Global Calculator

Iron & Steel Workshop
Products & Manufacturing of the Global Calculator
Workshop of April 24th 2014 (version of July 17th)
Brussels
This document
  – Supported workshop discussions of April 24\textsuperscript{th} 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 1\textsuperscript{st}

All this documentation is open source
<table>
<thead>
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</tr>
</thead>
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Introduction to the Global Calculator

Background

Expert & Literature review
• 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)

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

Main sources used for this analysis

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

### Content

- Introduction to the Global Calculator  9-10h

<table>
<thead>
<tr>
<th>Iron &amp; steel demand prospective</th>
<th>10-11</th>
</tr>
</thead>
</table>

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

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)

Total final energy use 358 EJ

- Renewable and waste 68 EJ
- Fossil fuels 411 EJ
- Nuclear 29 EJ
- Transport 93 EJ
- Buildings 115 EJ
- Other end-use 23 EJ
- Refineries and other transformation 177 EJ
- Power plants 191 EJ
- Own use, conversion and distribution losses 149 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.

Energy Sankey in 2009 for the industry, (EJ)

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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

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 pace (1).

SOURCE: (1) World steel 2011, through IEA ETP 2012
At global level, steel production is correlated to GDP

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

- 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)

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

- 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.
### Steel offers unique combination of characteristics:
- Toughness
- Thermal expansion
- Corrosion resistance
- Electrical resistance
- Ductility
- Availability

#### Steel materials characteristics (including various alloys and treatments)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td>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).</td>
</tr>
<tr>
<td>Stable</td>
<td>Low thermal expansion (similar to cement).</td>
</tr>
<tr>
<td>Durable</td>
<td>High melting temperature and can be protected from corrosion.</td>
</tr>
<tr>
<td>Ductile/Recyclable</td>
<td>Steel can be made to change shape without cracking. Through melting, steel can theoretically be recycled an infinite number of times.</td>
</tr>
<tr>
<td>Affordable/Available</td>
<td>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).</td>
</tr>
<tr>
<td>Conductor</td>
<td>Can be used to conduct heat and electricity (less than several other metals such as aluminium or copper).</td>
</tr>
</tbody>
</table>

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).
Iron & steel demand driving products

Steel driving products (2011)

Steel

1518 Mt steel
2991 M tCO₂e
1,97 tCO₂e/t steel

Transport
13%: 194 Mt steel

Industrial equipment
16%: 246 Mt steel

Construction
55%: 832 Mt steel

Metal products
16%: 247 Mt steel

Energy
0,6%: 10 Mt steel

Cars & light trucks
8%: 123 Mt steel

Trucks
2%: 28 Mt steel

Ships
2%: 23 Mt steel

Rail
1%: 20 Mt steel

Electrical equipment
3%: 46 Mt steel

Mechanical equipment
10%: 153 Mt steel

Infrastructure
22%: 332 Mt steel

Residential Buildings
28%: 422 Mt steel

Other Buildings
5%: 77 Mt steel

Metal goods
13%: 193 Mt steel

Consumer packaging
1%: 11 Mt steel

Domestic appliances
3%: 43 Mt 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
Today, this is the model generated demand, it will evolve based on Product demand defined by the other sectors.

