

Steel, Plastics, Cement, and EE

HEJC

20 Nov 2014

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Materials, Energy, Environment

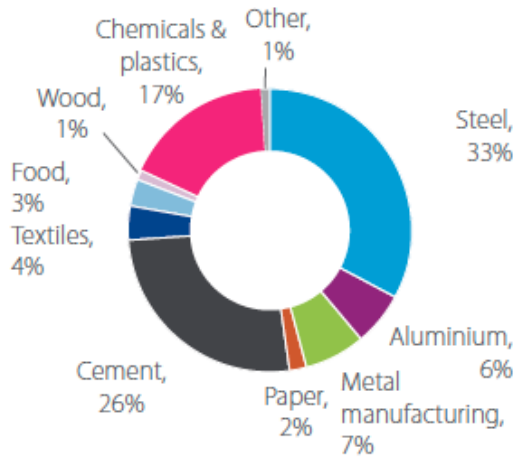
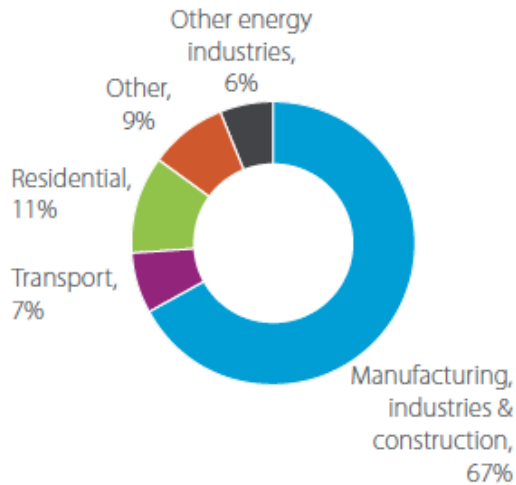


Figure 2.4—Sources of Chinese CO₂ emissions

Steel:

- CO₂ policy → can't use coal

Plastics:

- No petroleum → no petrochemicals
- Bioplastics → competing with land for energy and food

Aluminum, cement, paper

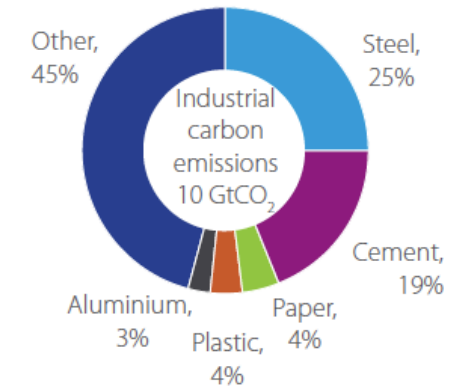
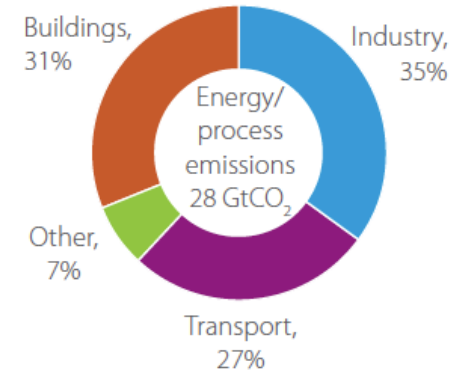
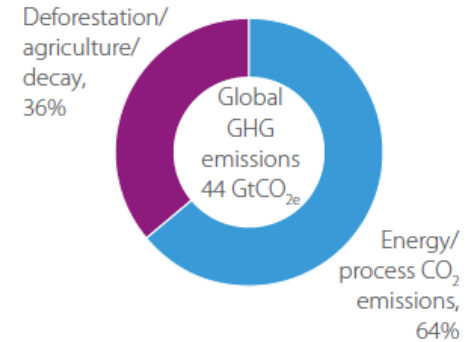


Figure 2.1—Pie charts showing the sources of global CO₂ emissions

Sector	GtCO₂	Direct	Indirect	Process
Steel	2.49	1.88	0.50	0.11
Cement	1.85	0.72	0.19	0.94
Plastic	0.35	0.20	0.15	
Paper	0.42	0.19	0.23	
Aluminium	0.24	0.08	0.17	
Other	4.5	2.54	19.6	
Total	9.86	5.61	3.20	1.05

Sources—For direct and process emissions of all materials, see IEA (2008a) Table 16.4. For indirect emissions, see: Figure 16.6 for steel, Figure 16.9 for minerals, of 94% is cement (p.489); Figure 16.2 for chemicals of which 31% is plastic (Allwood et al. 2010); Figure 16.3 for paper, Figure 16.5 for aluminium; Table 16.3 for other.

Steel and aluminum make up 39% of China's emissions.

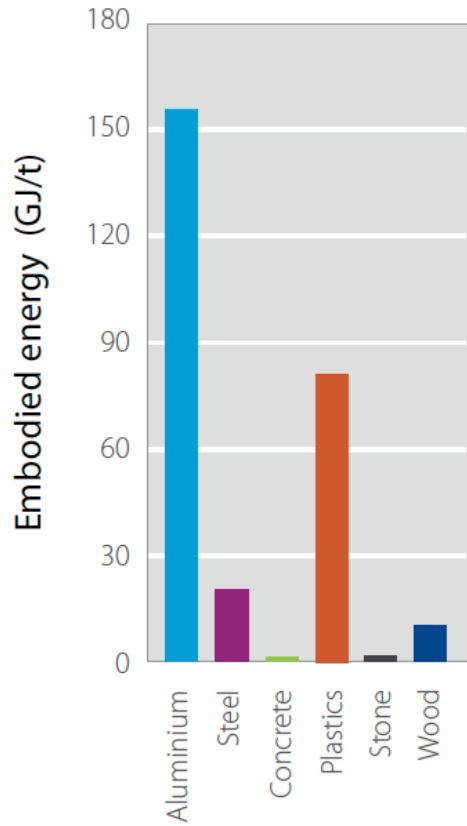


Figure 3.14—Embodied energy in conversion for key materials

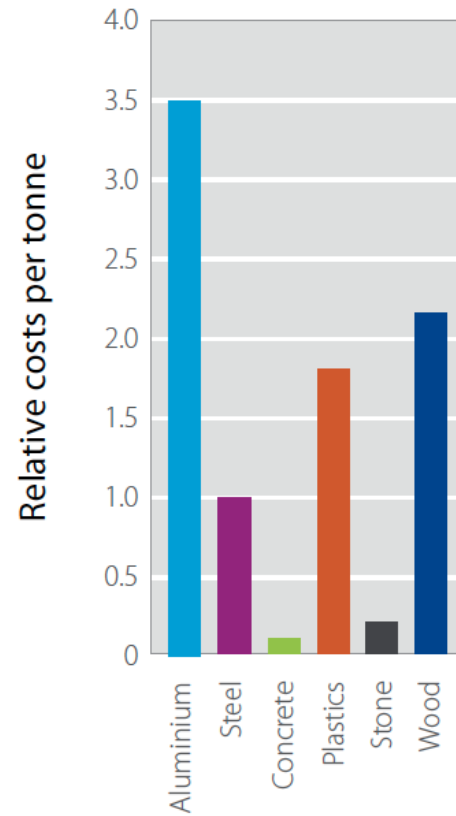
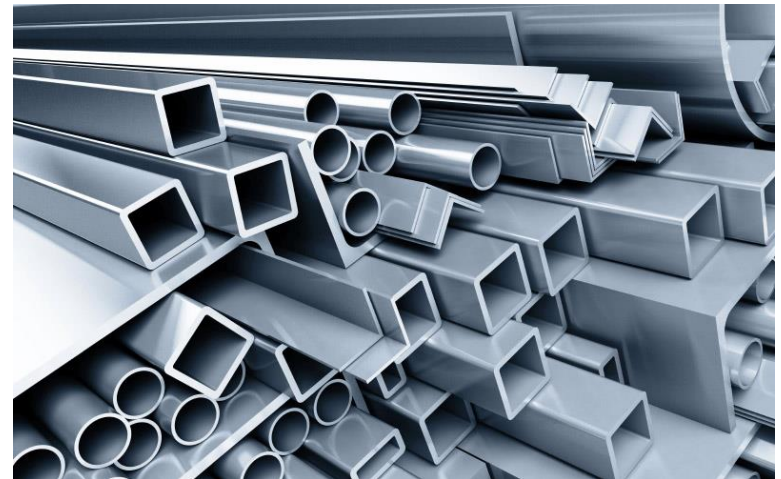


Figure 3.15—Relative costs per tonne for conversion of key materials to useful forms

Steel

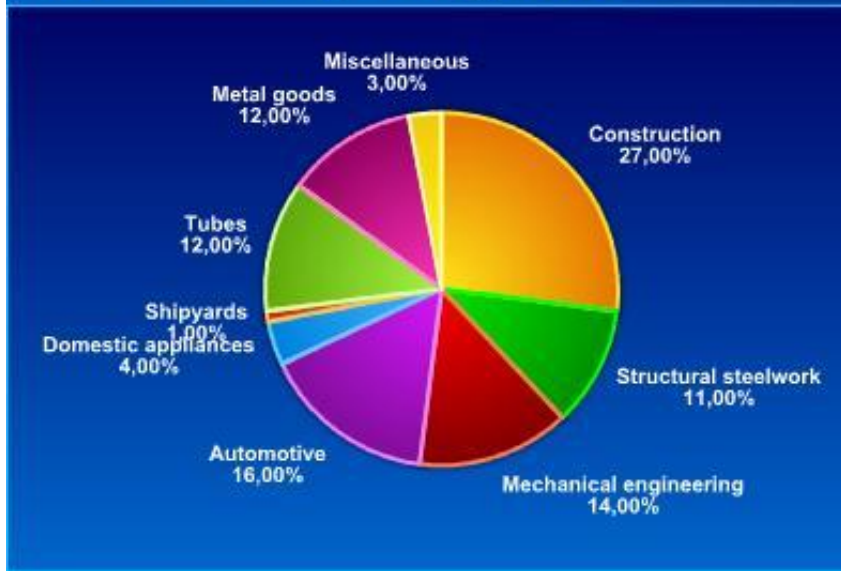
- Iron
- Carbon $\leq 2.1\%$
- (Mo, S, Cr, Ni, Si)

