Global Calculator
Technical documentation

Manufacturing sector

Technical documentation (Part 1/3 Links to material demand)

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

Introduction to the global calculator
Model structure

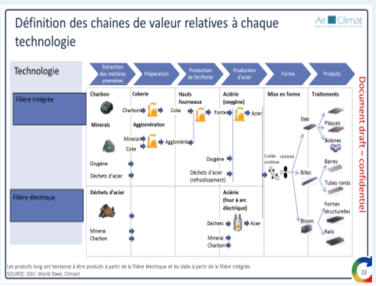
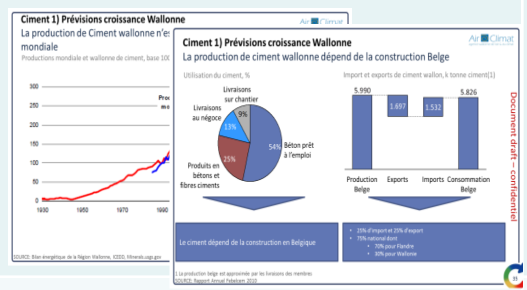
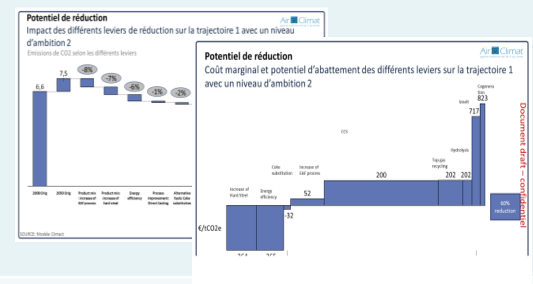
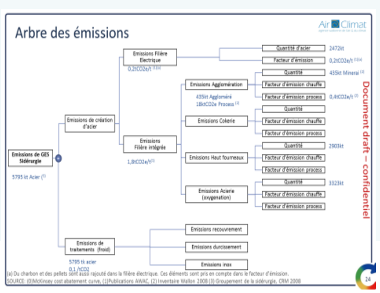
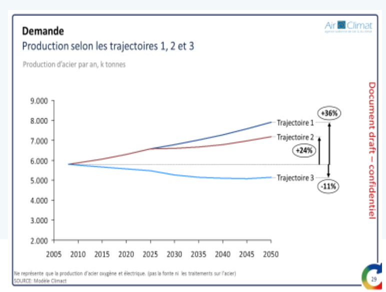
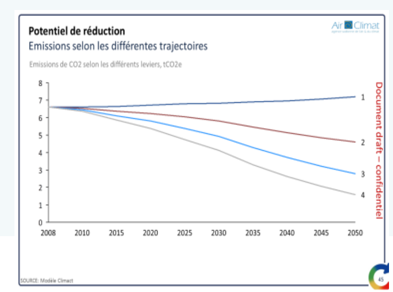
Expert & Literature review

Historical energy evolution and link to materials demand

To model the manufacturing sector a detailed analysis has been performed in each industrial sector

Global Calculator

Methodology

	Understanding the industry and product link	Modelling demand trajectories	Modelling trajectories with intensity levels
Analyses	**Value chain definition** 	**Analyses of growth and competitiveness** 	**Potential of CO_2 reduction incl. costs** 
Results	**Modelling the emissions tree** 	**Demand trajectories** 	**Trajectories with different intensity levels (incl. CCS)** 

SOURCE: Climact

Manufacturing is modelled through 3 main lever groups, split into 8 lever families

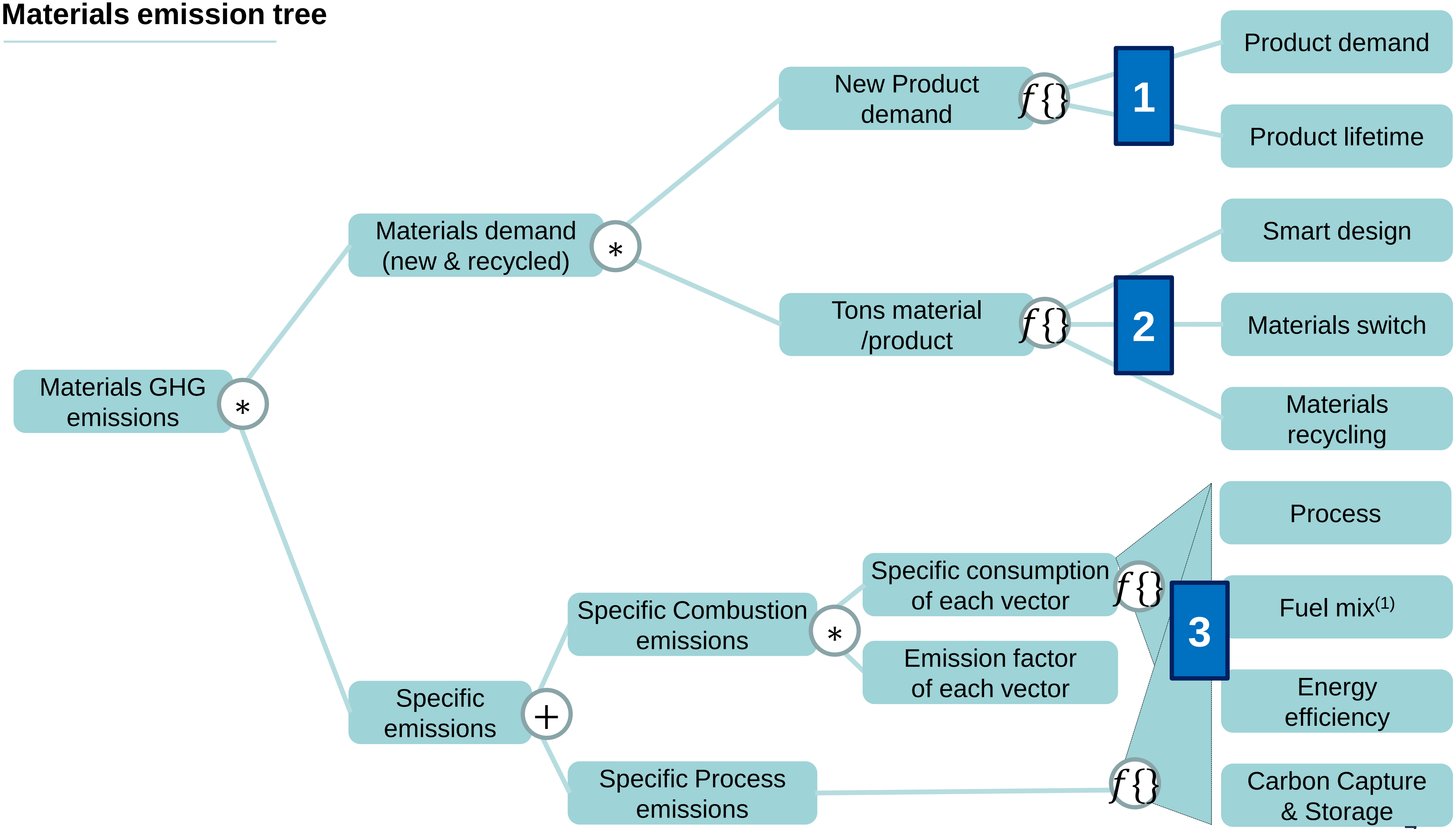
Global Calculator

	Lever groups	Lever families	Lever descriptions
1	**Product demand**	1. Reduce demand [(1)] & increase lifetime [(2)]	• End consumer demand of products • Solutions for sharing the product amongst different users
2	**Material demand per product**	2. Smart design 3. Materials switch 4. Materials recycling	• Amount & type of materials required to supply the products (includes new product types and substitution materials) • Materials recycling potential
3	**Carbon intensity of material production**	5. Process change 6. Fuel switch 7. Energy efficiency 8. Carbon capture and storage	• Production CO_2 intensity of various improvements levers in each industry (~60improvements types)

NOTES: (1) These levers don't apply in the materials analysis when the product demand is defined by the other sectors
(2) For consumer goods: cars & household goods

The interactions between the lever groups and families is illustrated with this emission tree

Materials emission tree



NOTE: (1) The fuel mix does not influence the specific process emissions

Reduction potential

Modelling choices on Scope

Impact in Product life is addressed by the other sectors	• To reduce overall emissions, we must take an overall perspective including both the production and the use phase • For example steels produce efficient transformers and motors enabling to reduce more CO_2 emissions than what was required during the production phase[(1)]
Use of by products is accounted for in the other sectors	• The material production can result in the generation of by-products that reduce CO_2 emissions by substituting natural resources in other industries • For example, blast furnace slag is used by the cement industry allowing it to reduce its CO_2 emissions significantly [(1)]

- Taking these dimensions into account typically provides a view on the material impact as a CO_2 mitigator
- Applied to steelmaking and steel use in Europe, such an approach shows that steel can save six times as much CO_2 where it is used than is emitted in production [(2)]

NOTES: Global calculator assumptions

SOURCES: (1) Worldsteel, steel's contribbution to a low carbon future

(2) Eurofer A steel Roadmap for a low carbon Europe 2050 (1013)

Material demand / product: Design, Switch & Recycling

Levers are assessed in each industry

Global Calculator

List of actions & levers assessed

Industry groups		Design	Switch	Recycling
Steel		• Product Design • High strength steel	• In vehicles : To aluminium & to plastics (fibres) • In buildings/Infrastructure : to timber	• Product recycling • % scrap based (for each various technologies exist)
Chemicals	All	• Product design	• /	• Product recycling • Material recycling
	High value		• Substitutes steel, aluminium & cement in vehicles & buildings/infrastructure	• Green chemistry
	Ammonia	• Fertilizers composition	• /	
	Methanol		• /	
	Other	• Green chemistry	• /	
Aluminium		• Product design	• In Planes: To plastic (fibres)	• Product recycling • Material recycling
Cement		• Product design	• In buildings/Infr. : To plastics & to timber	• Composed/metallurgical cement
Pulp & paper				• More recycled paper • Other cellulose sources • Bio-refineries
Timber		• Product design	• Switch from steel &cement	

SOURCE: Climact

Carbon intensity of material production

An additional ~50 levers then reduce the carbon intensity

Global Calculator

List of actions & levers assessed

Industry groups		Process improvements	Alternative fuels	Efficiency	CCS
Steel		• Carbon material reduction • Portion of Classic BOF/ Top gas recycling & Hisarna/ EAF DRI/ EAF scrap • Smelt reduction, Hydrogen, Electrolysis	• Coke to gas injection • Coal PCI to biomass	• Material efficiency • Energy efficiency • CHP	• CCS
Chemicals	All	• Process intensification • Catalyst optimization	• Oil to gas	• Clustering and sustainable integration • CHP	• CCS
	High value	• Included in energy efficiency		• Energy efficiency	• CCS
	Ammonia	• Included in energy efficiency		• Energy efficiency	• CCS
	Methanol			• Energy efficiency	• CCS
	Other	• Included in energy efficiency • Selective catalytic reduction	• Hydrogen production by electrolysis • Natural gas or biomass	• Energy efficiency • Switch Mercury to membrane	• CCS
Aluminium		• Included in energy efficiency	• Gas injection	• Material efficiency • Energy efficiency	• CCS
Cement		• Dry process	• Coal & oil to waste & biomass	• Energy efficiency • CHP /heat recovery	• CCS
Pulp & paper		• Black liquor gasification • Drying innovation	• Coal & oil to gas • Coal & oil to biomass	• Energy efficiency • CHP	• CCS
Timber		• /	• /	• /	• /

