Global Manufacturing

ARAUJO, Anna Carla

AUG, 2015

Mechanical Engineering Department – POLI/COPPE/UFRJ

Steel Making [#3]

Steel Making

- Why steel is used in Engineering?
- How steel is produced?
- What is needed to produce steel?
- What are the types of steel?
- Where in the world can steel be produced?
- In what "forms" (geometries) steel is produced? / How steel is sold?

"Globalization is the integration and interdependency of world markets and resources in producing consumer goods and services"

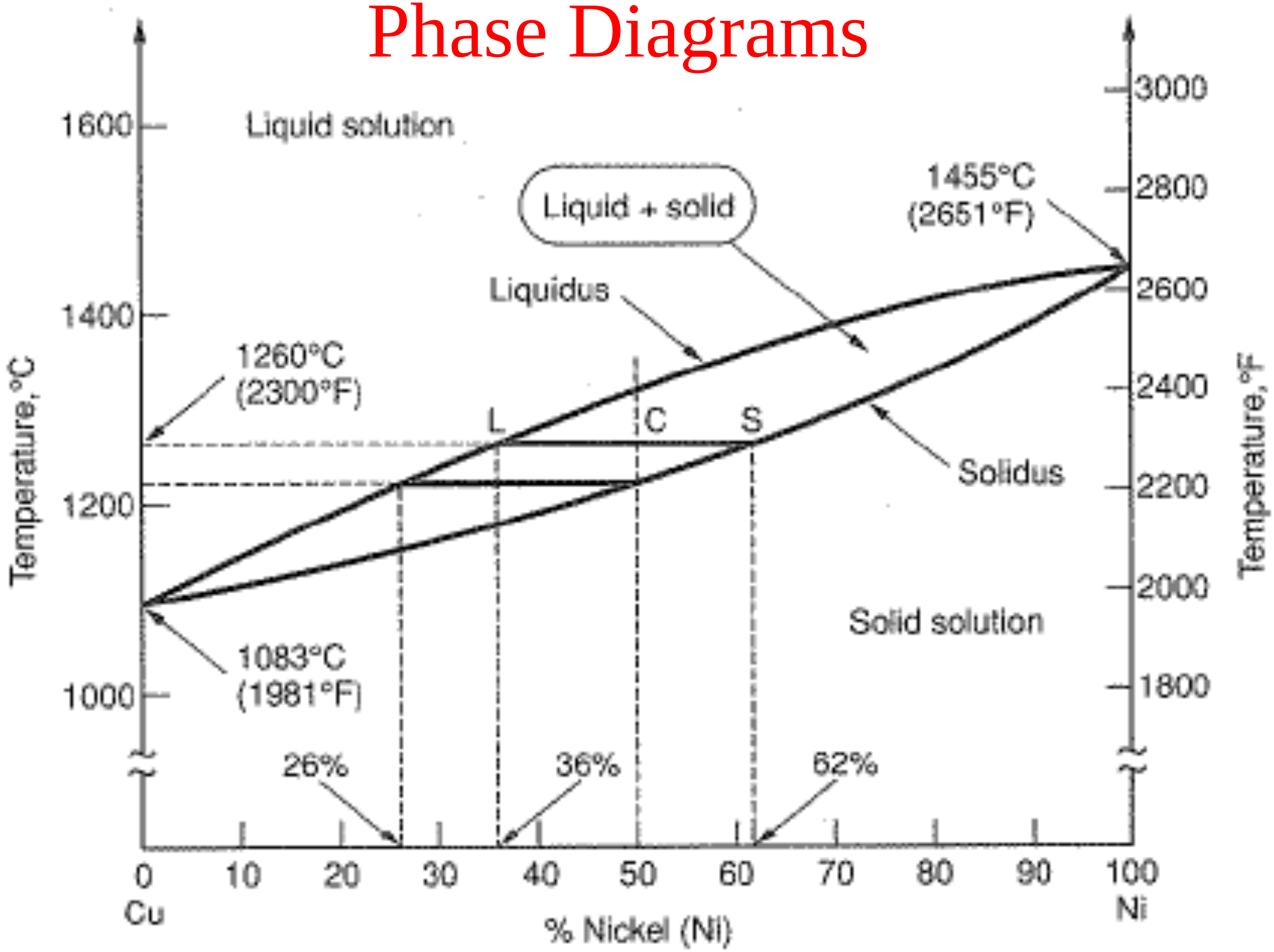
Why steel is used in Engineering?

Table 1.1 Materials used in manufacturing

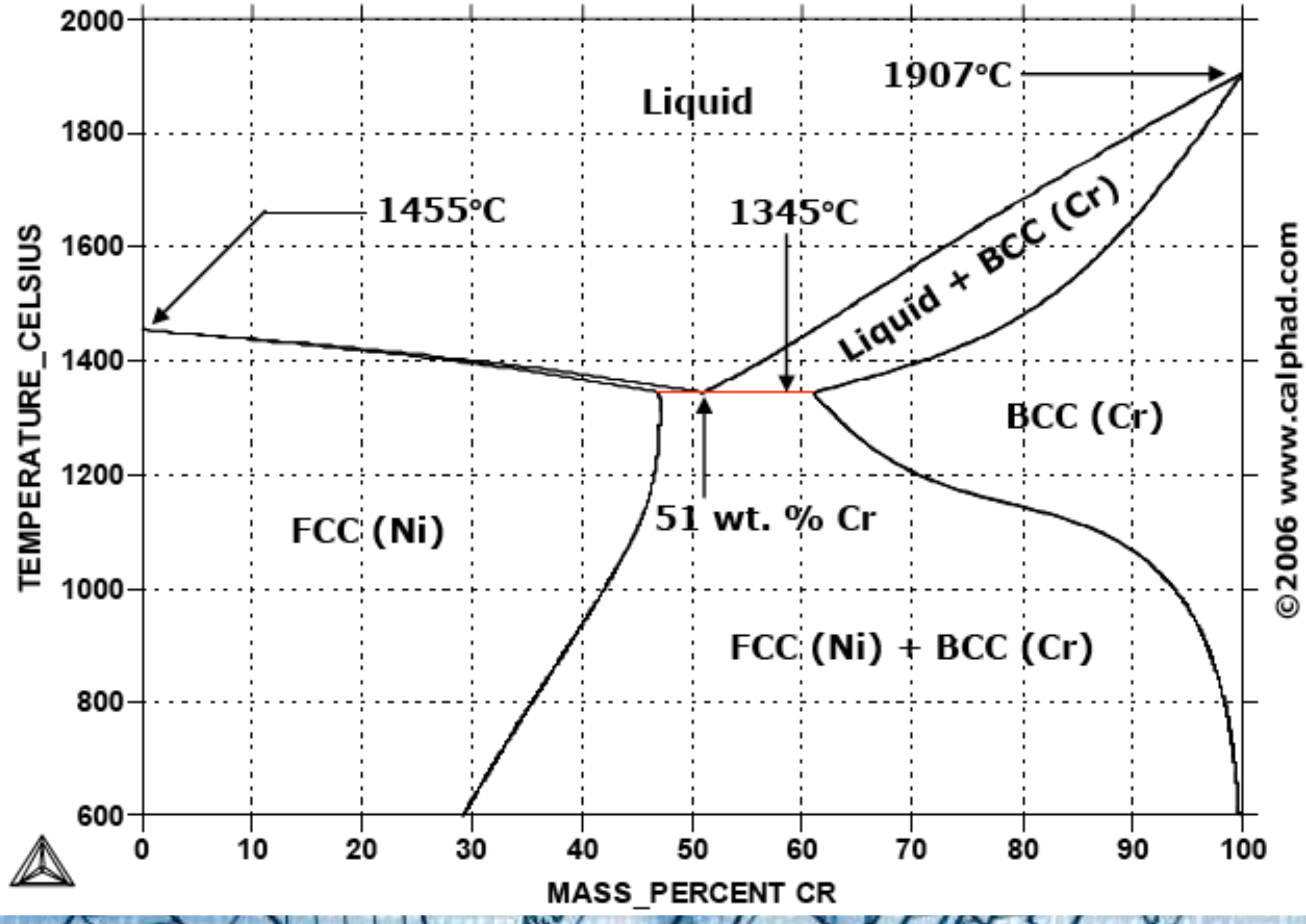
Material	Approximate world production (tonnes $\times 10^6$)	Approximate relative cost	Density (kg/m^3)	Approximate volume produced ($m^3 \times 10^6$)
Iron (steel)	768	1	7 900	97
Aluminium	18	3	2 700	6.7
Copper	11	5	8 900	1.2
Zinc	7	4	7 100	1
Lead	5	3	11 300	0.41
Nickel	0.7	10	8 900	0.08
Magnesium	0.4	8	1 700	0.23
Tin	0.3	20	5 800	0.05
Titanium	0.1	26	4 500	0.02
Polymers	85		900–2200	56