SAE designation	Composition
13xx	Mn 1.75%
40xx	Mo 0.20% or 0.25% or 0.25% Mo & 0.042% S
41xx	Cr 0.50% or 0.80% or 0.95%, Mo 0.12% or 0.20% or 0.25% or 0.30%
43xx	Ni 1.82%, Cr 0.50% to 0.80%, Mo 0.25%
44xx	Mo 0.40% or 0.52%
46xx	Ni 0.85% or 1.82%, Mo 0.20% or 0.25%
47xx	Ni 1.05%, Cr 0.45%, Mo 0.20% or 0.35%
48xx	Ni 3.50%, Mo 0.25%
50xx	Cr 0.27% or 0.40% or 0.50% or 0.65%
50xxx	Cr 0.50%, C 1.00% min
50Bxx	Cr 0.28% or 0.50%, and added boron
51xx	Cr 0.80% or 0.87% or 0.92% or 1.00% or 1.05%
51xxx	Cr 1.02%, C 1.00% min
51Bxx	Cr 0.80%, and added boron
52xxx	Cr 1.45%, C 1.00% min
61xx	Cr 0.60% or 0.80% or 0.95%, V 0.10% or 0.15% min
86xx	Ni 0.55%, Cr 0.50%, Mo 0.20%
87xx	Ni 0.55%, Cr 0.50%, Mo 0.25%
88xx	Ni 0.55%, Cr 0.50%, Mo 0.35%
92xx	Si 1.40% or 2.00%, Mn 0.65% or 0.82% or 0.85%, Cr 0.00% or 0.65%
94Bxx	Ni 0.45%, Cr 0.40%, Mo 0.12%, and added boron



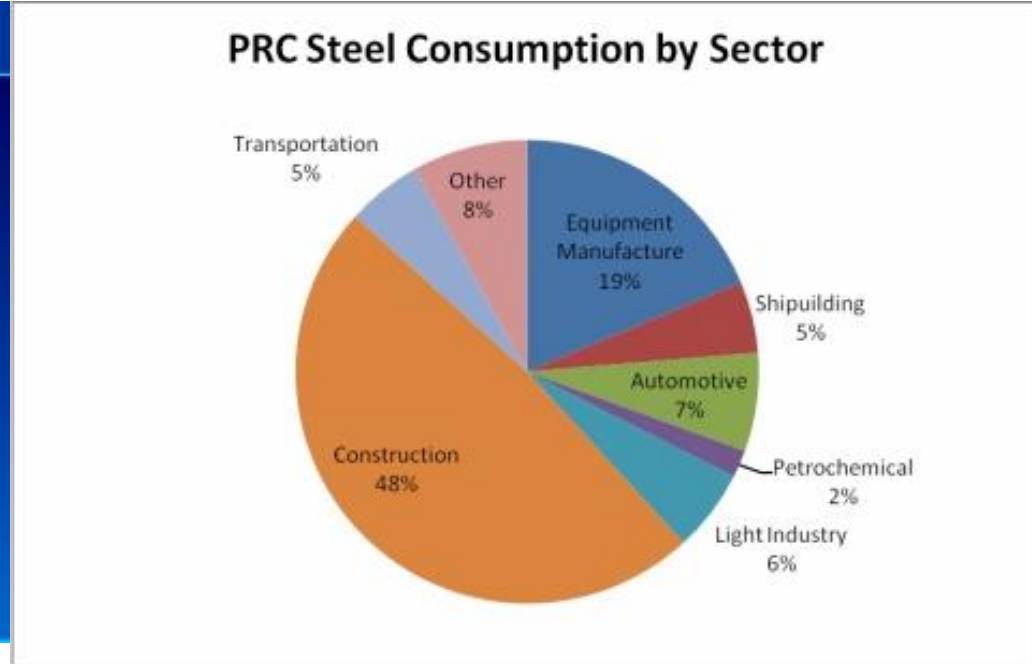
Steel Products

Steel Consumption by sectors in %



Europe

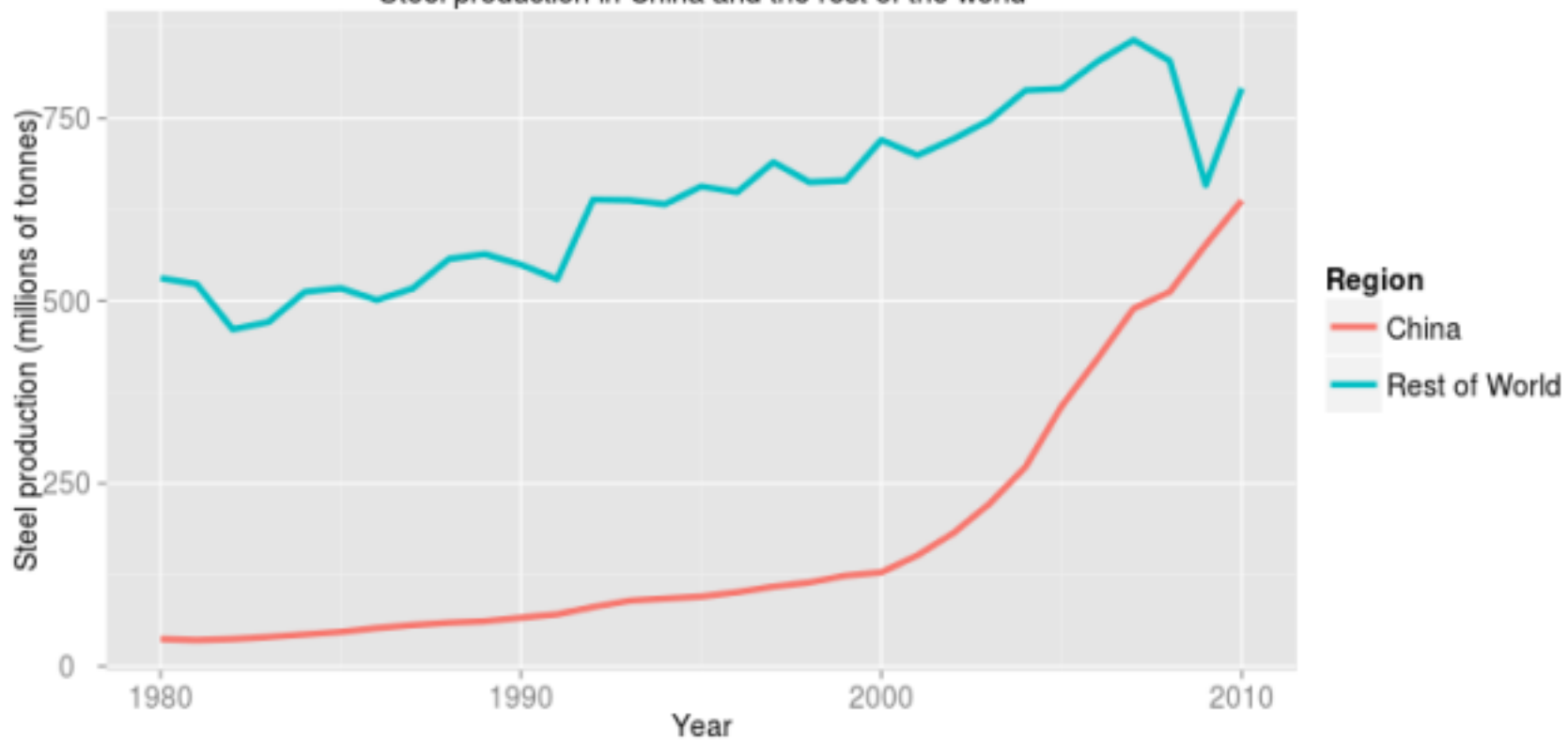
PRC Steel Consumption by Sector



China

Construction
Transport
Energy
Packaging
Appliances and Industry

Steel production in China and the rest of the world



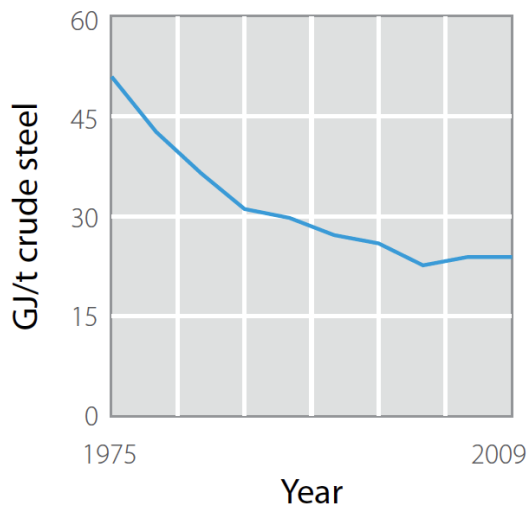


Figure 5.4—The history of energy intensity improvements in primary steel production⁶

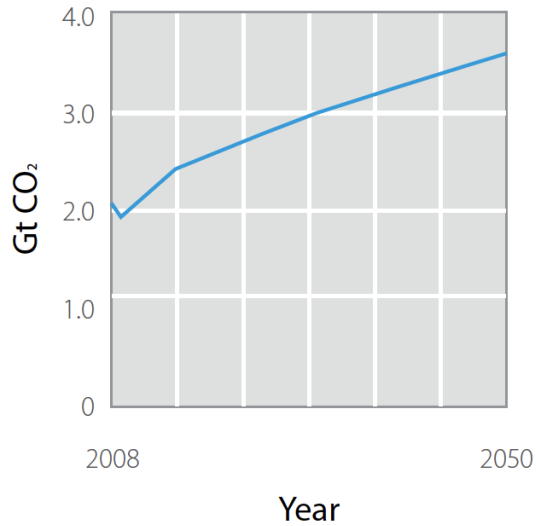


Figure 5.7—Forecast CO₂ emissions in steel production if business continues as usual