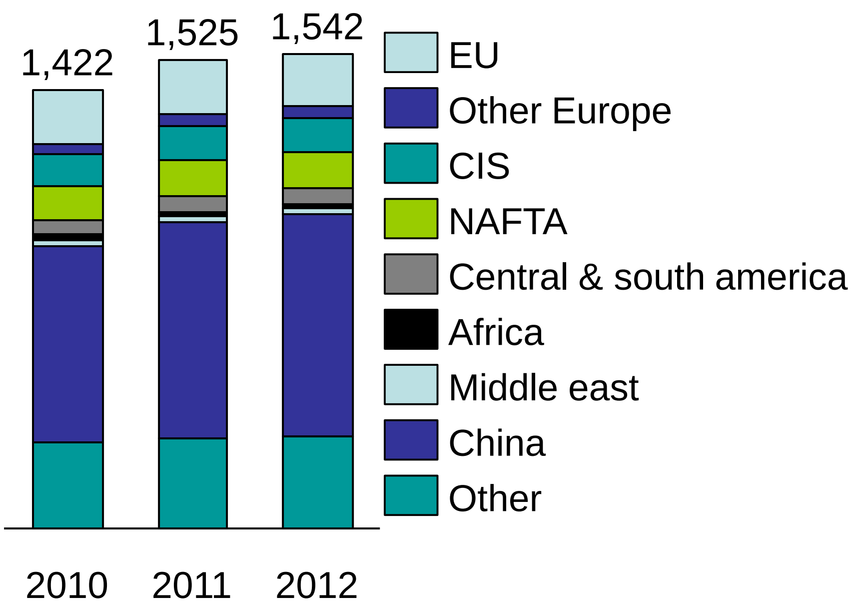
SOURCE: Climact

Regional differences are assessed when evaluating the global estimates, they are not modelled

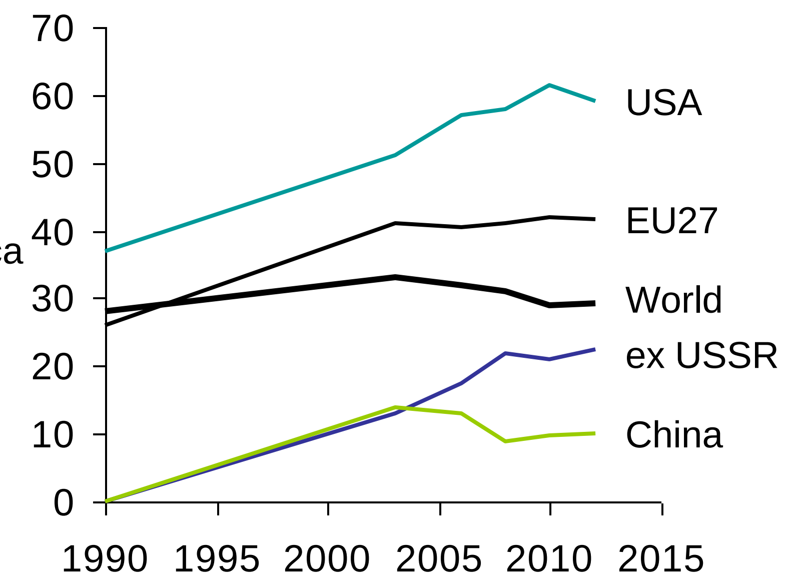
Global Calculator

STEEL EXAMPLE

Crude steel output [1]
(Mt)



Historic evolution of the Electric steel production in the total crude steel production[2] (%)



SOURCE: (1) World steel in figures 2013
(2) IISI, Worldsteel in figure 2013, Eurostat, Groupement de la Sidérurgie

Global Calculator

An innovative characteristic of this modelling is that the materials demand is derived from the product demand (1/4)

Value chain

Illustrations

Products

Materials

Steel | Cement | Alu minium | Chemicals | Pulp & paper | Timber | Other

Taking advantage of the global scope, the materials analysis can include embedded emissions and resources impact

An innovative characteristic of this modelling is that the materials demand is derived from the product demand (2/4)

Global Calculator

Selection of products and materials and resources (excluding energy resources)

Out of scope

Sector	Products	Materials	Resources
Energy	Nuclear & Fossil plants	➔ Infrastructures	/
	Wind turbines	Steel, ~~Aluminium~~	Iron ore, ~~bauxite,~~
	PV	Chemicals, Steel & Aluminium	Hydrocarbons, rare metals
	Transmission, distribution networks	Steel, Aluminium	Iron ore, bauxite
	Other	/	/
Infrastructures	Infrastructure, Buildings	Steel, Aluminium, cement, timber	Iron ore, bauxite, biomass, clinker substitutes
	Industrial & mechanical equipment	Steel, Aluminium	Iron ore, bauxite
	Roads	Cement, ~~Asphalt~~	clinker substitutes
	Rail	➔ Infrastructures	/
	CCS pipes	Steel	Iron ore
	Other	/	/
Consumer goods	Vehicles (cars, light trucks, truck, ships)	Steel, Aluminium, chemicals	Iron ore, bauxite, Lithium, fossil fuels
	Metal goods, consumer packaging, domestic appliances, clothing	Chemicals, steel, aluminium	Iron ore, bauxite, metals, hydrocarbons
	Other	/	/
Other	Other	/	/

Comments

- Only significant relationships will be kept so to reduce complexity and feedback loops, other are ~~skipped~~
- Skipped examples
  - Wind turbines represent only 5% of the aluminium demand
  - asphalt is less energy intensive, it is not a major source of GHG emissions, excluding aggregates, it overlaps with cement and plastics

An innovative characteristic of this modelling is that the materials demand is derived from the product demand (3/4)

Steel driving products
(2011)

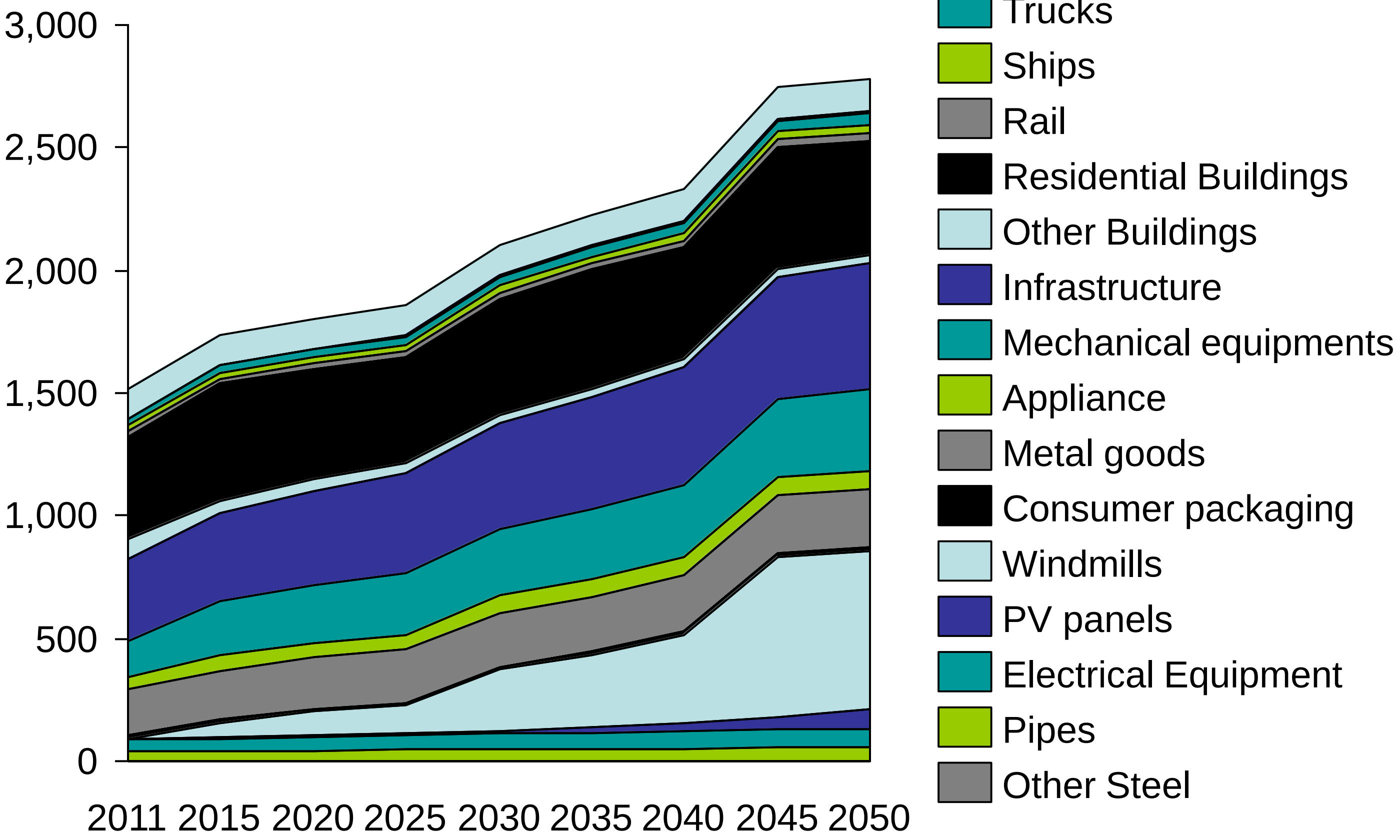
- **Steel** — 1518 Mt steel; 2991 M tCO_2e; 1,97 tCO_2e/t steel
  - **Transport** — 13%: 194 Mt steel
    - **Cars & light trucks** — 8%: 123 Mt steel
    - **Trucks** — 2%: 28 Mt steel
    - **Ships** — 2%: 23 Mt steel
    - **Rail** — 1%: 20 Mt steel
  - **Industrial equipment** — 16%: 246 Mt steel
    - **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

An innovative characteristic of this modelling is that the materials demand is derived from the product demand (4/4)

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

Most product demand is defined by each sector's activity, Some products are driven by the "Product demand" lever,

Global Calculator

Key drivers of demand to be challenged

Sector	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. It's demand evolution is currently following the transport demand only.

