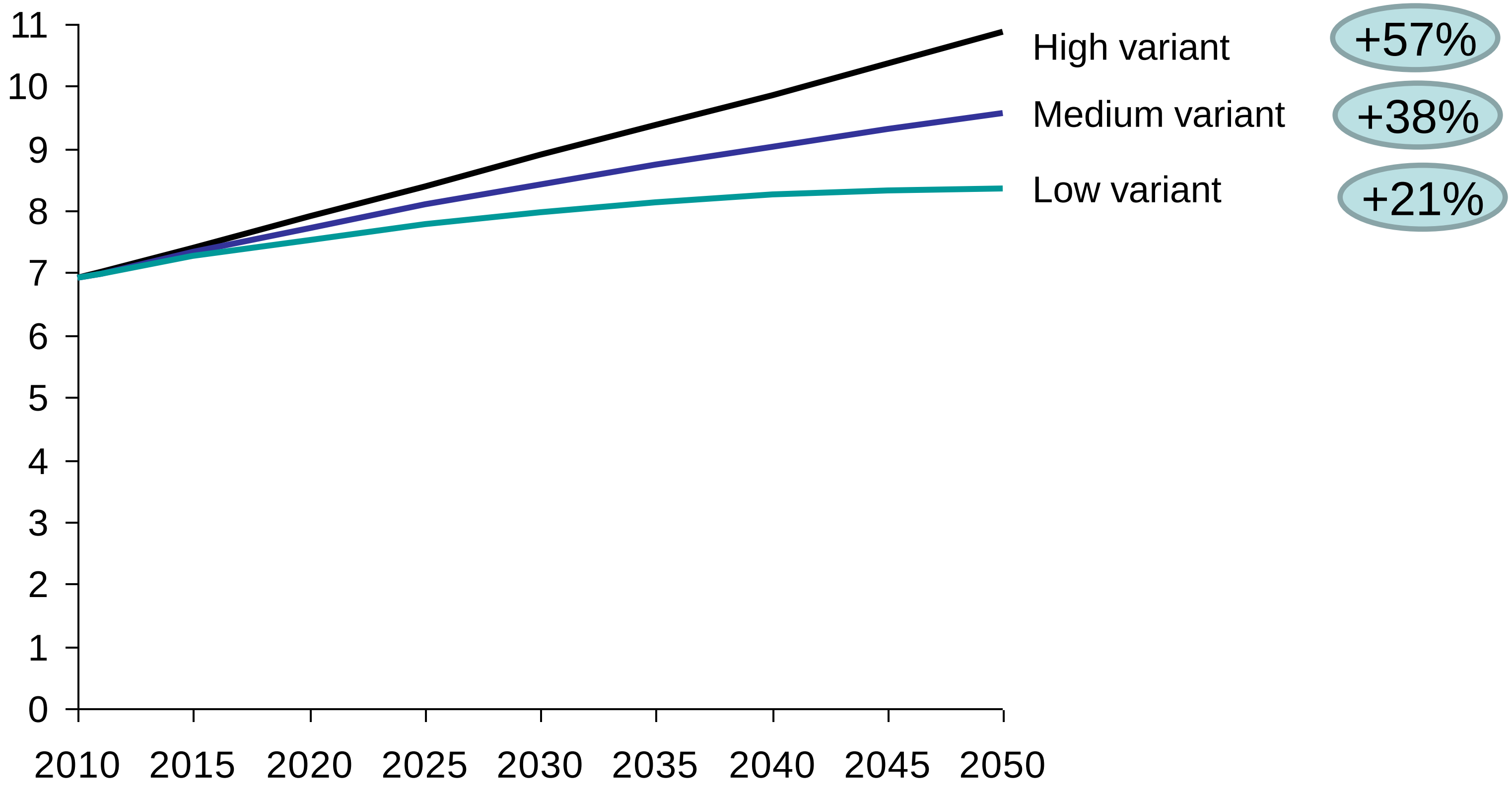
SOURCE: ETP 2012, IEA

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

Global Calculator

World population (billions)

2010-2050 growth (%)



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

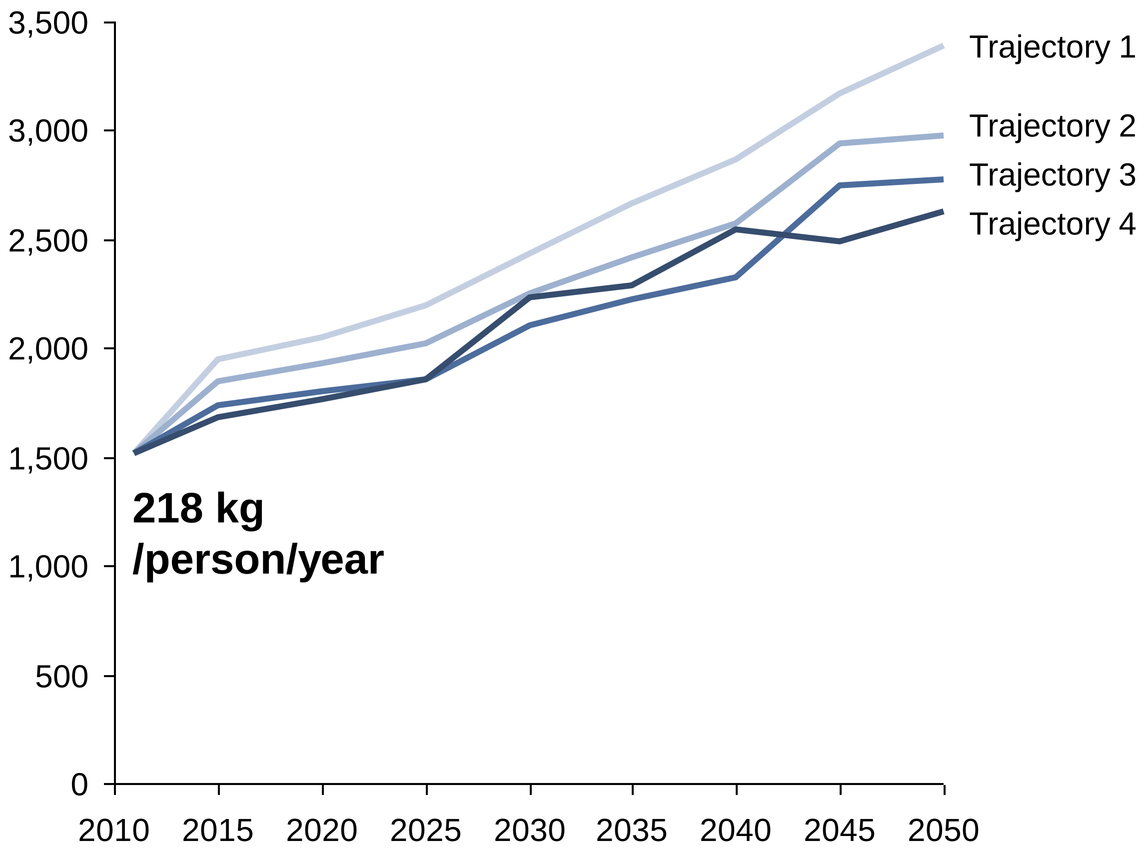
1

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
Trajectory 1	+124%	355 kg /person/year
Trajectory 2	+96%	316 kg /person/year
Trajectory 3	+83%	291 kg /person/year
Trajectory 4	+73%	275 kg /person/year

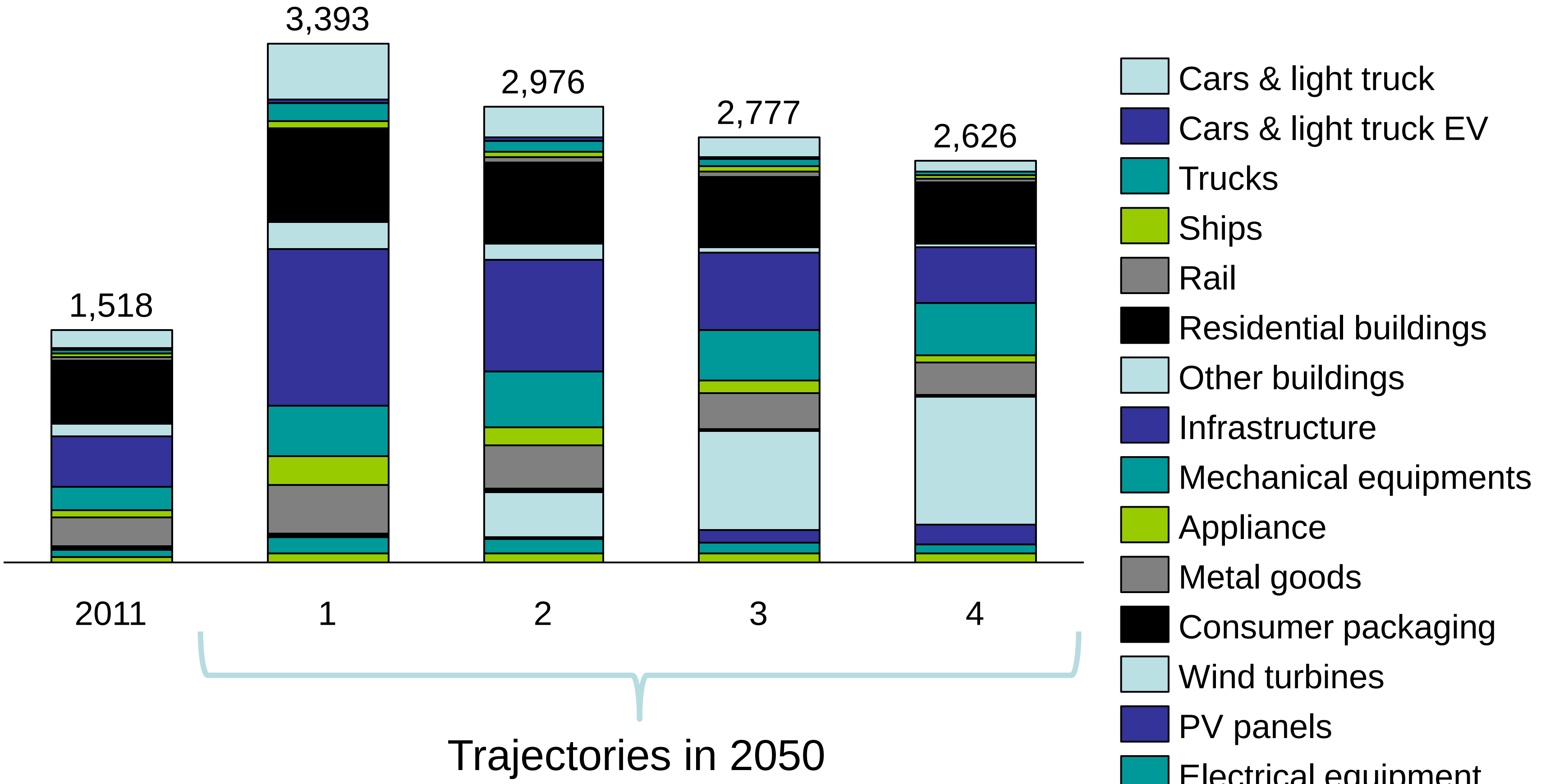
NOTE: (1) The population follows the average UN projection in all four trajectories
SOURCE: Global calculator model

Global calculator growth forecasts

Key driving demand sectors in trajectories 1, 2 and 3

Global Calculator

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



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

Global Calculator

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• **Iron & steel manufacturing with lower energy intensity**	**11h30-13h**