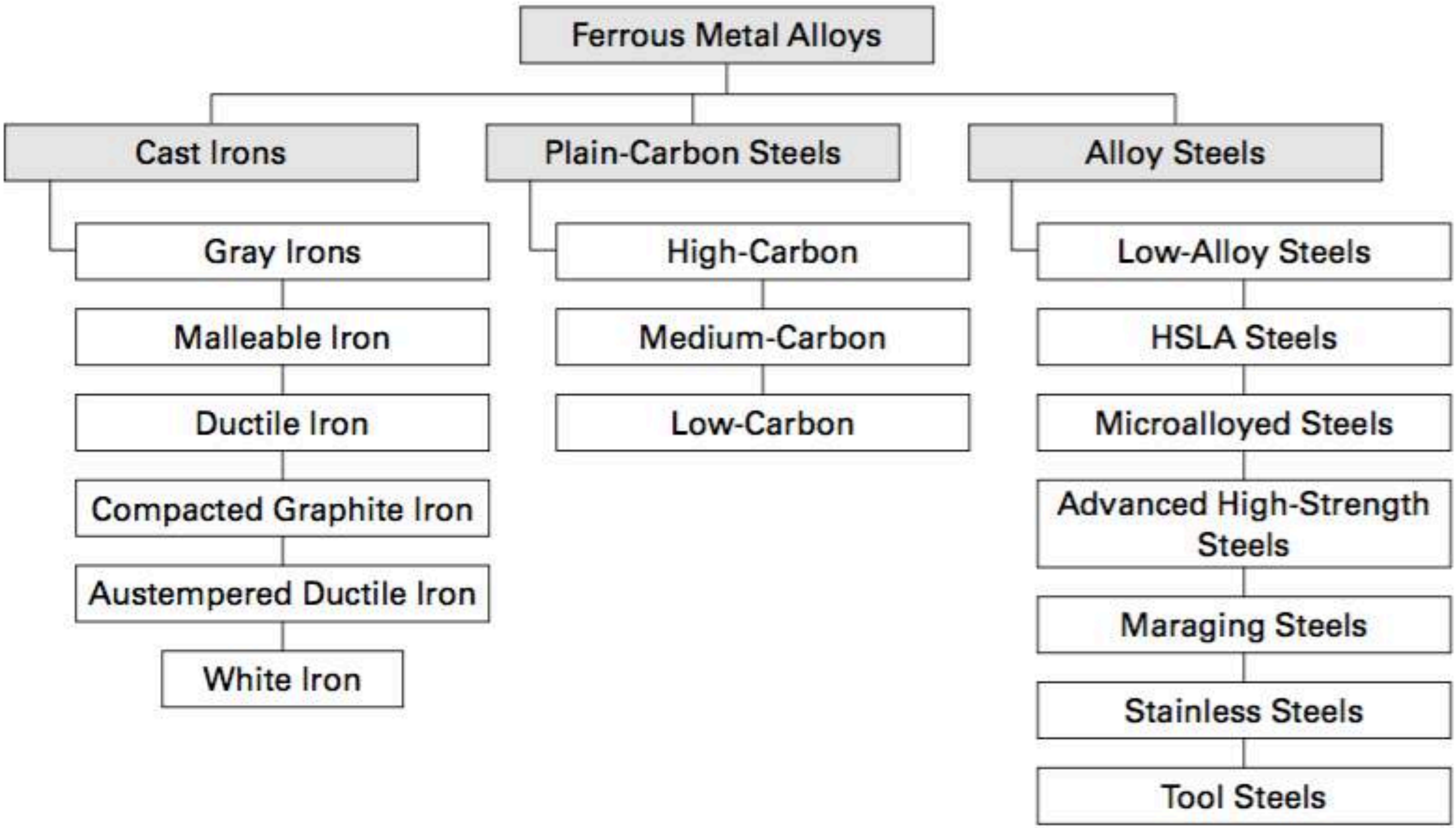
“Principles of Metal Manufacturing Processes” - J. Beddoes & M. J. Bibby, 1999 - Elsevier ButtenNorth-Heinemann

Phase Diagrams

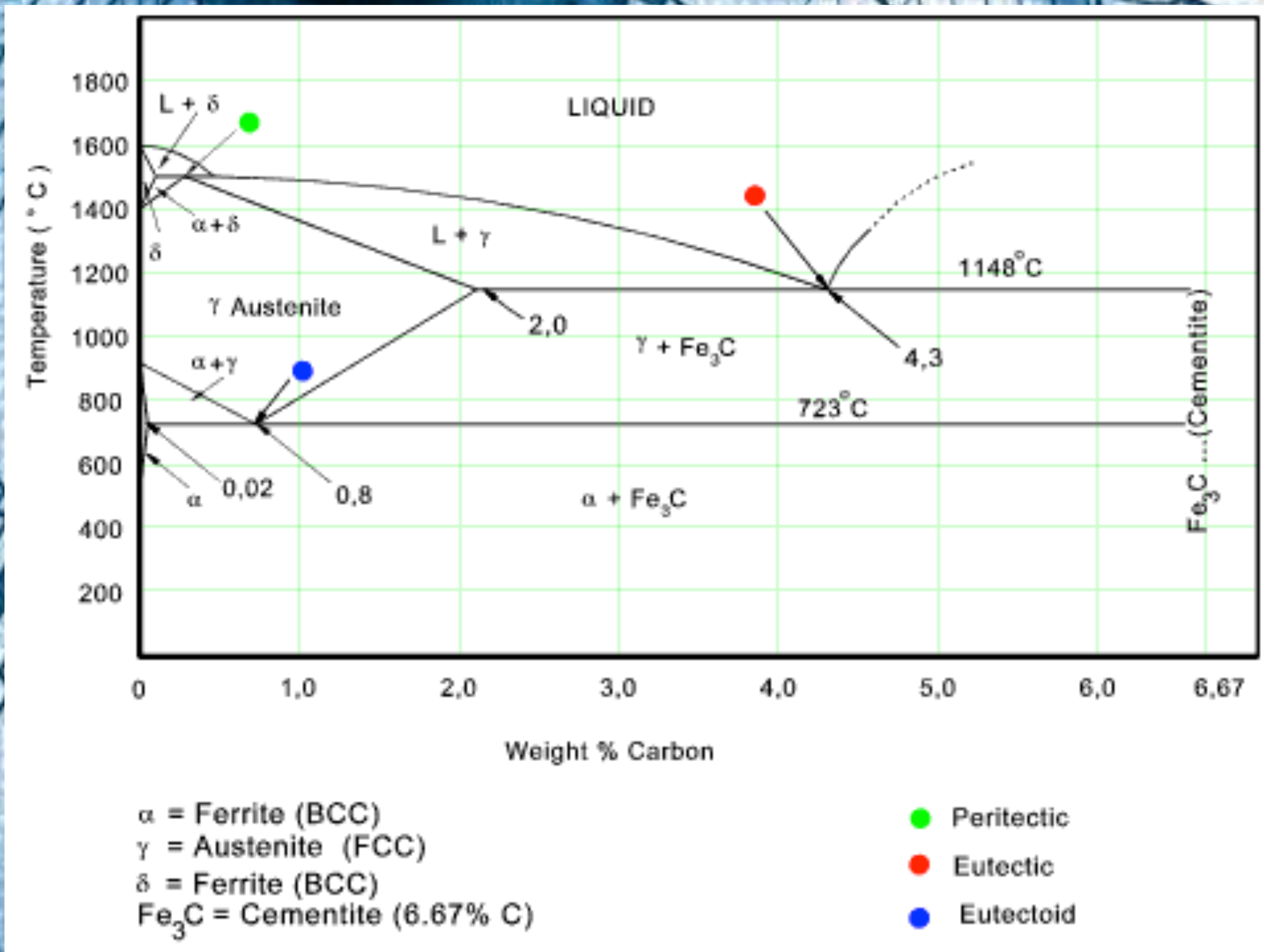


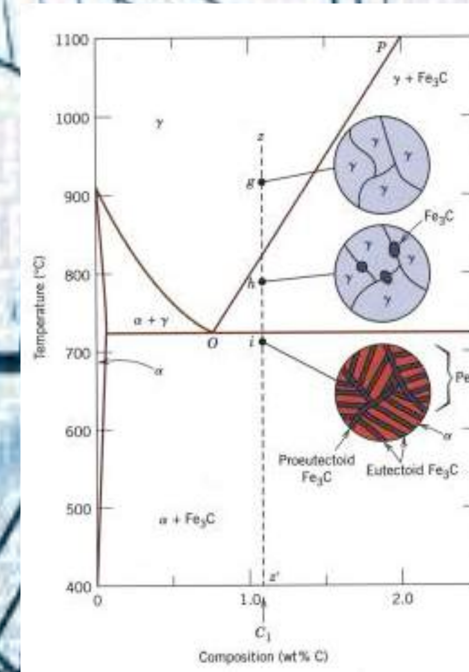
Nickel-Chromium Phase Diagram

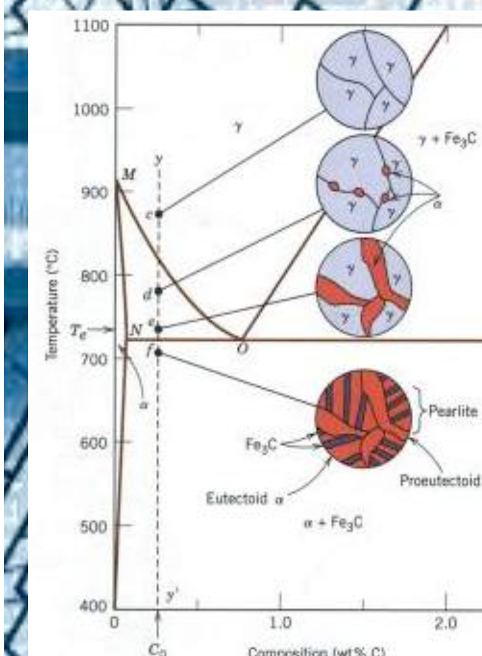



Ferrous Metal Alloys
Cast Irons
Plain-Carbon Steels
Alloy Steels
Gray Irons
Malleable Iron
Ductile Iron
Compacted Graphite Iron
Austempered Ductile Iron
White Iron
High-Carbon
Medium-Carbon
Low-Carbon
Low-Alloy Steels
HSLA Steels
Microalloyed Steels
Advanced High-Strength Steels
Maraging Steels
Stainless Steels
Tool Steels