Cost ranges are modelled for each lever along the capex, fuel & other opex dimensions

Global Calculator

Rationale on Lever costing

Baseline	• A base cost (capital, fuel & other opex) is provided to estimate the manufacturing costs prior the application of the various levers
Process improvements	• When these are modelled as a change to a different technology (e.g. a switch from Oxygen to Oxygen Hisarna steel), they are estimated based on costs mentioned in the literature (and detailed in the relative technical slides) • When these are modelled as an energy efficiency improvement, the capex are associated to 4-5-6 years payback on the energy savings
Alternative fuels	• Only the price of fuels is taken into account for this lever
Energy efficiency	• The capex are associated to 4-5-6 years payback on the energy savings
CCS costs	• The capex are taken from the IEA estimates and the fuel costs are derived from the additional electricity consumption estimated per sector

Background on the ranges

- "High", "Point" & "Low" cost are provided for each lever
- Costs are provided with high uncertainties for several reasons:
  - The costs obtained through the various sources are often obtained through different methodologies
  - Costs estimates are often not available or confidential for the industrial players

Agenda

Global Calculator

Introduction to the global calculator

Model structure

Expert & Literature review

Historical energy evolution and link to materials demand

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

Global Calculator

Federations and organisations

WBCSD, Cement sustainability Initiative
- Roland Hunziker

Worldsteel Association
- Henk Reimink, Clare Broadbent

CEFIC
- Peter Botschek, Isabelle Chaput (alumni)

CEPI
- Marco Mensink

Zero Emissions Platform (ZEP)
- Gert-Jan van der Panne

European Wood Federation (CEI Bois)

Institute of Industrial perspective (alumni)
- Julia Reinaud

World Aluminium
- Chris Bayliss

Academic, consultancies & research groups

- **Dechema** Florian Ausfelder
- **Fraunhofer institute,** Marlene Arens
- **Steel VDEh** Marten Sprecher
- **Tsinghua University**
- **UK Engineering** and Physical Sciences Research Council (EPSRC), author of With both eyes open, Jonathan M Cullen
- **LBNL** (China Energy Group)
- **BEE** (India)
- **TERI**

Companies in other sectors

- **Dow** Michael Mazor
- **Vinci**
- **Toyota**
- **Bombardier**
- **GE**

NGOs & cooperation agencies

- **Greenpeace**, Jan Vande Putte
- **WWF**
- **GIZ**

Legend
Presence at workshop or later

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

The following stakeholders will be provided with an opportunity to review the steel assumptions (1)

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

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

Global Calculator

Main sources used for the steel 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, UK, Algeria, the Balkans & India

The following stakeholders have been provided with an opportunity to review the steel assumption

Chemicals specific experts

International Council of Chemical associations
- Rachelina Baio

CEFIC (European Chemical Industry Council
- Peter Botschek
- William Garcia, Isabelle Chaput (cross sectoral)

CPCIF (China Petroleum and Chemical Industry Federation)
- Dr. Ye Jianhui

Japan PetroChemical Industry Association

Dechema
- Alexis Bazzanella, Florian Ausfelder

Steel Institute VDEh
- Marten Sprecher

BASF
- Susan Kuschel, Charlene Wall-Warren

Dow Chemicals
- Mark Weick, Keith (K) Kenebrew, Michael (MH) Mazor

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

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

Global Calculator

Main sources used for the Chemicals analysis

Organisation	Source
Cambridge	• With both eyes open
IEA	• Energy Technology Perspectives 2012, Pathways to a clean energy system • Chemical and Petrochemical Sector – Potential of Best Practice Technology and Other Measures for Improving Efficiency (IEA, 2009) • Summary report
ICCA	• Technology Roadmap: Energy and GHG Reductions in the Chemical Industry via Catalytic Processes (IEA, ICCA, Dechema) • The role of the chemical industry in achieving targets of IEA roadmaps on biofuel and bioenergy (2011)(ICCA and SRI International) • Building Technology Roadmap: The Chemical Industry's Contribution to Energy and GHG Savings in Residential and Commercial Construction Buildings roadmaps (2012) (ICCA)
CEFIC	• European chemistry for growth, Unlocking a competitive, low carbon and energy efficient future (2013)
Plastics Europe	• Plastics- the facts 2013
Utrecht University	• Ren, T. 2009. Petrochemicals from Oil, Natural gas, Coal and Biomass: Energy Use, Economics and Innovation. PhD
McKinsey	• McKinsey cost abatement curves v2.1 • Manufacturing the future: the next era of growth and innovation (2012)
Ecofys	• SERPECC studies
European Climate change Foundation	• Europe's low carbon transition: Understanding the challenges and opportunities for the chemical sector (2014)
Other	• Chemical Industry of the Future: New Process Chemistry Technology Roadmap, July 2001 • Catalysis - a key technology for sustainable growth"
Previous consultations	• Similar roadmaps performed in Belgium, UK, Algeria, the Balkans & India

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

Global Calculator

Main sources used for the Aluminium analysis

Organisation	Source
World Aluminium	• A Review of the Global Aluminium Industry: 1972-2012 (2013) • Aluminium Intensive Electric Vehicle Report (2012) • Aluminium for Future Generations Sustainability Update: 2010 data (2011) • Current and (global) scenarios for metal flow, inc recycling: www.world-aluminium.org/publications/tagged/mass%20flow%20model/ • building: http://www.alueurope.eu/publications-building/, greenbuilding.world-aluminium.org/home.html • transport: transport.world-aluminium.org/home.html , www.drivealuminum.org, www.alueurope.eu/publications-transport , www.alueurope.eu/publications-automotive • recycling: recycling.world-aluminium.org/ , www.thealuminiumstory.com
European Aluminium Association	• www.alueurope.eu
Cambridge	• With both eyes open
IEA	• Energy Technology Perspectives 2012, Pathways to a clean energy system • ETP 2014 data
McKinsey	• McKinsey cost abatement curves v2.1
Ecofys	• SERPECC studies
Previous consultations	• Similar roadmaps performed in Belgium, UK, Algeria, the Balkans & India

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

Global Calculator

Cement specific

WBCSD, Cement sustainability Initiative
- Roland Hunziker

US Portland cement association
- David D. Shepherd

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

Japan Cement Association

Cement, Concrete & Aggregates Australia

Lafarge
- Mr. Vincent Mages

Italcementi
- Ms. Manuela Ojan

Cimpor
- Mr. Paulo Rocha

All sectors (interaction planned later)

Think tanks
- WBCSD
- GIZ

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

NGOs
- Greenpeace
- WWF

Legend	
●	Workshop presence

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

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

Global Calculator

Main sources used for the Cement analysis

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

Main sources used for the Paper analysis

Organisation	Source
Cambridge	• With both eyes open
IEA	• Energy Technology Perspectives 2012, Pathways to a clean energy system
CEPI	• roadmap • Two team project report (presents 8 breakthrough technologies)
Carbon Trust	• Carbon Trust, 2011. Industrial Energy Efficiency Accelerator - Guide to the paper sector (CTG059). London
FAO	• Statistics on link between product demand and materials demand
McKinsey	• McKinsey cost abatement curves v2.1
Ecofys	• SERPECC studies
Previous consultations	• Similar roadmaps performed in Belgium, UK, Algeria, the Balkans & India

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

Global Calculator

Main sources used for the Timber analysis

Organisation	Source
Cambridge	• With both eyes open
IEA	• Energy Technology Perspectives 2012, Pathways to a clean energy system
CEI Bois	• Wood in carbon efficient constructions: Tools, methods & applications/ Lutter contre le changement climatique: utiliser le bois
Previous consultations	• Similar roadmaps performed in Belgium, UK, Algeria, the Balkans & India

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

Global Calculator

Main sources used for the CCS specifics

Organisation	Source
IEA	• Energy Technology Perspectives 2012, Pathways to a clean energy system • IEA: Technology Roadmap: Carbon Capture and Storage (2013) • IEA, UNIDO : Technology Roadmap Carbon Capture and Storage in Industrial Applications (2011)
Imperial Grantham	• Briefing paper Carbon Capture Technology (Nov 2010)
ZEP	• Application of CCS in EU energy intensive industries
McKinsey	• McKinsey cost abatement curves v2.1
Ecofys	• SERPECC studies
Previous consultations	• Similar roadmaps performed in Belgium, UK, Algeria, the Balkans & India

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

Global Calculator

Main sources used for the Resources specifics

Organisation	Source
IEA	• US geological survey (USGS)
Cambridge	• With both eyes open
Bath University	• Construction materials database; inventory of carbon energy. Bath database

NOTES: Resource availability is only partially addressed in this release of the calculator
In an ulterior release focusing more on this topic, Ecofys reports on heavy materials and BNL reports should also be assessed.

Agenda

Global
Calculator

Introduction to the global calculator

Historical energy evolution and link to materials demand

Manufacturing

Steel

Chemicals

Aluminium

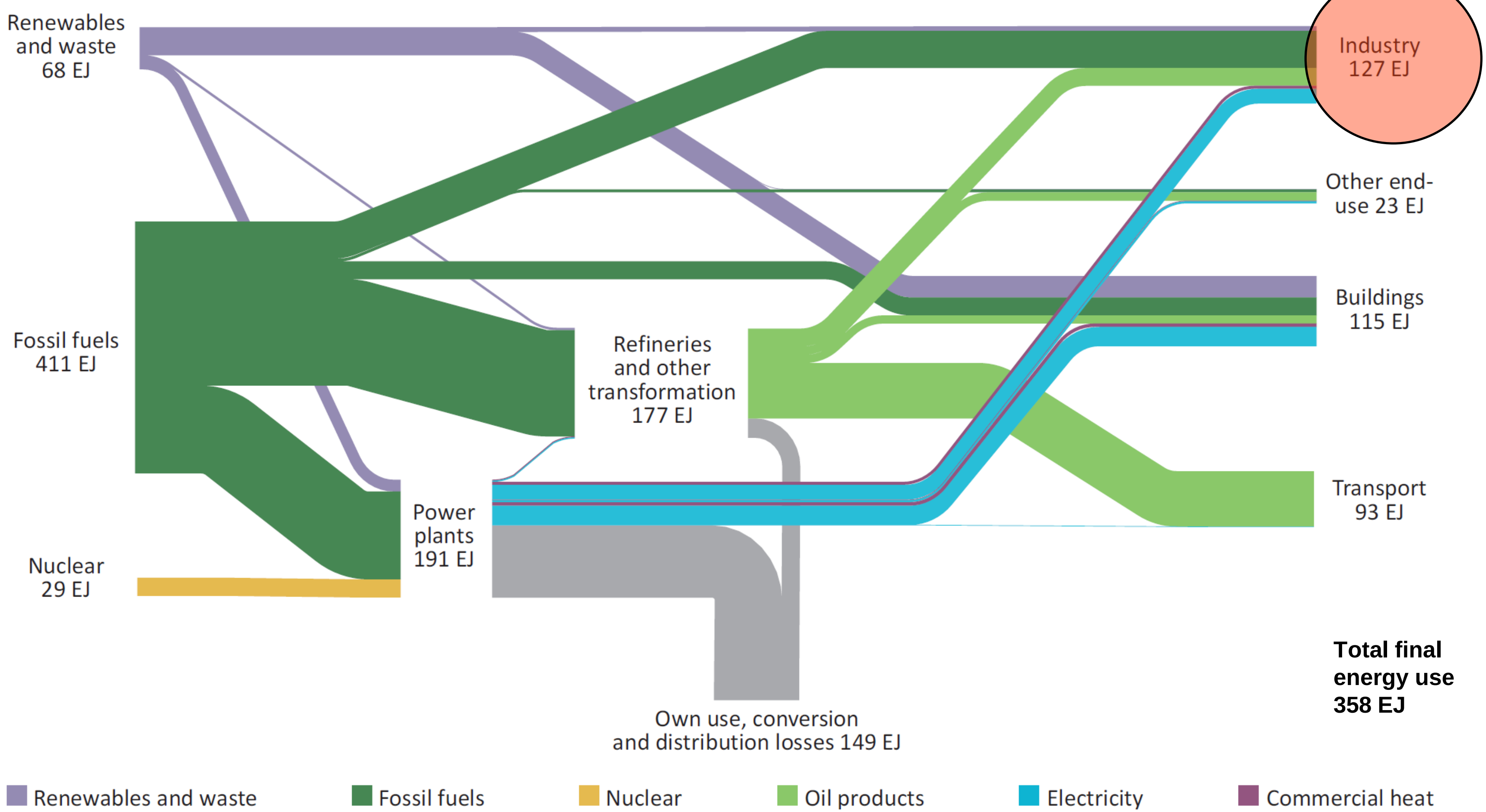
Cement

Paper & timber

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

Global Calculator

Energy Sankey in 2009, (EJ)