Steel manufacturing with lower energy intensity

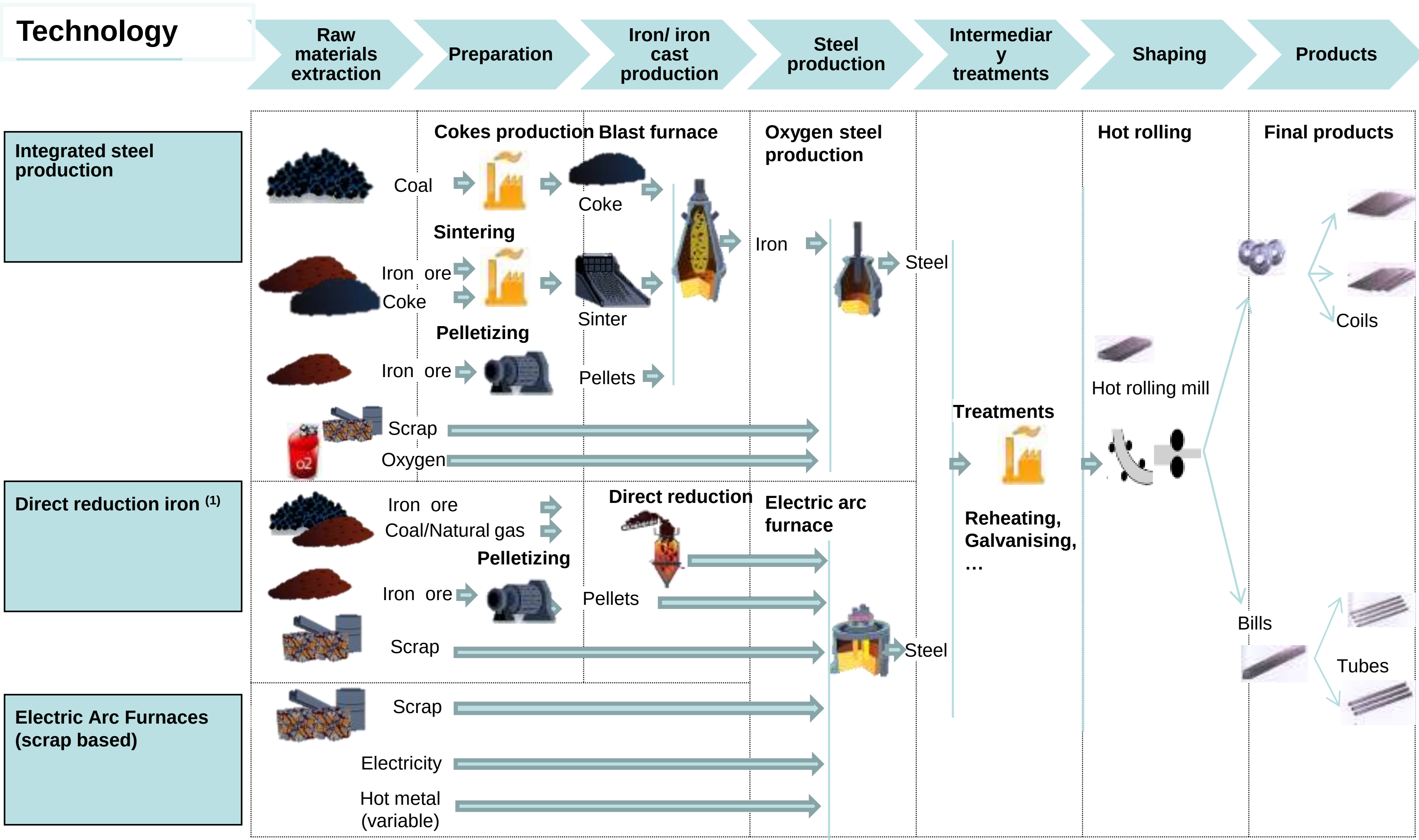
Steel manufacturing process

Estimation of the reduction potentials

Resulting scenarios

3 technologies are currently used to make most of the steel

Global Calculator

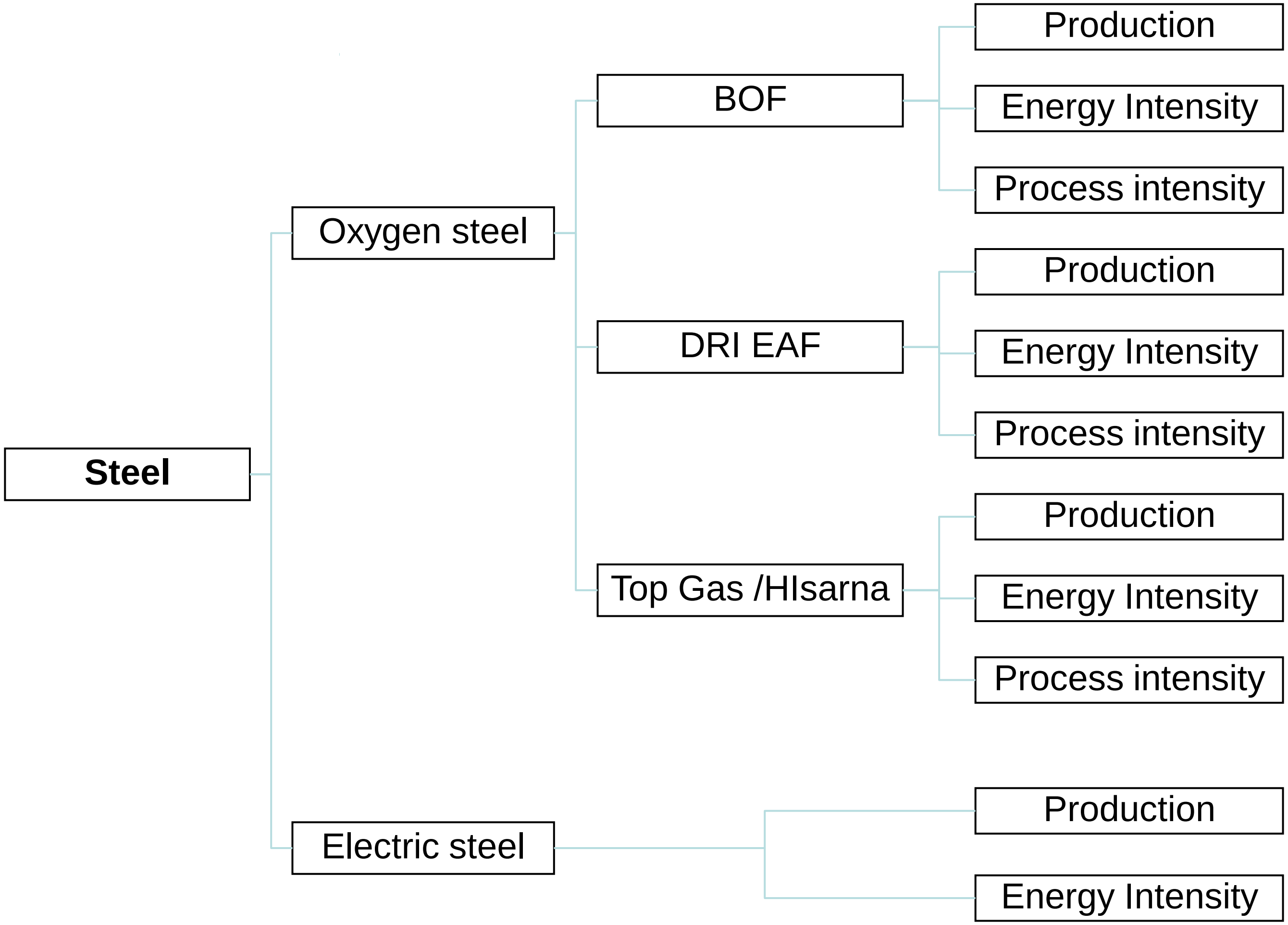


NOTE: (1) DRI is illustrated here with the Electric arc furnaces. It can also be performed with Blast furnaces
SOURCE: GSV, World Steel, Climact

Steel emissions are being modelled

Global Calculator

Steel emission tree



SOURCES: Climact

Agenda

Global Calculator

Steel manufacturing with lower energy intensity

Steel manufacturing process

Estimation of the reduction potentials

Resulting scenarios

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

List of actions & levers assessed

Design

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

Smarter design with similar steel grades

Increase proportion of high strength steel

Switch

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

In vehicles :
To aluminium
& to plastics

In buildings/Infr. :T
o green plastics
& to timber

Recycling

- Recycle the product or the material

Product recycling

Material recycling:
Electric arc furnace

SOURCE: Climact

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

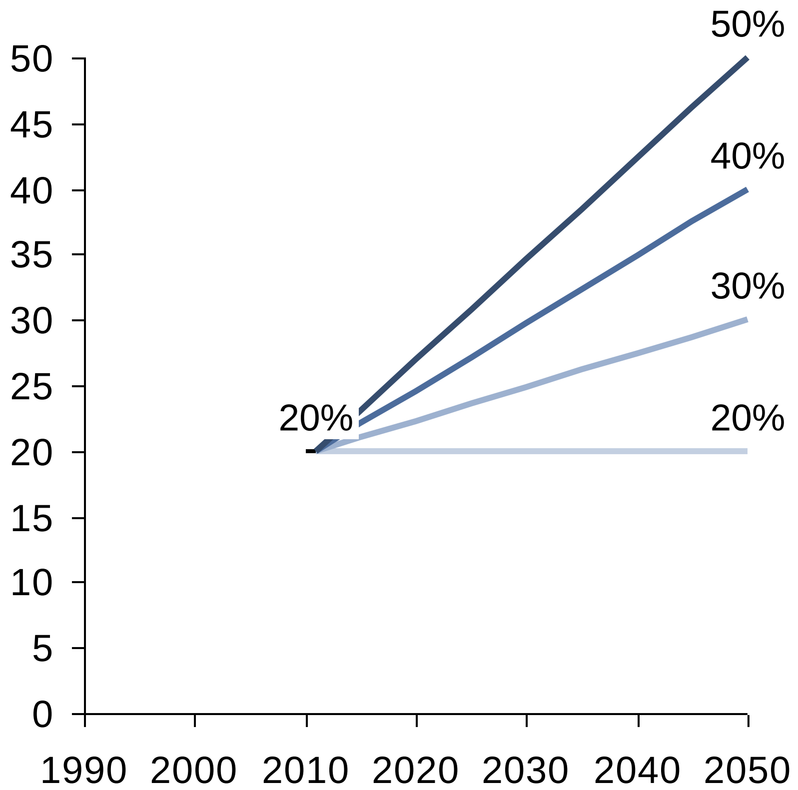
SOURCE: (1) Arcelor, (2) WorldSteel fact sheet the 3Rs (Reduce, Reuse, Recycle), based
A) on ULSAB research (WorldAutoSteel), carmakers' own body structure designs
B) 'Determination of Weight Elasticity of Fuel Economy for Conventional ICE Vehicles, Hybrid Vehicles and Fuel Cell Vehicles', fka, June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

2 Design: Smarter design & high strength steel increase

Proposed lever ambitions

Global Calculator

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

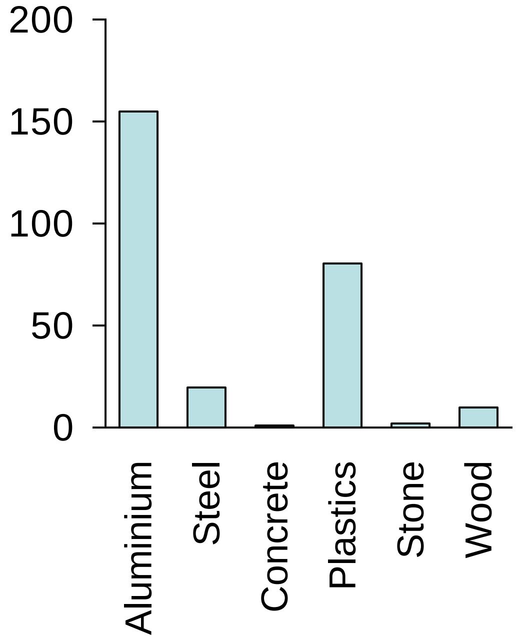
SOURCE: Climact national consultations

2 Material switch

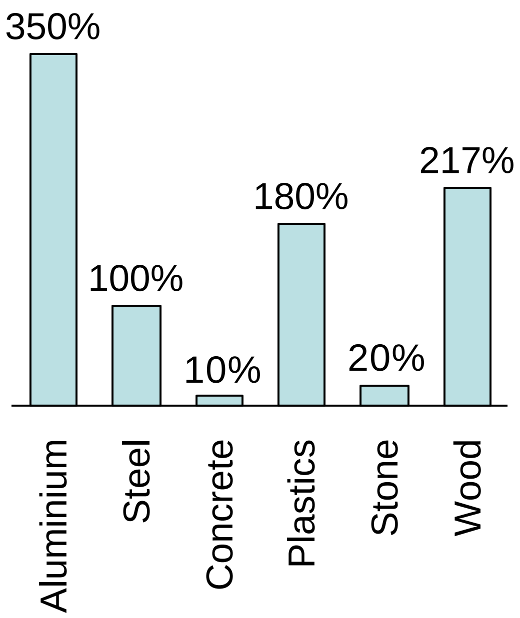
Steel is a relatively cheap material

Global Calculator

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

2 Material switch
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
• **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)

2

Materials recycling : Scrap based steel

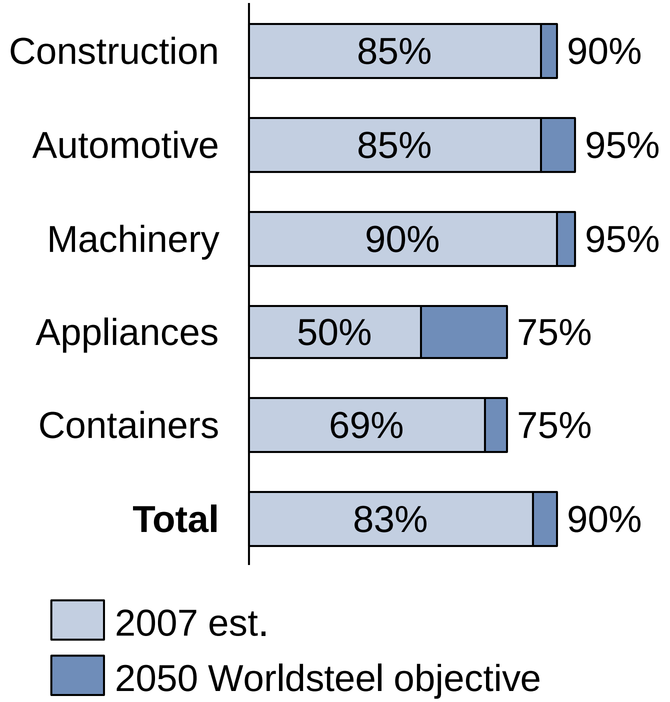
Up to 90% of steel could come from be recycled streams by 2050

Global Calculator

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, %)

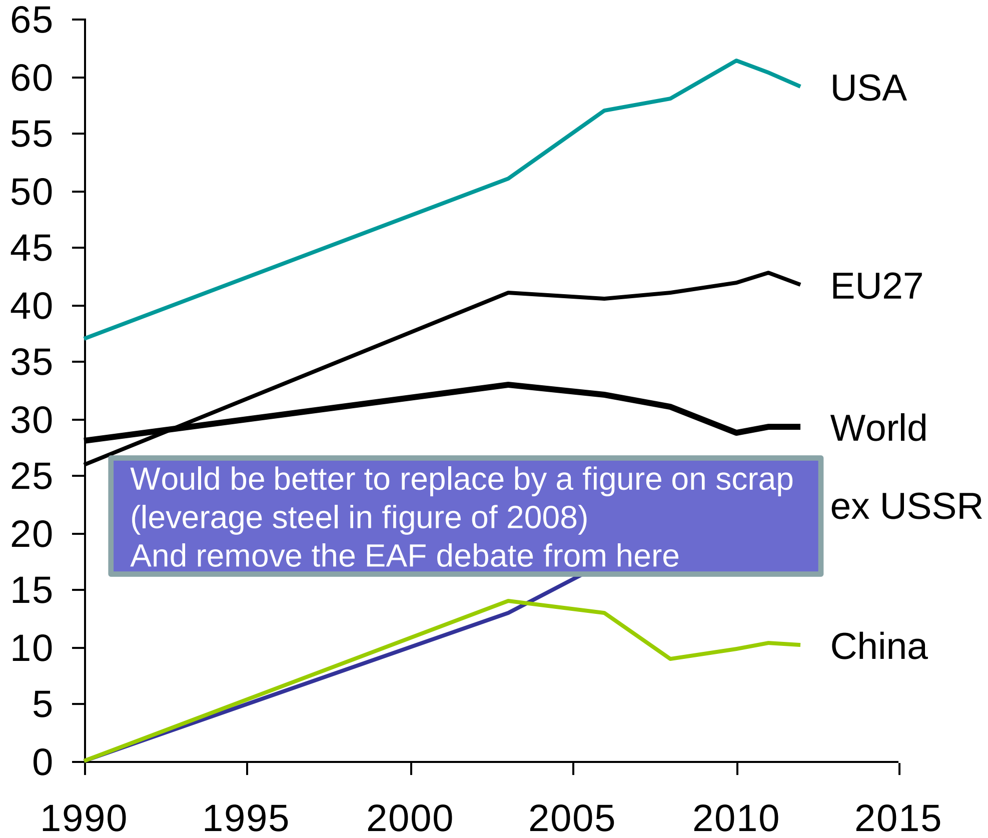


SOURCE: (1) Professor Robert Ayres (INSEAD) (2) (with both eyes open) (3) Worldsteel fact sheet, the 3 Rs(Reduce, Reuse, Recycle) (4) Global Calculator consultations