### Technologies & Products

<table>
<thead>
<tr>
<th></th>
<th>Amounts (units, 2011)</th>
<th>Intensity (t steel/product)</th>
<th>Annual Steel production (M tons, 2011)(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transport</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cars &amp; light truck</td>
<td>113 (M Vehicles)</td>
<td>1100 kg/vehicle</td>
<td>123</td>
</tr>
<tr>
<td>Trucks</td>
<td>5,7 (M Vehicles)</td>
<td>4900 kg/vehicle</td>
<td>28</td>
</tr>
<tr>
<td>Ships</td>
<td>1 (k units)</td>
<td>20 000</td>
<td>23</td>
</tr>
<tr>
<td>Rail</td>
<td>5 (k units)</td>
<td>4000</td>
<td>20</td>
</tr>
<tr>
<td><strong>Buildings</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buildings Residential</td>
<td>3 930 (km² (4))</td>
<td>107 kg/m² (1)</td>
<td>422</td>
</tr>
<tr>
<td>Buildings Others</td>
<td>830 (km² (4))</td>
<td>93 kg/m² (1)</td>
<td>77</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>1750 (km² (4))</td>
<td>187 kg/m²</td>
<td>332</td>
</tr>
<tr>
<td>Mechanic al equipment</td>
<td>160 (M tons)</td>
<td>0,97</td>
<td>153</td>
</tr>
<tr>
<td>Appliance</td>
<td>253 (M tons)</td>
<td>0,17</td>
<td>43</td>
</tr>
<tr>
<td><strong>Consumer goods</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal goods</td>
<td>257 (M tons)</td>
<td>0,75</td>
<td>193</td>
</tr>
<tr>
<td>Consumer packaging</td>
<td>530 (M tons)</td>
<td>0,02kg/kg packaging</td>
<td>11</td>
</tr>
<tr>
<td><strong>Energy</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windmills</td>
<td>17,500 2MW turbines</td>
<td>350 tons/2MW turbine(3)</td>
<td>6,1</td>
</tr>
<tr>
<td>PV panels</td>
<td>160 M m²</td>
<td>2kg /m²</td>
<td>0,320</td>
</tr>
<tr>
<td>Electrical equipment</td>
<td>61,1 (M tons)</td>
<td>0,75</td>
<td>46</td>
</tr>
<tr>
<td>CCS + oil pipes</td>
<td>100 000 km</td>
<td>0,4 ton/m</td>
<td>40</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>Other Steel</td>
<td>~0M (tons)</td>
<td>~0</td>
</tr>
</tbody>
</table>

**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

### Additional Information

- **Zhang** mentions that it is just the ground surface, not including the public area and road area.
- **JPE** states that according to IEA, there is a stock of 1454 million cars, with a lifetime average of 12.5 years, so 116 million per year of new cars, so we will have to update the transport section of the model.
- **Où sont les trains d’ailleurs?**
- **MC** suggests that they are negligible as they are not a large part of the total (contrary to aluminum).
Steel demand perspectives

Current situation

Steel demand drivers

Resulting steel demand at constant technology
As income/person increases, steel demand increases, an upper boundary is experienced in some countries.

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

Steel stocks 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 & Cambridge University (2014 04 10 International Materials Education Symposium)
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
## Rationale for expected 2050 Iron & steel demand (2/2)

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

**SOURCE:** (1) Global Calculator team assumptions
The IEA ETP 2012 suggests an increase in Iron & Steel production in all scenarios in most regions.

**Production evolution per scenario per region for Steel**

### Total steel (crude) (Mton)

<table>
<thead>
<tr>
<th>Year</th>
<th>Region</th>
<th>2009</th>
<th>2050 Low</th>
<th>2050 High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Asean</td>
<td>1,232</td>
<td>2,438</td>
<td>2,943</td>
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<td></td>
<td>Brazil</td>
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<td>Other</td>
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</tbody>
</table>

### Scrap consumption (part of Total steel) (Mton)

<table>
<thead>
<tr>
<th>Year</th>
<th>Region</th>
<th>2009</th>
<th>2050 Low</th>
<th>2050 High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Asean</td>
<td>354</td>
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<td></td>
<td>Other</td>
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</tbody>
</table>

**World steel comment:** The global figures for 2030 are as follows:

- **Total crude steel production:**
  - Range: 1980 - 2450 Mt
- **Global scrap demand for steelmaking:**
  - Range: 750 - 950 Mt

The numbers are taken from the book "Sustainable materials. With both eyes open," Worldsteel is using another methodology and sector definition. We will need to find a common ground to compare the numbers.

---

1. The IEA ETP 2012 suggests an increase in Iron & Steel production in all scenarios in most regions.
By 2050, the world population is expected by the UN to grow by ~20 to ~55%.

