2015-2016 Spring Semester Material and Energy Balance

Energy Requirements

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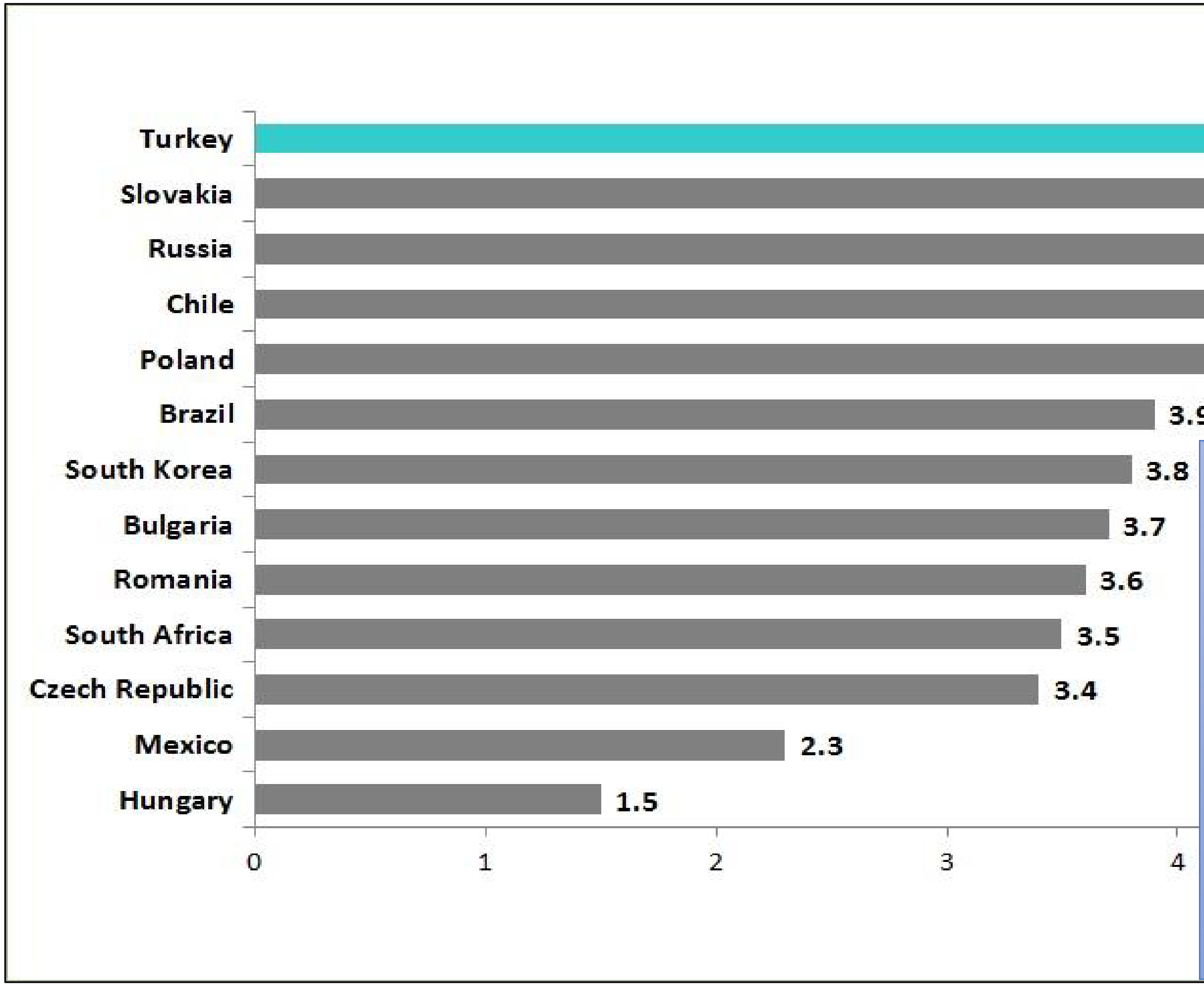
23.02.2016