Steel

Aluminum

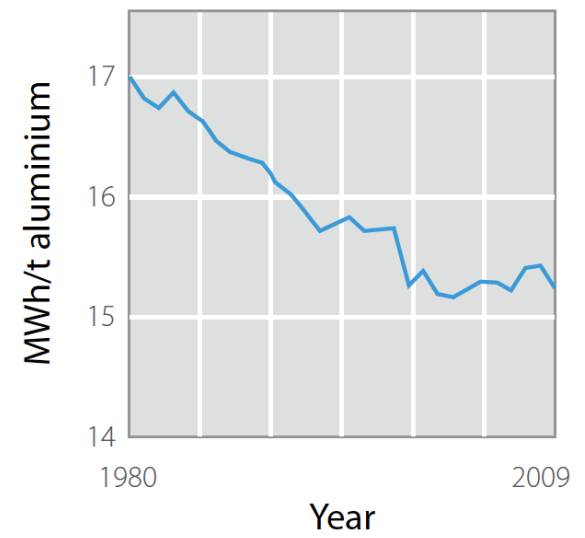


Figure 5.6—Historical electricity intensity of primary aluminium production

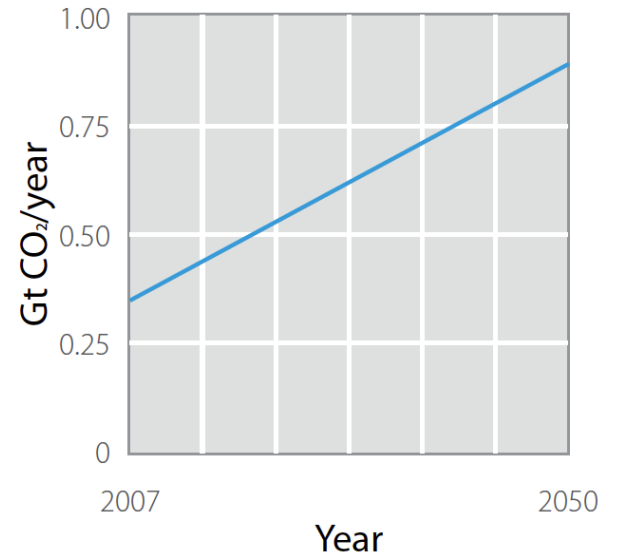


Figure 5.8—Forecast CO₂ emissions in aluminium production if business continues as usual

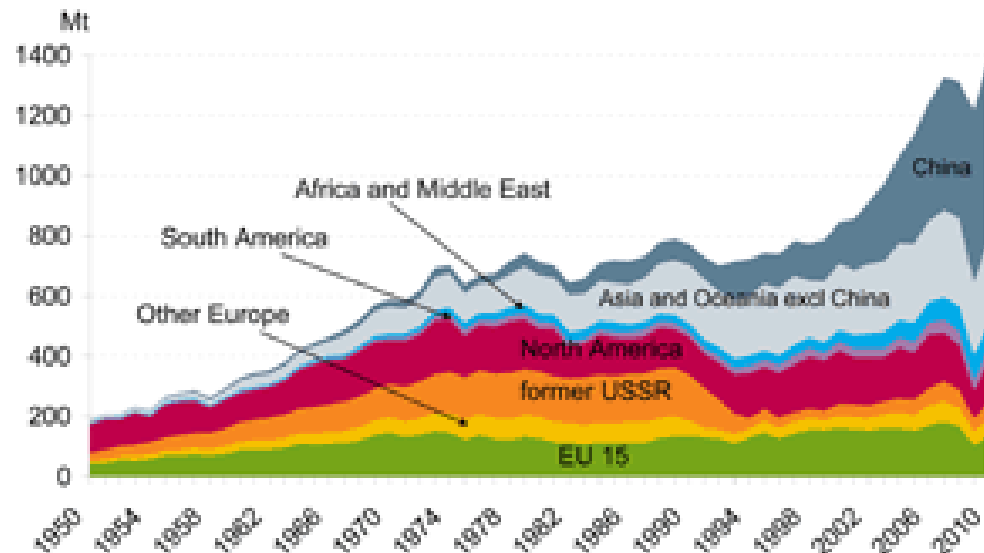
Steel Consumption

Regional steel demand breakdown in 1950-2010

- Regional structure of steel demand has been changing continuously along with:
 - Regional economic growth trends
 - Evolution of global manufacturing base through creation and relocation of industries

See PDF
pg 30

Apparent crude steel use in 1950-2010

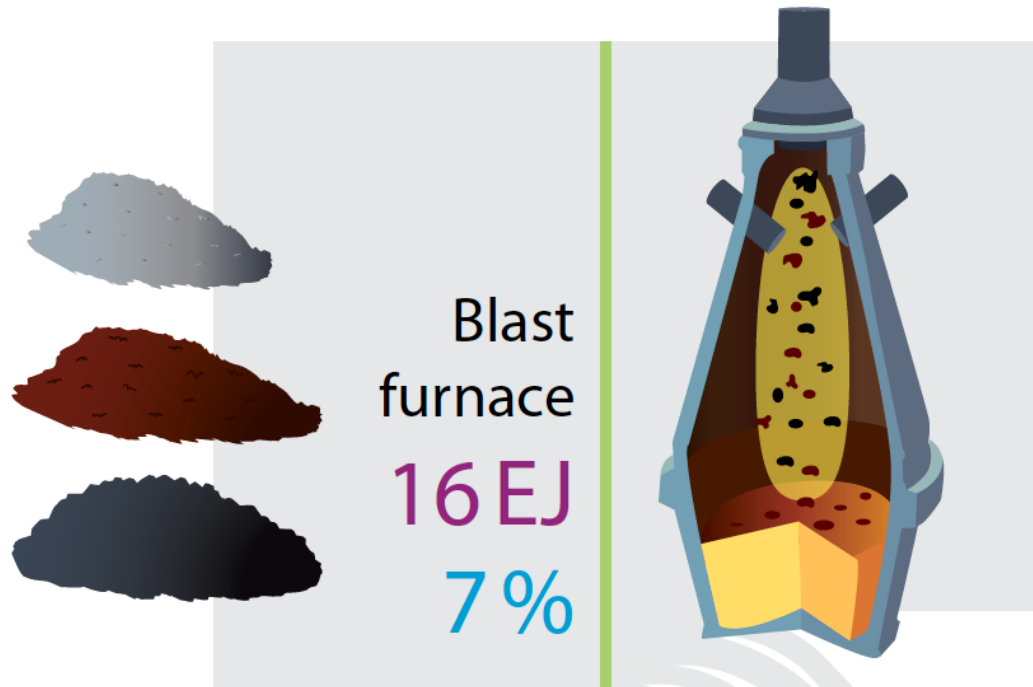


Source: worldsteel, SSY

History of steel

- 16th century BC – The Hittites develop crude iron metallurgy
- 13th century BC – Invention of steel when iron and charcoal are combined
- 1200BC – 700AD – “Iron Age” (Christian Thomsen)
- 3rd century BC – Wootz steel developed in India
- 4th century AD – Iron pillar of Delhi is the oldest surviving example of corrosion-resistant steel
- 1740 – Crucible steel technique developed by Benjamin Huntsman
- 1855 – Bessemer process for mass production of steel patented by Henry Bessemer
- 1912 – Stainless steel (>10% Cr) invented by Harry Brearley
- 1980 – Duplex stainless steels developed (austenite and ferrite)

Steel: Blast Furnace



Energy = 38 EJ
Electricity = 39%

Coal and iron ore are processed and fed with lime into the top of the blast furnace. Hot air and additional fuels are blown in from the bottom. Coke reacts with air to form carbon monoxide, which reduces iron oxide to iron. The lime reacts with impurities in the ore to form a slag. Liquid iron collects at the bottom of the furnace and is tapped into ladles.