World population (billions)

2010-2050 growth (%)

- High variant: +57%
- Medium variant: +38%
- Low variant: +21%

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

Steel production per year per ambition level\(^{(1)}\)
(M tons)

<table>
<thead>
<tr>
<th>Year</th>
<th>Trajectory 1</th>
<th>Trajectory 2</th>
<th>Trajectory 3</th>
<th>Trajectory 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>218 kg</td>
<td>218 kg</td>
<td>218 kg</td>
<td>218 kg</td>
</tr>
<tr>
<td>2015</td>
<td>+124%</td>
<td>+96%</td>
<td>+83%</td>
<td>+73%</td>
</tr>
<tr>
<td>2020</td>
<td>355 kg</td>
<td>316 kg</td>
<td>291 kg</td>
<td>275 kg</td>
</tr>
<tr>
<td>2025</td>
<td>+10-50,%</td>
<td>+83%</td>
<td>+73%</td>
<td>+65%</td>
</tr>
<tr>
<td>2030</td>
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<td>2035</td>
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<tr>
<td>2050</td>
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</tbody>
</table>

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

Steel production per year per ambition level\(^{(1)}\)
(M tons)

<table>
<thead>
<tr>
<th>Year</th>
<th>Trajectory</th>
<th>Residential buildings</th>
<th>Other buildings</th>
<th>Wind turbines</th>
<th>Metal goods</th>
<th>Consumer packaging</th>
<th>Electrical equipment</th>
<th>Mechanical equipments</th>
<th>Appliances</th>
<th>Rail</th>
<th>Infrastructure</th>
<th>Cars &amp; light truck</th>
<th>Cars &amp; light truck EV</th>
<th>Trucks</th>
<th>Ships</th>
<th>Other steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>1</td>
<td>3,393</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2,976</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td></td>
<td>3</td>
<td>2,777</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>4</td>
<td>2,626</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Trajectories in 2050

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

SOURCE: IEA ETP 2012, Global calculator model
Content

• Introduction to the Global Calculator 9-10h

• Iron & steel demand prospective 10-11

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

**Integrated steel production**

**Direct reduction iron (1)**

**Electric Arc Furnaces (scrap based)**

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

**SOURCE:** GSV, World Steel, Climact
Steel emissions are being modelled

Steel emission tree

Steel
  Oxygen steel
  DRI EAF
  Top Gas / HIsarna
  Electric steel

Production
Energy Intensity
Process intensity
Production
Energy Intensity
Process intensity
Production
Energy Intensity
Process intensity
Production
Energy Intensity

SOURCES: Climact
Steel manufacturing with lower energy intensity

Steel manufacturing process

Estimation of the reduction potentials

Resulting scenarios
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/Infra: To 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
• 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 CO₂e 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)
• 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

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

Share of high strength steel (%)

- Ambition 1: 20%
- Ambition 2: 30%
- Ambition 3: 40%
- Ambition 4: 50%

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

Lever cost (2)
€/t crude steel

| Input (fuel & material) | -x |
| Other opex            | 0  |
| Capex                 | +x |

NOTE: (2) Assuming the additional capex is balanced by the input reduction
SOURCE: Climact national consultations
Material switch
Steel is a relatively cheap material

Embodied energy (Gj/t)

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>150</td>
</tr>
<tr>
<td>Steel</td>
<td>20</td>
</tr>
<tr>
<td>Concrete</td>
<td>10</td>
</tr>
<tr>
<td>Plastics</td>
<td>10</td>
</tr>
<tr>
<td>Stone</td>
<td>5</td>
</tr>
<tr>
<td>Wood</td>
<td>0</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Material</th>
<th>Relative Useful Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>350%</td>
</tr>
<tr>
<td>Steel</td>
<td>100%</td>
</tr>
<tr>
<td>Concrete</td>
<td>10%</td>
</tr>
<tr>
<td>Plastics</td>
<td>180%</td>
</tr>
<tr>
<td>Stone</td>
<td>20%</td>
</tr>
<tr>
<td>Wood</td>
<td>217%</td>
</tr>
</tbody>
</table>

- 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
## Material switch
Steel can be substituted to enable less CO₂ emissions along product life cycles