Fe-C Diagram


LIQUID
L + δ
α+δ
δ
L + γ
γ Austenite
1148°C
2,0
4,3
γ + Fe3C
α+γ
723°C
0,02
0,8
α
α + Fe3C
Fe3C ...(Cementite)
Temperature (° C)
1800
1600
1400
1200
1000
800
600
400
200
0
1,0
2,0
3,0
4,0
5,0
6,0
6,67
Weight % Carbon
α = Ferrite (BCC)
γ = Austenite (FCC)
δ = Ferrite (BCC)
Fe3C = Cementite (6.67% C)
Peritectic
Eutectic
Eutectoid


γ + Fe3C
γ
α + γ
α
α + Fe3C
Fe3C
Proeutectoid Fe3C
Eutectoid Fe3C
Temperature (°C)
Composition (wt% C)


γ
γ + Fe3C
Pearlite
Fe3C
Proeutectoid
Eutectoid α
α + Fe3C
Temperature (°C)
Composition (wt% C)

Hardening with solution atom (Instestitial and Substitutional)

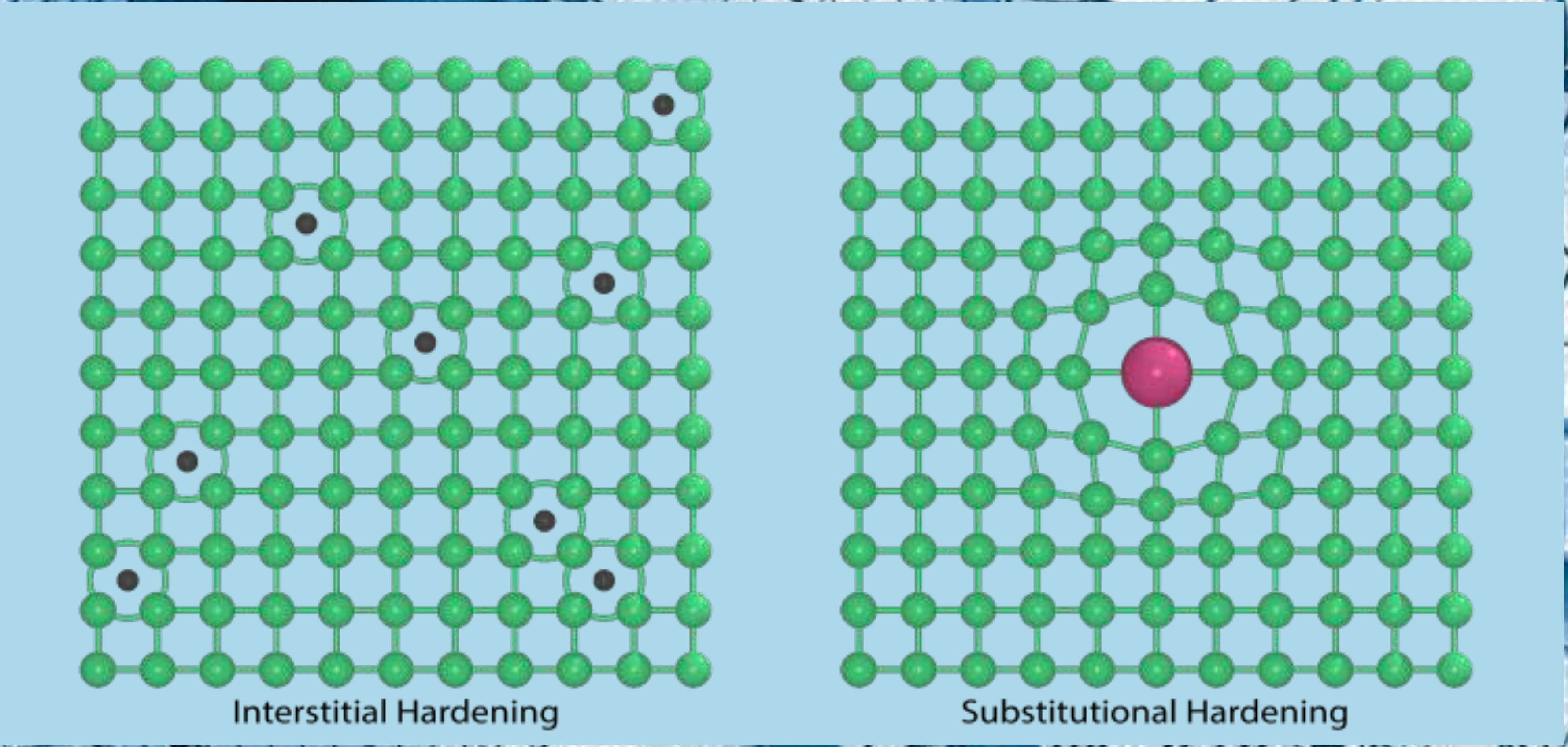
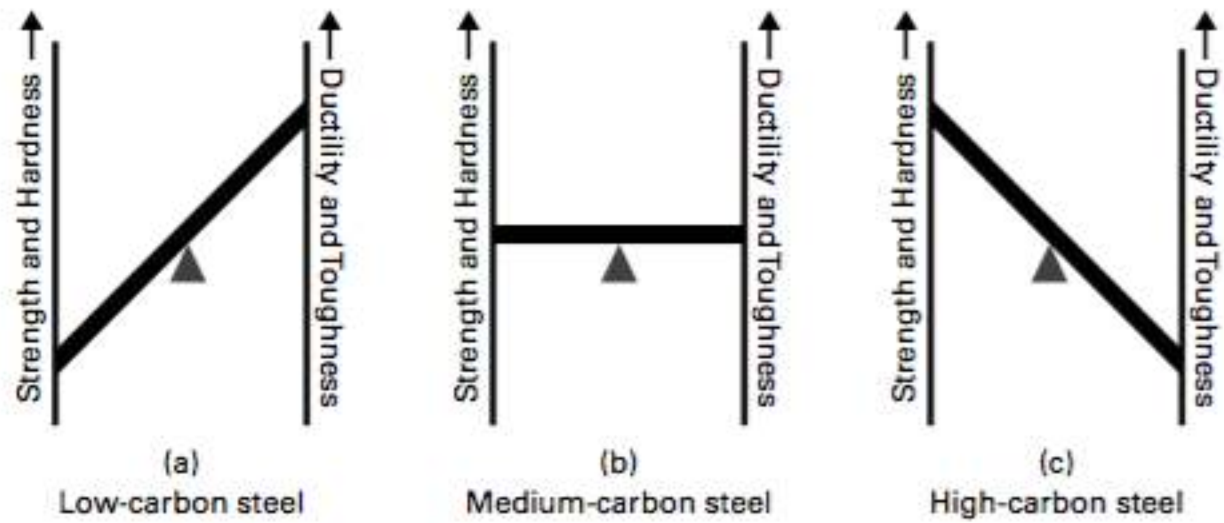


TABLE 7-1 Effect of Carbon on the Strength of Annealed Plain-Carbon Steels[a]			
		Minimum Tensile Strength	
Type of Steel	Carbon Content	Mpa	ksi
1020	0.20%	414	60
1030	0.30%	448	65
1040	0.40%	517	75
1050	0.50%	621	90

[a] Data are from ASTM Specification A732.

FIGURE 7-7 A comparison of low-carbon, medium-carbon, and high-carbon steels in terms of their relative balance of properties. (a) Low-carbon has excellent ductility and fracture resistance, but lower strength. (b) Medium-carbon has balanced properties. (c) High-carbon has high strength and hardness at the expense of ductility and fracture resistance.



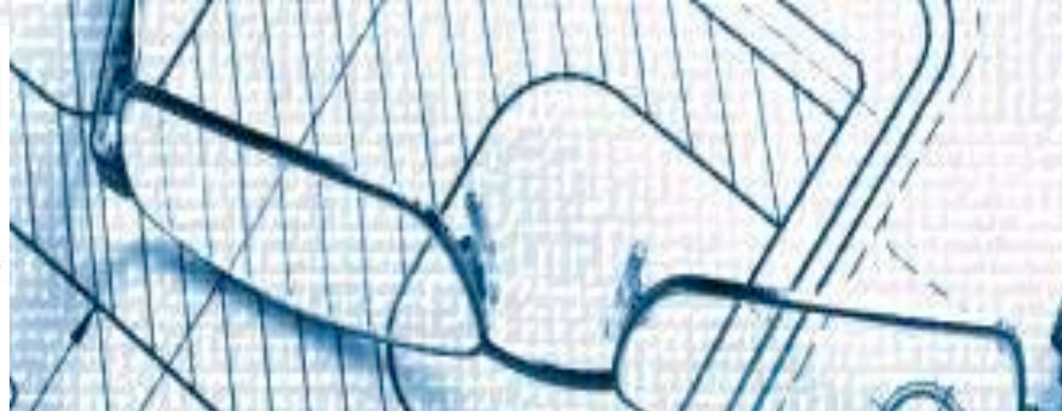


TABLE 7-2 Effect of Carbon on the Strength of Quenched-and-Tempered Alloy Steels[a]

Type of Steel	Carbon Content	Minimum Tensile Strength Mpa	ksi
4130	0.30%	1030	150
4330	0.30%	1030	150
8630	0.30%	1030	150
4140	0.40%	1241	[illegible]
4340	0.40%	1241	[illegible]

[a] Data from ASTM Specification A732.