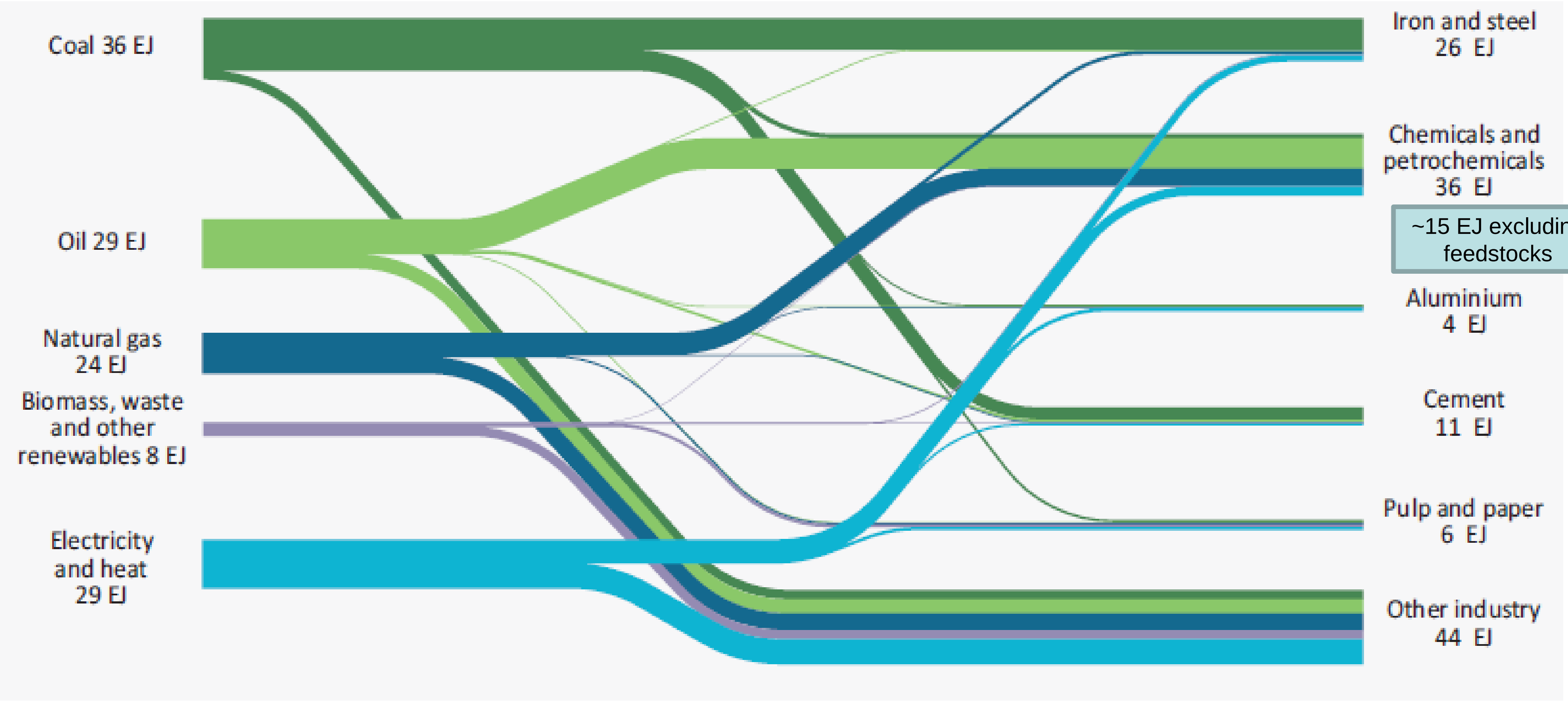
SOURCE: ETP 2012, IEA

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

Patterns differ but most industries heavily depend on fossil fuels. Other industries are more electrified

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

REMINDER : For manufacturing, the analysis starts from the demand for products and derives material production and resource use

Global Calculator

Value chain | **Illustrations**

Resources

Materials analysis: Rare materials | Iron ore | Sand

Energy analysis: Uranium | Fossil hydro-carbons | Biomass

Materials

Steel | Cement | Aluminium | Chemicals | Pulp & paper

Products

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

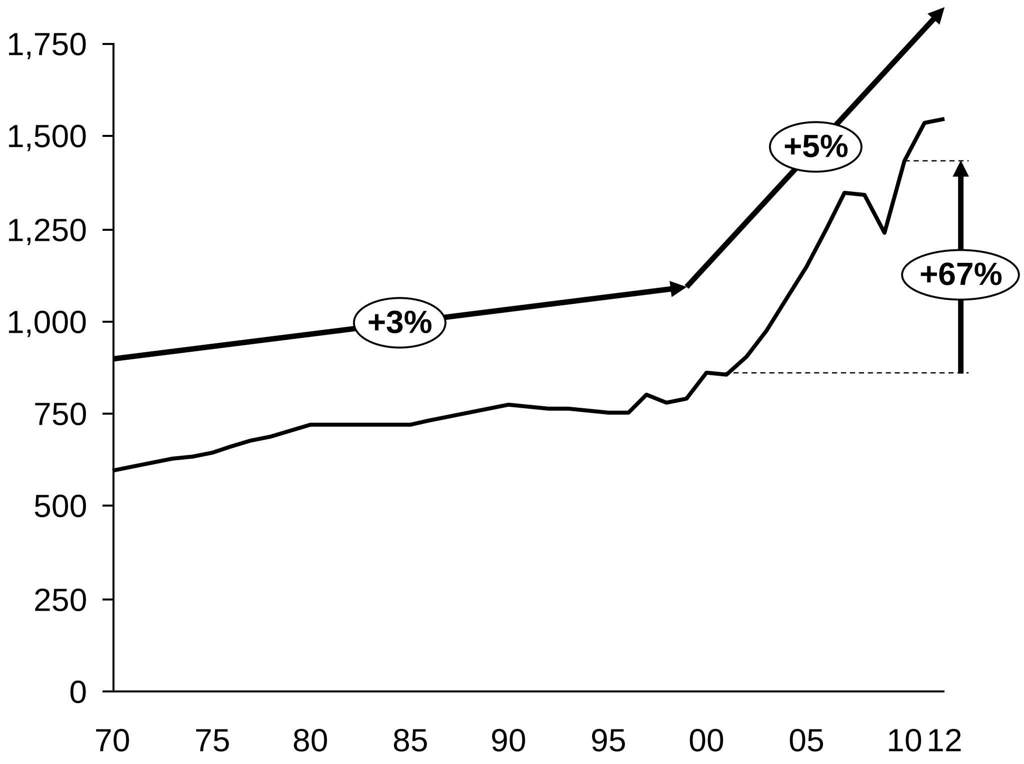
Agenda

Global Calculator

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)

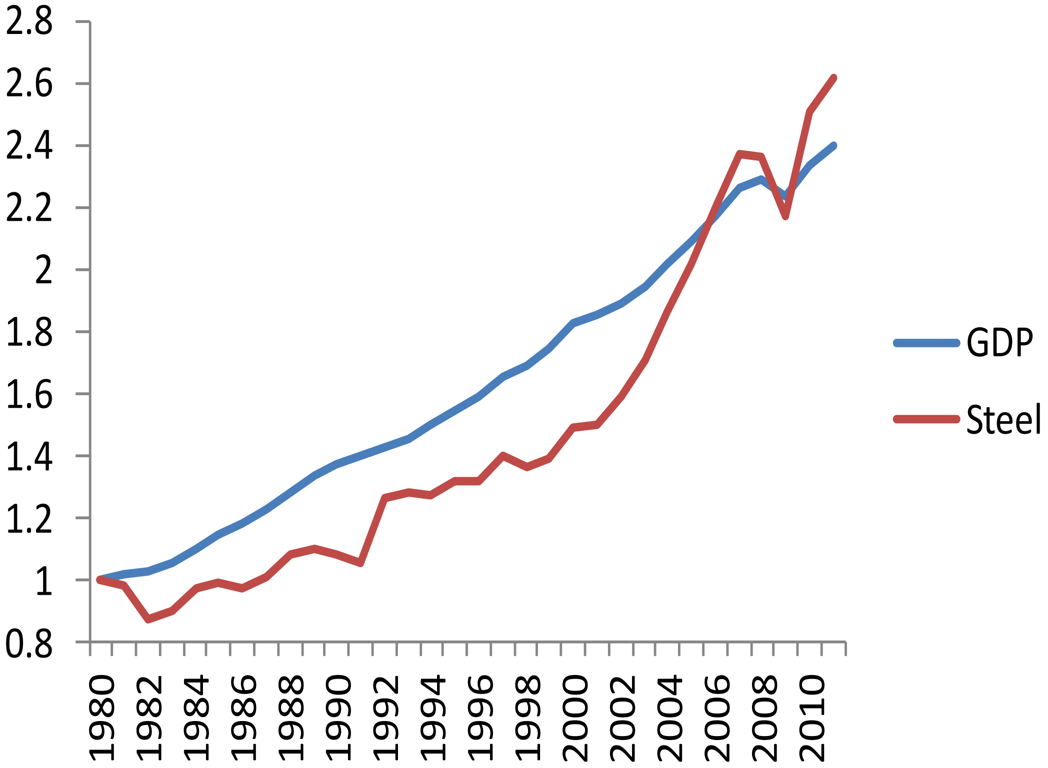
SOURCE : (1) World steel 2011, through IEA ETP 2012

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

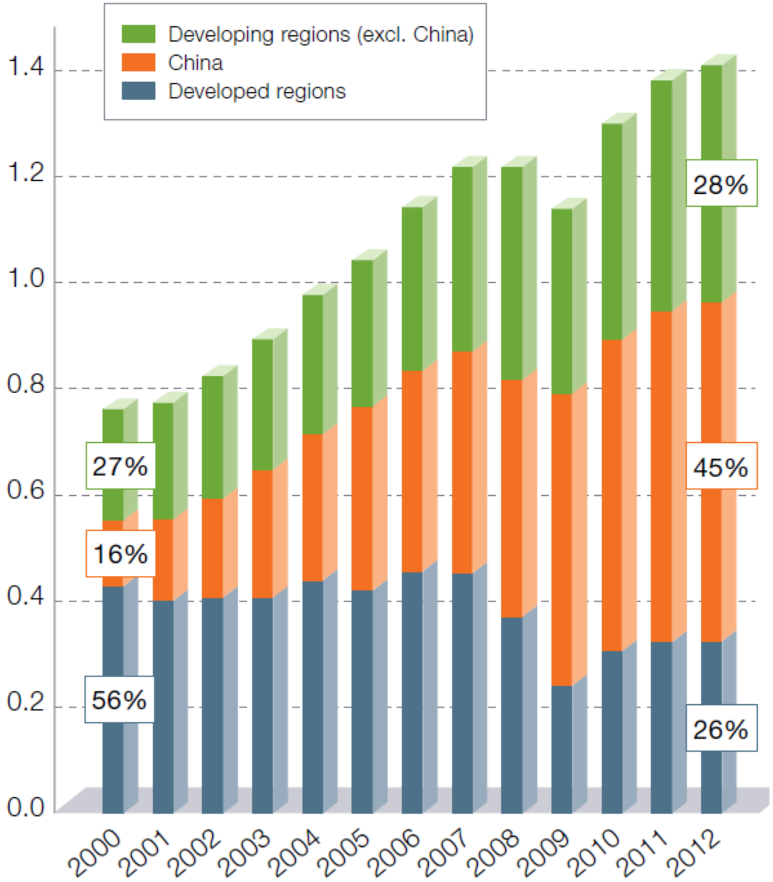
SOURCE : World steel association and World Bank