### Materials which can replace /be replaced by steel

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Steel replacement assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td><strong>Vehicles (8%)</strong></td>
</tr>
<tr>
<td><strong>Aluminium</strong></td>
<td>Density</td>
</tr>
<tr>
<td></td>
<td>Less strong, less recyclable</td>
</tr>
<tr>
<td></td>
<td>Higher cost &amp; embodied energy</td>
</tr>
<tr>
<td><strong>Concrete</strong></td>
<td>Steel compatibility (rebar), Low cost &amp; embodied energy, no corrosion</td>
</tr>
<tr>
<td></td>
<td>Weak in tension</td>
</tr>
<tr>
<td></td>
<td>Non recyclable</td>
</tr>
<tr>
<td><strong>Plastics</strong></td>
<td>Density, Strength per density (of some plastic types)</td>
</tr>
<tr>
<td>(Composite materials, glass/ carbon fibres reinforced epoxies)</td>
<td>Lower recyclability</td>
</tr>
<tr>
<td></td>
<td>Less repairable (e.g. carbon fibre cars)</td>
</tr>
<tr>
<td></td>
<td>Higher embodied energy</td>
</tr>
<tr>
<td></td>
<td>Difficult manufacturing</td>
</tr>
<tr>
<td><strong>Stone &amp; Masonry</strong></td>
<td>Lower embodied emissions</td>
</tr>
<tr>
<td></td>
<td>Must be reinforced with mortar (from cement)</td>
</tr>
<tr>
<td></td>
<td>Cannot be reinforced or moulded into shapes</td>
</tr>
<tr>
<td><strong>Timber</strong></td>
<td>Strength and stiffness per density (^{(1)})</td>
</tr>
<tr>
<td></td>
<td>Less durable, requires protection against fire and rot, less stable Lower, uniformity</td>
</tr>
</tbody>
</table>

---

\(^{(1)}\) With both eyes open (Orr et Al. (2010), research of efficient concrete shapes)
## Material switch
### Proposed lever ambitions

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

- **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)

<table>
<thead>
<tr>
<th>Material switch</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel ➔ Aluminium</td>
<td>0</td>
</tr>
<tr>
<td>Steel ➔ Timber</td>
<td>0</td>
</tr>
<tr>
<td>Steel ➔ Plastics</td>
<td>0</td>
</tr>
</tbody>
</table>

### 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
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.

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

<table>
<thead>
<tr>
<th>Category</th>
<th>2007 est.</th>
<th>2050 Worldsteel objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>85%</td>
<td>90%</td>
</tr>
<tr>
<td>Automotive</td>
<td>85%</td>
<td>95%</td>
</tr>
<tr>
<td>Machinery</td>
<td>90%</td>
<td>95%</td>
</tr>
<tr>
<td>Appliances</td>
<td>50%</td>
<td>75%</td>
</tr>
<tr>
<td>Containers</td>
<td>69%</td>
<td>75%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>83%</strong></td>
<td><strong>90%</strong></td>
</tr>
</tbody>
</table>

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)

Would be better to replace by a figure on scrap (leverage steel in figure of 2008)
And remove the EAF debate from here

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
Global Calculator

Materials recycling: Scrap based steel
Scrap availability is limited

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

- 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.)
- Higher scrap estimates (up to 75%), assuming 25% additional by including industrial scrap
- Scrap availability rate could go much higher by 2100

SOURCE: IEA ETP 2012, (2) Worldsteel, (3) With Both Eyes open
Materials recycling: Scrap based steel
In lower demand scenario, NTNU & Cambridge scenarios forecast earlier market saturation and higher scrap%
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.