TABLE 7-3 Principal Effects of Alloying Elements in Steel

Element	Percentage	Primary Function
Aluminum	0.95–1.30	Alloying element in nitriding steels
Bismuth	—	Improves machinability
Boron	0.001–0.003	Powerful hardenability agent
Chromium	0.5–2	Increase of hardenability
	4–18	Corrosion resistance
Copper	0.1–0.4	Corrosion resistance
Lead	—	Improved machinability
Manganese	0.25–0.40	Combines with sulfur to prevent brittleness
	>1	Increases hardenability by lowering transformation points and causing transformations to be sluggish
Molybdenum	0.2–5	Stable carbides; inhibits grain growth
Nickel	2–5	Toughener
	12–20	Corrosion resistance
Silicon	0.2–0.7	Increases strength
	2	Spring steels
	Higher percentages	Improves magnetic properties
Sulfur	0.08–0.15	Free-machining properties
Titanium	—	Fixes carbon in inert particles
		Reduces martensitic hardness in chromium steels
Tungsten	—	Hardness at high temperatures
Vanadium	0.15	Stable carbides; increases strength while retaining ductility, Promotes fine grain structure

TABLE 7-4 AISI–SAE Standard Steel Designations and Associated Chemistries

AISI Number	Type	Alloying Elements (%)					
		Mn	Ni	Cr	Mo	V	Other
1xxx	Carbon steels						
10xx	Plain carbon						
11xx	Free cutting (S)						
12xx	Free cutting (S) and (P)						
13xx	High manganese	1.60–1.90					
15xx	High manganese						
2xxx	Nickel steels		3.5–5.0				
3xxx	Nockel–chromium		1.0–3.5	0.5–1.75			
4xxx	Molybdenum						
40xx	Mo				0.15–0.30		
41xx	Mo, Cr			0.40–1.10	0.08–0.35		
43xx	Mo, Cr, Ni		1.65–2.00	0.40–0.90	0.20–0.30		
44xx	Mo				0.35–0.60		
46xx	Mo, Ni (low)		0.70–2.00		0.15–0.30		
47xx	Mo, Cr, Ni		0.90–1.20	0.35–0.55	0.15–0.40		
48xx	Mo, Ni (high)		3.25–3.75		0.20–0.30		
5xxx	Chromium						
50xx				0.20–0.60			
51xx				0.70–1.15			
6xxx	Chromum–vanadium						
61xx				0.50–1.10		0.10–0.15	
8xxx	Ni, Cr,Mo						
81xx			0.20–0.40	0.30–0.55	0.08–0.15		
86xx			0.40–0.70	0.40–0.60	0.15–0.25		
87xx			0.40–0.70	0.40–0.60	0.20–0.30		
88xx			0.40–0.70	0.40–0.60	0.30–0.40		
9xxx	Other						
92xx	High silicon						1.20–2.20Si
93xx	Ni, Cr,Mo		3.00–3.50	1.00–1.40	0.08–0.15		
94xx	Ni, Cr,Mo		0.30–0.60	0.30–0.50	0.08–0.15		

TABLE 7-9 AISI Designation Scheme for Stainless Steels

Series	Alloys	Structure
200	Chromium, nickel, manganese, or nitrogen	Austenitic
300	Chromium and nickel	Austenitic
400	Chromium and possibly carbon	Ferritic or martensiti
500	Low chromium (<12%) and possibly carbon	Martensitic

Cast Iron

TABLE 7-14 Typical Properties of Pearlitic Gray, Compacted Graphite, and Ductile Cast Irons

Property	Gray	CGI	Ductile
Tensile strength (MPa)	250	450	750
Elastic modulus (Gpa)	105	145	160
Elongation (%)	0	1.5	5
Thermal conductivity (w/mk)	48	37	28
Relative damping capacity (Gray = 1)	1	0.35	0.22

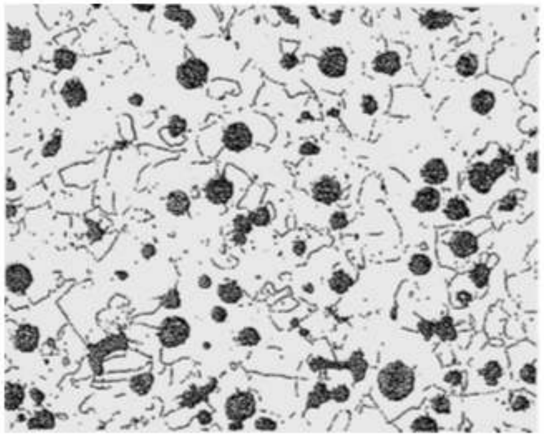


FIGURE 7-13 Ductile cast iron with a ferrite matrix. Note the spheroidal shape of the graphite, 100×. *(Courtesy Ronald Kohser)*

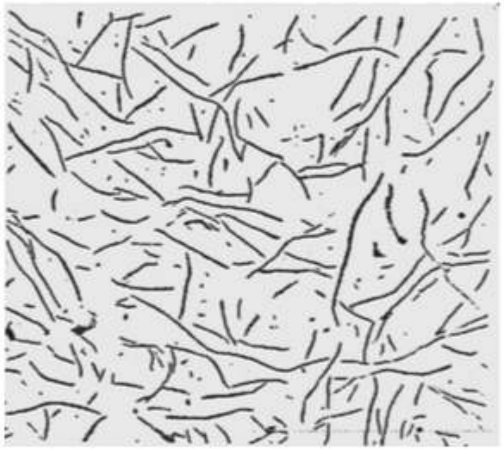


FIGURE 7-11 Photomicrograph showing the distribution of graphite flakes in gray cast iron; unetched, 100×. *(Courtesy Ronald Kohser)*

Primary manufacturing processes

Manufacturing operations can be generally classified into primary and secondary processes. For metals, primary manufacturing usually refers to the conversion of ores into metallic materials. Secondary manufacturing is generally understood to mean the conversion of the products from the primary operation into semifinished or finished parts.

- refining steel from iron ore
- aluminium from bauxite

PIG IRON (Ferro Gusa)

- Pig iron is produced from iron ores by blast furnaces.
- The high carbon product of the 20th century furnaces became known as cast iron.
- Blast furnaces are typically more than 30 m high and about 10m in diameter. The structure is roughly cylindrical and lined with refractory firebrick, supported by a water-cooled outer steel shell.

Carbon	3.0–4.5%
Manganese	0.15–2.5%
Phosphorus	0.1–2.0%
Silicon	1.0–3.0%
Sulfur	0.05–0.1%

PIG IRON

Iron Ore;	Coke;	Limestone;	Hot Air
• Iron Supply	• residual solid of heating coat • Fuel • Reduction for Fe • Carbon Supplier	• rock of calcium carbonate $CaCO_3$ • Reacts with impureties / Produces slag (scoria) • Low melting point	• Or blast to burn the coke

↓

Blast Furnace

Iron Ores

The iron itself is usually found in the form of:

- magnetite (Fe_3O_4, 72.4% Fe),
- hematite (Fe_2O_3, 69.9% Fe),
- goethite (FeO(OH), 62.9% Fe),
- limonite ($FeO(OH)._n(H2O)$) or
- siderite ($FeCO_3$, 48.2% Fe)

Magnetite and pyrite from Piedmont, Italy

Siderite (Brazil)

Limonite

Hematite: the main iron ore in Brazilian mines

Goethite, Cornwall, England

Iron Ores (Mining)

What are pellets?

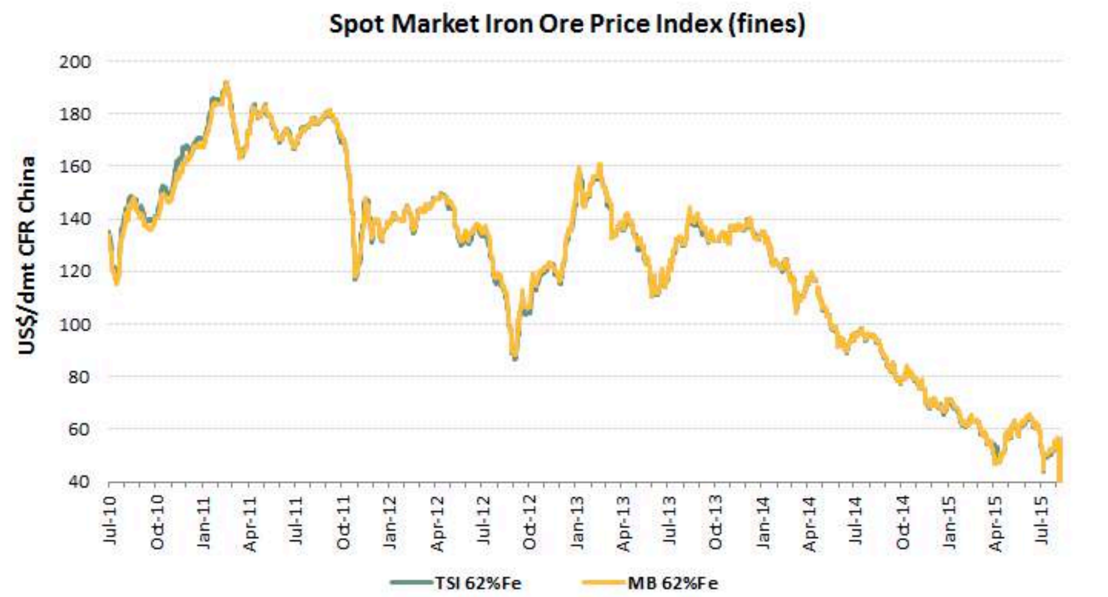
Pellets are small balls of iron ore used in the production of steel. They are made with technology that uses the powder that is generated during the ore extraction process, once considered waste.

http://assets.vale.com/ui/Documents/en/business/mining/iron-ore-pellets/carajas/index.html