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)]

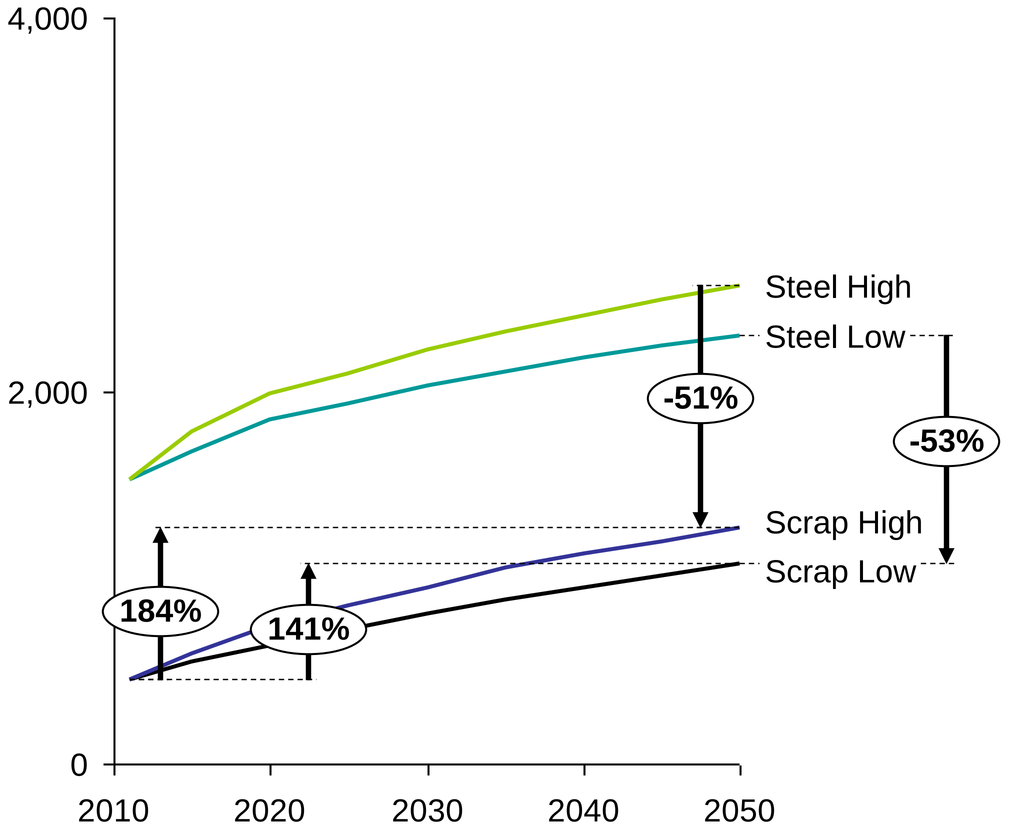
NOTES: (1) the EAF includes the both 100% scrap based EAF as well as EAF that uses DRI and/or hot metal in addition to scrap
(3) Length is function of the sector. 50 years is typically applicable in the buildings sector, automotive and consumer goods sector typically have shorter life times

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

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

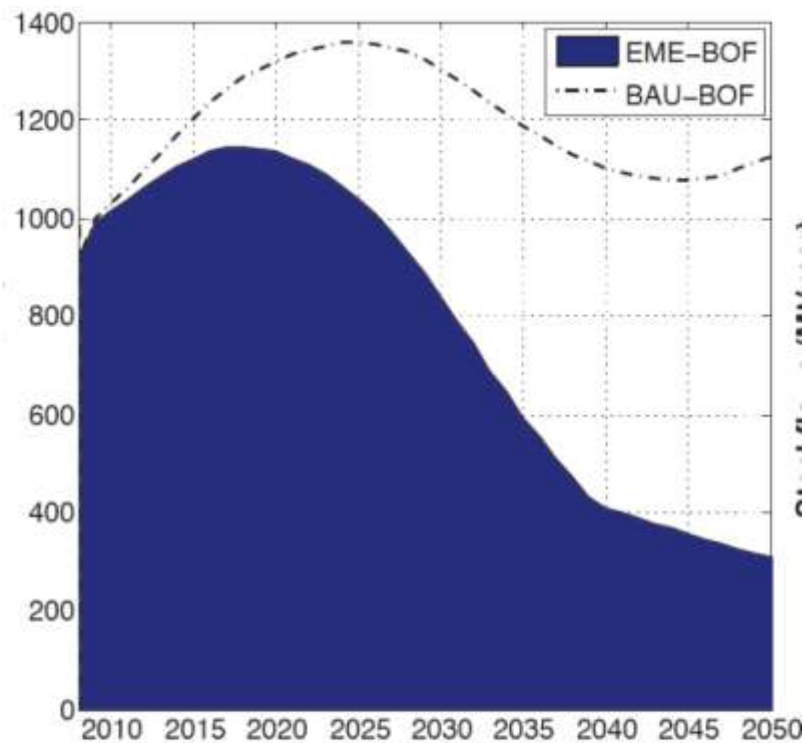
2

Materials recycling: Scrap based steel

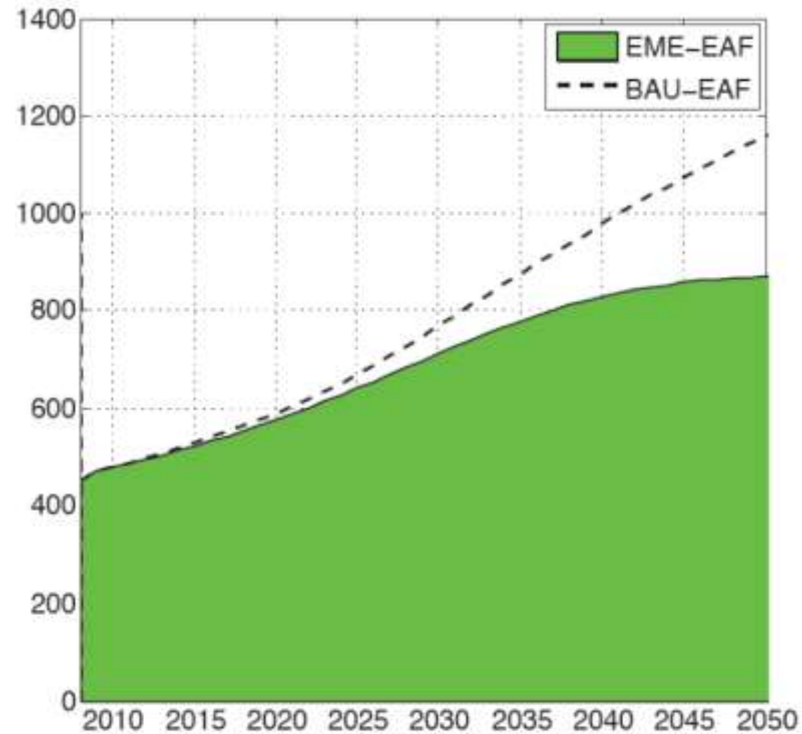
In lower demand scenario, NTNU & Cambridge scenarios forecast earlier market saturation and higher scrap%

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

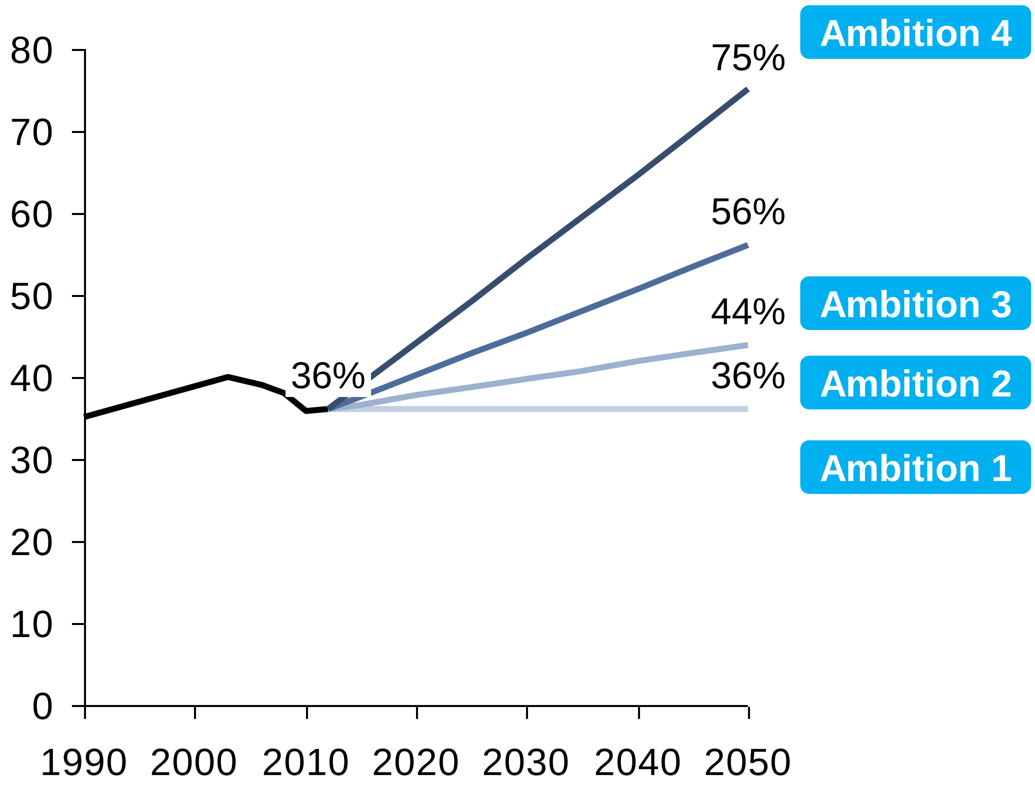
SOURCES: (1) Wallonia Steel consultation (2) Wallonia cement consultation, (3) GSV, (4) Ulcos, (5) McKinsey , (6) Duferco, (7) Worldsteel

2 **Materials recycling: Scrap based steel**

Proposed lever ambitions

Global Calculator

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

3 Carbon intensity of material production

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

Global Calculator

List of actions & levers assessed

Process improvement

- Towards fuels which emit less CO_2

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

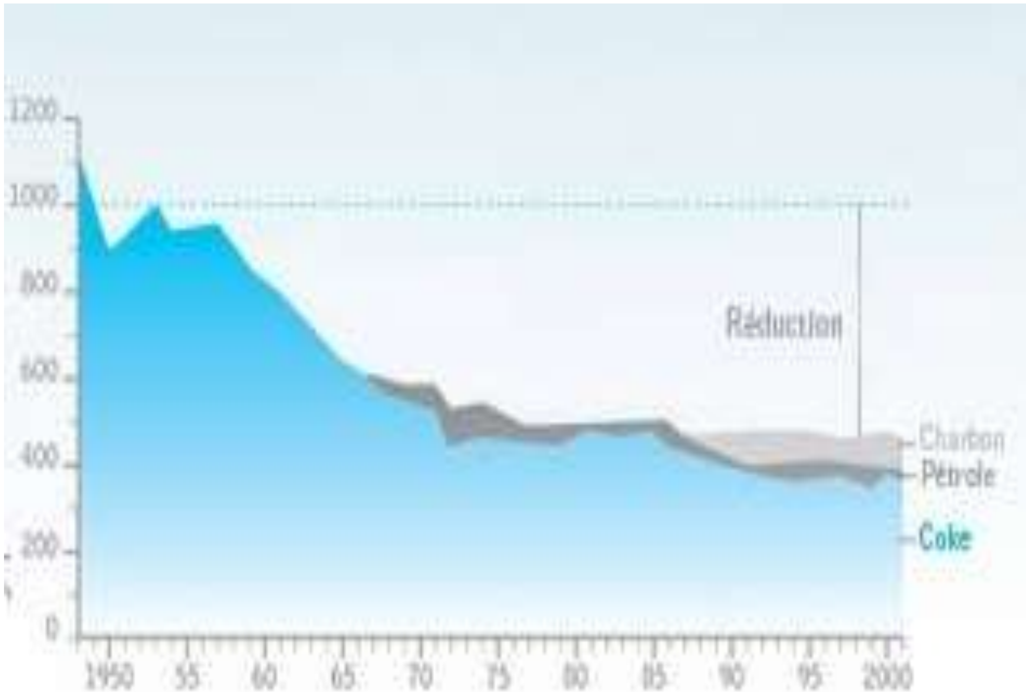
NOTE: Process choice has consequences on applicability of other levers Some combinations are exclusive whilst others can be added in sequential order

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

Process : Reduction of carboniferous materials

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

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



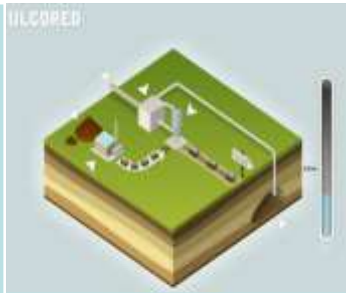
- The amounts of carboniferous materials per ton of steel have been significantly reduced during the last decades
- To date, the blast furnaces in the EU15 use today an average of 0,49 kg of carboniferous materials per kg of liquid iron cast produced(1), or 115kg of input materials for 100kg of steel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

Global Calculator

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

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

3 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

3

Process improvements: Penetration of DRI EAF

Proposed lever ambitions

Global Calculator

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

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

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 technology breakthrough and we therefore do not include it, even in level 4 ambition

SOURCE: Steel consultation Wallonia Low Carbon 2050

3 Process improvements: Electrolysis

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 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

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
• /	• **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