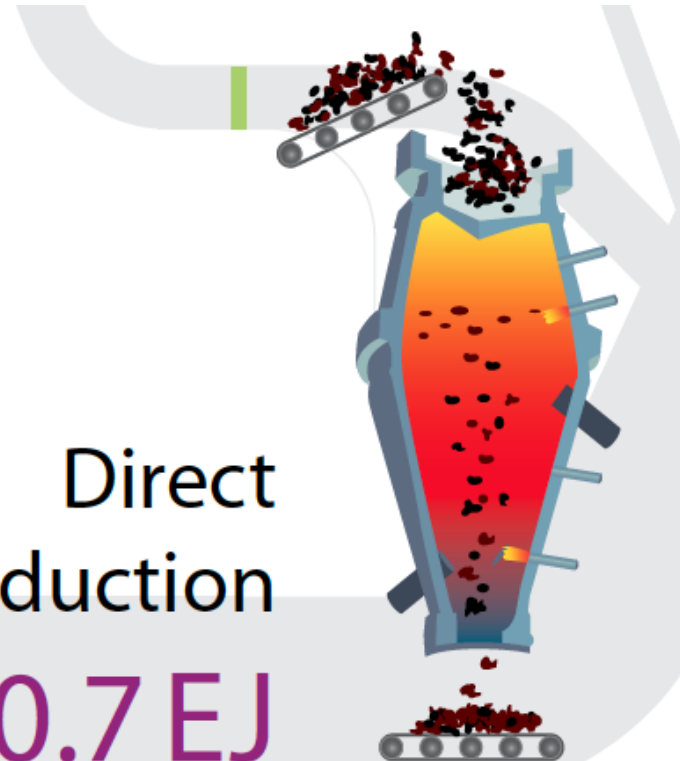
Direct-Reduced Iron

Direct
reduction

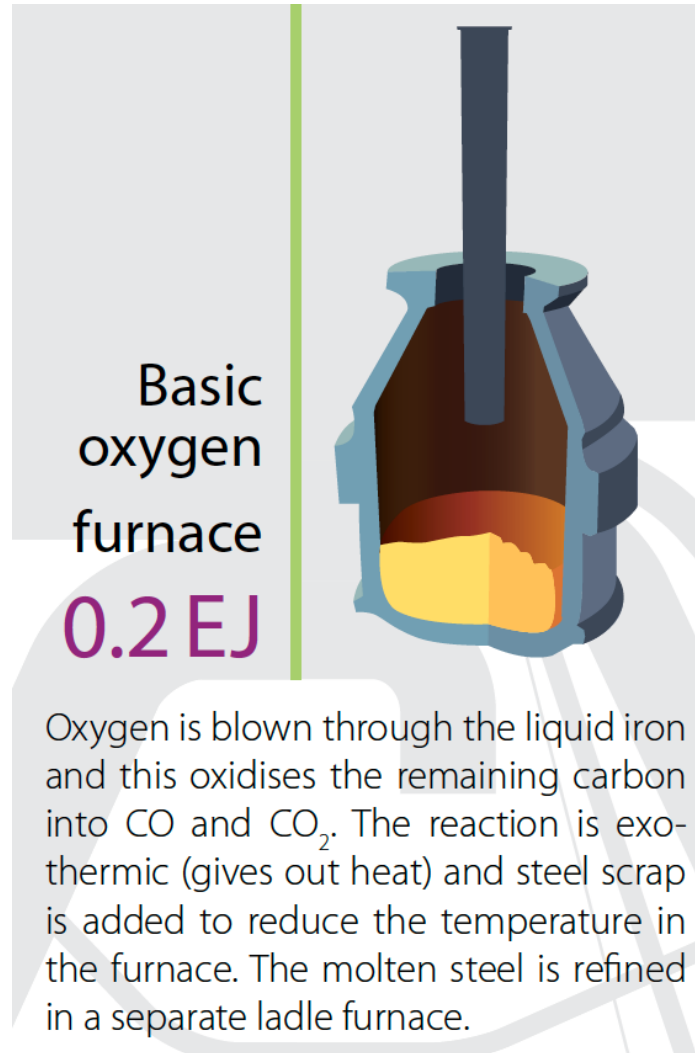
0.7 EJ

Energy = 38 EJ
Electricity = 39%

In direct reduction, iron ore is reduced into iron in a shaft or rotary furnace using natural gas or coal.

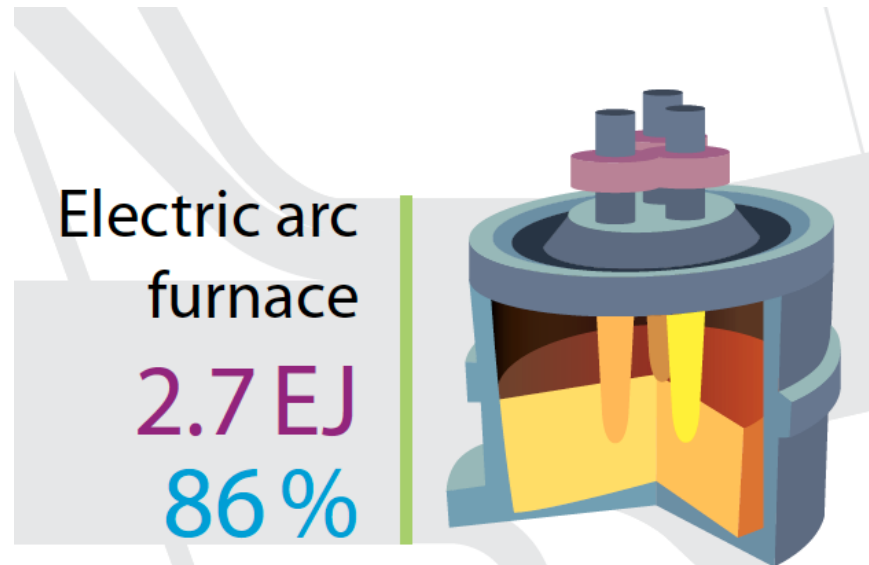


Steel: Basic Oxygen Furnace



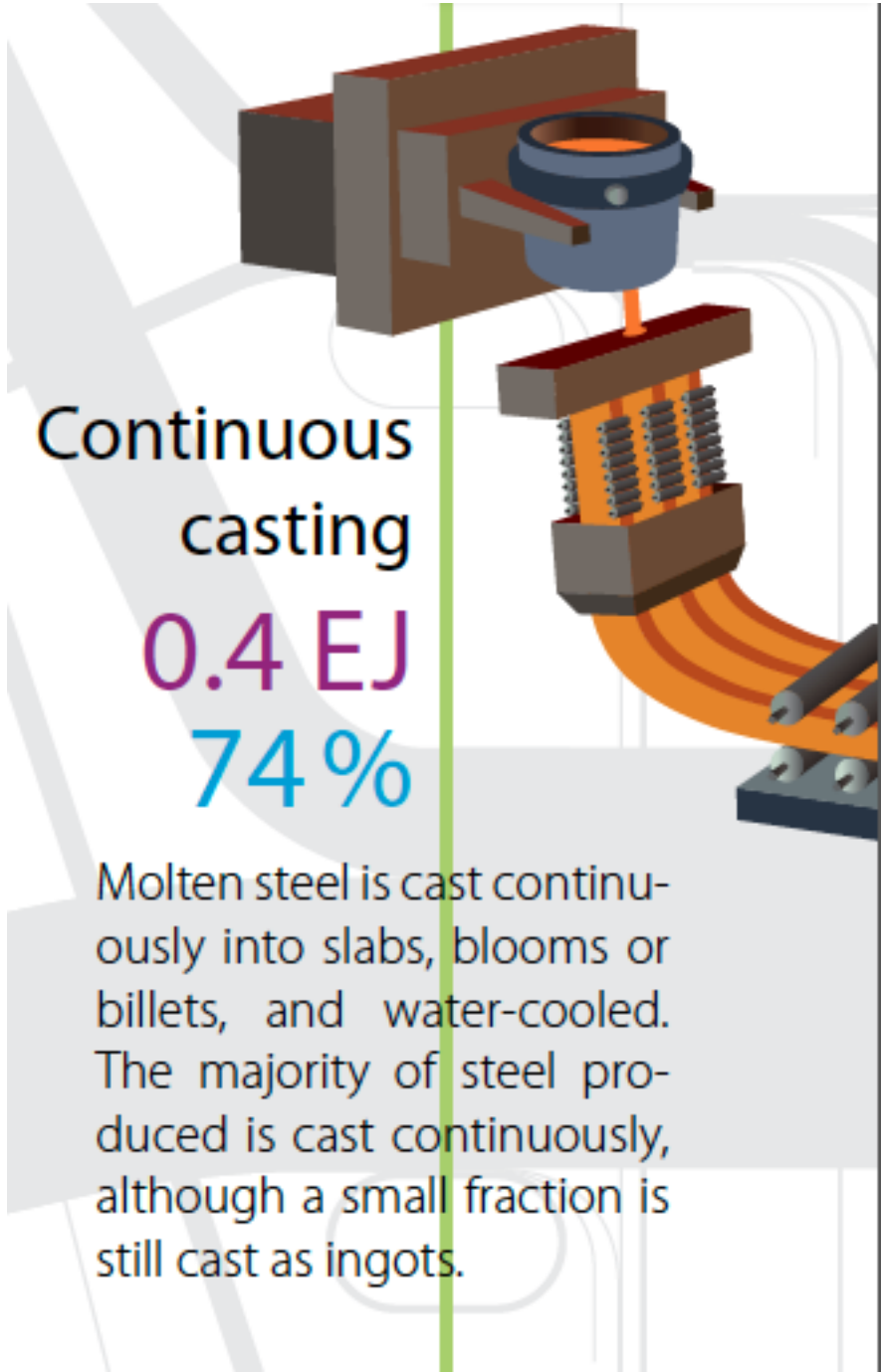
Energy = 38 EJ
Electricity = 39%

Electric arc furnace



Energy = 38 EJ
Electricity = 39 %

Carbon electrodes are lowered into the furnace and a high temperature arc forms between the electrodes and the metal charge. If the charge is not completely scrap, carbon or other fossil fuels may be injected with oxygen for the reduction reaction.



Continuous casting

0.4 EJ
74%

Molten steel is cast continuously into slabs, blooms or billets, and water-cooled. The majority of steel produced is cast continuously, although a small fraction is still cast as ingots.

Energy = 38 EJ
Electricity = 39%

Shape
casting

2.1 EJ

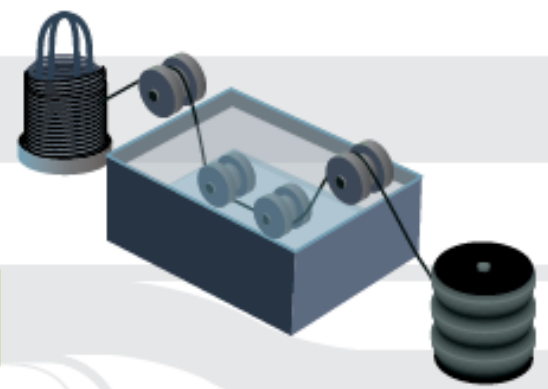
46%



Iron or steel is melted before pouring into a mould. Once solidified, the casting may undergo cycles of heat treatments to achieve the desired properties.