Iron Ore Indices

Spot Market Indices	August, 11th	Weekly Average (last 5 days)	Monthly Average (last 30 days)
	US$/dmt	US$/dmt	US$/dmt
The Steel Index 62%Fe	55,90	56,20	52,67
Metal Bulletin 62%Fe	56,22	56,47	53,26
Platts 62% Fe	To Platts 62%Fe, visit Platts website		

* Numbers is US$/dmt



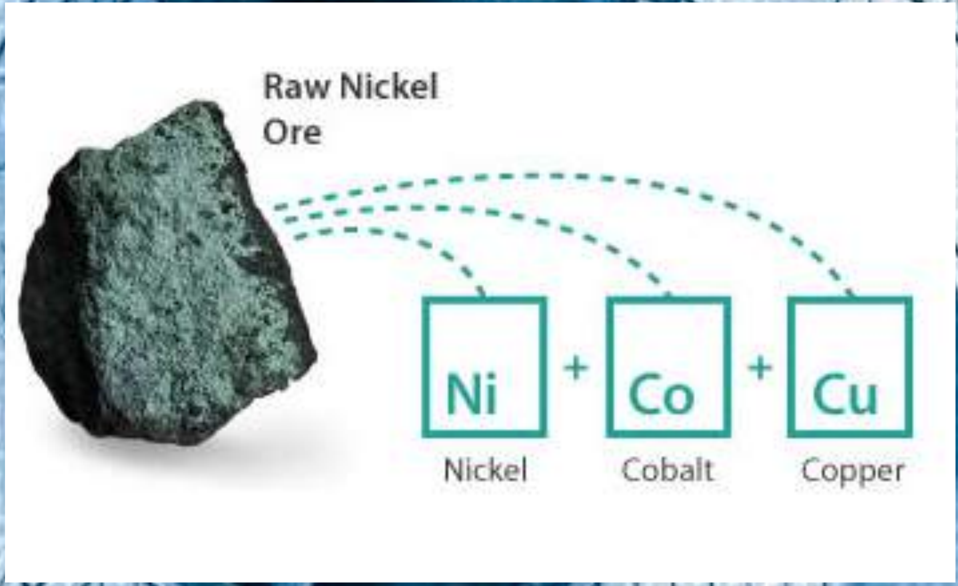
Sources:

The Steel Index: www.thesteelindex.com

Metal Bulletin: www.mbironoreindex.com

Platts: www.platts.com

Other Ores



Copper ore extraction site at Sossego Mine, Pará state

Aluminun Ore (Baixite)

Museos Nacional UFRJ – Mining / Ores

- http://www.museunacional.ufrj.br/
- http://www.museunacional.ufrj.br/exposicoes/geologia/exposicao/meteoritos
- http://www.museunacional.ufrj.br/exposicoes/geologia/acervo/amostras-e-outros-meteoritos

- Museu de Ouro Preto: http://www.museu.em.ufop.br/museu/mineracao.php

Coke (Coal)

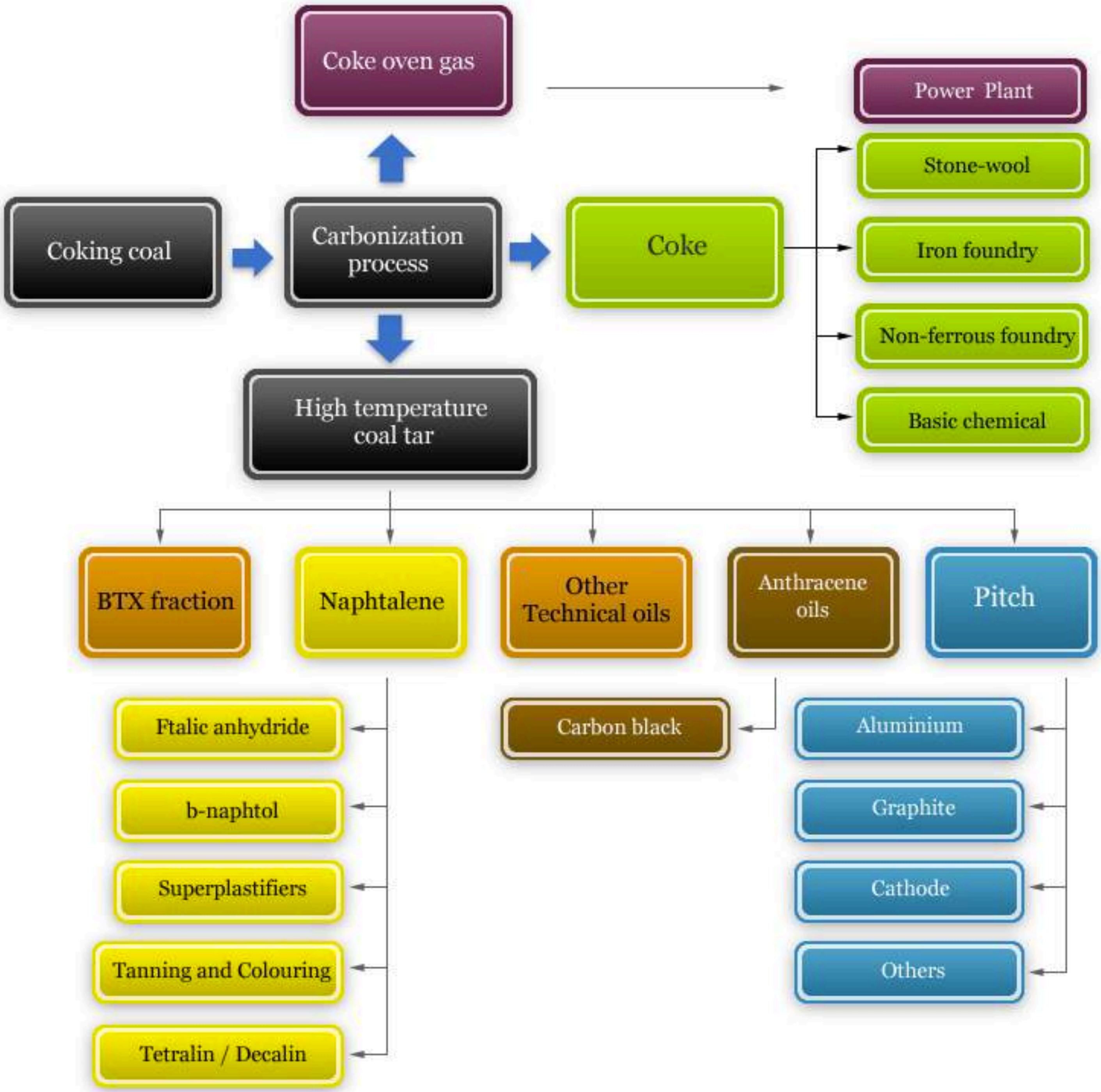
“Global steel production is dependent on coal. 70% of the steel produced today uses coal. Metallurgical coal – or coking coal – is a vital ingredient in the steel making process. World crude steel production was 1.4 billion tonnes in 2010. Around 721 million tonnes of coking coal was used in the production of steel.”

http://www.worldcoal.org/coal/uses-of-coal/coal-steel/

It acts as the fuel, burning to produce carbon monoxide and to reduce the iron oxide to iron.
Coking coal is found in many parts of the world.

Coke (Coal)

- Coking coal is converted to coke by driving off impurities to leave almost pure carbon.
- The physical properties of coking coal cause the coal to soften, liquefy and then resolidify into hard but porous lumps when heated in the absence of air. Coking coal must also have low sulphur and phosphorous contents. Almost all metallurgical coal is used in coke ovens.
- The coking process consists of heating coking coal to around 1000-1100ºC in the absence of oxygen to drive off the volatile compounds (pyrolysis).
- This process results in a hard porous material - coke.
- Coke is produced in a coke battery which is composed of many coke ovens stacked in rows into which coal is loaded. The coking process takes place over long periods of time between 12-36 hours in the coke ovens. Once pushed out of the vessel the hot coke is then quenched with either water or air to cool it before storage or is transferred directly to the blast furnace for use in iron making.



Coke oven gas
Power Plant
Coking coal
Carbonization process
Coke
Stone-wool
Iron foundry
Non-ferrous foundry
Basic chemical
High temperature coal tar
BTX fraction
Naphtalene
Other Technical oils
Anthracene oils
Pitch
Ftalic anhydride
b-naphtol
Superplastifiers
Tanning and Colouring
Tetralin / Decalin
Carbon black
Aluminium
Graphite
Cathode
Others

Limestone (calcário)

- Limestone is a sedimentary rock consisting predominantly of calcium carbonate ($CaCO_3$).
- Within the blast furnace it combines with impurities in the ore to form a slag which floats on molten pig iron and is separately tapped into a ladle.
- Slags consist mostly of the oxides of silicon, aluminium, calcium and magnesium, and can be used in making concrete or as railroad ballast.