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

Ambitions reflect the 2050 scrap availability
This is different from the proportion of EAF

Materials recycling: Scrap based steel
Proposed lever ambitions

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
**List of actions & levers assessed**

**Process improvement**
- Towards fuels which emit less CO₂
- 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 substitution 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$_2$e/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 115 kg of input materials for 100 kg 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
ULCOS is performing prototypes to assess the feasibility of four technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Top gas recycling (+ Carbon capture)</th>
<th>ULCORED + EAF (+ Carbon Capture)</th>
<th>Hlsarna smelter (+ Carbon capture)</th>
<th>Ulcowin – Electrolysis</th>
</tr>
</thead>
</table>
| **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)  |
### Process changes
For each ambition level, a combination of the various technologies is proposed

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

<table>
<thead>
<tr>
<th>Ambition</th>
<th>Oxygen steel</th>
<th>Electric steel</th>
<th>Technology applicability along the different ambitions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Classic</td>
<td>Top Gas Recycling (HIsarna, not ULCORED)</td>
<td>Hydrogen based reduction</td>
</tr>
<tr>
<td>1</td>
<td>✓ 70% (7,7% scrap)</td>
<td>✓ 0% (-scrap)</td>
<td>✓ -</td>
</tr>
<tr>
<td>2</td>
<td>✓ 61% (8,5% scrap)</td>
<td>✓ 2% (0,1% scrap)</td>
<td>✓ -</td>
</tr>
<tr>
<td>3</td>
<td>✓ 48% (9,8% scrap)</td>
<td>✓ 5% (0,5% scrap)</td>
<td>✓ -</td>
</tr>
<tr>
<td>4</td>
<td>✓ 25% (10,0%scrap)</td>
<td>✓ 10% (3% scrap)</td>
<td>✓ -</td>
</tr>
</tbody>
</table>

**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

<table>
<thead>
<tr>
<th></th>
<th>Retrofit</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>€/t crude steel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input</td>
<td>117,36</td>
<td>117,36</td>
</tr>
<tr>
<td>Other opex</td>
<td>371,64</td>
<td>371,64</td>
</tr>
<tr>
<td>Capex</td>
<td>171</td>
<td>441</td>
</tr>
</tbody>
</table>

### Scrap based EAF cost assumptions

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>€/t crude steel</td>
<td></td>
</tr>
<tr>
<td>Input (fuel &amp; material)</td>
<td>58,68</td>
</tr>
<tr>
<td>Other opex</td>
<td>430,32</td>
</tr>
<tr>
<td>Capex</td>
<td>184</td>
</tr>
</tbody>
</table>

### DRI based EAF cost assumptions

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>€/t crude steel</td>
<td></td>
</tr>
<tr>
<td>Input (fuel &amp; material)</td>
<td>74,36</td>
</tr>
<tr>
<td>Other opex</td>
<td>497,64</td>
</tr>
<tr>
<td>Capex</td>
<td>414</td>
</tr>
</tbody>
</table>
### Lever applicability along the main technical options

<table>
<thead>
<tr>
<th>Type of lever</th>
<th>Improvement Lever</th>
<th>Oxygen steel</th>
<th>Electric steel</th>
<th>Electrolysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product mix</strong></td>
<td>Increase in higher strength steel</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Process improvement</strong></td>
<td>Reduction of carboniferous materials (non-fuel related)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Smelt reduction</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Alternatives fuels</strong></td>
<td>Coal substitution by gas injection</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Coal substitution by biomass</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Energy efficiency</strong></td>
<td>Reduce mechanical and thermal losses</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>CHP potential</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>End of pipe</strong></td>
<td>Carbon capture &amp; storage</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
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
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<sup>(1)</sup>
• 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
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
### Process improvements: Hydrogen based reduction

Proposed lever ambitions

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

This technology is considered a far away technology breakthrough and we therefore do not include it, even in level 4 ambition.
### Process improvements: Electrolysis
Proposed lever ambitions

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Minimum effort</strong> (following current regulation)</td>
<td><strong>Moderate effort</strong> easily reached according to most experts</td>
<td><strong>Significant effort</strong> requiring cultural change and/or important financial investments</td>
<td><strong>Maximum effort</strong> to reach results close to technical and physical constraints</td>
</tr>
<tr>
<td>• 0%</td>
<td>• 0%</td>
<td>• 0%</td>
<td>• 0%</td>
</tr>
</tbody>
</table>

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
**Fuel substitution : Coke substitution by Gas injection**

**Proposed lever ambitions**

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Minimum effort</strong> (following current regulation)</td>
<td><strong>Moderate effort</strong> easily reached according to most experts</td>
<td><strong>Significant effort</strong> requiring cultural change and/or important financial investments</td>
<td><strong>Maximum effort</strong> to reach results close to technical and physical constraints</td>
</tr>
</tbody>
</table>