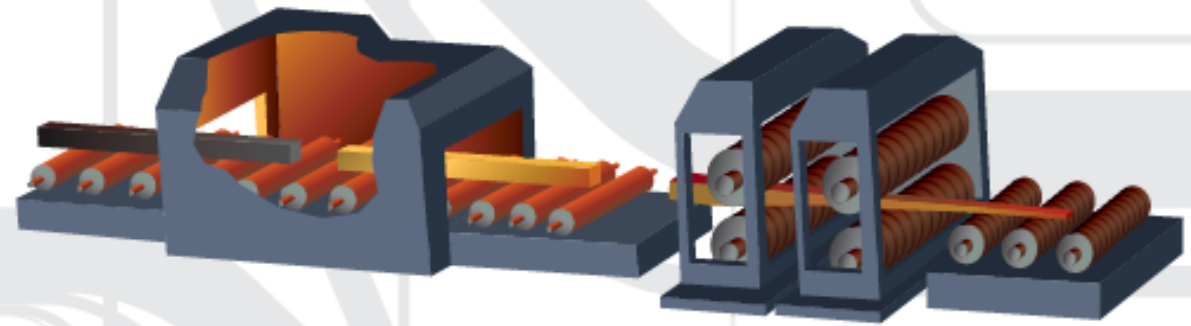
Energy = 38 EJ
Electricity = 39%

Coating
0.6 EJ
46 %



Steel is cleaned before being coated with zinc (galvanised), tin plate or a range of paints (organic coatings). This provides corrosion protection for steel outside or in demanding applications such as food cans.

Rolling
3.6 EJ
46 %



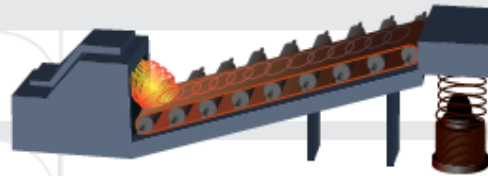
Steel is reheated and descaled before being rolled into strip/coil (from slabs), rod/bar (from billets) and sections (from blooms). The number and sequence of mill stands is matched to the thickness reduction and material properties required. Cold rolling, descaling, tempering and shearing processes can follow.

Energy = 38 EJ
Electricity = 39 %

Forming

0.2 EJ

82%



Steel slabs and billets are formed into stock products using a range of techniques, including: extrusion, wire drawing, pipe bending/rolling and welding. Forming may take place cold to minimise oxidation, or closer to the melting temperature to soften the steel.

Fabrication

11 EJ

70%

Stock steel is cut, bent, drilled, milled, welded and painted to make bespoke components ready for assembly into end-use products.

Energy = 38 EJ

Electricity = 39%

History of Aluminum

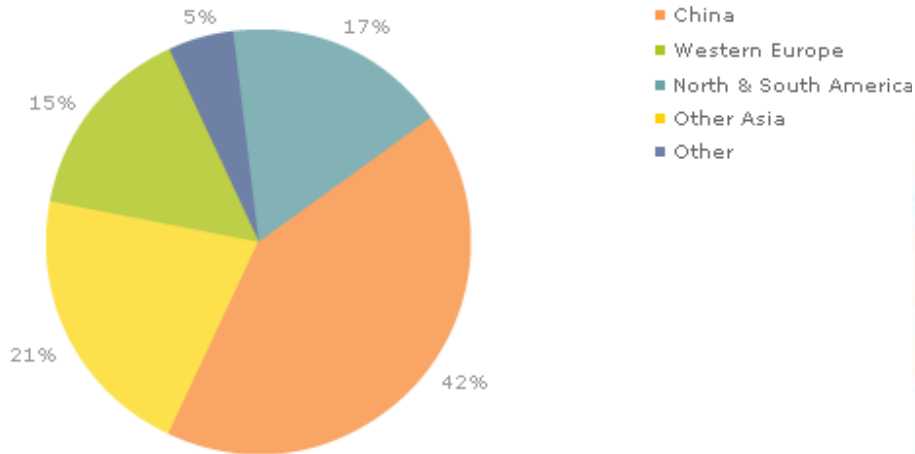
- Ancient to 1800s – Al found in low oxygen environments. Luxurious.
- 1825 – Hans Christian Ørsted develops chemical process for Al from ore.
- 1827 – Friedrich Wöhler isolates Al (similar process to Ørsted)
- 1886 – Charles Martin Hall (Ohio) and Paul Héroult (France) independently invent Hall–Héroult electrolytic process
- 1914 – 1917 – WWI airplane industry demands aluminum

Aluminum Products

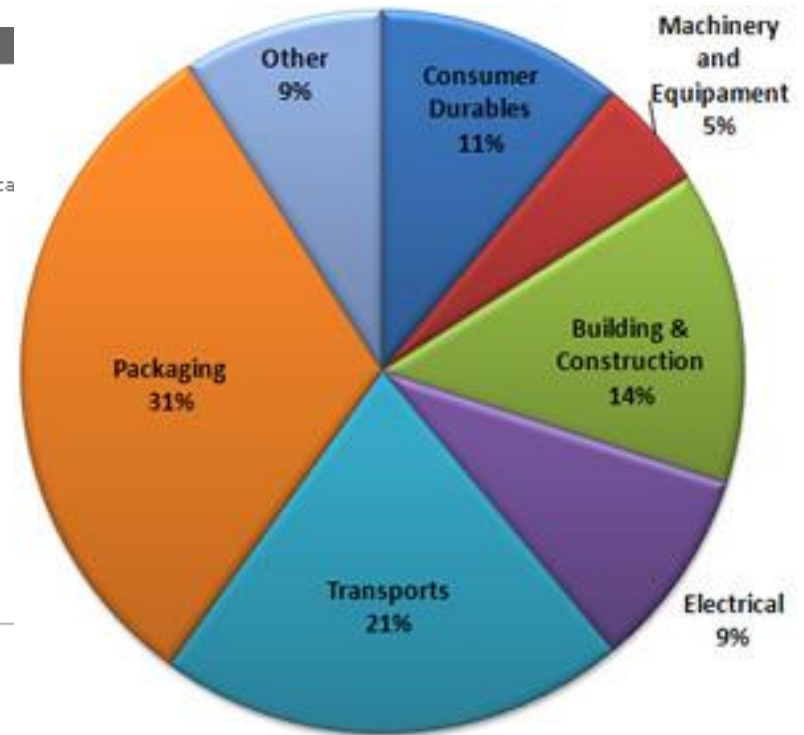
Large-scale possible when large-scale electricity (e.g. Great Depression dams) available.

See PDF

Aluminum Consumption



Source: UC Rusal



Alumina
mining
+refining

1.1 EJ

2%



Bauxite is mined—mainly from open cast mines—washed and crushed before being dissolved in hot sodium hydroxide (caustic soda) in ‘digesters’. The aluminium oxide reacts to form sodium aluminate, leaving residues, which sink to form ‘red mud’. The solution is cooled and the water removed, leaving alumina as a white powder.

Aluminium (overall)

Energy = 7.6 EJ

Electricity = 76%

Electrolysis

5.0 EJ

100%

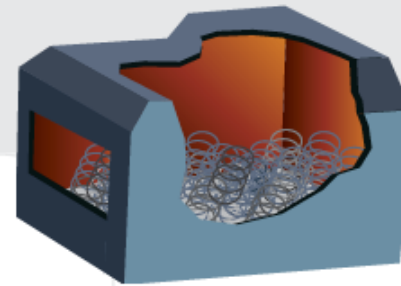


Alumina is dissolved in cryolite (sodium aluminium fluoride) at about 950°C. Electric current passing from the suspended carbon anodes to the graphite cathode lining the electrolysis cell causes the deposition of molten aluminium at the bottom of the cell (or pot) where it is periodically tapped.

Scrap remelting

0.04 EJ

30%



Clean, wrought process and post-consumer scrap is melted, mostly via the hot combustion gases in reverberatory furnaces, but sometimes using the heat generated during electromagnetic induction in induction furnaces.

Aluminium (overall)

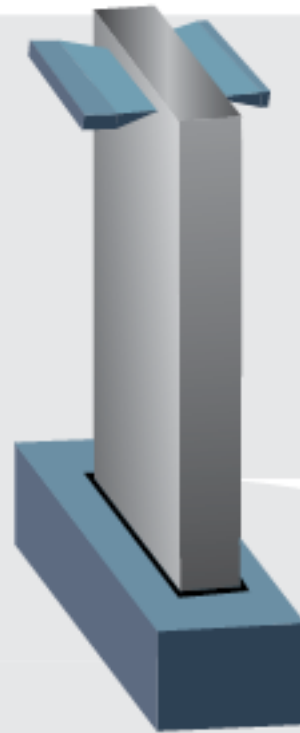
Energy = 7.6 EJ

Electricity = 76%

Ingot
casting

0.05 EJ

44 %



Crucibles of liquid aluminium from the smelters are cast via the direct chill route, where large rectangular or log shaped ingots are lifted up from a water cooled casting mould.

Aluminium (overall)

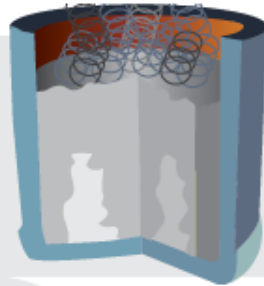
Energy = 7.6 EJ

Electricity = 76 %

Scrap refining

0.15 EJ

14%



Scrap is melted in rotary or ladle furnaces. Salt is used as a fluxing agent to remove impurities, resulting in the production of slag. Refiners produce mostly foundry ingot and so add silicon and metals like copper and magnesium to achieve the required composition.

Alloy ingot casting

0.03 EJ

44%



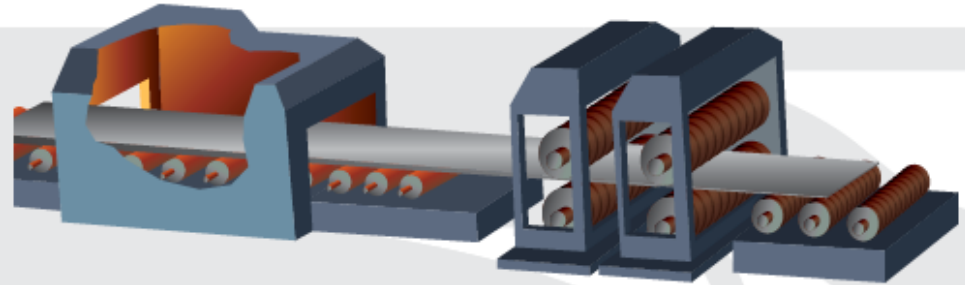
Alloying elements, such as silicon, are added to crucibles of liquid aluminium from the smelters, and then purified before casting by blowing gases through the melt. Liquid aluminium is cast into smaller ingots ready for shape casting.