How steel is produced?

$$3CO + Fe_2O_3 \rightleftharpoons 2Fe + 3CO_2$$

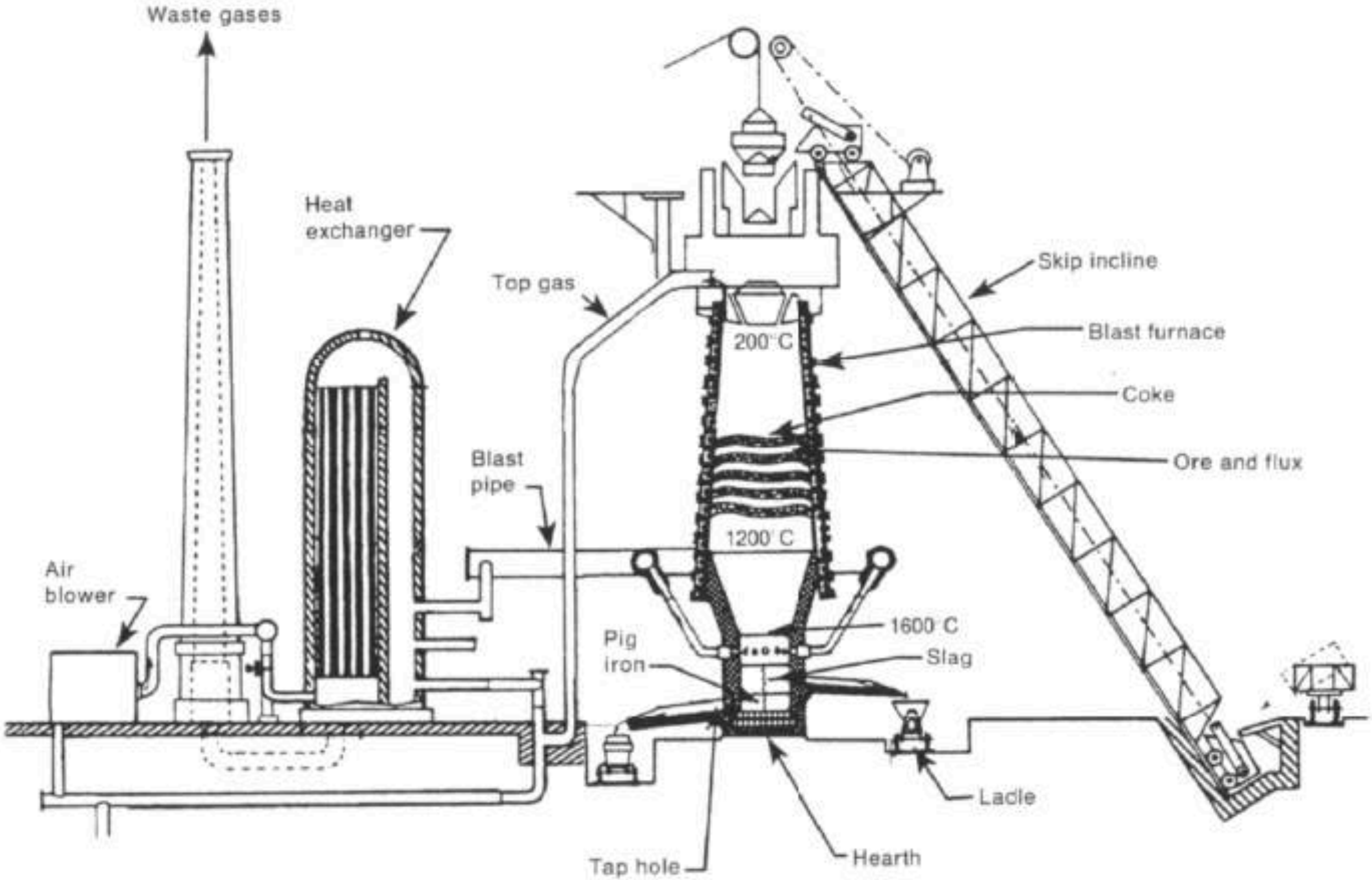


Fig. 1.1 Diagram of a blast furnace for the production of pig iron.

"Principles of Metal Manufacturing Processes" - J. Beddoes & M. J. Bibby, 1999 - Elsevier Butten North-Heinemann

How steel is produced?

Approximately 800 t of pig iron are tapped from the blast furnace about five times a day, with the blast furnace operated continuously 7 days a week. To produce 800 t:

- 1400 t of ore,
- 500 t of coke,
- 320 t of limestone and
- 3200 t of air

About 90% of the iron contained in the ore is converted to pig iron. The remaining product is removed primarily as slag or as a gaseous *top gas*, which is combustible and is used for heating the incoming blast.

The pig iron produced contains 2.5-5% carbon, 1-3% silicon and various amounts of manganese, sulphur and phosphorus originally from the ore, or picked up from the coke.

How steel is produced?

- Steel is produced from molten blast furnace pig iron in a *converter* furnace by oxidizing the carbon, sulphur, phosphorus and other impurities in the pig iron.
- Molten pig iron is brought into contact with air, or more recently oxygen, so that impurities are burned by transforming them into oxides.
- The oxides are less dense than the molten steel and float on the surface as a liquid slag, which can be separated.
- In addition to pig iron, some converter furnaces can process recycled scrap steel.
- Due to the ability to process scrap, such converter furnaces are often the initial processing step at many steel mills.

https://www.youtube.com/watch?v=Ea_7Rnd8BTM

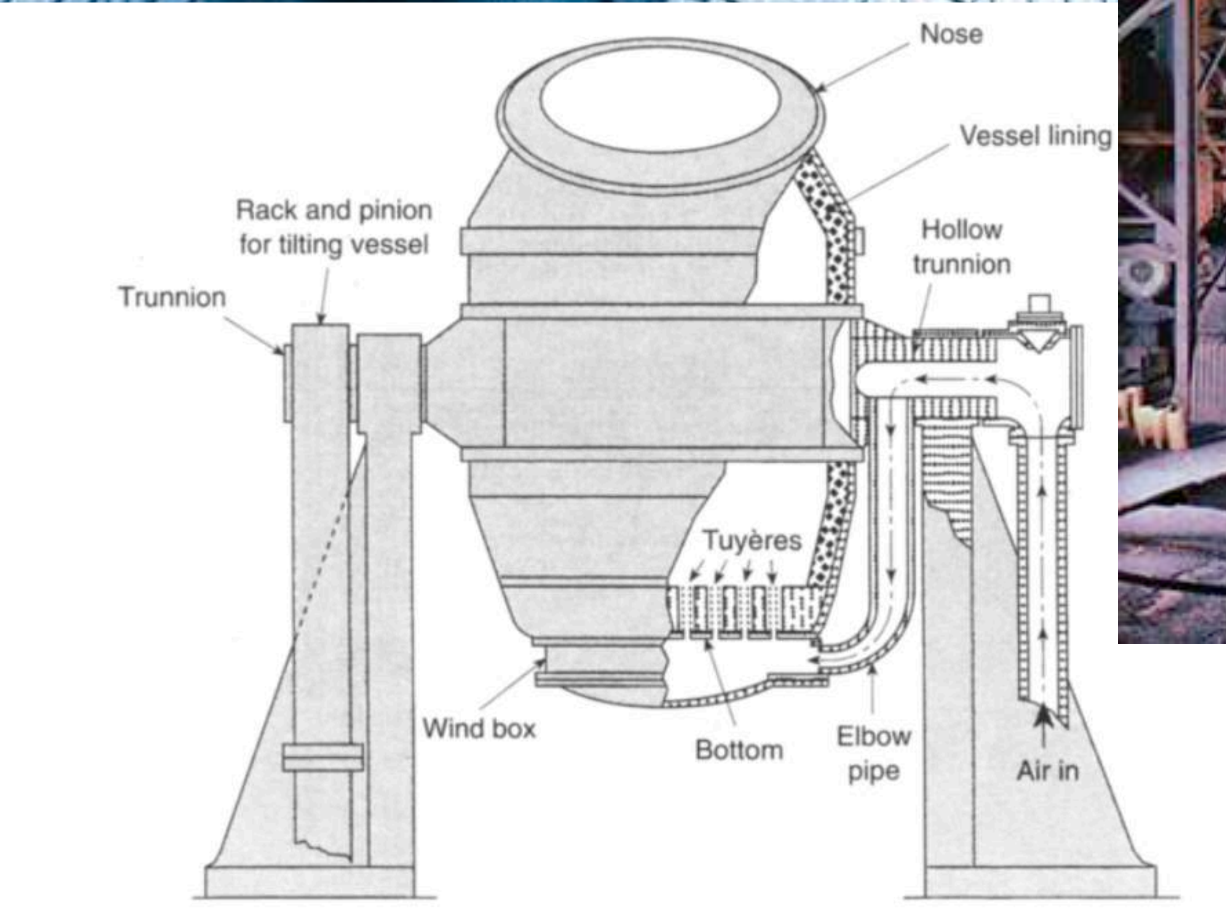


Fig. 1.2 Schematic of a Bessemer steel converter. (Reproduced courtesy of The AISE Steel Foundation.)