2nd Week

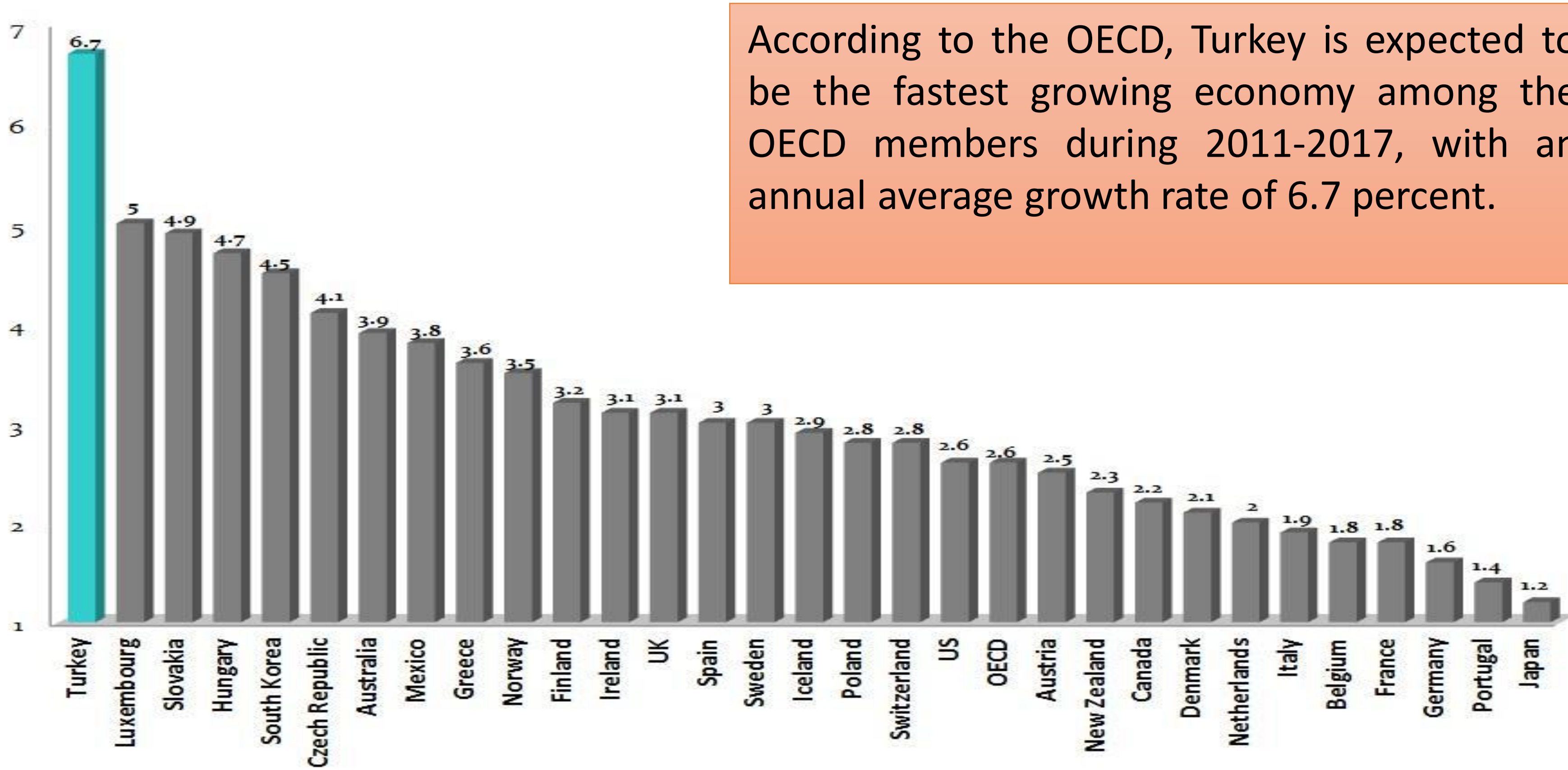
Average Annual Real GDP Growth (%) 2002-2011