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

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

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

Figures of July 2014

Global Calculator

Iron & Steel
Materials demand is driven by the product demand

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 (km² [4])	107 kg/m² [1]	422
	Buildings Others	830 (km² [4])	93 kg/m² [1]	77
	Infrastructure	1750 (km² [4])	187 kg/m²	332
	Mechanical 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 m²	2kg /m²	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

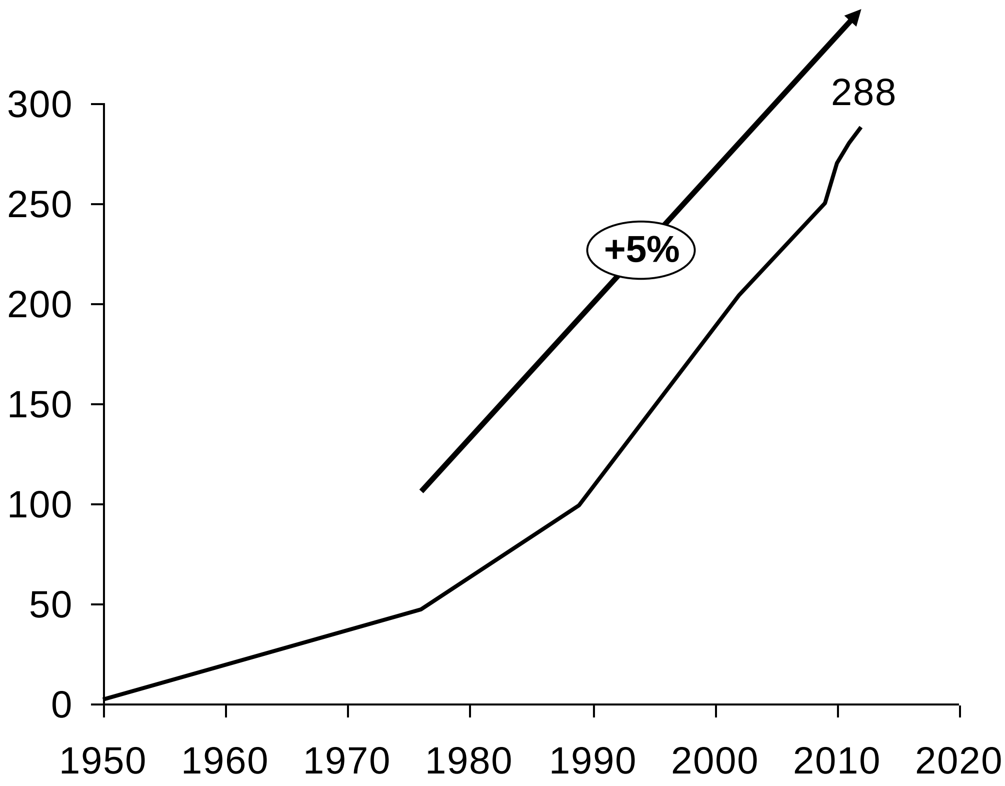
Agenda

Global Calculator

Chemicals demand has experienced a strong growth (5% CAGR) since the 1980s

Global Calculator

World Plastics production [3]
(M tons)



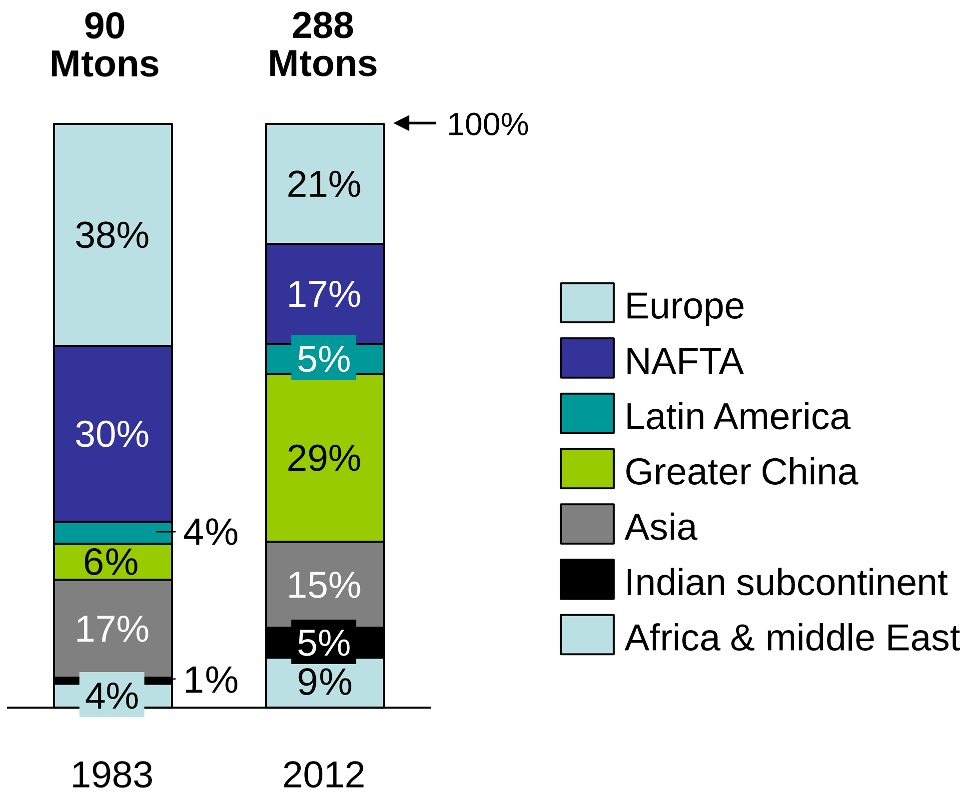
- More than 95% of all manufactured products rely on chemistry [2]
- While growth has levelled off in some industrialised counties, production in China and other emerging economies continues to increase rapidly [1]

SOURCE : (1) IEA ETP 2012 (2) ICCA, 2010), (3) PlasticsEurope (PEMRG) / Consultic via Plastics Europe Association of Plastics manufacturers

Plastics demand is moving east

Global Calculator

Evolution of demand per region
(M tons)



- Consumption of plastics isn't averaged uniformly around the world:
  - Europe, Japan & the US consume ~120kg/ person/year
- In the UK 11kg for plastics packaging

NOTE: This regional segmentation will differ from production estimations (e.g. Europe is an exporter)
SOURCE: Applied Market Information Ltd., Bristol, England

1 Output from the chemical industry covers three wide ranges of products

Base chemicals

- Acrilates
- Adipic acid
- Amines
- Ammonia
- Aniline
- Benzene
- Butadiene
- Caprolactam
- Ethylene
- Ethylene oxide
- Formaldehyde
- Hydrogen
- Mono vinyl chloride
- Nitric acid
- Propylene
- Styrene
- Sulfuric acid
- Toluene
- …

Specialty chemicals

- Adhesives
- Agrichemicals
- cleaning materials
- cosmetic additives
- construction chemicals
- Elastomers
- Flavours
- food additives
- Fragrances
- Industrial gases
- Lubricants
- Polymers
- Surfactants
- Textile auxiliaries
- …

Consumer chemicals

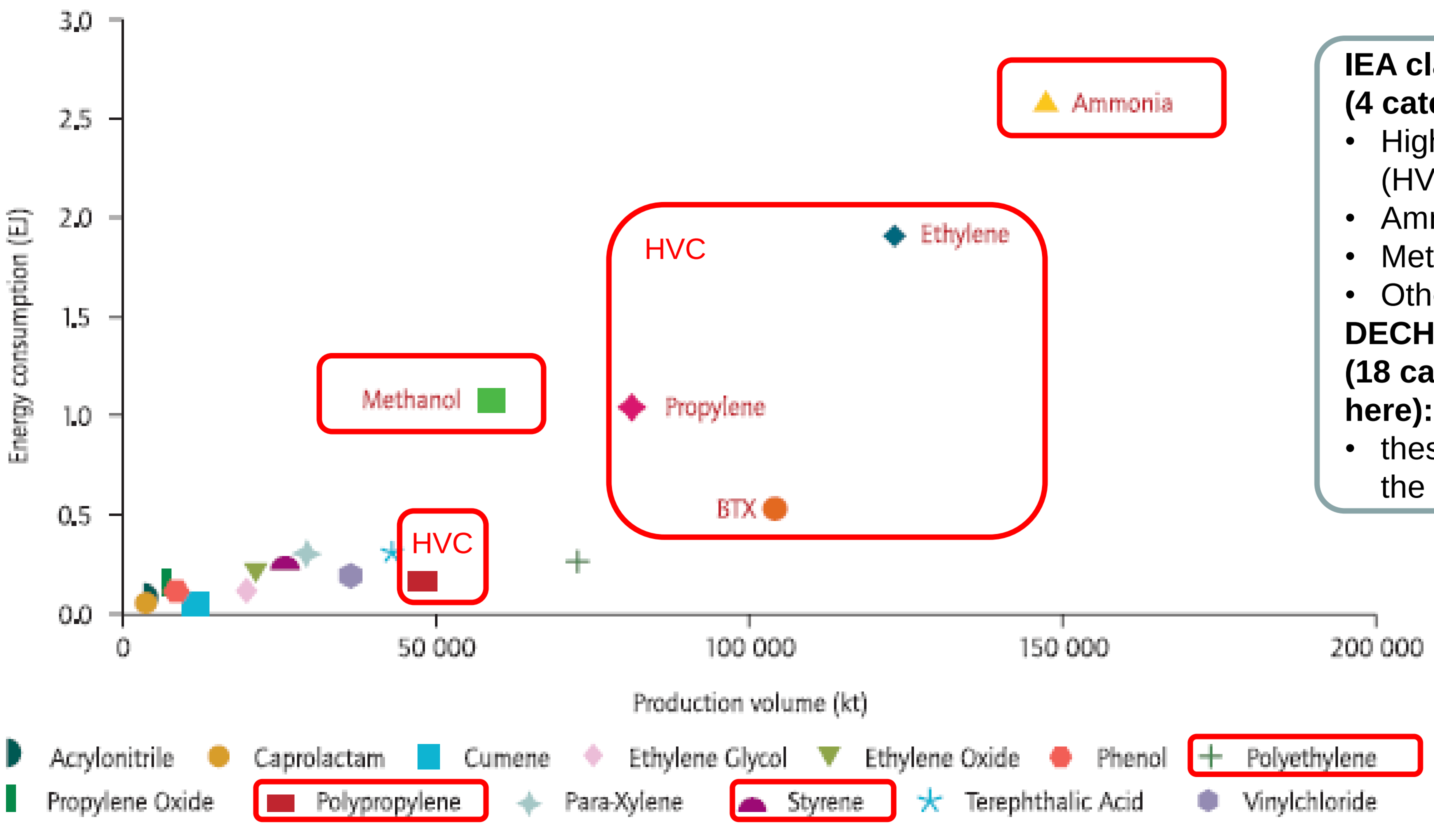
- Automobiles
- Cleaning materials (e.g. detergents)
- Cosmetics (e.g. Soaps)
- Electronic gadgets
- Materials used to construct home
- Paints & coatings
- Plastics
- …

SOURCE: Climact analysis

1 3 categories (used by the IEA) cover most of the chemical production & energy consumption

Global Calculator

Energy consumption and volume production of chemical products (EJ, Kt)