“Principles of Metal Manufacturing Processes” - J. Beddoes & M. J. Bibby, 1999 - Elsevier Butten North-Heinemann

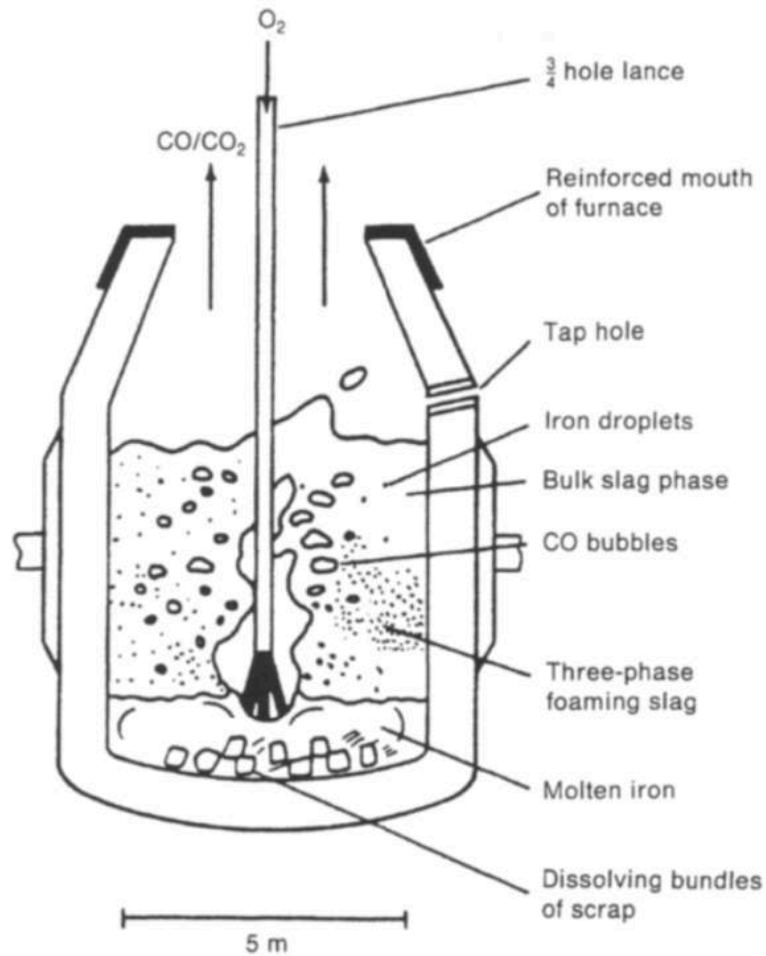
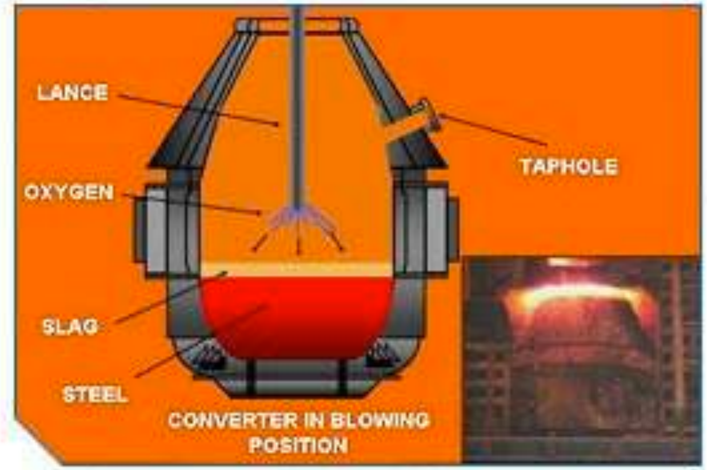


Fig. 1.4 Cross-section through a basic oxygen steel converter. (Reprinted with permission from *ASM Materials Engineering Dictionary*, edited by J.R. Davis (1992) ASM International, Materials Park, OH 44073-0002, Fig. 30, p. 33.)



LD Converter

"Principles of Metal Manufacturing Processes" - J. Beddoes & M. J. Bibby, 1999 - Elsevier Butten North-Heinemann

What is needed to produce steel?

- Where normally there are Steel Plants? Why?
- What is needed?

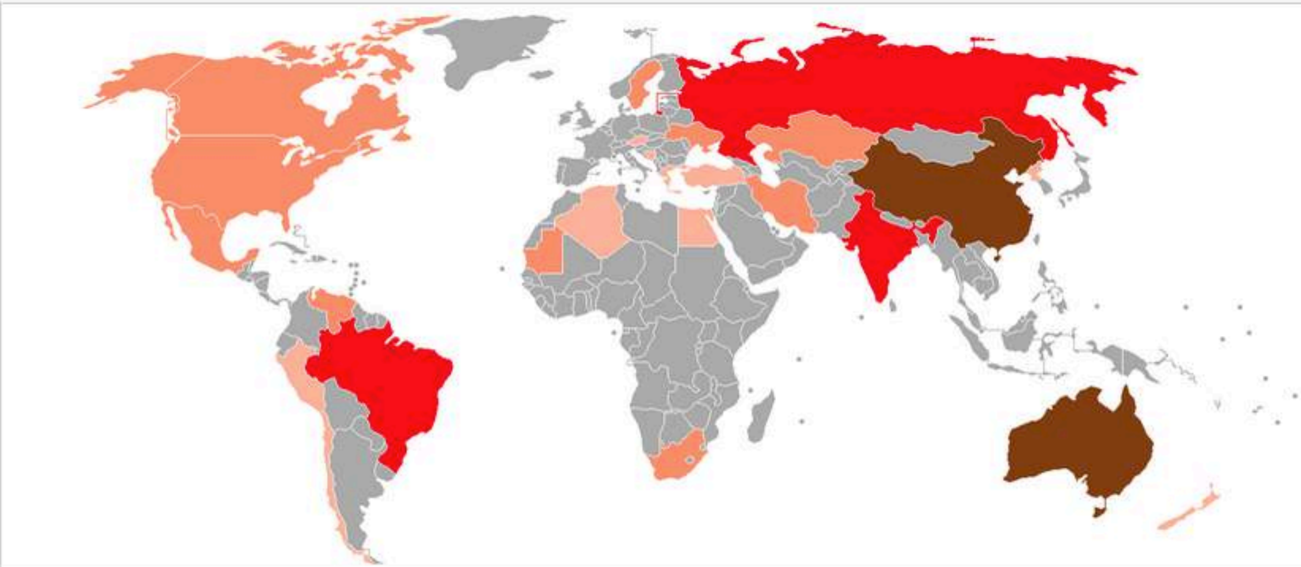
Waste and Energy?

During the manufacturing of steel, a significant amount of dust is produced that contains zinc and other metals and minerals generated from the steel making process.

This dust is typically extracted by the air pollution control system on an Electric Arc Furnace (EAF).

Steel plant waste is difficult to recycle back through the primary steel plant facility because of environmental compliance issues and their physical form as particulates/ dusts. The challenge is finding a viable solution that is capable of separating the valuable recyclable metals from the hazardous waste.

Where in the world can steel be produced?
Iron Ore Suppliers



World iron ore production (thousands of tonnes) in 2008:

- 500,000+
- 100,000–500,000
- 10,000–99,999
- 1,000–9,999
- 0–999

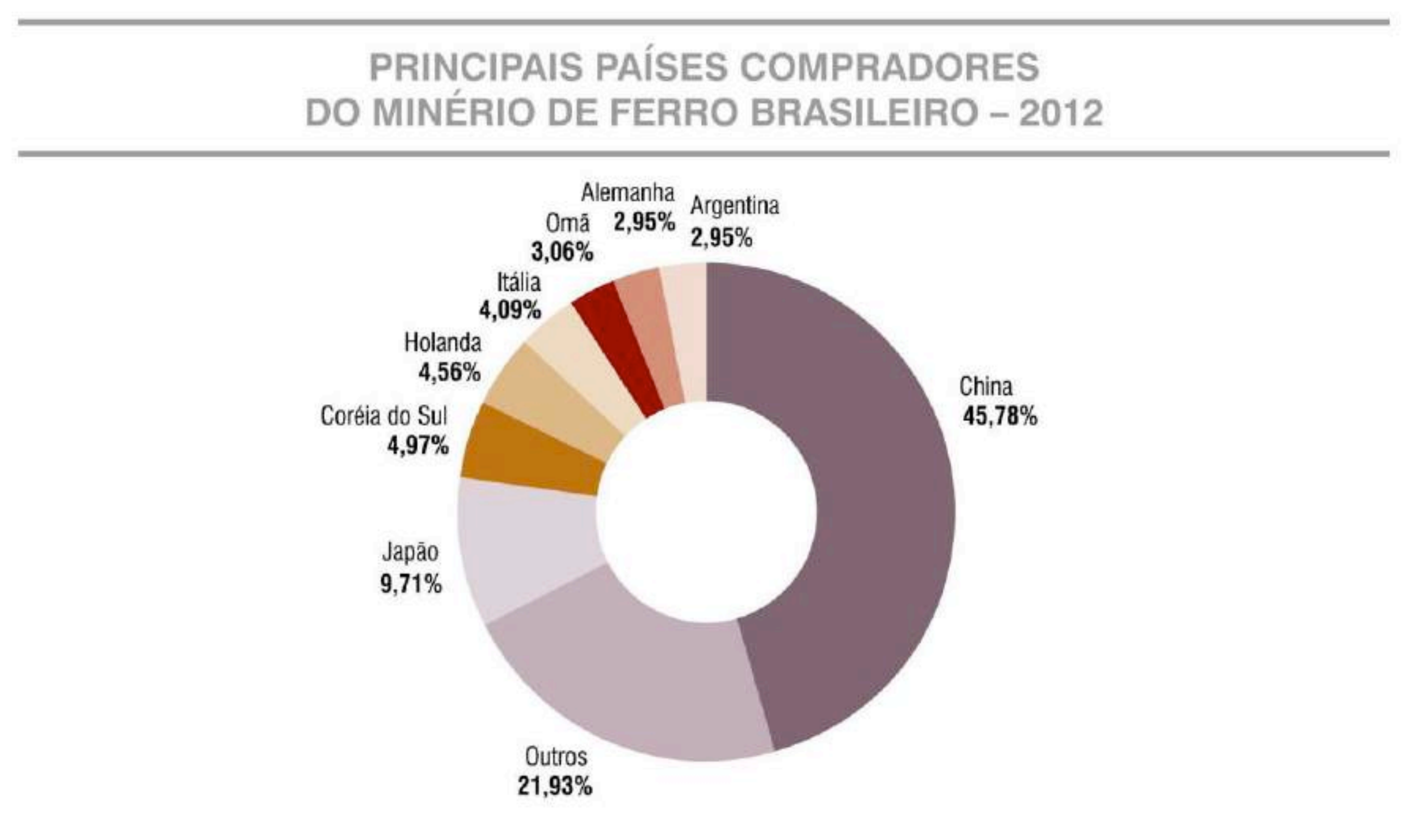
Estimated iron ore production in million metric tons for 2013 according to U.S. Geological Survey

Country	Productio
China	1320*
Australia	530
Brazil	398
India	240
Russia	102
Ukraine	80
South Africa	67
United States	52
Canada	40
Iran	37
Venezuela	30
Sweden	26
Kazakhstan	25
Chile	13
Other countries	60
Total world	2800

As maiores empresas produtoras no Brasil são: Vale com 84,52%, CSN com 5,45%, Samarco com 6,29%, MMX com 2,03% e Usiminas com 1,71%.