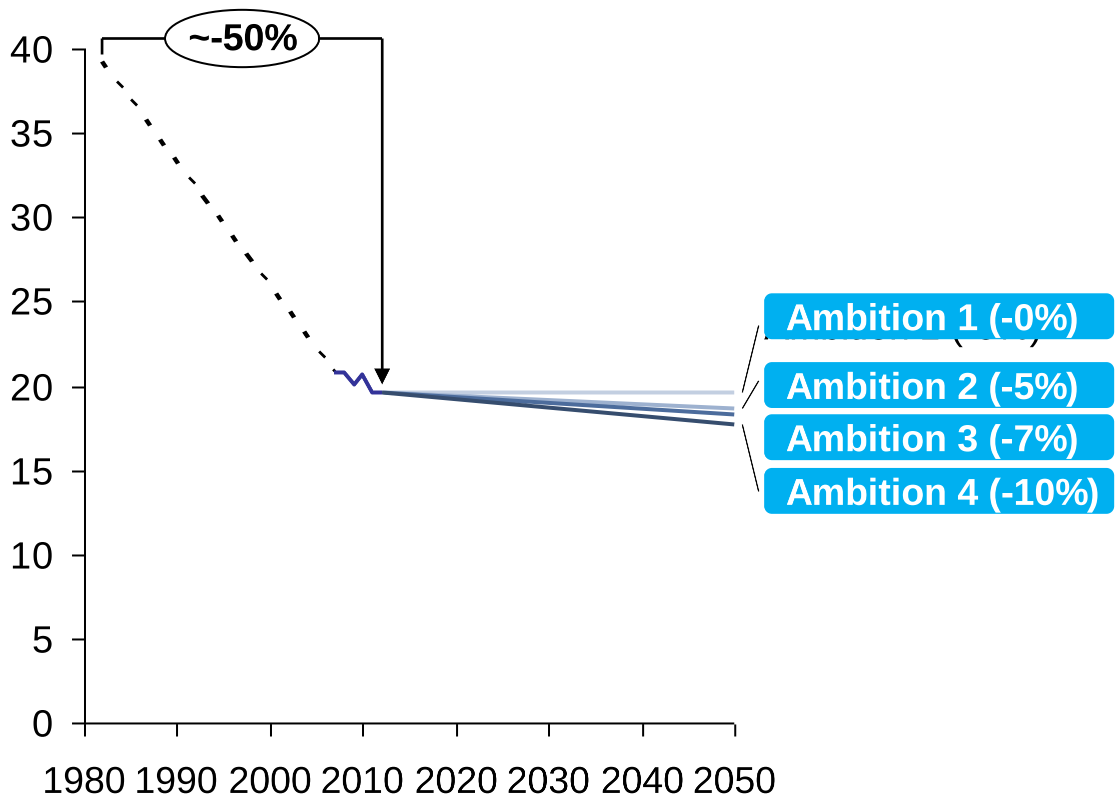
SOURCE: SERPECCC study

3 Energy (and material) efficiency

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

Global Calculator

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	+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

3 Energy efficiency : CHP potential

Proposed lever ambitions

Global Calculator

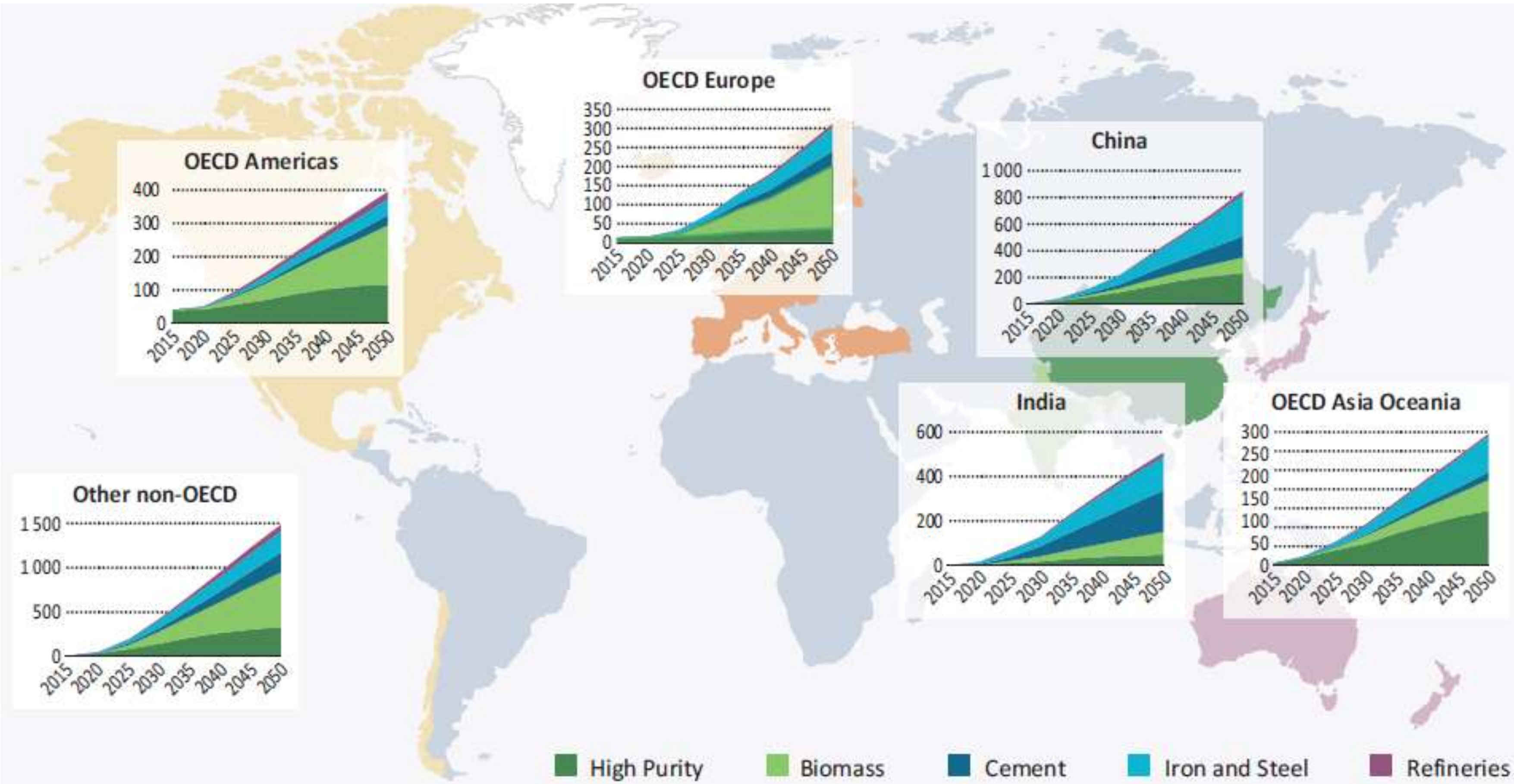
Level 1	Level 2	Level 3	Level 4
Minimum effort (following current regulation)	**Moderate effort** easily reached according to most experts	**Significant effort** requiring cultural change and/or important financial investments	**Maximum effort** to reach results close to technical and physical constraints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

Carbon Capture & Storage
Projections from the IEA ETP 2012 by region

Capture rate
($MtCO_2$/year)

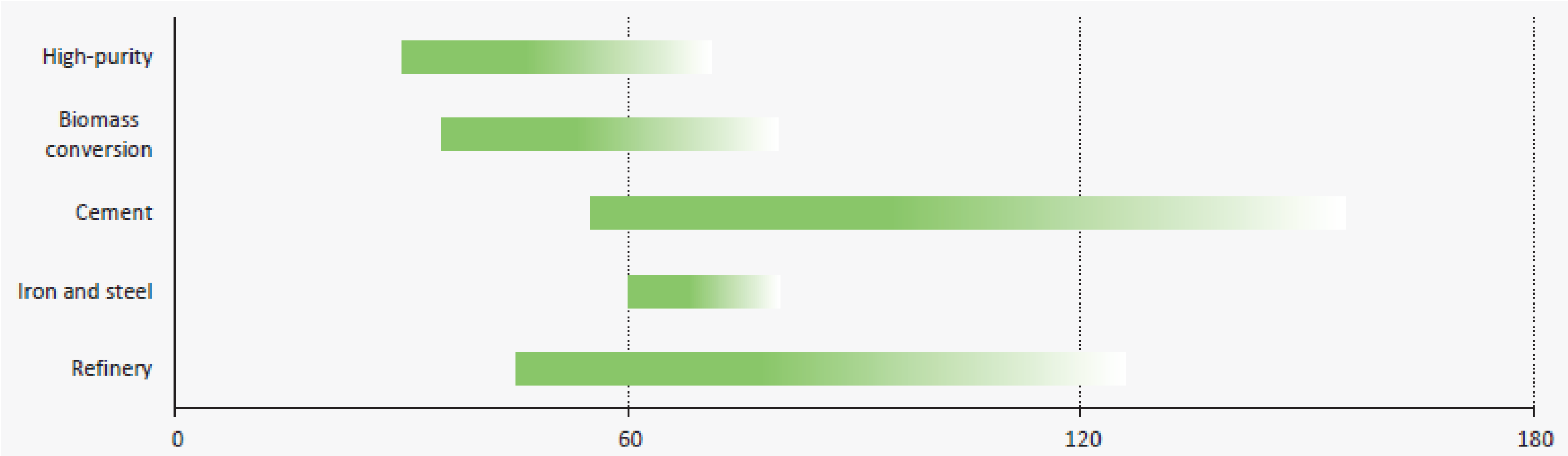


SOURCE: IEA ETP 2012

Carbon Capture & Storage

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

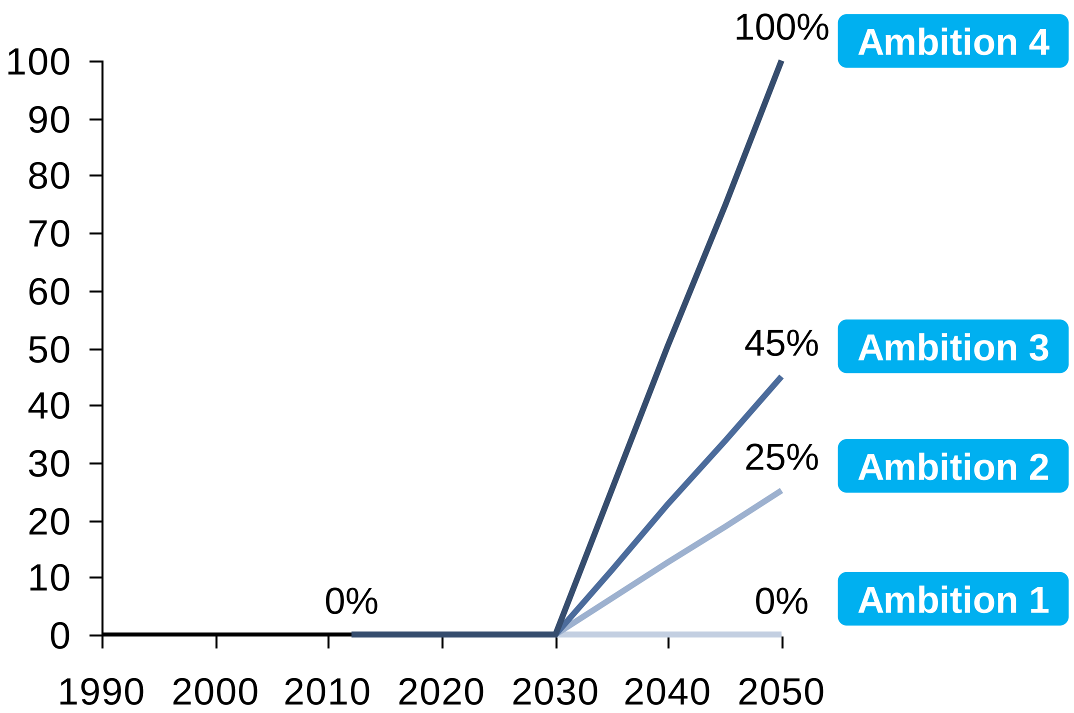
NOTE: The range of costs shown here reflect the regional average costs of applying CCS in each sector, and, therefore, the overall cost of abatement in a sector will be affected by the assumed level of CCS uptake in each sector (IEA, 2009 and IEA and UNIDO 2011). These costs include the cost of capture,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

Carbon Capture & Storage
Proposed lever ambitions

Global Calculator

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).