IEA classification (4 categories):

- High Value Chemicals (HVC)
- Ammonia
- Methanol
- Other chemicals

DECHEMA classification (18 categories (illustrated here):

- these represents 75% of the sector GHG emissions

Covered by 3 IEA categories

NOTE: Energy consumption for olefins in this figure represents that of the steam cracking process
SOURCE DECHEMA

HVC drivers

HVC demand is modelled through plastics demand[1]

Plastics materials characteristics (including various alloys and treatments)

Diversity	Plastics encompass a broad range of materials with diverse composition and treatments. This leads to a very diverse set of properties
Mouldability	One common characteristic of plastics is the ability to be moulded [2]
Recycling	Some of the plastics can be recycled but not all (to simplify the thermoplastics can be reprocessed while the thermosets get their properties once and for all) Some are biodegradable and this is not directly correlated to the fact they are made of bioplastics The diversity of their composition makes recycling complex
Strength	Some plastics can be stronger than most other materials available. They can be resistant to traction (e.g. fibres) and compression (e.g. blocks). Hybrid mixes combine the advantages of both
Light	Some plastics can be lighter than most other materials
Durability	Some plastics can keep their properties for a very long time and be resistant to chemical reactions

It is this possibility to reach a wide range of characteristics which explains the strong demand for plastics

NOTE: (1) Aromatix (BTX) are HVC but are not plastics
(2) The word plastics comes from πλαστικος which means « can be moulded

SOURCE: with both eyes open

1

HVC drivers

A large variety of plastics compositions are available; & for each, properties can then be modified by treatments

Global Calculator

Plastics types (non-exhaustive)

Plastic type		Market share(3)	Properties	Applications
HDPE	High density polyethilene	12%	Stronger , stiffer , chemical resistance	Containers, caps, toys, pipes
LDPE (LLDPE)	Low density polyethilene	17,5%	Flexible, can be transparent, chemical resistance	packaging (bags & films), bottles; wire cables
PP	Polypropylene	18,8%	Tough & flexible, chemical resistance	Textiles, stationary, automotive components (e.g. car bumper), packaging
PS	Polystyrene	7,4%	Light	Protective packaging, glass frames, yoghurt pots
PVC	Polyvinylchloride	10,7%	Cheap & versatile, chemical resistance (e.g. corrosion)	Boots, window frames, pipes, fittings, canoes, garden hoses
ABS	Acrylonitrile butadiene styrene		Tough & easy to mould, glossy, shiny finish	Helmets, machinery casing, children toys (lego)
PMMA	Polymethylmethacrylate)		Tough transparent plastic	Windows & safety spectacles
PA	Polyamide		Tough	Nylon, car tires, ropes, tubing
PET	Polyethylene terephthalate	6,5%	Resistant	Beverage bottles
PUR	Polyurethane	7,3%	Strength	Sponges, Lycra, spandex, gears, bearings & wheels
PLA	Polylactic acid		Bioplastic	Wide, also medical implants
Other		19,8%		

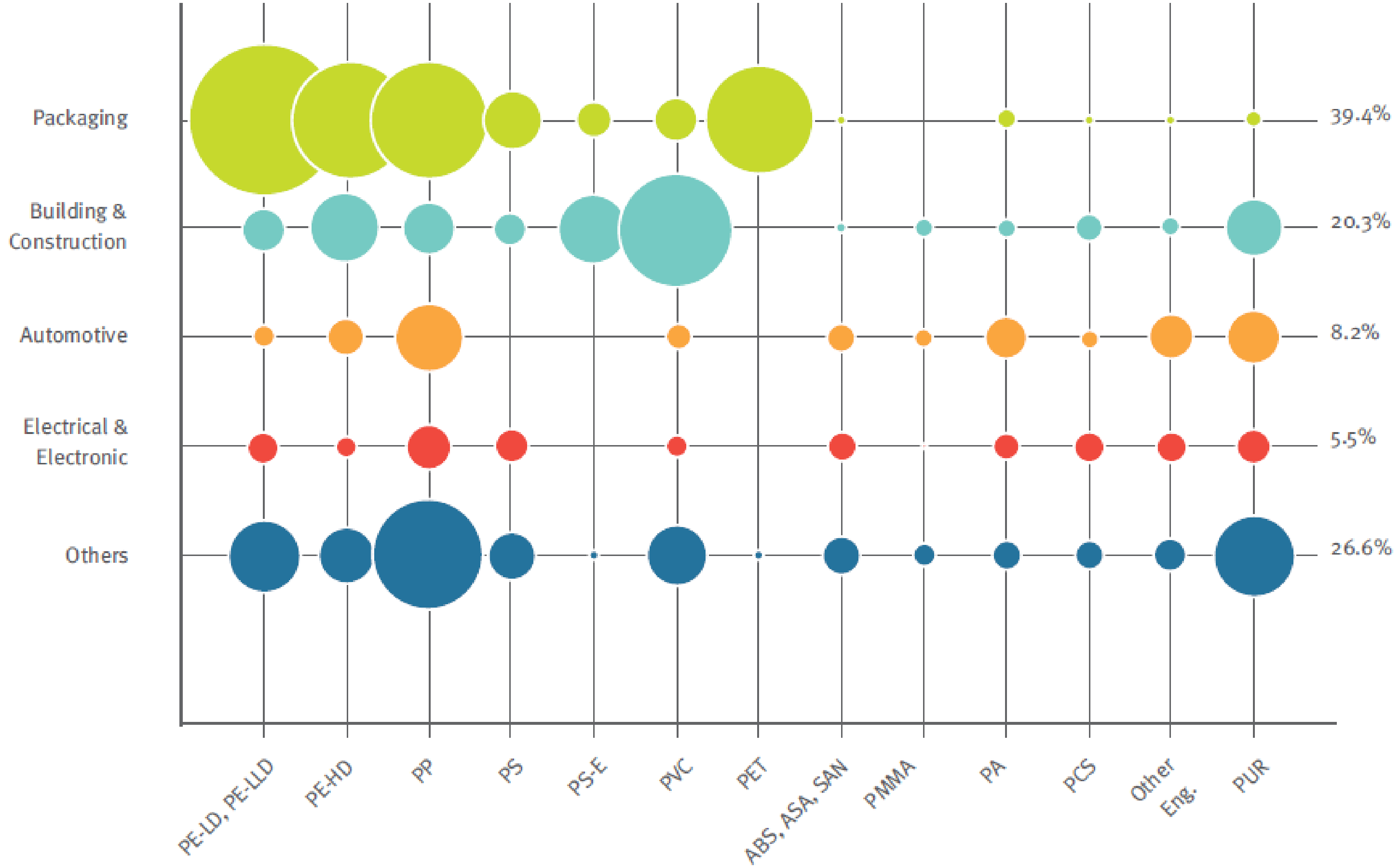
Properties can also be modified through the use of additives, fillers, heat treatment processes and mechanical deformation

NOTE: (3) Of European demand
SOURCE: With both eyes open, (3) PlasticsEurope (PEMRG) / Consultic via Plastics Europe Association of Plastics manufacturers

HVC drivers

There is no simple correlation between plastic types and applications

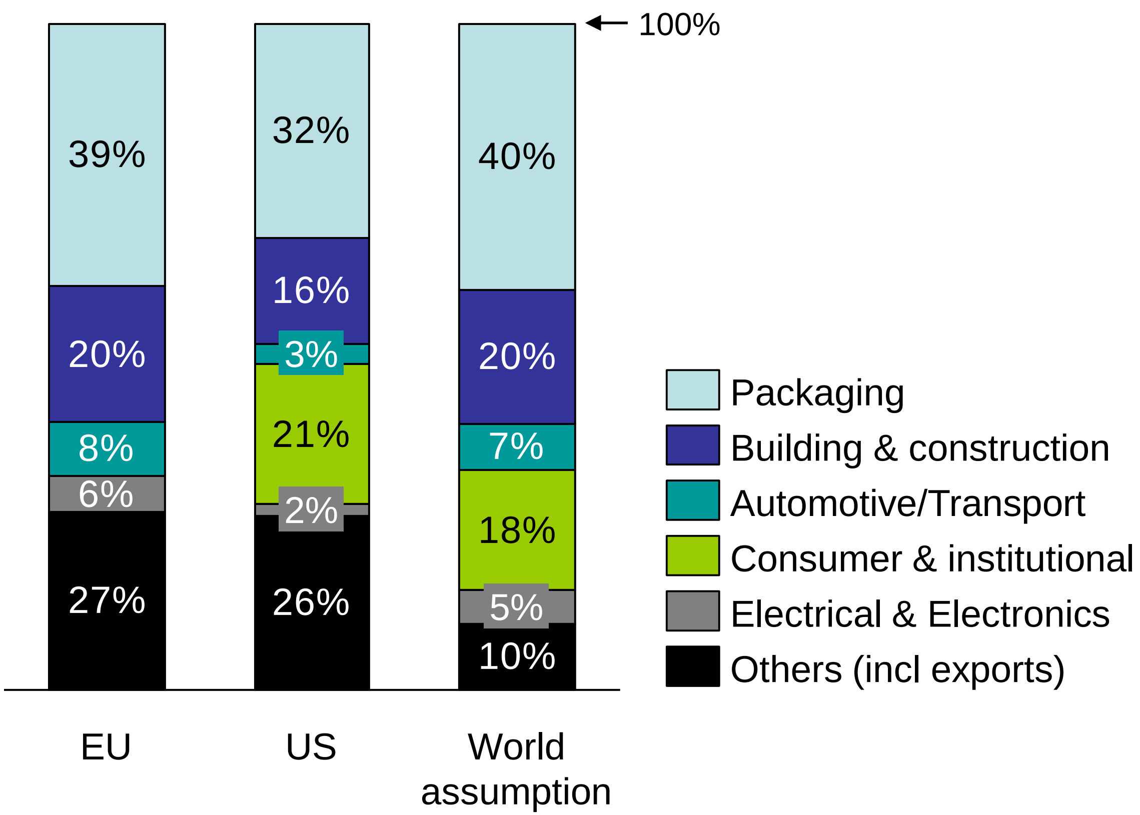
Plastics demand by segment and resin type
(2012, European market EU 27+CH,%)



SOURCE: PlasticsEurope (PEMRG) / Consultic / ECEBD

HVC drivers
Plastics demand drivers are being identified

Plastics demand drivers
(%)



In the Global calculator, it can be linked to:

- Packaging (40%)
- Appliances (35%)
- Transport (5%)
- Buildings (20%)

NOTE: World segmentation is a Climact estimate based on the EU and US data

SOURCE: With both eyes open, PlasticsEurope (PEMRG) / Consultic / ECEBD for 2012

1 Ammonia drivers

Global Calculator

Rationale for ammonia demand

- Ammonia contributes to the nutritional needs of terrestrial organisms by serving as a precursor to food and fertilizers. About 50% of the world's food production relies on ammonia-based fertilisers [(1)]
- Ammonia is used for the synthesis of many pharmaceuticals
- Ammonia is used in many commercial cleaning products
- Emissions caused by the application of fertilizers are assessed in the Land/Food/Biomass section of the global calculator

- Fertilizer consumption evolution is linked to the evolution of yield in the agriculture sector as follows:
- % change in fertilizer =
  - 30%[(2)]
  - *% change in yield
  - *% change in food production
- This way the fertilizer production is even linked to the consumer food habits (which drive food production demand)

NOTE: (2) Factor reflects yield growth can evolve for a number of factors (genotype + environment), e.g., irrigation, better farm management and crop varieties.