- **Level 1**: 0% coke replaced by gas in non-Hisarna oxygen
- **Level 2**: 2% coke replaced by gas in non-Hisarna oxygen
- **Level 3**: 3% coke replaced by gas in non-Hisarna oxygen
- **Level 4**: 5% coke replaced by gas in non-Hisarna oxygen

**Lever cost €/t crude steel**

<table>
<thead>
<tr>
<th>Input (fuel &amp; material)</th>
<th>Cost of fuels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other opex</td>
<td>0</td>
</tr>
<tr>
<td>Capex</td>
<td>0</td>
</tr>
</tbody>
</table>

**SOURCE:** Steel consultation Wallonia Low Carbon 2050
## Fuel substitution: Coal substitution by biomass

### Proposed lever ambitions

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

- • / •
- • Substitution of 15% coal PCI by biomass in non-Hisarna oxygen
- • idem level 2
- • idem level 2

### Lever cost

<table>
<thead>
<tr>
<th>Input (fuel &amp; material)</th>
<th>Cost of fuels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other opex</td>
<td>0</td>
</tr>
<tr>
<td>Capex</td>
<td>0</td>
</tr>
</tbody>
</table>

This technology has limited impact after Hisarna.
3 Energy (and material) efficiency

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

![Graph showing energy intensity over time]

- 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)

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input (fuel &amp; material)</td>
<td>-x</td>
</tr>
<tr>
<td>Other opex</td>
<td>0</td>
</tr>
<tr>
<td>Capex</td>
<td>+x</td>
</tr>
</tbody>
</table>

**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
### Energy efficiency: CHP potential

**Proposed lever ambitions**

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

- No additional potential
- No additional potential
- No additional potential
- No additional potential

No potential remains after all energy efficiency measures have been implemented.

**NOTE:** (1) Includes the behavioural, the energy audits
Capture rate
(MtCO₂/year)

SOURCE: IEA ETP 2012
Typical ranges of costs of emission reductions from industrial applications of CCS (USD/tCO$_2$e avoided)

In addition, an electricity consumption of 0.33 TWh/MtCO$_2$e 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
Penetration of CCS (% of plants equipped)

- Ambition 1
- Ambition 2
- Ambition 3
- Ambition 4

- Several pilots available but industrial scale not rolled out before 2030
- Could be cheaper than top-gas recycling to reduce emissions
- Ambition 3 aligned to ETP 2012 ambition of 40-45% plants
- 80% capture rate
- 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

<table>
<thead>
<tr>
<th>Input (fuel &amp; material)</th>
<th>0.33 TWh Elec/Mt captured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other opex</td>
<td>$20 USD/ton captured</td>
</tr>
<tr>
<td>Capex</td>
<td>$40 USD/ton captured</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Year</th>
<th>Trajectory 1</th>
<th>Trajectory 2</th>
<th>Trajectory 3</th>
<th>Trajectory 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>1,500</td>
<td>1,500</td>
<td>1,500</td>
<td>1,500</td>
</tr>
<tr>
<td>2015</td>
<td>2,000</td>
<td>2,500</td>
<td>2,500</td>
<td>2,500</td>
</tr>
<tr>
<td>2020</td>
<td>2,500</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
</tr>
<tr>
<td>2025</td>
<td>3,000</td>
<td>3,500</td>
<td>3,500</td>
<td>3,500</td>
</tr>
<tr>
<td>2030</td>
<td>3,500</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>2035</td>
<td>4,000</td>
<td>4,500</td>
<td>4,500</td>
<td>4,500</td>
</tr>
<tr>
<td>2040</td>
<td>4,500</td>
<td>5,000</td>
<td>5,000</td>
<td>5,000</td>
</tr>
<tr>
<td>2045</td>
<td>5,000</td>
<td>5,500</td>
<td>5,500</td>
<td>5,500</td>
</tr>
<tr>
<td>2050</td>
<td>5,500</td>
<td>6,000</td>
<td>6,000</td>
<td>6,000</td>
</tr>
</tbody>
</table>