Iron & steel manufacturing with lower energy intensity

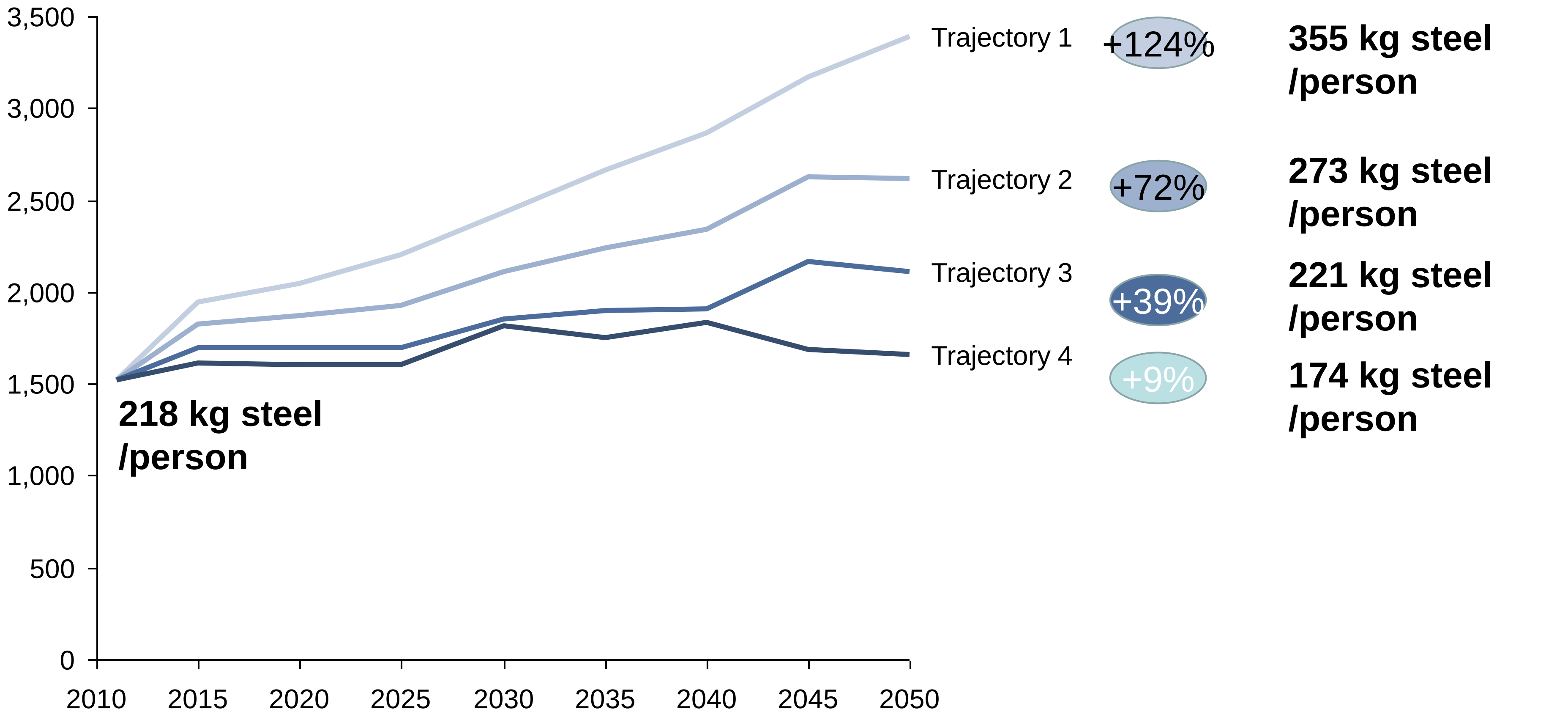
Steel manufacturing process

Estimation of the reduction potentials

Resulting scenarios

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

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



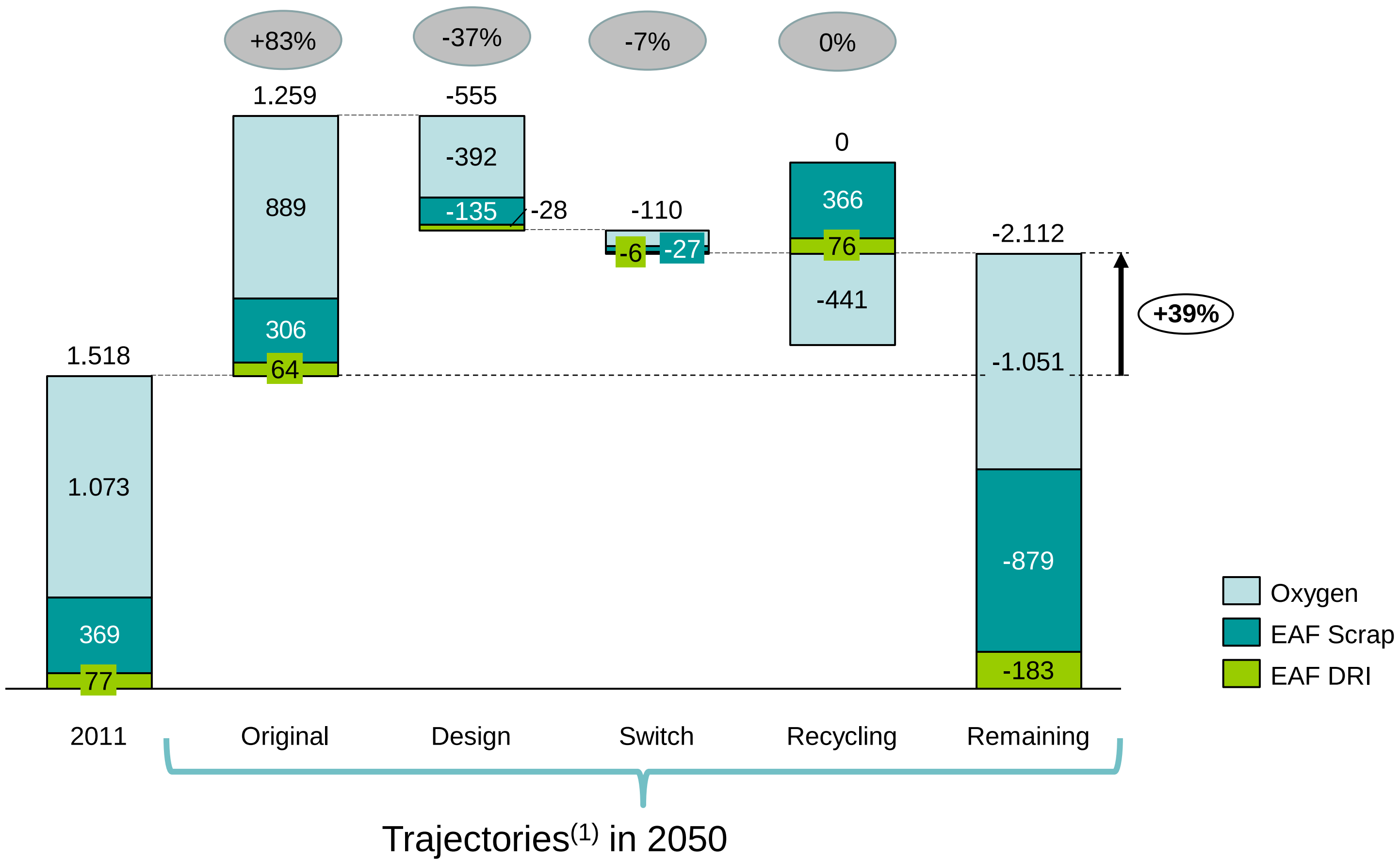
NOTE: (1) The population follows the average UN projection in all four trajectories
(2) Other sectors are impacted by these transitions (e.g. additional productions are created in the aluminium and plastics sectors)

SOURCE: IEA ETP 2012, Global calculator model

Reduction potential
Details for ambition level 3(1)

Global Calculator

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



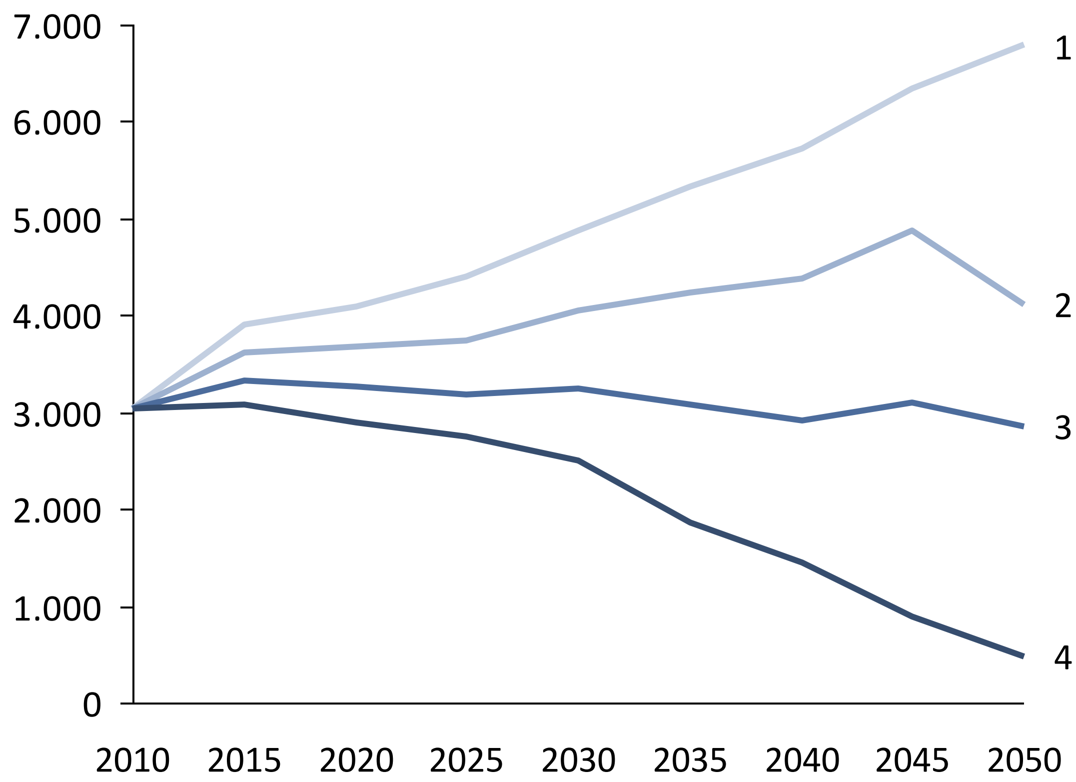
NOTE: (1) The population follows the average UN projection in all four trajectories
(2)Assuming biomass emits, not including electricity related emissions
SOURCE: IEA ETP 2012, Global calculator model

Reduction potential

Emissions according to different trajectories

Global Calculator

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



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

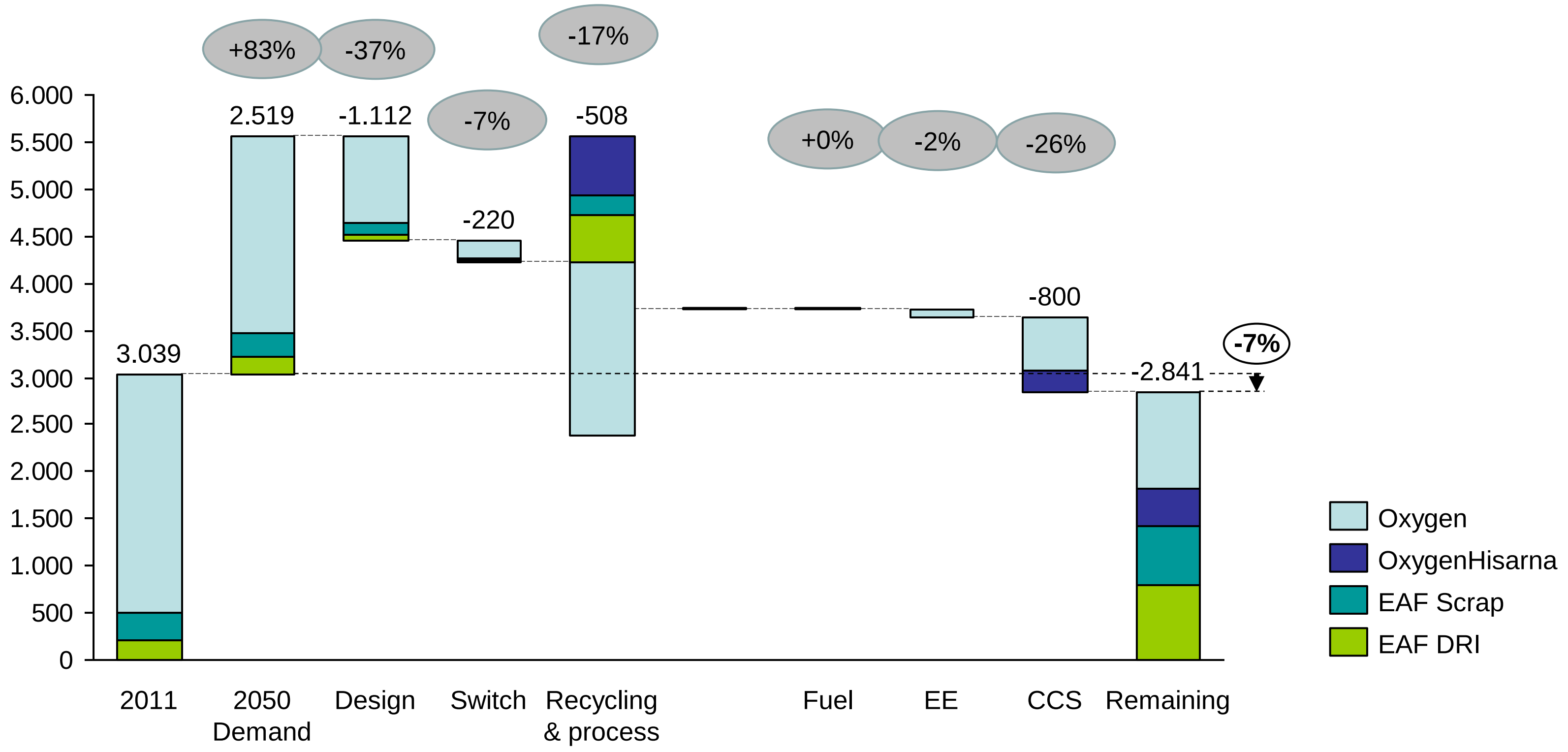
Reduction potential

Details for ambition level 3 (1)

Global Calculator

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

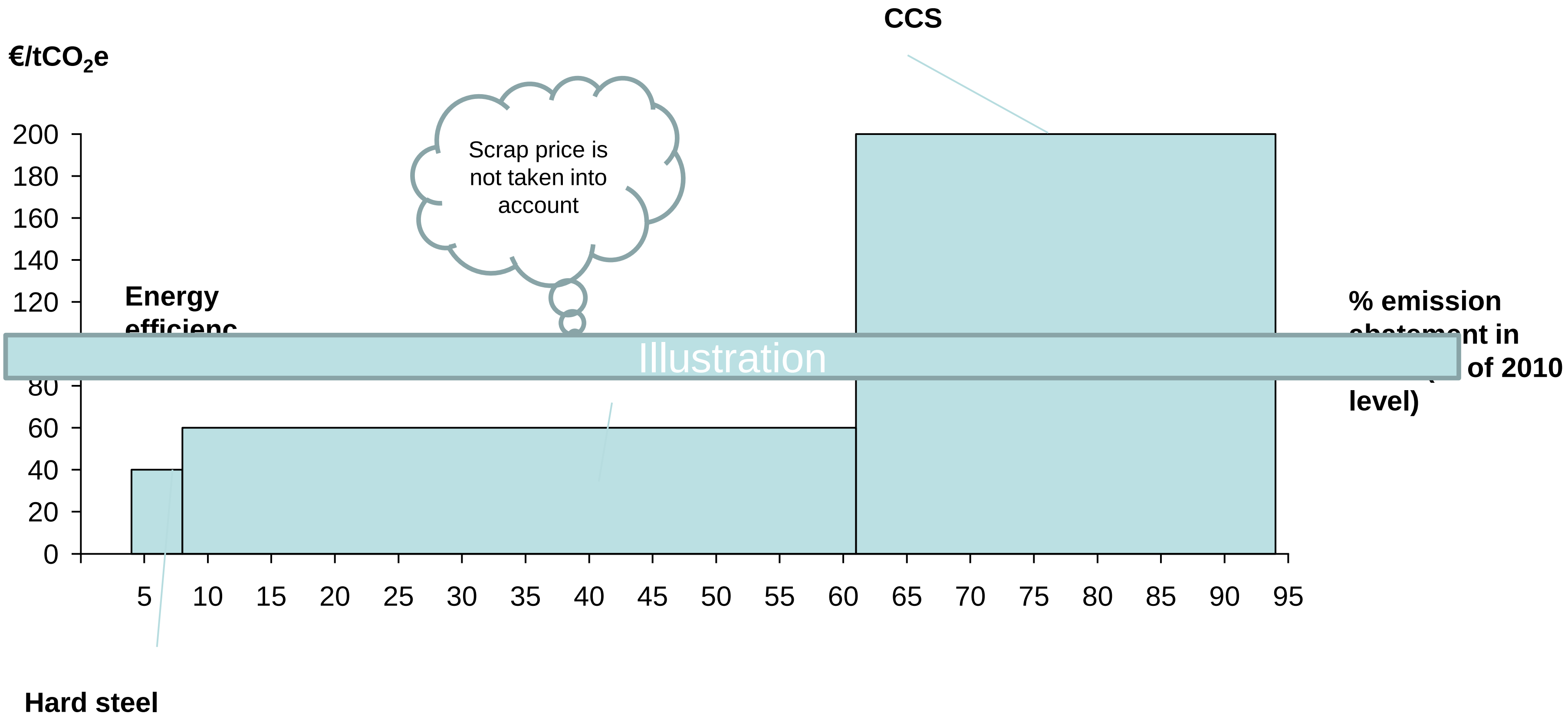
SOURCE: IEA ETP 2012, Global calculator model

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

Thank you.