Aluminium (overall)

Energy = 7.6 EJ

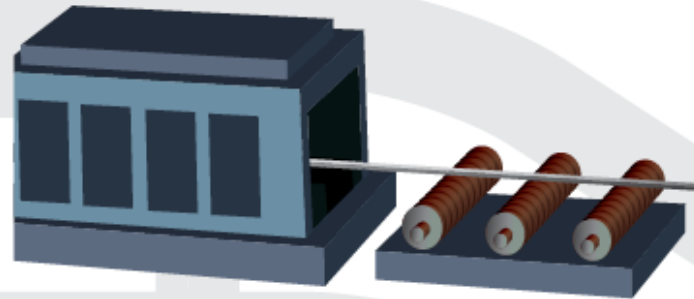
Electricity = 76%

Rolling
0.23 EJ
72%



Ingots are preheated to around 500°C before rolling. Several rolling passes are required to reduce the ingot to the required thickness for sheet (4-6 mm) or plate. Some sheet is cold rolled further down to 0.05 mm for foil, and passed through annealing furnaces and slitting if required.

Extrusion
+drawing
0.09 EJ
19%



For extrusion, the billet is typically heated to 450-500°C and pushed through extrusion dies at a pressure of 500 to 700 MPa. Extrusion billets may have a diameter of 50 to 500 mm. For wire drawing aluminium rod is drawn through a series of dies with a decreasing aperture.

Aluminium (overall)

Energy = 7.6 EJ

Electricity = 76%

Shape
casting
0.17 EJ
1 %



Sand casting and die casting are the most important types of mould casting, sand casting moulds are one-use, whilst die casting moulds are generally re-used, being made of cast iron or steel. Foundry ingots are melted and the molten aluminium is poured into the moulds. Pressure may be applied during die casting.

Fabrication
0.62 EJ
70 %

Aluminium stock products are cut, bent, drilled, milled, welded and painted to make bespoke components ready for assembly into end-use products.

Aluminium (overall)
Energy = 7.6 EJ
Electricity = 76 %

Process	Emissions (t CO ₂ /t)
Iron making—blast furnace	0.5
Coking	0.2
Sintering	0.4
Direct-reduction	1.2
Steelmaking—oxygen blown furnace	0.2
Steelmaking—electric arc furnace	0.5
Scrap preparation	0.01
Steelmaking—open hearth furnace	1
Continuous casting	0.01
Ingot casting	0.05
Hot strip mill	0.1
Cold strip mill	0.4
Plate mill	0.1
Rod and bar mill	0.2
Section mill	0.2
Galvanising plant	0.2
Tinning mill	0.04
Extrusion	0.2
Primary mill	0.1
Forming	0.1
Steel product casting	2.4
Iron foundry casting	1.7
Fabrication	1

Table 5.1—Emissions estimates per unit processed for major steel production processes⁵

Process	Emissions (t CO ₂ /t)
Bauxite extraction	0.02
Alumina production	1
Anode production	0.1
Electrolysis	5.4
Scrap preparation	0.3
Scrap remelting	0.3
Scrap refining	0.6
Ingot casting	0.2
Hot rolling mill	0.2
Cold rolling mill	0.2
Extrusion	0.3
Wire drawing	0.6
Shape casting/secondary casting	0.5
Foil mill	0.9

Table 5.2—Emissions estimates per unit processed for major steel and aluminium production processes

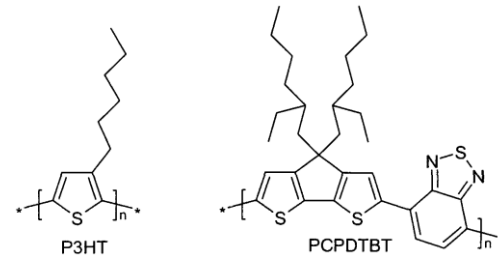
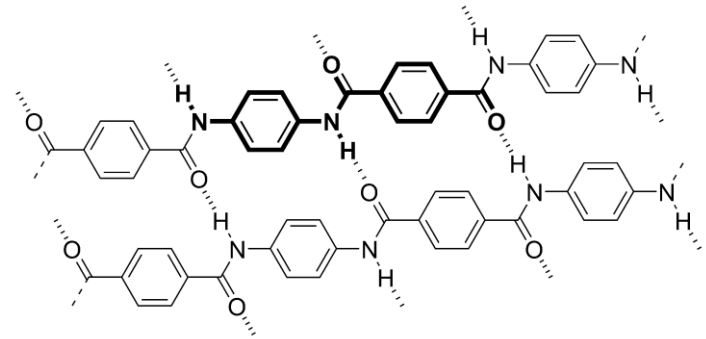
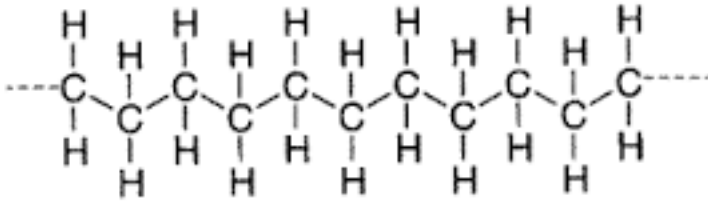
Recycling

60% steel recycled globally (US: 83%)

CCS

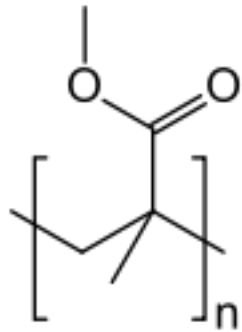
Steel and Aluminum: Substitutions

Plastics

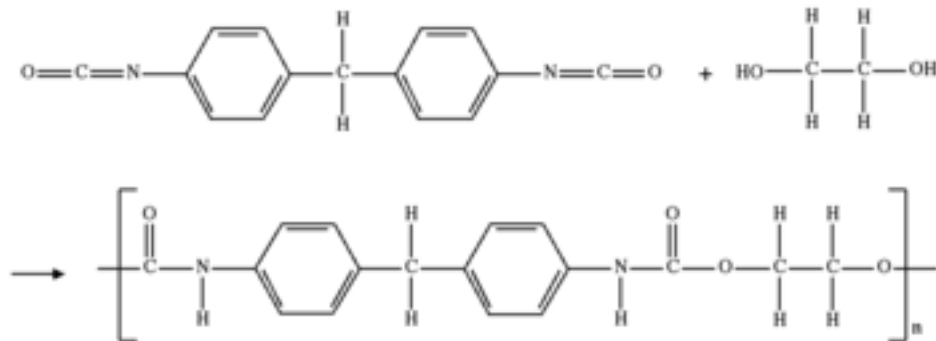


Plastic

Thermoplastics – moldable above T_{critical}



Thermosets – irreversible curing



History of Plastics

- Antiquity – Protein-derived plastics (shellac, egg, blood, horns)
- 1600 BC – Mesoamericans use natural rubber
- 1839 AD – Goodyear invents vulcanized rubber
- 1856 – first man-made plastic, Parkesine (cellulose + nitric acid)
- 1907 – Bakelite invented (first synthetic thermoset)
- Post-WWII – Large increase in plastic variations and production

Plastics consumption

Europe/Japan/US, ~120kg/person/year

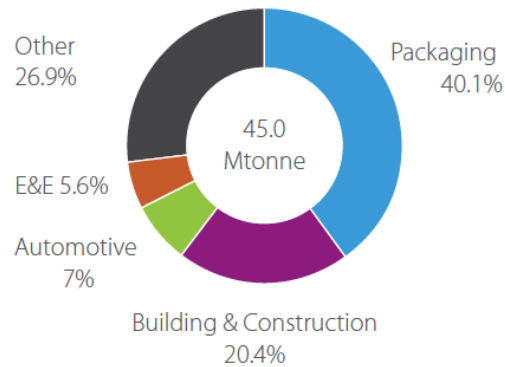


Figure 21.2—Plastic product categories in Europe

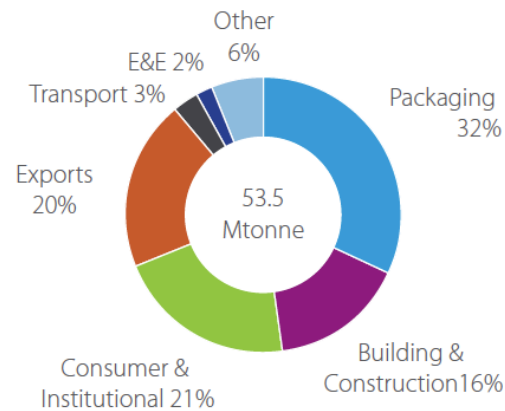


Figure 21.3—Plastic product categories in the US

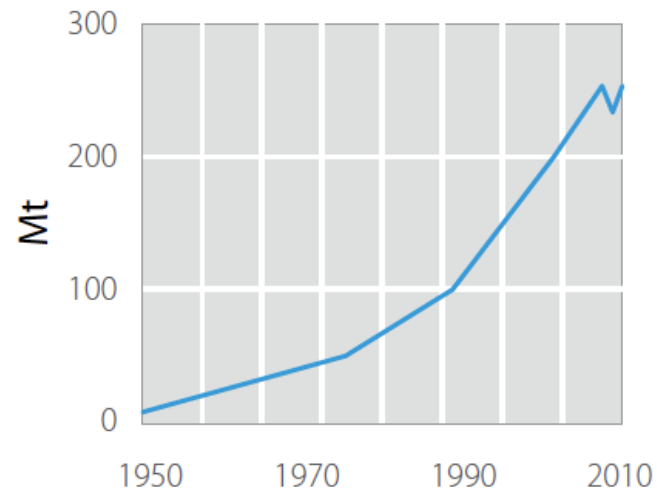


Figure 21.4—Global growth in plastics demand since 1950

Plastics: Energy and CO₂

- IEA assumed emissions from plastics production will more than double from 2005 to 2050
- 8% of oil production (4% material)