- As the GDP levels more than tripled to USD 772 billion in 2011, up from USD 231 billion in 2002,
- GDP per capita soared to USD 10,444, up from USD 3,500 in the given period

Source: IMF World Economic Outlook April 2012, Turkish Statistical Institute (TurkStat)

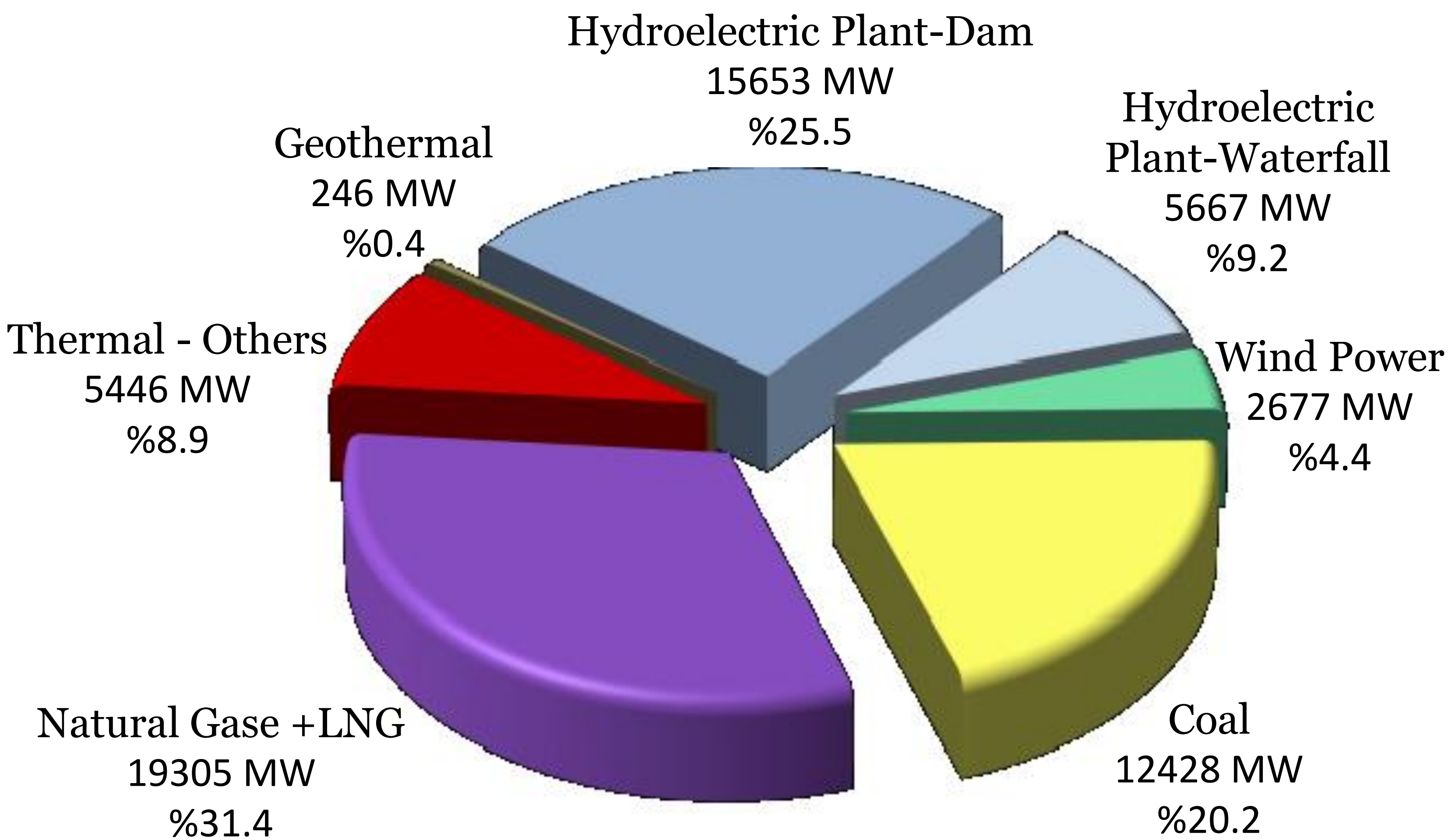
Annual Average Real GDP Growth (%) Forecast in OECD Countries 2011-2017



According to the OECD, Turkey is expected to be the fastest growing economy among the OECD members during 2011-2017, with an annual average growth rate of 6.7 percent.