SOURCE: (1) Erismann, 2008, Global Calculator workshops

Methanol drivers

Global Calculator

Rationale for methanol demand

Making other chemicals	• The largest use of methanol by far • ~40% of methanol is converted to formaldehyde, and from there into products as diverse as plastics, plywood, paints, explosives, and permanent press textiles
Fuel	• Methanol is used on a limited basis to fuel internal combustion engines
Other uses	• Solvent • antifreeze in pipelines and windshield washer fluid

In the Global calculator, it can be linked to the HCV evolution (and therefore to the same drivers)

SOURCE: Global Calculator analysis

1

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

Global Calculator

Products		Amounts (units, 2011)	Intensity (tons/product/year)				Chemicals (M tons, 2011)(2)			
			HVC	Ammonia	Methanol	Others	HVC	Ammonia	Methanol	Others
Transport	Cars & light trucks	113 (M Vehicles)	0,12	-	0,02	0,07	14	-	3	8
	Trucks	5,7 (M Vehicles)	0,4		0,07	0,24	2		0,4	1
	Ships	1 (k units)	-	-	-	-	-	-	-	-
	Batteries (not modelled in v1)	-	-	-	-	-	-	-	-	-
Buildings	Buildings residential	3930 (km^2 (4))	0,014	-	0,002	0,009	54	-	10	35
	Buildings Others	830 (km^2 (4))	0,012	-	0,002	0,008	10	-	2	6,5
	Appliances	250 (Mt)	0,438	-	0,08	0,29	111	-	20	73
Consumer goods	Packaging	530 (Mt)	0,24	-	0,04	0,16	128	-	23	84
	3D Printing (not modelled in v1)	-	-	-	-	-	-	-	-	-
	Population (Fertilizers)	7,0 Bln people	-	23 kg/person	-	-	-	164	-	-
Energy	Windmill (blades in carbon fibre)	17,600 2MW turbines	30 tons	-	-	-	0,5	-	-	-
	PV panels	160 M m^2	5kg /m^2	-	-	-	0,7	-	-	-
Total	**Total**	**/**	**/**	**/**	**/**	**/**	**320**	**164**	**58**	**208**

Model demand drivers

Legend

Representative Products

Niche product (for the analysis)

NOTES: (1) High Value chemicals typically include Ethylene, Propylene, BTX aromatics(benzene, toluene and mixed xylenes)

(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

In a later model version, Plastics Europe could be contacted to validate this allocation as well as the total production of other chemicals

Agenda

Global Calculator

Introduction to the global calculator

Historical energy evolution and link to materials demand

Manufacturing

Steel

Chemicals

Aluminium

Cement

Paper & timber

Figures of Sept. 2014

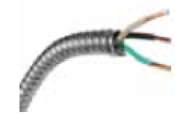
Global Calculator

Aluminium
Demand driving products

Aluminium — 67,7 Mt aluminium (semi)

Transport	27%: 18 Mt aluminium	Cars & light trucks	18%: 12,0 Mt aluminium
		Trucks	7%: 4,5 Mt aluminium
		Other	2%: 1,4 Mt aluminium
Industrial equipment	20%: 14 Mt aluminium	Electrical equipment	4%: 3 Mt aluminium
		Electrical cable	9%: 6 Mt aluminium
		Mechanical equipment	7%: 4,5 Mt aluminium
Construction	24%: 16 Mt aluminium	Buildings Residential	19%: 12,9 Mt aluminium
		Buildings Other	3%: 2 Mt aluminium
		Infrastructure	2%: 1,4 Mt aluminium
Metal products	29%: 20 Mt aluminium	Packaging	13%: 9,0 Mt aluminium
		Appliances	7%: 4,5 Mt aluminium
		Metal goods	9%: 6 Mt aluminium
		PV panels	0,4%: 0,3 Mt aluminium







NOTES: Electricity can be the largest emission component
Electricity mix is typically not so related to the national, regional or world electricity mix.
In recent years, newer plants tended to rely on more coal based electricity

SOURCE: With both eyes open, Copyright 2012 UIT Cambridge Ltd.

Figures of Sept. 2014

Global Calculator

Aluminium
Materials demand is driven by the product demand

Technologies & Products		Amounts (units, 2011)	Intensity (tons/ product)	Aluminium production (M tons)[2]
Transport	Cars & light truck	113 (M vehicles)	0,13 tons/vehicles	12
	Trucks	5,7 (M vehicles)	0,94 ton/vehicle	5
	Ships	1 (k units)	0 tons/unit	0
	Airplanes	35 000 (units)	500 tons/unit	2
Buildings	Buildings residential	3930 (km^2 [4])	4,4 kg/m^2 [1]	13
	Buildings others	830 (km^2 [4])	3,8 kg/m^2 [1]	2
	Infrastructure	1750 (km^2 [4])	1,2 kg/m^2 [1]	2
	Mechanical Equipment	160 (M tons)	34kg/ton eqpt	5
	Appliance	253 (M tons)	21 kg/ton appliance	5
Consumer goods	Metal goods	257 (M tons)	0,3 tons/ton goods	6
	Consumer packaging	530 (M tons)	0,02 tons/ton packaging	9
Energy	PV panels	160 M m^2	2kg /m^2	0,31
	Electrical Equipment	61,4 (M tons)	0,03 tons/ton eqpt	3
	Electrical cables	24 (M km)	0,3 tons/km	6
Other	Other Aluminium	0 (M tons)	1 ton/ton product	0

Model demand drivers

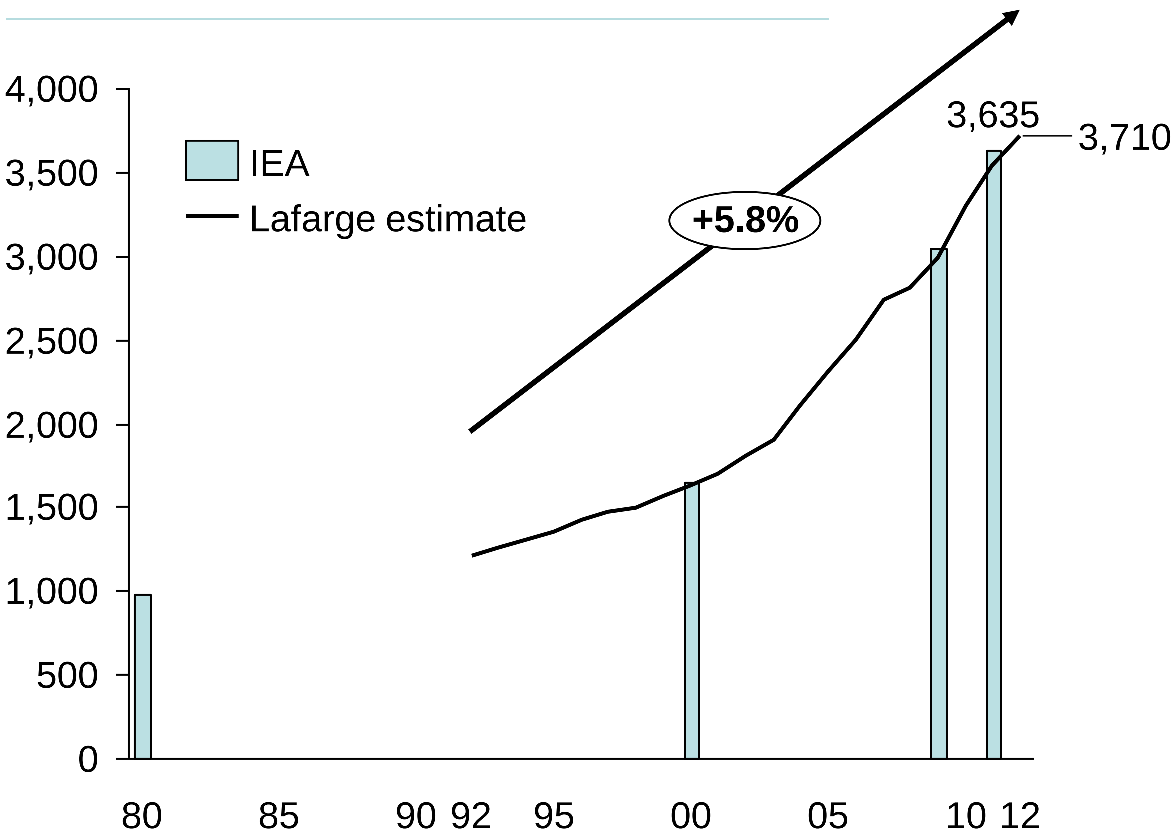
Total 67,7 Mton (100%)

SOURCE: (1) Model defined, with both eyes open provides 5kg/m^2
(2) With both eyes open base, adapted to IEA figures & new products
(4) Of ground surface

Agenda

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

Historic evolution of cement production
(Mtons)

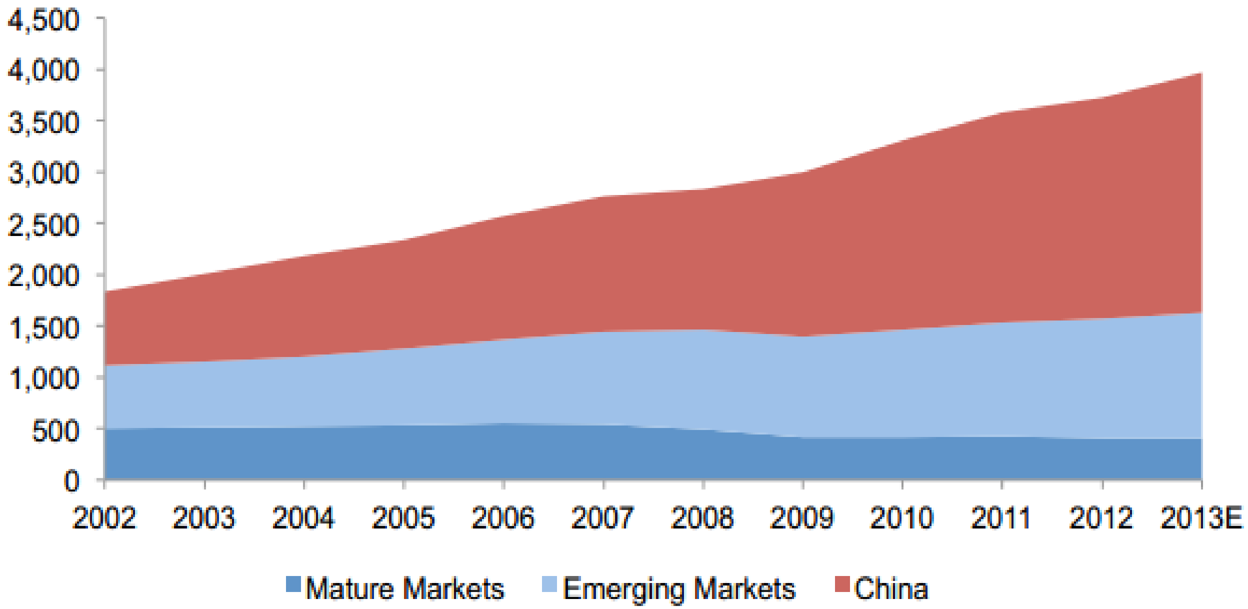


- North American and European demand stagnated from 1970 to 1995, while Chinese demand has expanded at a phenomenal rate

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

Cement demand is largely driven by China

Evolution of cement demand
(2002-2013 M tons)