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Julien Pestiaux – +32 471 96 13 90 – jpe@climact.com

Global Calculator

Backup

Existing studies

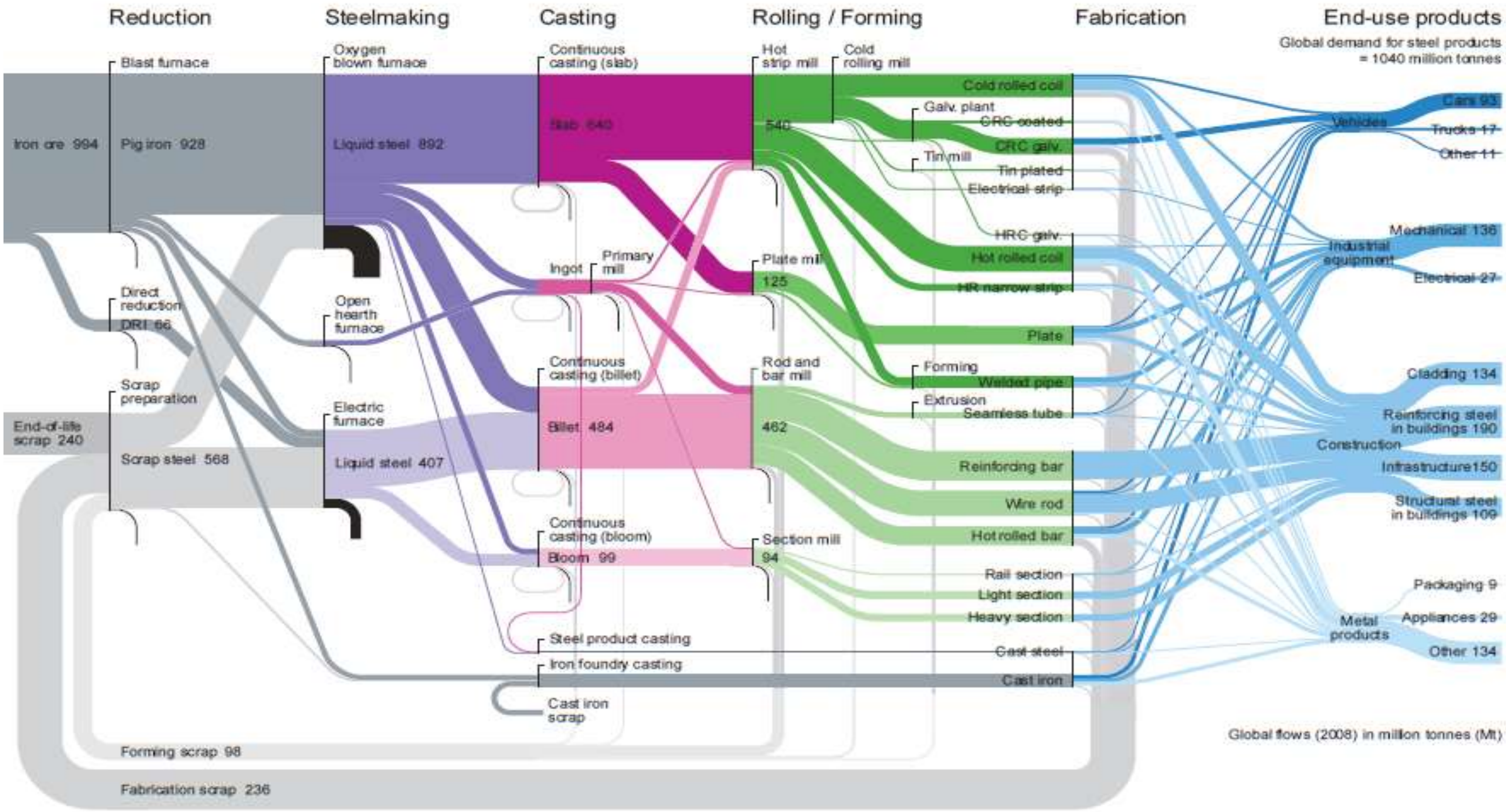
Other informations on the sector

Industry overview

With both eyes open is a key analysis on the flows from resources to end products

Sankey of global steel flows

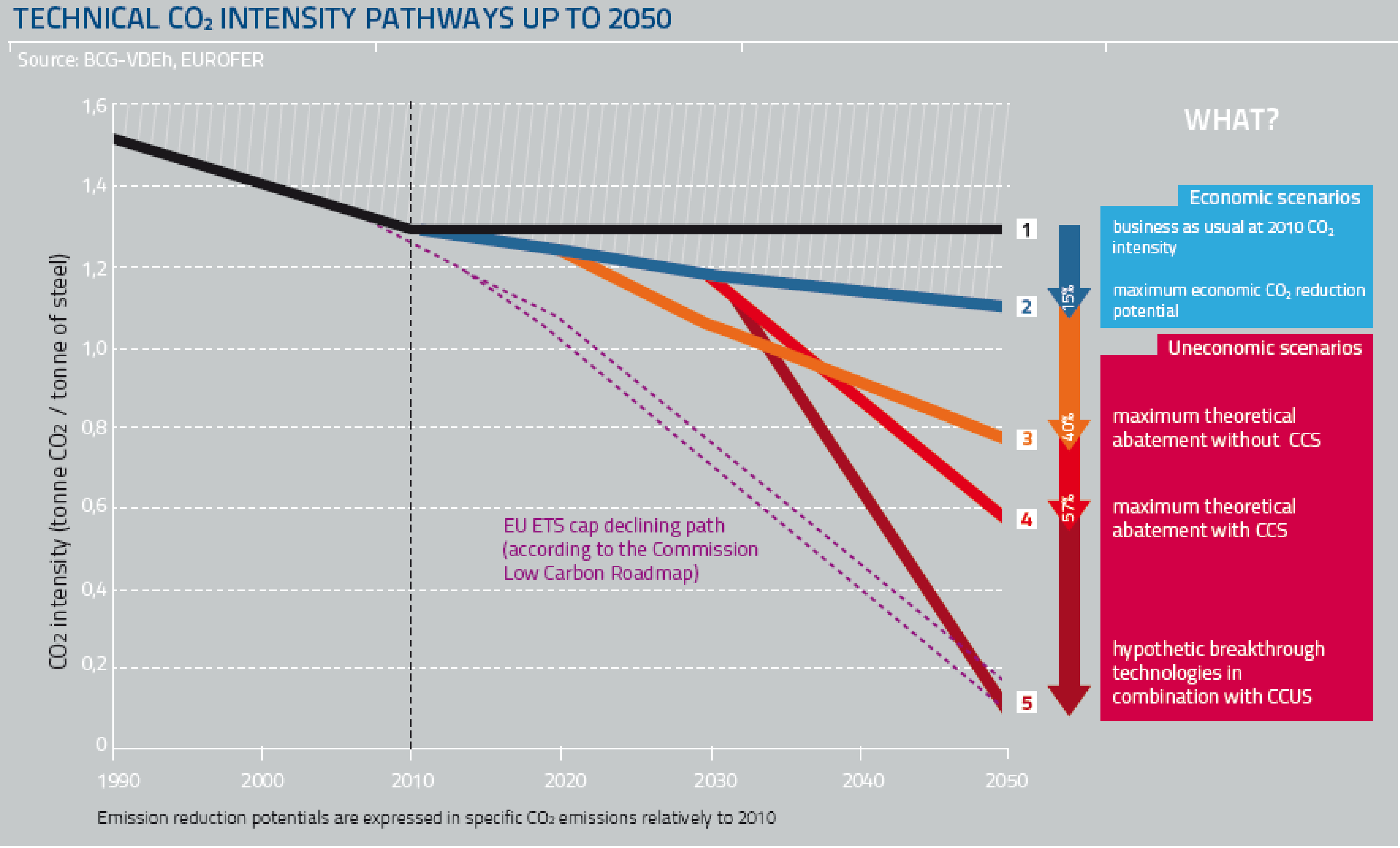
(Mt 2008)



SOURCE : With both eyes open

Eurofer 2013 roadmap

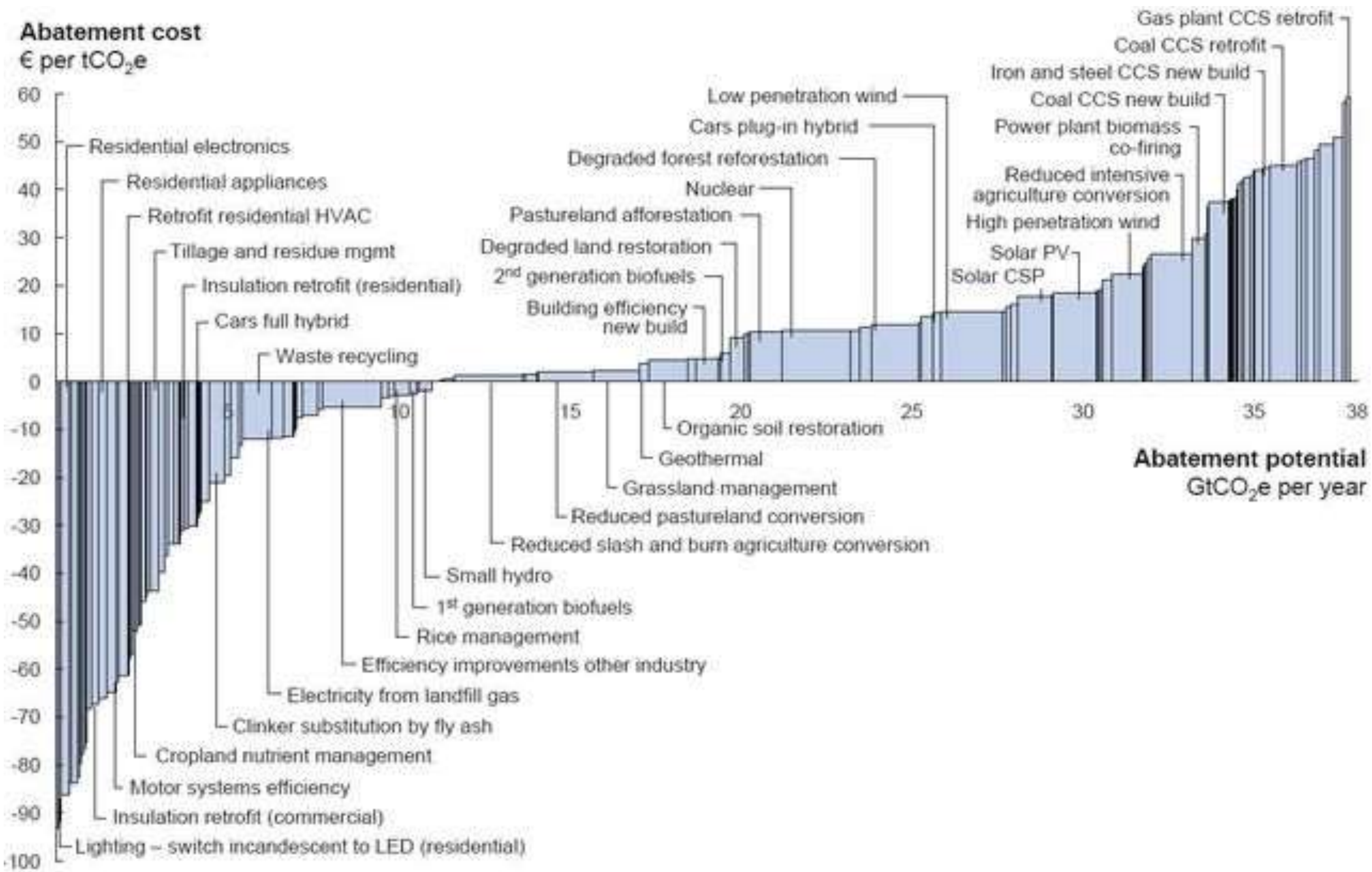
Global Calculator



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

Global Calculator

Example of a study – McKinsey global abatement cost curve

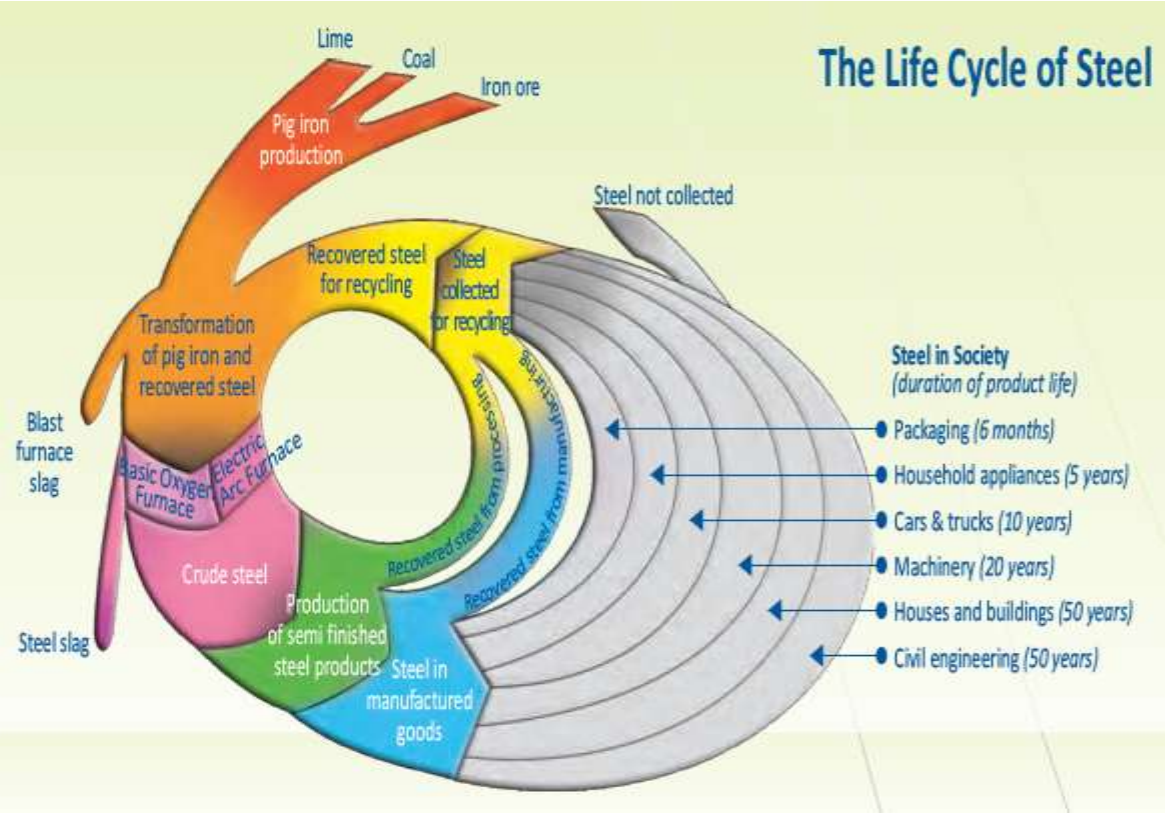


Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.0

The life cycle of steel shows the importance of scrap collection

Global Calculator

Life cycle of steel



Despite of excellent recyclability of steel, continuous growth in world demand and long lead time of recycling still urge for an important fraction of pig iron production