Source: OECD Economic Outlook No: 86

INSTALLED POWER CAPACITY (MW) OF TURKEY (30.09.2013)



INSTALLED POWER CAPACITY : 61422 MW

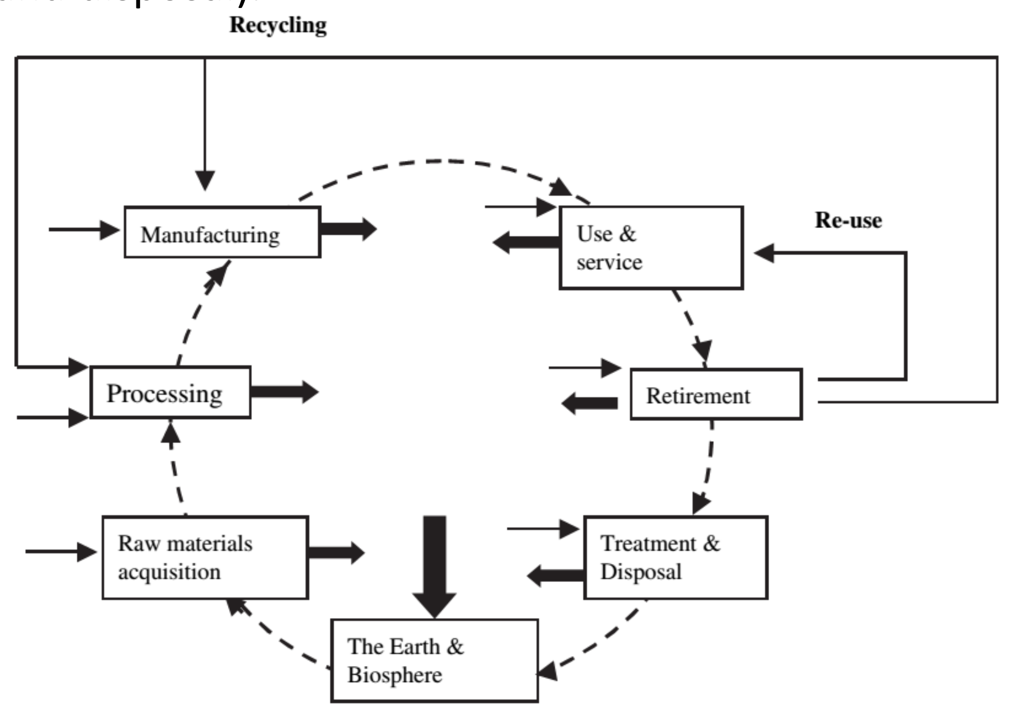
Source: TEİAŞ 08.10.2013 (http://www.emo.org.tr/genel/bizden_detay.php?kod=88369)

Life Cycle Assessment

Life Cycle Assessment (LCA) methodology essentially involves the compilation of an inventory of relevant environmental exchanges during the life cycle of a product and evaluating the potential environmental impacts associated with those exchanges. The full product life cycle is usually divided into the following stages

- cradle to entry gate (raw material extraction to refining);
- entry gate to exit gate (product manufacture);
- exit gate to grave (product use, recycling and disposal).

The form of energy use included in LCAs is the Gross Energy Requirement (GER), also referred to as embodied energy or cumulative energy demand, which is the cumulative amount of primary energy consumed in all stages of a metal's production life cycle.



The product life cycle system.