Delta 10-50%, Implied demand per person

<table>
<thead>
<tr>
<th>Trajectory</th>
<th>Delta</th>
<th>Implied demand per person</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+124%</td>
<td>355 kg steel/person</td>
</tr>
<tr>
<td>2</td>
<td>+72%</td>
<td>273 kg steel/person</td>
</tr>
<tr>
<td>3</td>
<td>+39%</td>
<td>221 kg steel/person</td>
</tr>
<tr>
<td>4</td>
<td>+9%</td>
<td>174 kg steel/person</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Year</th>
<th>Original</th>
<th>Design</th>
<th>Switch</th>
<th>Recycling</th>
<th>Remaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>1.518</td>
<td>1.073</td>
<td>0.369</td>
<td>0.387</td>
<td>0.056</td>
</tr>
<tr>
<td>2050</td>
<td>1.259</td>
<td>0.889</td>
<td>0.306</td>
<td>0.366</td>
<td>0.183</td>
</tr>
</tbody>
</table>

#### Trajectories in 2050

- **Original**: +83%
- **Design**: -37%
- **Switch**: -7%
- **Remaining**: 0%

### Reduction potential
Details for ambition level 3

**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

GHG emissions for different ambition levels (1,2,3) (MtonCO$_2$e)

<table>
<thead>
<tr>
<th>Delta 10-50,%</th>
<th>Specific emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>+123%</td>
<td>2,0 tCO$_2$e /tsteel</td>
</tr>
<tr>
<td>+35%</td>
<td>1,6 tCO$_2$e /tsteel</td>
</tr>
<tr>
<td>-6%</td>
<td>1,3 tCO$_2$e /tsteel</td>
</tr>
<tr>
<td>-84%</td>
<td>0,3 tCO$_2$e /tsteel</td>
</tr>
</tbody>
</table>

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

Steel GHG emissions in 2050, for ambition level 3\(^{(1,2)}\), using different levers\(^{(3)}\)
(MtCO\(_2\)e, % of 2010)

<table>
<thead>
<tr>
<th>Year</th>
<th>Demand</th>
<th>Design</th>
<th>Switch</th>
<th>Recycling &amp; process</th>
<th>Fuel</th>
<th>EE</th>
<th>CCS</th>
<th>Remaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>3.039</td>
<td>2.519</td>
<td>-1.112</td>
<td>-220</td>
<td>-508</td>
<td></td>
<td>-800</td>
<td>2.841</td>
</tr>
</tbody>
</table>

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)
€/tCO₂e, % 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.

Michel Cornet – +32 486 92 06 37 – mc@climact.com
Julien Pestiaux – +32 471 96 13 90 – jpe@climact.com
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
Global Calculator

Eurofer 2013 roadmap

TECHNICAL CO₂ INTENSITY PATHWAYS UP TO 2050

Source: BCG-VDEh, EUROFER

WHAT?

Economic scenarios
- business as usual at 2010 CO₂ intensity
- maximum economic CO₂ reduction potential

Uneconomic scenarios
- maximum theoretical abatement without CCS
- maximum theoretical abatement with CCS
- hypothetic breakthrough technologies in combination with CCUS

EU ETS cap declining path (according to the Commission Low Carbon Roadmap)

Emission reduction potentials are expressed in specific CO₂ emissions relatively to 2010
Existing studies suggest at least a total 50% improvement is feasible

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 €80 per tCO₂e 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.

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 CO₂ emissions reduction potential by 2020

<table>
<thead>
<tr>
<th>Industry sector</th>
<th>Average energy efficiency</th>
<th>Recycling and energy recovery</th>
<th>CCS</th>
<th>Fuel and feedstock switching/alternative materials</th>
<th>Total savings (Mt CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron and steel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>354</td>
</tr>
<tr>
<td>Cement</td>
<td></td>
<td></td>
<td>na</td>
<td></td>
<td>119</td>
</tr>
<tr>
<td>Chemicals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>440</td>
</tr>
<tr>
<td>Pulp and paper</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>49</td>
</tr>
<tr>
<td>Aluminium</td>
<td></td>
<td></td>
<td>na</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>969</td>
</tr>
</tbody>
</table>

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 BÅTs 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 CO₂ emissions from industry.
Agenda

Backup

Existing studies

Other informations on the sector

Industry overview
Global Calculator

Largest steel producers

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

SOURCE: World Steel in figure 2013
Historically steel production has tended to reach a plateau level with respect to population.