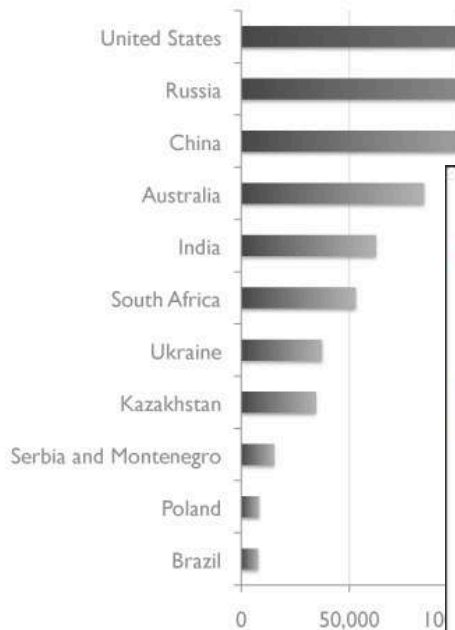
Os principais estados produtores no Brasil são: MG (67%), PA (29,3%) e outros (3,7%).

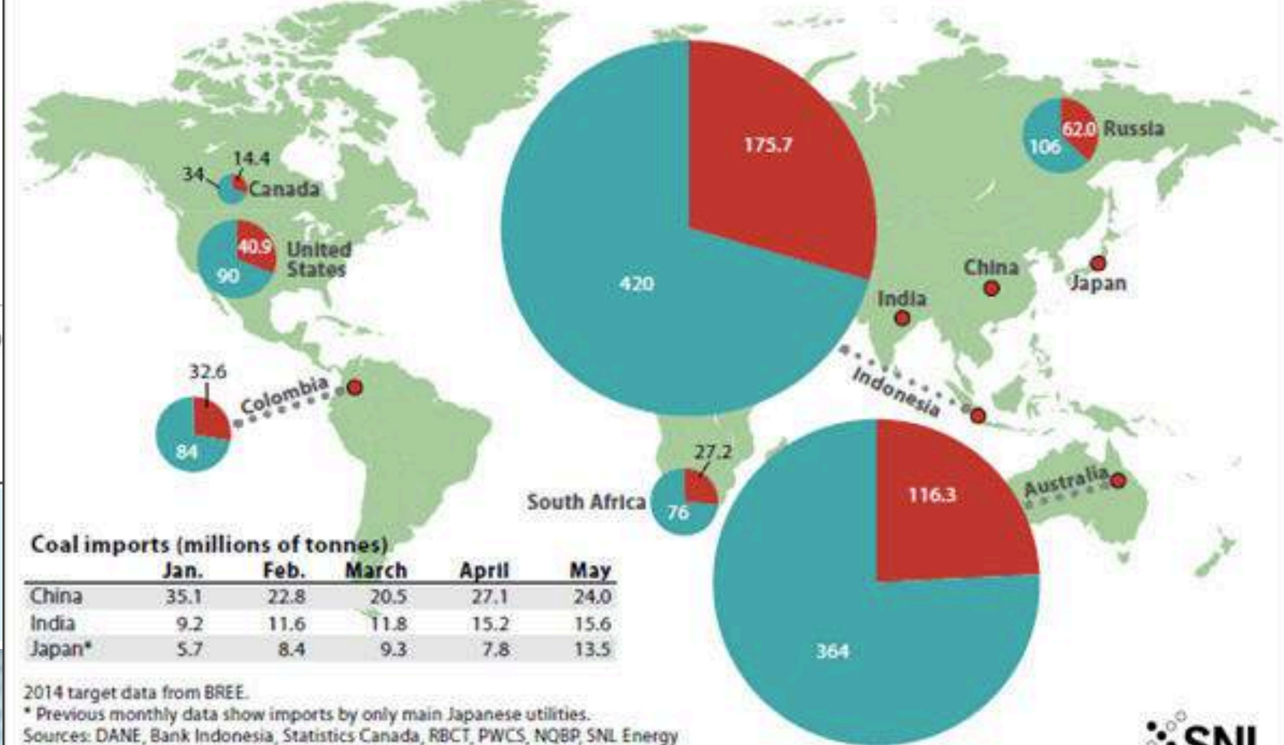
Brazil as a Iron Ore Supplier



COAL

WORLD RECOVERABLE RESERVES





Coal imports (millions of tonnes)

	Jan.	Feb.	March	April	May
China	35.1	22.8	20.5	27.1	24.0
India	9.2	11.6	11.8	15.2	15.6
Japan*	5.7	8.4	9.3	7.8	13.5

2014 target data from BREE.
* Previous monthly data show imports by only main Japanese utilities.
Sources: DANE, Bank Indonesia, Statistics Canada, RBCT, PWCS, NQBP, SNL Energy
Credit: Cat VanVliet

In what “forms” (geometries) steel is produced? How steel is sold?

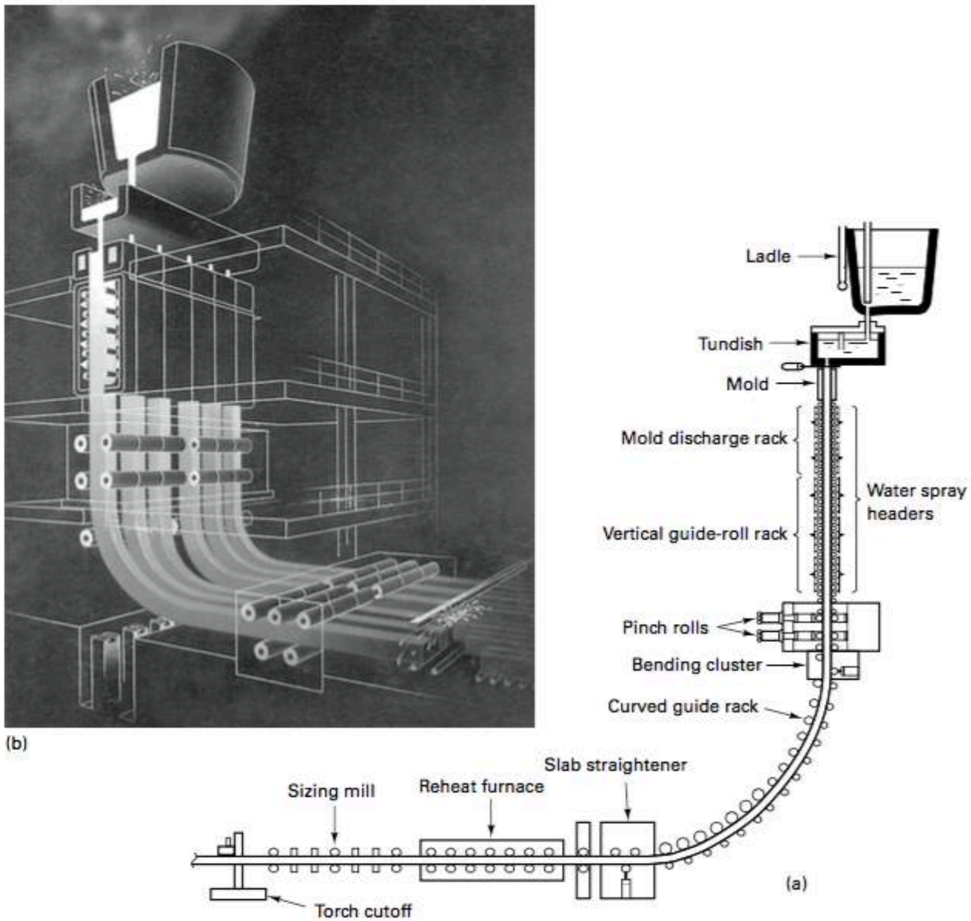
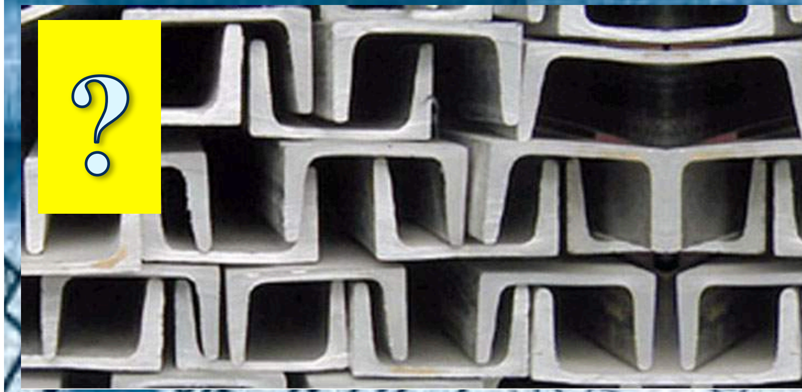


FIGURE 7-3 (a) Schematic representation of the continuous casting process for producing billets, slabs, and bars. (b) Simultaneous continuous casting of multiple strands. *(Reproduced with permission from Penton Media)*




85h11/h10
10


亚 泰
www.shyatai.com

HOME WORK (For next class)

- What are the companies of selling steel in your home country ?
- Could you search the medium prices of steel?
- In what forms? Bars? Slab? Ingot?