Source:
Journal of Cleaner Production 15 (2007) 838-848

Energy intensities of common materials

In general, metals consume significantly more energy in their production than both ceramic and plastic materials, the high energy intensities associated with wood and plastics largely reflect their inherent fuel value rather than energy associated with production. There are important physical and chemical reasons for the high energy consumption associated with metal productions, namely: chemical stability, availability and processing route.

1Mj/kg = 277.78 kWh/t

	Material	Energy intensity (MJ/kg)
Metals	Aluminium	227 - 342
	Copper	60 - 125
	Lead	30 - 50
	Silicon	230 - 235
	Steel	20 - 50
Ceramic	Bricks	2 - 5
	Cement	5 - 9
	Glass	18 - 35
	Gravel	0.08 - 0.1
	Limestone	0.07 - 0.1
	Sand	0.08 - 0.1
Organic	Paper	25 - 50
	Plastics	60 - 120
	Wood	3 - 7

Source: Green Processing Conference, 281-286

Energy Use in Metal Production

Energy is consumed at all stages in the production of primary metals – mining, beneficiation and chemical extraction – directly in the processes and indirectly through the production of inputs used in the processes.

The sum of the direct and indirect energies of the individual stages along the value-adding chain is the embodied energy of the metal.

The main factors determining the embodied energy content of primary metals are:

- the stability of the minerals from which the metal is produced (determined by the ΔG of formation);
- the ore grade, since the lower the grade, the more ore that has to be mined and processed per unit of metal produced;
- the degree of beneficiation required, particularly grinding to achieve liberation since this is the most energy intensive operation in beneficiation; and
- the overall recovery, since losses along the value-adding chain require more ore to be mined per unit of metal produced.

Source: High Temperature Processing Symposium 2012, Presentation-1, 7-9

Mining and mineral processing operations

The extraction of metallic ores involves both surface (open-pit) and underground mining techniques. The method selected depends on a variety of factors, including the nature and location of the deposit, and the size, depth and grade of the deposit. Underground mining requires more energy than surface mining due to greater requirements for hauling, ventilation, water pumping and other operations.

Drilling

Drilling is the act or process of making a cylindrical hole with a tool for the purpose of exploration, blasting preparation, or tunneling.

Drilling equipment includes explosive loader trucks, diamond drills, rotary drills, percussion drills and drill boom jumbos.

Drills are run from electricity, diesel power and to a lesser extent, indirectly from compressed air. The energy is used to power components of the drill that perform tasks such as hammering and rotation.

The number of drilling machines is about 2–6 depending on the mine production capacity.

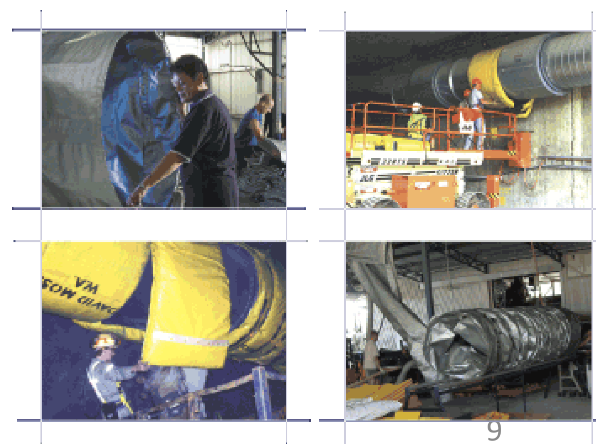
Source: Journal of Cleaner Production 18 (2010) 266–274

Blasting

Blasting uses explosives to aid in the extraction or removal of mined material by fracturing rock and ore by the energy released during the blast. The energy consumed in the blasting process is derived from the chemical energy contained in the blasting agents. This sets blasting apart from other processes, which are powered by traditional energy sources, such as electricity and diesel fuel. A common explosive used for mining is ammonium nitrate/fuel oil (ANFO) mixture. The powder factor is the amount of explosives used per unit of rock blasted, and varies depending on the rock type and strength. The blast holes are detonated with a nonel (non-electric) device for firing.

Ventilation

Ventilation is the process of bringing fresh air to the underground mine workings while removing stale and/or contaminated air from the mine and also for cooling work areas in deep underground mines. The mining industry uses fan systems for this purpose.