Steel production per person (kg/person/year)

- 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 Norwegian University of Science and Technology (NTNU) and Tao Weng)
There is however an overcapacity in the steel sector since the 2008 economic crisis.

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

SOURCE: World steel association
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 anthropogenic GHG emissions in 2005 (GtCO$_2$e)

- **Global GHG emissions**: 100%
  - LULUCF: 36%
  - Energy & process: 64%
  - Industry: 35%
  - Transport: 27%
  - Buildings: 31%
  - Other: 7%

- **Energy & process GHG emissions**: 28%
  - Industry: 35%
  - Transport: 27%
  - Buildings: 31%
  - Other: 7%

- **Industry GHG emissions**: 10%
  - Steel: 25%
  - Cement: 19%
  - Other: 45%

**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.

China anthropogenic GHG emissions in 2005 (%)

Manufacturing, industries & construction 67%
Transport 7%
Residential 11%
Other 9%
Other energy industries 6%

Energy & process emissions (%2005)

Steel 33%
Aluminium 6%
Metal manufacturing 7%
Cement 26%
Chemicals & plastics 17%
Paper 2%
Food 3%
Textile 4%
Wood 1%
Others 1%

Industry emissions (% 2005)

SOURCE: China government statistics: Linwei, 2011 for year
Large developing economies are moving up in global manufacturing.

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

<table>
<thead>
<tr>
<th>Rank</th>
<th>1980</th>
<th>1990</th>
<th>2000</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>United States</td>
<td>United States</td>
<td>United States</td>
<td>United States</td>
</tr>
<tr>
<td>2</td>
<td>Germany</td>
<td>Japan</td>
<td>Japan</td>
<td>China</td>
</tr>
<tr>
<td>3</td>
<td>Japan</td>
<td>Germany</td>
<td>Germany</td>
<td>Japan</td>
</tr>
<tr>
<td>4</td>
<td>United Kingdom</td>
<td>Italy</td>
<td>China</td>
<td>Germany</td>
</tr>
<tr>
<td>5</td>
<td>France</td>
<td>United Kingdom</td>
<td>United Kingdom</td>
<td>Italy</td>
</tr>
<tr>
<td>6</td>
<td>Italy</td>
<td>France</td>
<td>Italy</td>
<td>Brazil</td>
</tr>
<tr>
<td>7</td>
<td>China</td>
<td>China</td>
<td>France</td>
<td>South Korea</td>
</tr>
<tr>
<td>8</td>
<td>Brazil</td>
<td>Brazil</td>
<td>South Korea</td>
<td>France</td>
</tr>
<tr>
<td>9</td>
<td>Spain</td>
<td>Spain</td>
<td>Canada</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>10</td>
<td>Canada</td>
<td>Canada</td>
<td>Mexico</td>
<td>India</td>
</tr>
<tr>
<td>11</td>
<td>Mexico</td>
<td>South Korea</td>
<td>Spain</td>
<td>Russia²</td>
</tr>
<tr>
<td>12</td>
<td>Australia</td>
<td>Mexico</td>
<td>Brazil</td>
<td>Mexico</td>
</tr>
<tr>
<td>13</td>
<td>Netherlands</td>
<td>Turkey</td>
<td>Taiwan</td>
<td>Indonesia²</td>
</tr>
<tr>
<td>14</td>
<td>Argentina</td>
<td>India</td>
<td>India</td>
<td>Spain</td>
</tr>
<tr>
<td>15</td>
<td>India</td>
<td>Taiwan</td>
<td>Turkey</td>
<td>Canada</td>
</tr>
</tbody>
</table>


**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.
International prices strongly differ between regions

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

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

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

- 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