SOURCE : GSV

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

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

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

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

Global Calculator

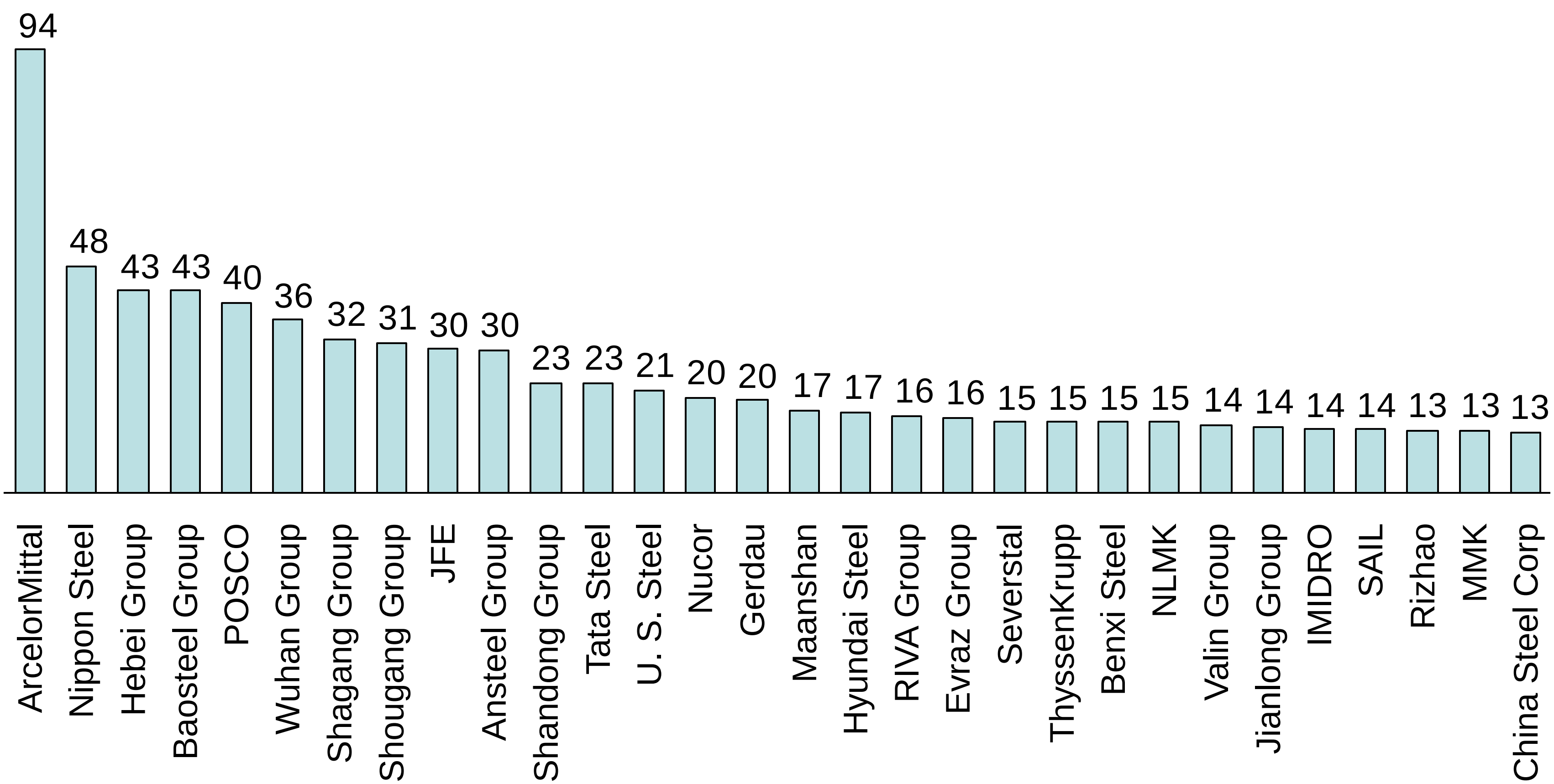
Backup

Largest steel producers

Global Calculator

Crude steel production of 30 largest producers
(M tons per year 2012)

BACKUP



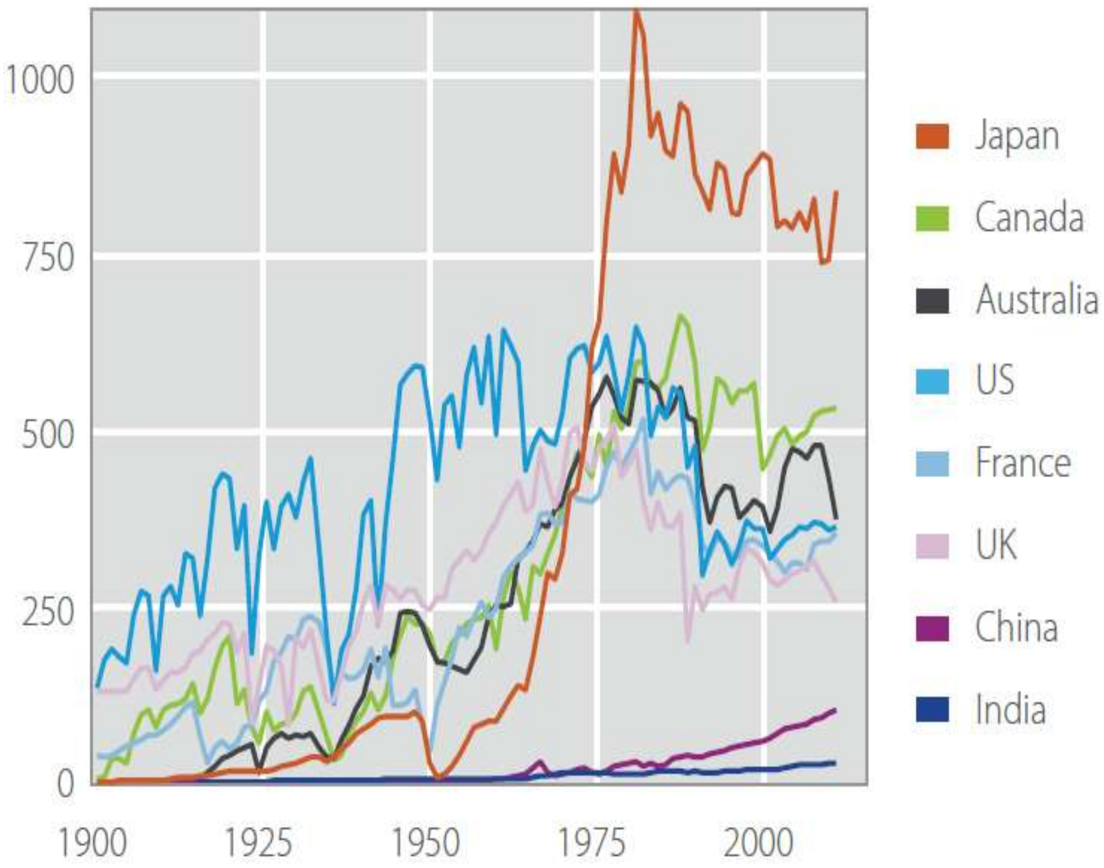
SOURCE: World Steel in figure 2013

Historically steel production has tended to reach a plateau level with respect to population

Global Calculator

Steel production per person
(kg/person/year)

BACKUP



- The plateau effect comes from the fact that as of a certain level of GDP, steel demand does not grow further (e.g. does not require more houses or cars)
- This is not representative of the consumption per capita

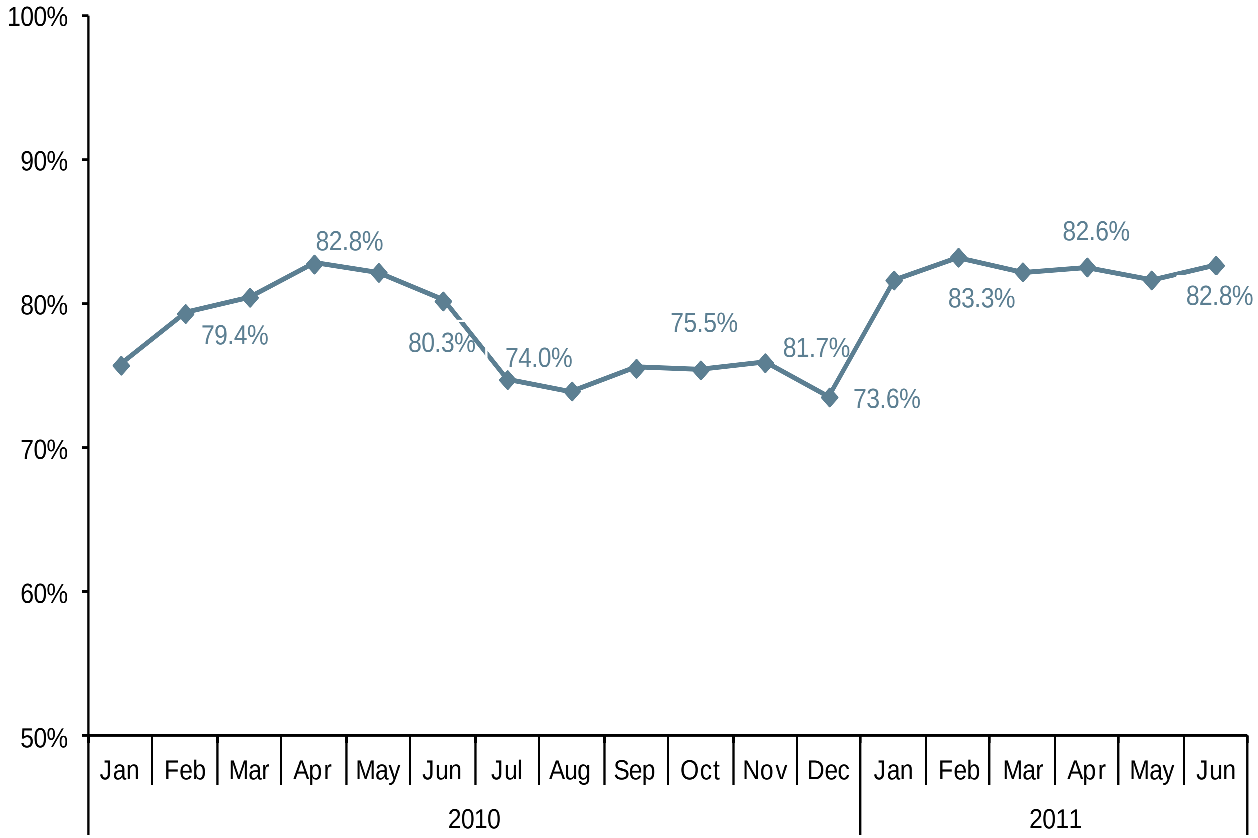
SOURCE : With both eyes open (research by Professor Daniel Mueller at the Nowegian University of Science and Technology (NTNU) and Tao Weng

There is however an overcapacity in the steel sector since the 2008 economic crisis

Global Calculator

BACKUP

World steel capacity utilisation ratio
(%)



- A capacity utilisation of 80% is too low and the consequence of an overcapacity

SOURCE : World steel association

Global Calculator

Backup

Existing studies

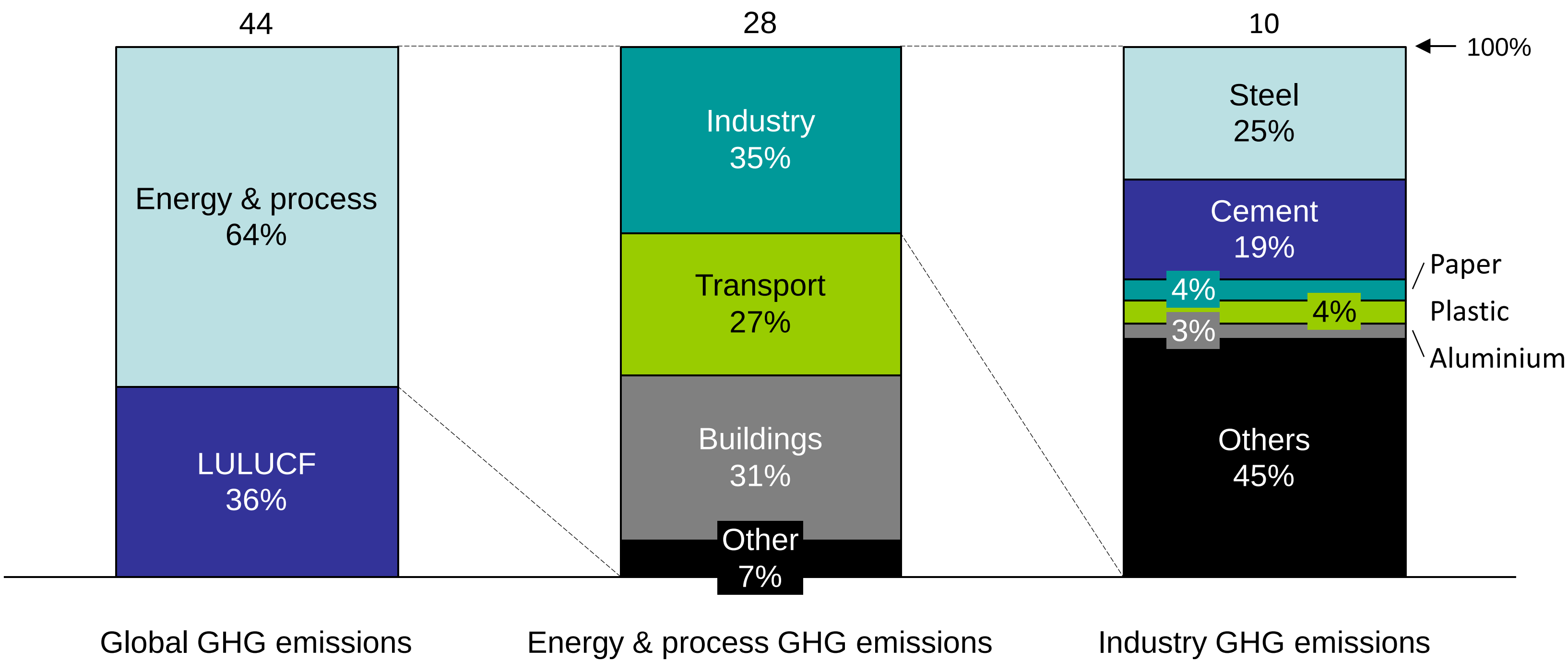
Other informations on the sector

Industry overview

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

Global Calculator

Global anthropogenic GHG emissions in 2005
($GtCO_2e$)