Source: Journal of Cleaner Production 18 (2010) 266–274

Dewatering

Dewatering is the process of pumping water from the mine workings. Pumping systems are large energy consumers. This study assumes that centrifugal pumps are used for dewatering the mine during ore extraction.

Loading and haulage

In open-pit mines, the broken rocks are generally excavated by either front-end loaders, excavators or shovels and loaded into a dump truck for haulage to the processing plant. Most mines have a loading fleet including wheel loaders, shovel units and excavators. The wheel loaders have a capacity ranging from 50 to 90 tonnes, while the shovel units and excavators have capacities ranging from 200 to 250 tonnes. The haulage units typically include off-road dump trucks with carrying capacities ranging from 150 to 300 tonnes of rocks. Typical number of these haul trucks can be from 10 to 22 depending the mine size. Much of the equipment used in the transfer or haulage of materials in mining is powered by diesel engines.

Source: Journal of Cleaner Production 18 (2010) 266–274

Auxiliary equipment

On most mine sites, there is other equipment such as dozers, graders, excavators and water tankers. They are used for road construction, maintenance and dust suppression within the mine site. It is assumed that these units use diesel fuel for their operation.

Crushing and grinding

Crushing is the process of reducing the size of run-of-mine material into coarse particles (typically coarser than 5 mm). Grinding is the process of reducing the size of material into fine particles (often below 0.1 mm or 100µm).

Crushing and grinding plants are usually powered by electric motors, with the electricity often generated onsite using a diesel fuel-based engine and generator. Crushing plants can include primary, secondary and tertiary crushers, while grinding plants can include SAG, rod and ball mills

Source: Journal of Cleaner Production 18 (2010) 266–274

Separations

The separation of mined material is achieved primarily by physical separations rather than chemical separations, where valuable substances are separated from undesired substances based on the physical properties of the materials. There is a wide variety of equipment used for separation processes, the largest energy-consuming separation method amongst these being centrifugal separation for coal mining, and flotation for metals and minerals mining. Flotation machines are designed to isolate valuable ore from other non-valuable substances. The surfaces of mineral particles are treated with chemical reagents to make some selectively hydrophobic. The ore is suspended in water that is mechanically agitated and aerated. The mineral particles that have been rendered hydrophobic attach to air bubbles and rise to the surface where they can be collected. In the case of iron ore mining, screening is the most common separation process which is used to separate the ore into lump and fines streams, while magnetic separation is used to separate magnetite from gangue