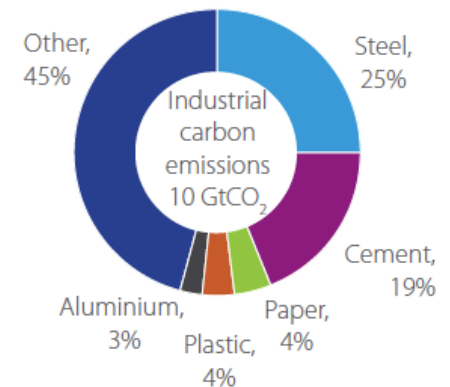
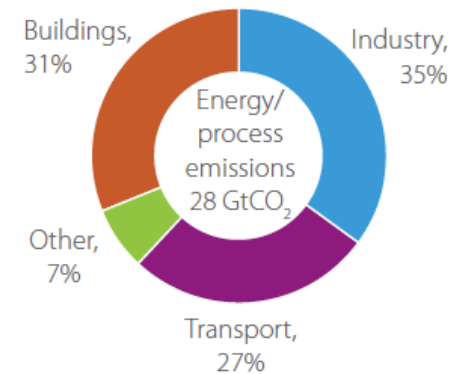
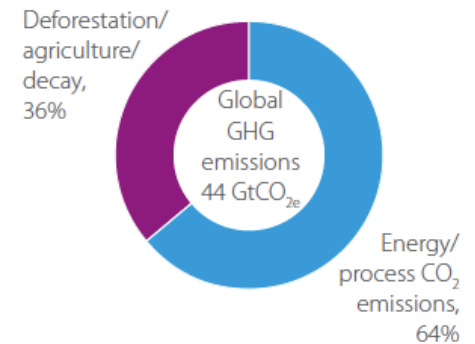
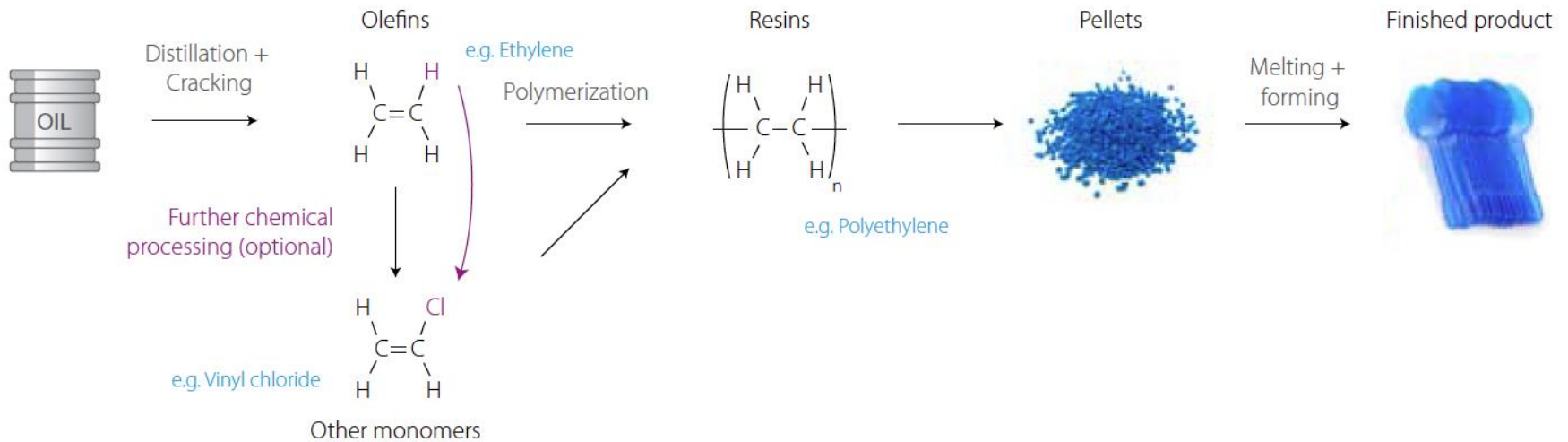


Figure 2.1—Pie charts showing the sources of global CO₂ emissions

Production (thermoplastics)

Most types ~80 MJ/kg (22 kWh/kg)



Produce monomer → synthesize polymer → precursors → mold

Recycling

- Additives and colors degrade them more quickly (less recyclable)
- Very difficult to separate types (obvious reasons) after they're mixed together
- Plastics from industry are recycled at very high rate (number?)
- Room for improvement:
 - Improved sorting
 - Improved separation in municipal waste

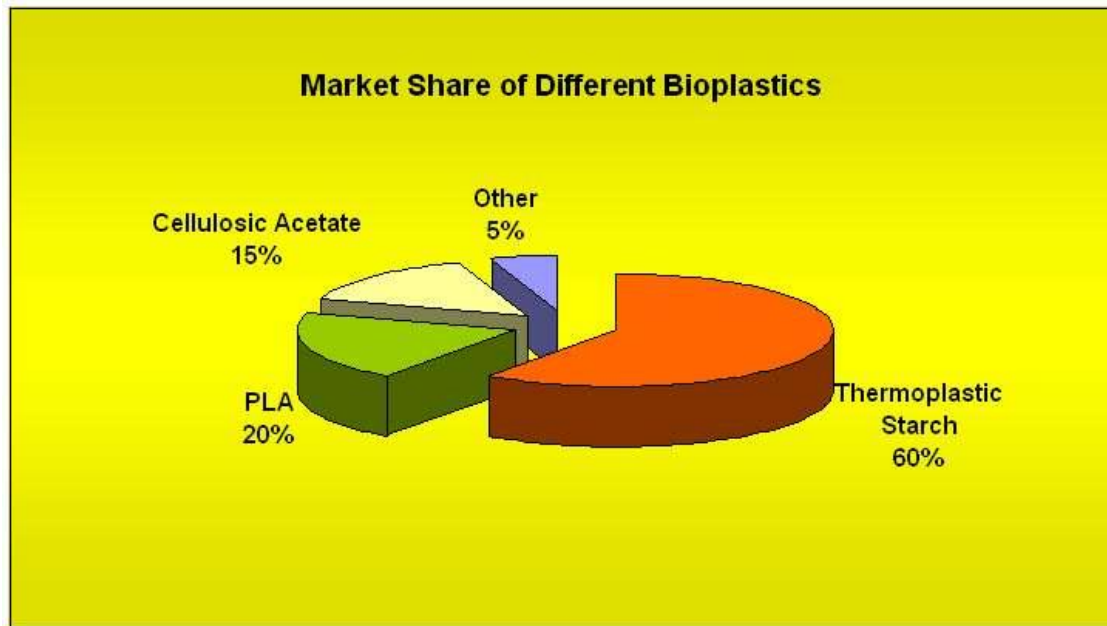
4 types of recycling

- Primary – re-extrusion
- Secondary – mechanical (ground up, re-used as resin)
- Tertiary – broken down chemically for new feedstock
- Quaternary – burn it

Bioplastics

PLA – polylactic acid (biodegradable)

Polyethylene from sugar cane ethanol



0.33 Mt bioplastics

12.3 Mt all flexible packaging

Cement

Lime production (825 C):



Clinker production:

Belite ($2\text{CaO}\cdot\text{SiO}_2$);

Alite ($3\text{CaO}\cdot\text{SiO}_2$);

Celite ($3\text{CaO}\cdot\text{Al}_2\text{O}_3$);

Brownmillerite

($4\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{Fe}_2\text{O}_3$).