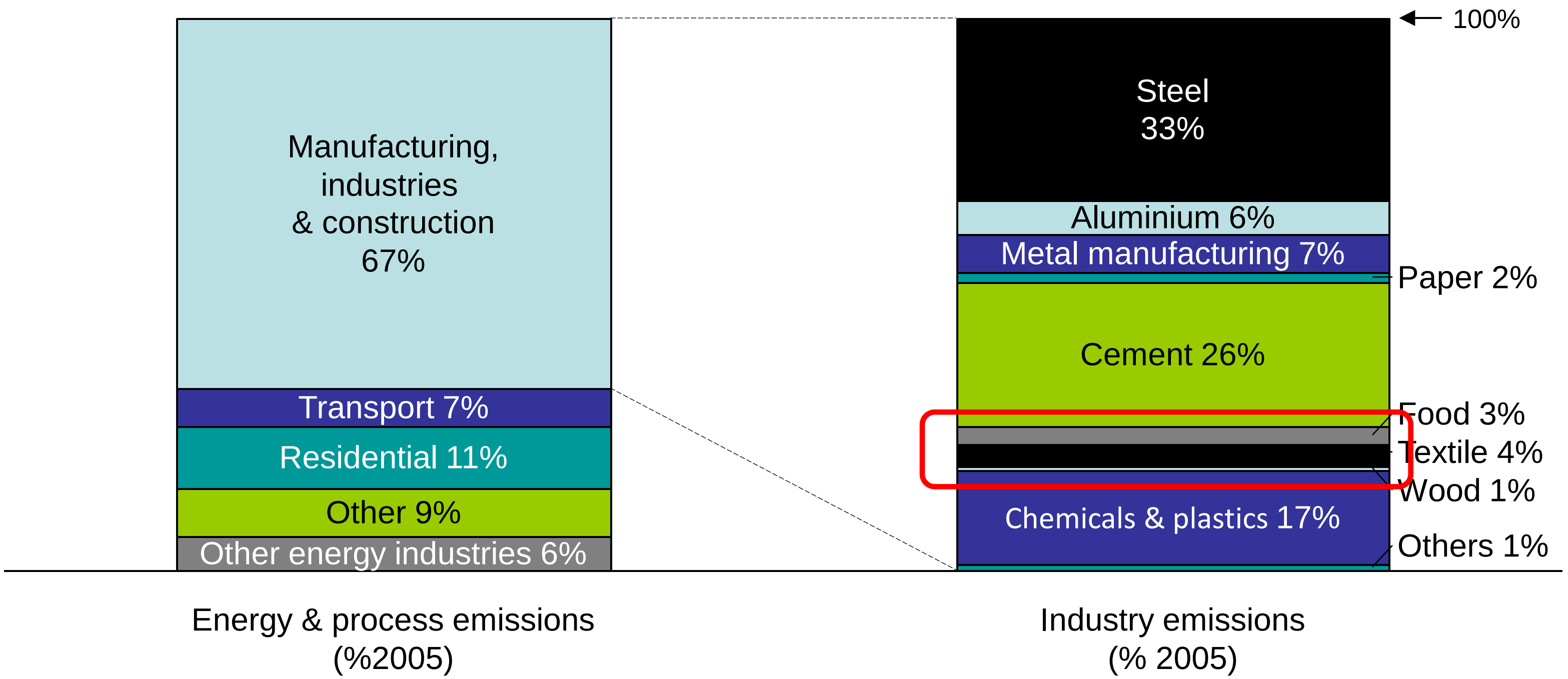


SOURCE: IEA 2008 on year 2005

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

Global Calculator

China anthropogenic GHG emissions in 2005
(%)



SOURCE: China government statistics: Linwei, 2011 for year

Large developing economies are moving up in global manufacturing

Global Calculator

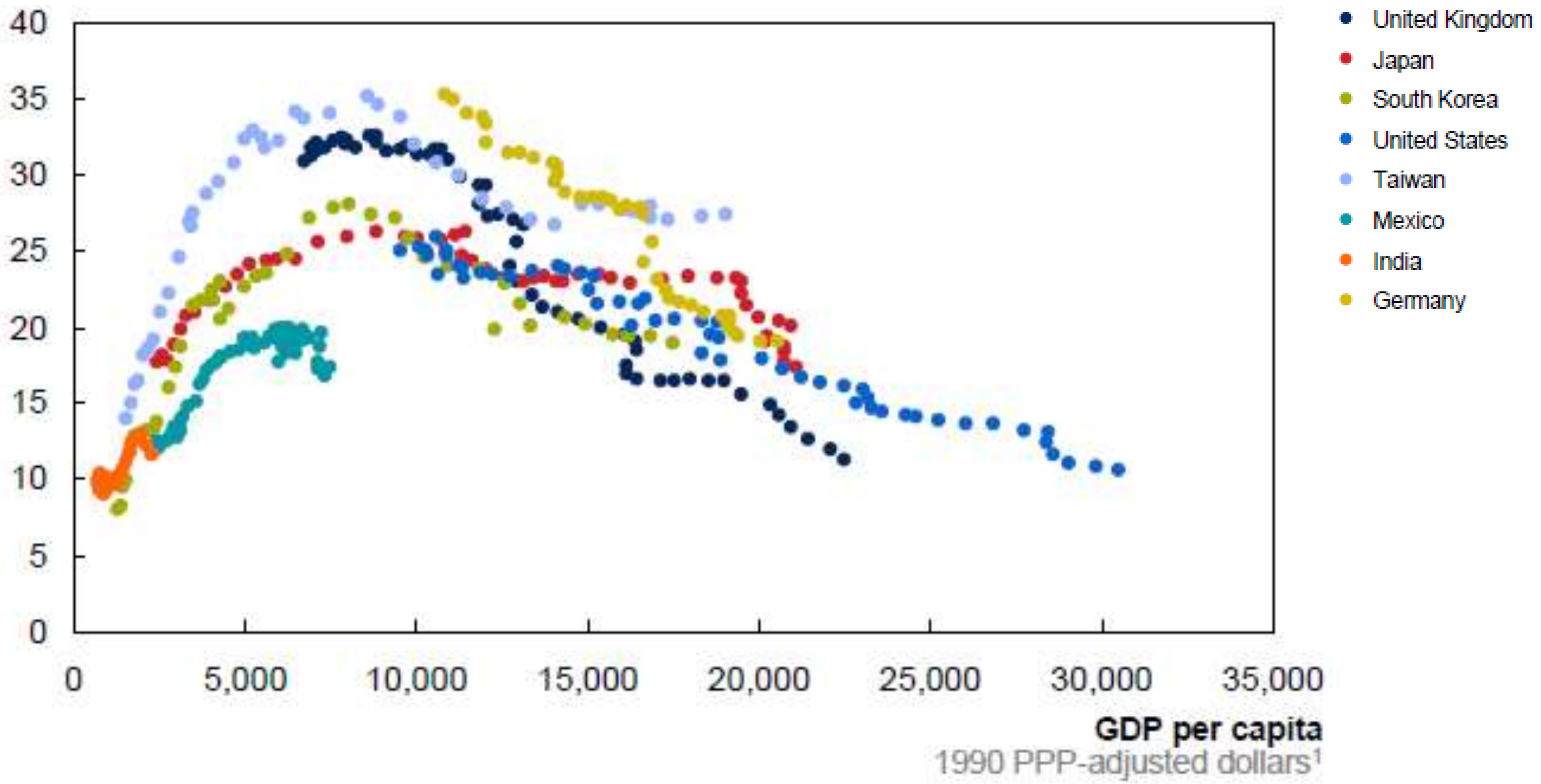
Top 15 manufacturers by share of global nominal manufacturing gross value added

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

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

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

Manufacturing employment
(% of total employment)



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

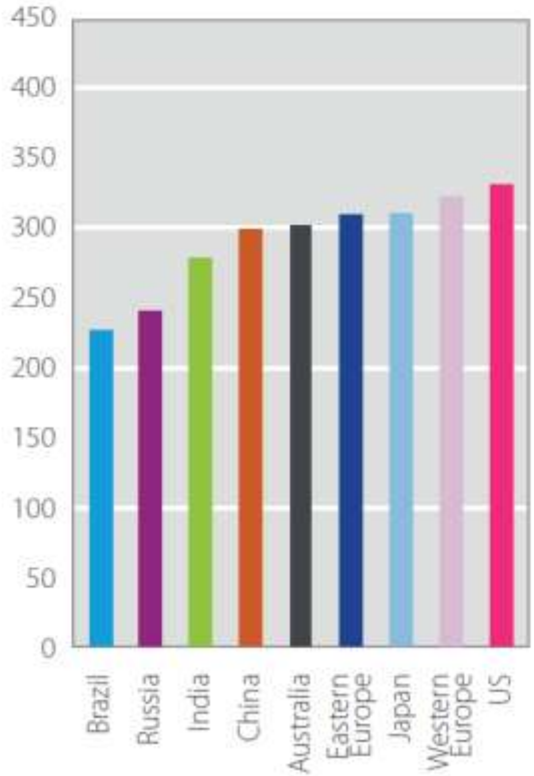
SOURCE: GGDC 10-Sector Database: "Structural change and growth accelerations in Asia and Latin America: A new sectoral data set," *Cliometrica*, volume 3, Issue 2, 2009; McKinsey Global Institute analysis

International prices strongly differ between regions

Global Calculator

Price of crude steel per region
(US$/ton crude steel)

BACKUP



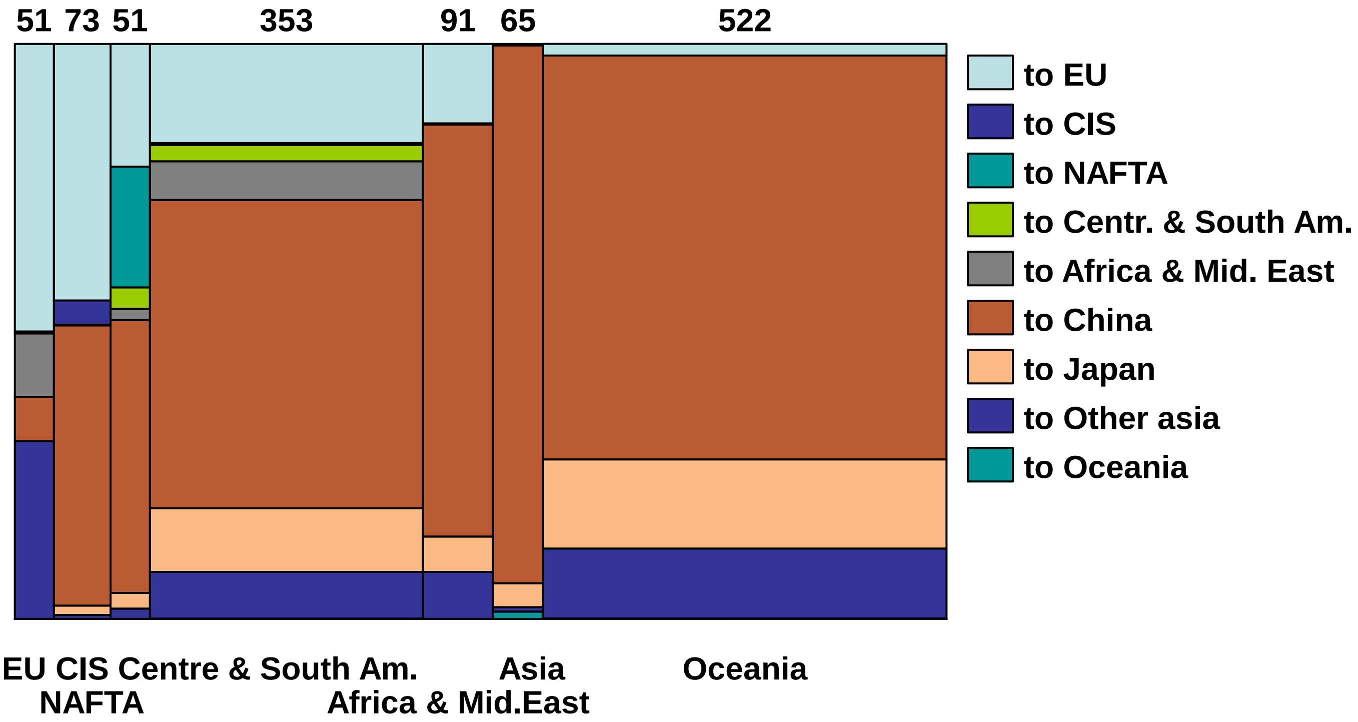
NOTE: This view does not reflect the recent shale gas developments
SOURCE : With both eyes open p91

Europe is major importer of Iron ore, Central and South America are major Exporters

Global Calculator

Important export of iron ore
(2012, million tons actual weight)

BACKUP



- Oceania, Central and South America are major exporters
- China is the largest importer, followed by the EU and Japan

SOURCE : World steel in figures 2013