Source: Journal of Cleaner Production 18 (2010) 266–274

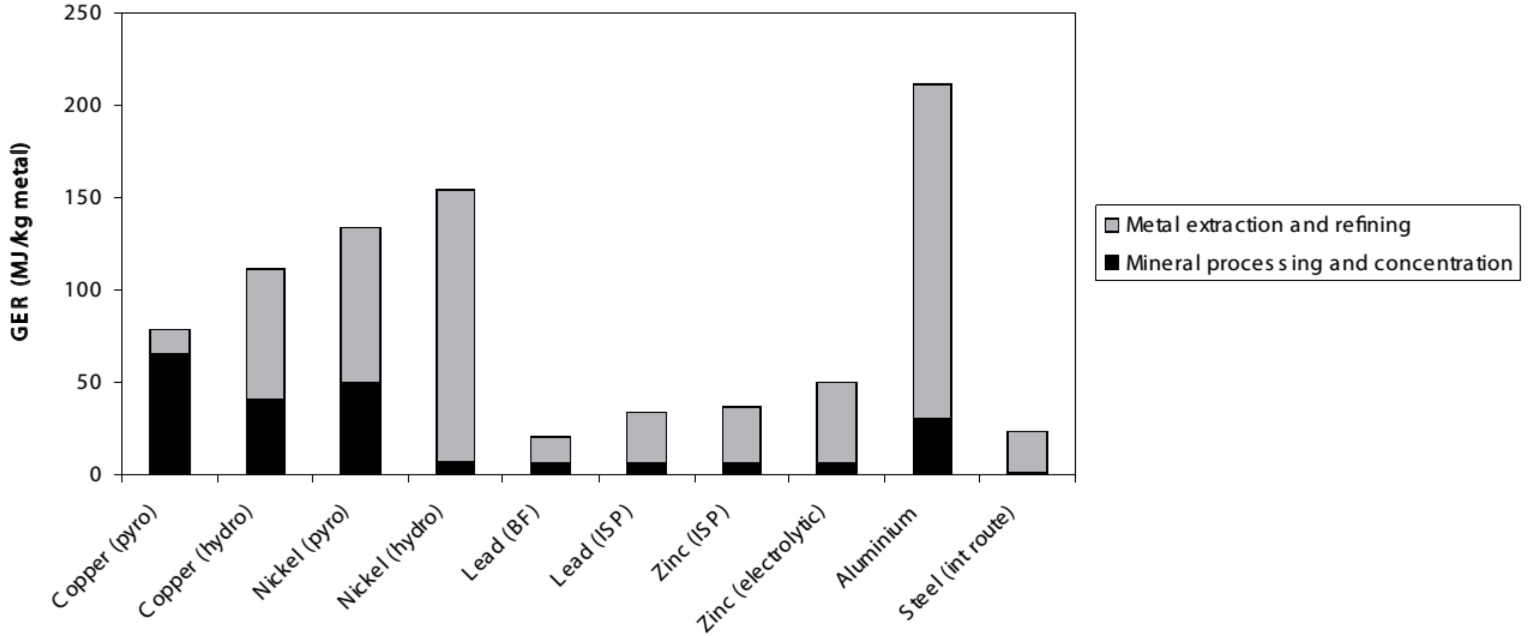


FIG 1 - Embodied energy (GER) for primary metal production.

World metal production and ore processing rates (Mt/y).

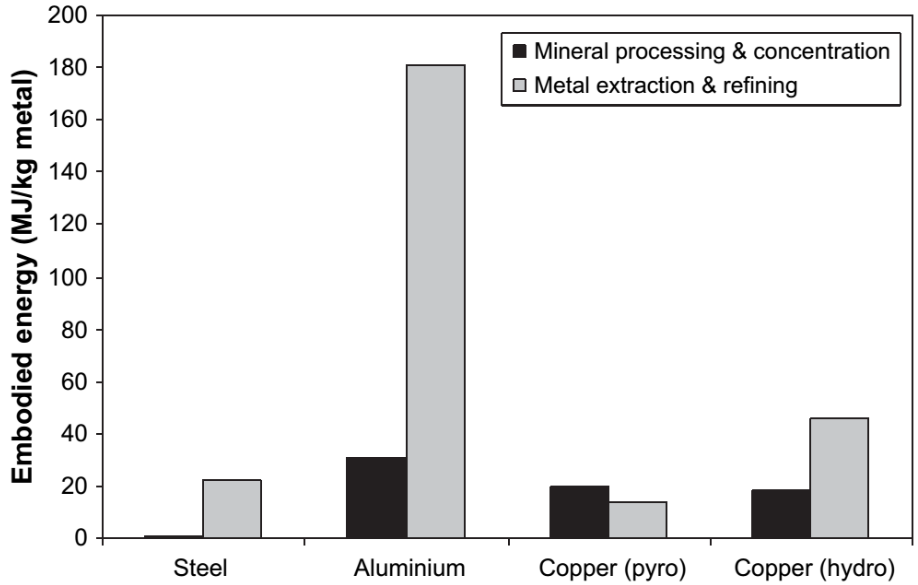
	Copper	Nickel	Lead	Zinc	Iron/steel	Aluminium
Metal	15.5	1.4	8.7	11.7	1327	25.7
Ore	1914	111	193	260	2633	143

World average ore grades – current and projected to 2030 (per cent metal).