Cement Production

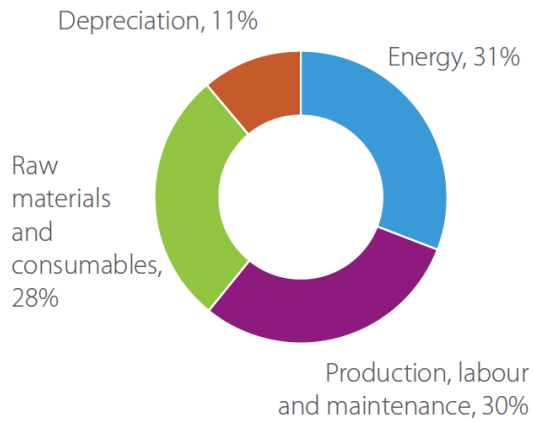
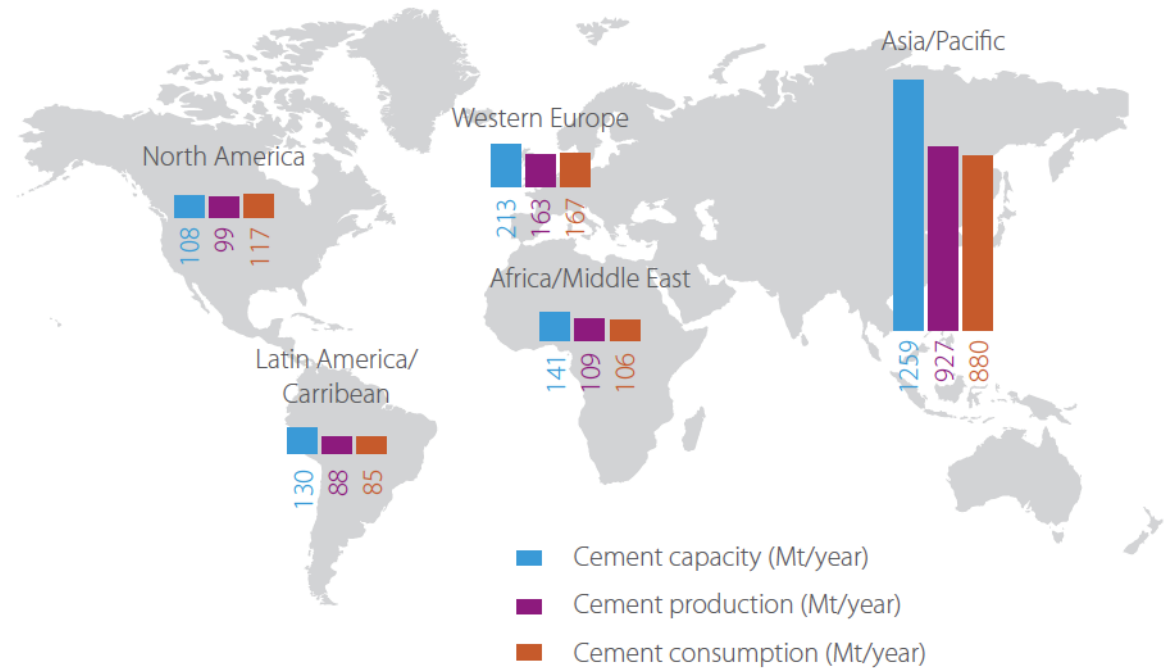
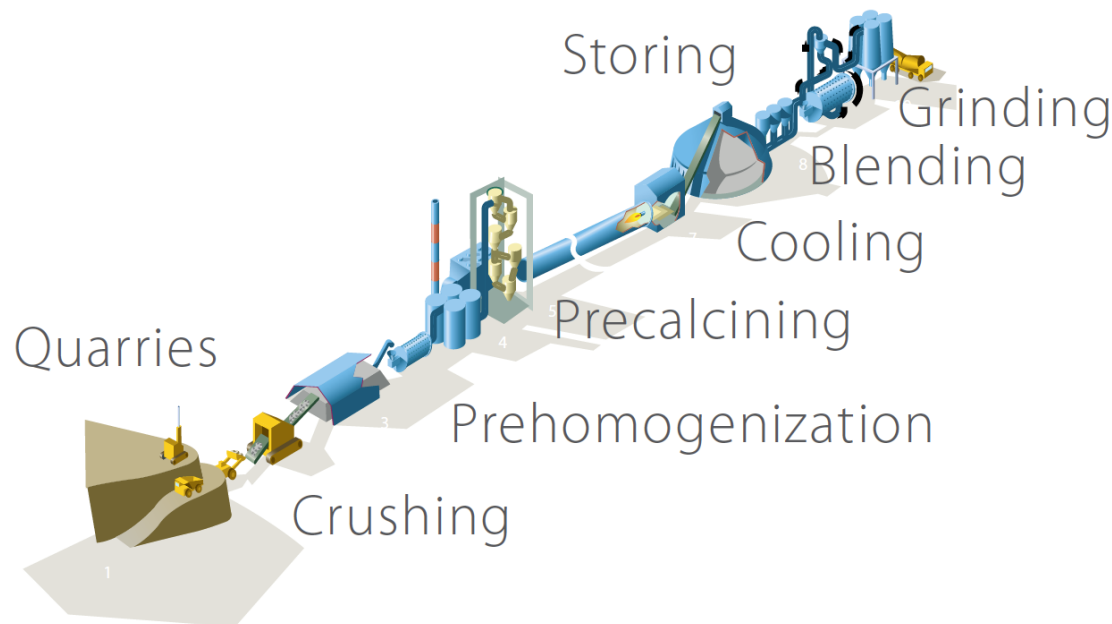


Figure 20.5—Breakdown of costs in cement production¹⁰



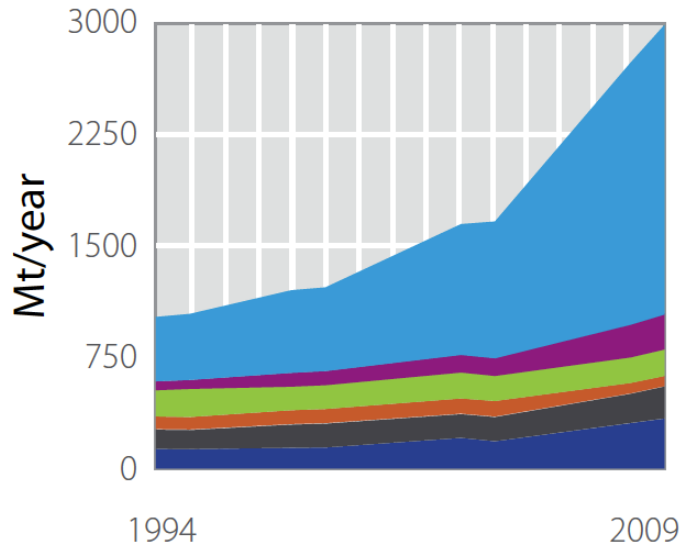
Cement Production

Raw materials well-distributed
Not recyclible



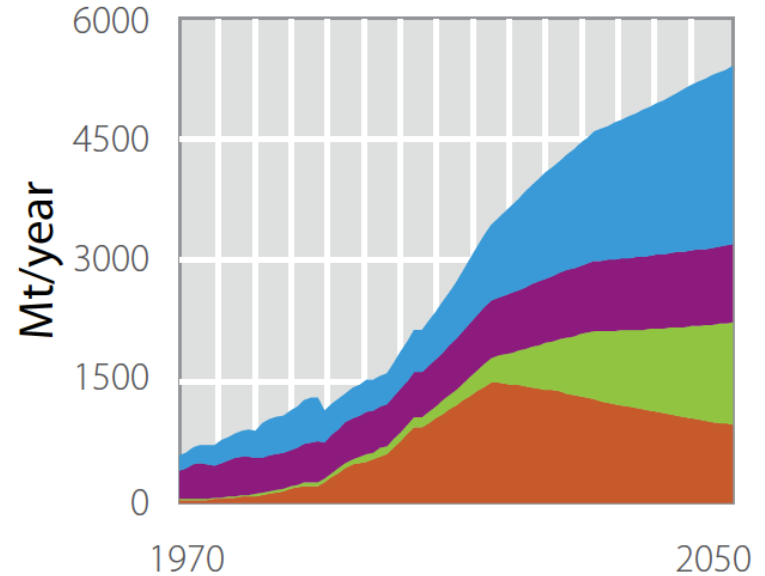
10 cm

Cement Demand



- China
- India
- Latin America
- Western Europe
- North America
- Middle East

Figure 20.2—Global cement production over time by region⁶



- Other
- OECD
- India
- China

Figure 20.4—Forecast growth in demand for cement by 2050⁸

Cement: CO₂

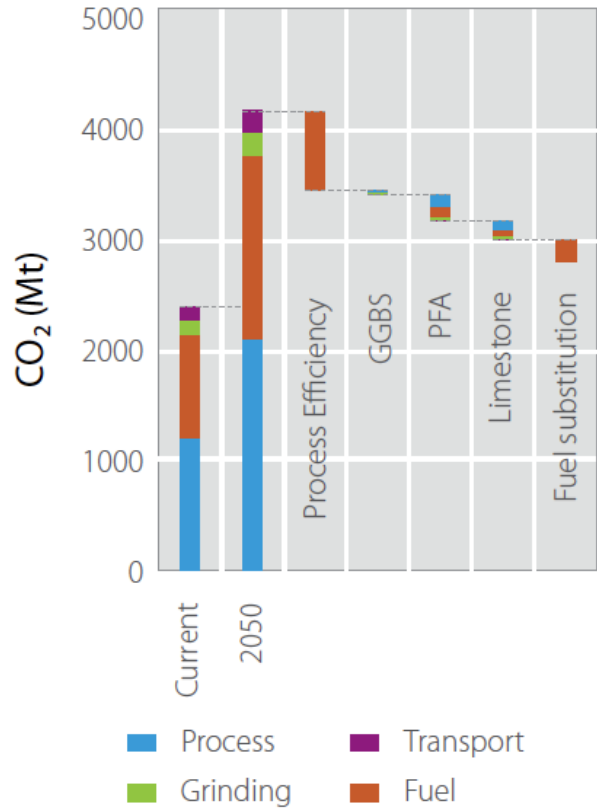


Figure 20.9—Forecast for emissions reductions in the cement industry

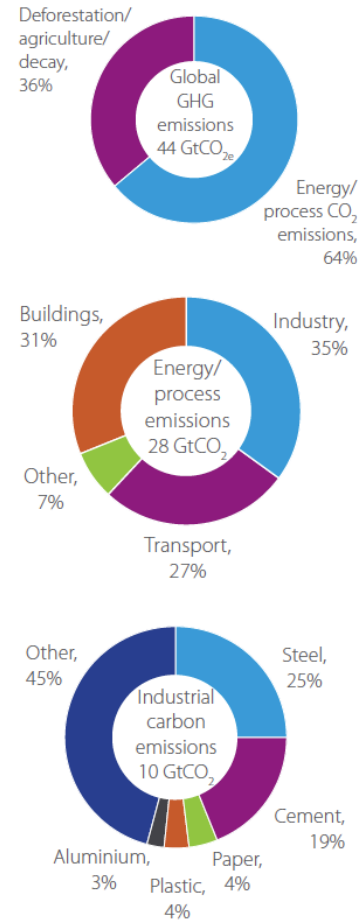


Figure 2.1—Pie charts showing the sources of global CO₂ emissions

Cement: Substitutions

- Ground granulated blast furnace slag
- Pulverised fly ash
- Natural Pozzolans (50% some applications)
- Limestone
- Crushed concrete
- (Enviro-friendly cement)

10-20% cement replaced this way. But:

GGBS + PFA + possolans = 850Mt

Global cement production = 2850Mt

Cement: CCS

Even more attractive, since CO₂ *has* to be produced.

Pure CO₂ stream easier to produce

CO₂