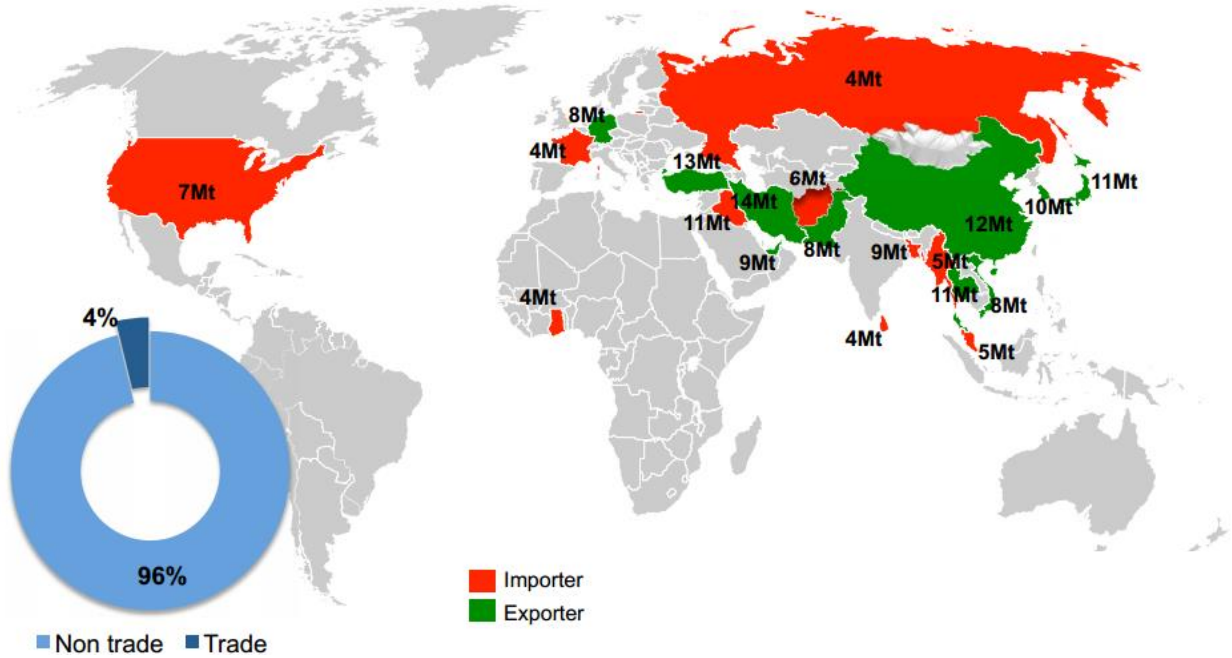
- Global cement demand is dominated by China (39% in 2002 vs 58% in 2012)
- Steady growth in emerging markets
- Mature markets entered into a period of contraction from 2008

SOURCE: International Cement Review, Global cement industry trends

Only 4% of the cement production is internationally traded

Global Calculator

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



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

SOURCE: International Cement Review, Global cement industry trends

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

Cement materials characteristics

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

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

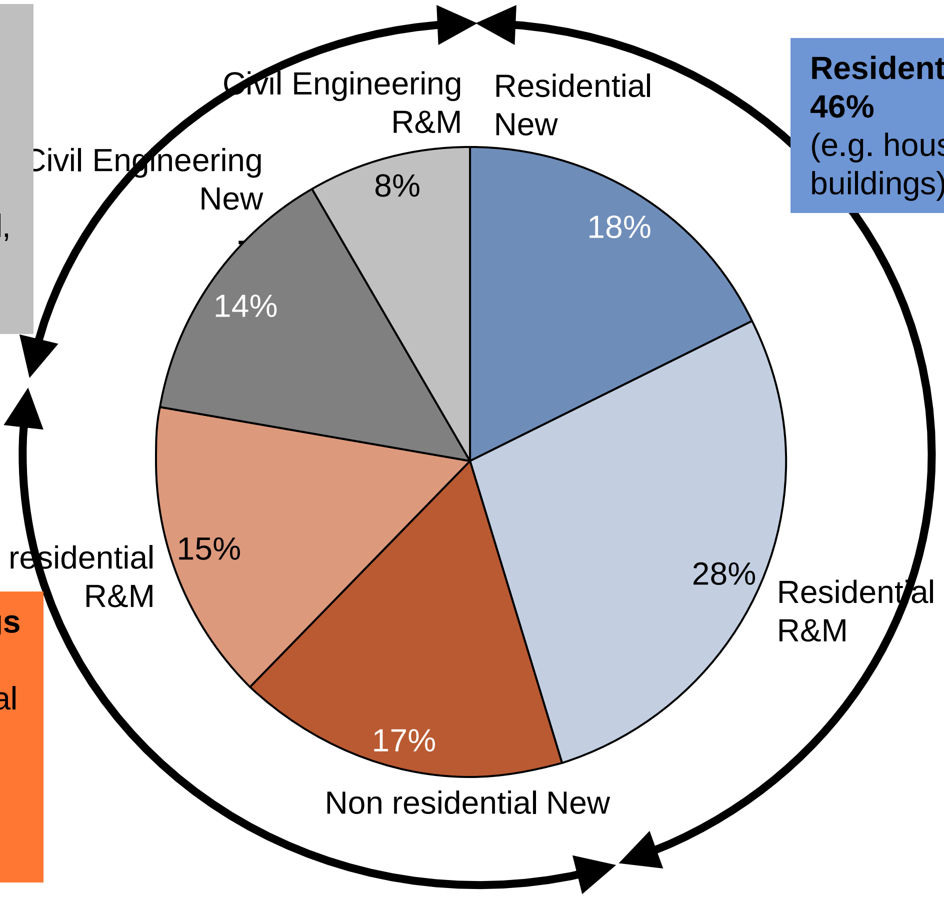
SOURCE: with both eyes open

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

Global Calculator

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

Infrastructure 22%
e.g. Roads, dams, ports, Airports, Bridges, Tunnel, Water, Pipes, Dikes



Residential 46%
(e.g. houses, buildings)

Other buildings 32%
e.g. Commercial buildings, schools, hospitals

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

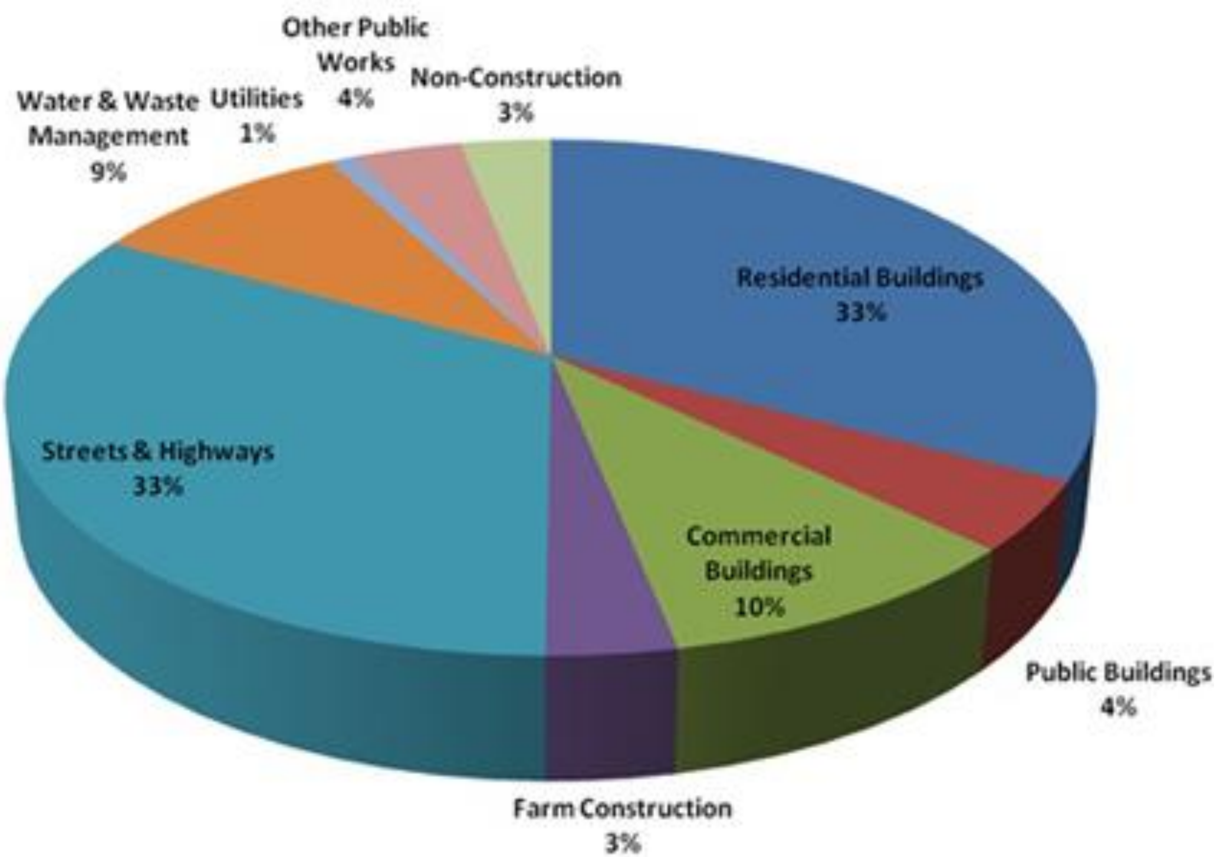
SOURCE: (1) Cembureau, The role of CEMENT in the 2050 LOW CARBON ECONOMY, (2) with both eyes open
(3) Euroconstruct, VTT, Buildecon, EU 27 (excl Cyprus, Greece, Luxembourg & Malta), plus Noway & Switzerland

1

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

Global Calculator

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



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

SOURCE USGS, PCA

Figures of July 2014

Global Calculator

Cement
Materials demand is driven by the product demand

Technologies & Products		Amounts (units, 2011)	Intensity (tons/ product)	Cement production (G tons, 2011[2])
Buildings	Residential Buildings	3930 million m² [4]	305 kg cement per m² of buildings [1]	1,200 Gton (33%)
	Other Buildings	830 million m² [4]	745 kg cement per m² of buildings [1]	618 Gton (17%)
	Infrastructure	1750 million m2 [4]	1023 rest kg cement per m² of buildings [1]	1,818 Gton (50%)

Model demand drivers

Total 3,635 Gton (100%)

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

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

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

(4) Of ground surface

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

Global Calculator

Figures of July 2014

Global Calculator

Paper
Materials demand is driven by the product demand

Technologies & Products		Amounts (units, 2011)	Intensity (tons/ product)	Paper production (M tons)[1,2]
Consumer goods	Printing & graphic	263 (M tons)	1	263
	Packaging	532 (M tons)	0,517 t paper/ton packaging	275
	Other (e.g. hygiene)	73 (M tons)	1	73

Model demand drivers

Total 611 Mton (100%)

SOURCE: (1) Global calculator

Figures of July 2014

Timber
Materials demand is driven by the product demand

Global Calculator

Technologies & Products		Amounts (units) (units, 2011)	Intensity (tons/ product)	Timber production (M tons)[2]
Buildings	Buildings residential	3930 (km² [4])	0,12	479
	Buildings Others	830 (km² [4])	0,11	87
Consumer goods	Other timber (incl. Furniture)	243 (tons)	1	243

Model demand drivers

Total 809 Mton (100%)

NOTES: (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) Global Calculator