	Copper	Nickel		Lead	Zinc	Iron	Aluminium
		Sulfides	Laterites				
Current	0.9	1.4	1.3*	5.0	5.0	56	20
2030	0.7	1.1	1.0	4.0	4.0	56	20

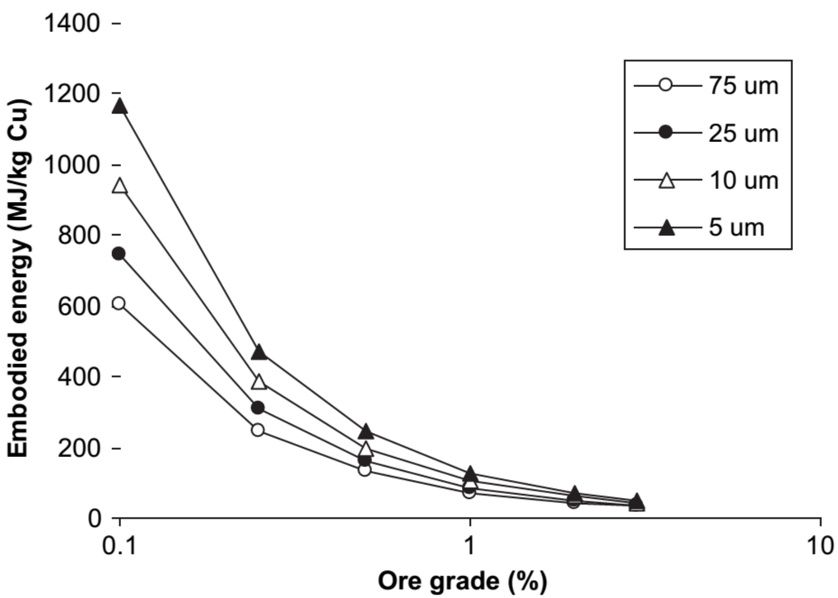
* Hydrometallurgical processing 1.55 per cent, pyrometallurgical processing 1.15 per cent.

Source: XXV International Mineral Processing Congress (2010) Proceedings, 3575-3584

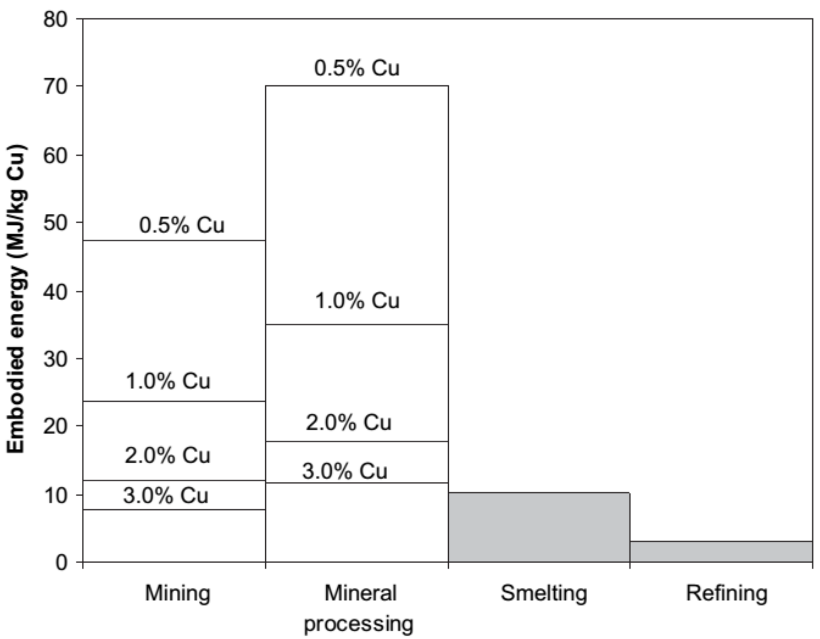


1MJ/kg = 277.78 kWh/t

Processing stage contributions to embodied energy of steel, aluminium and copper production



Combined effect of ore grade and grind size on embodied energy for pyrometallurgical copper production.



Effect of ore grade on embodied energy for pyrometallurgical copper production.

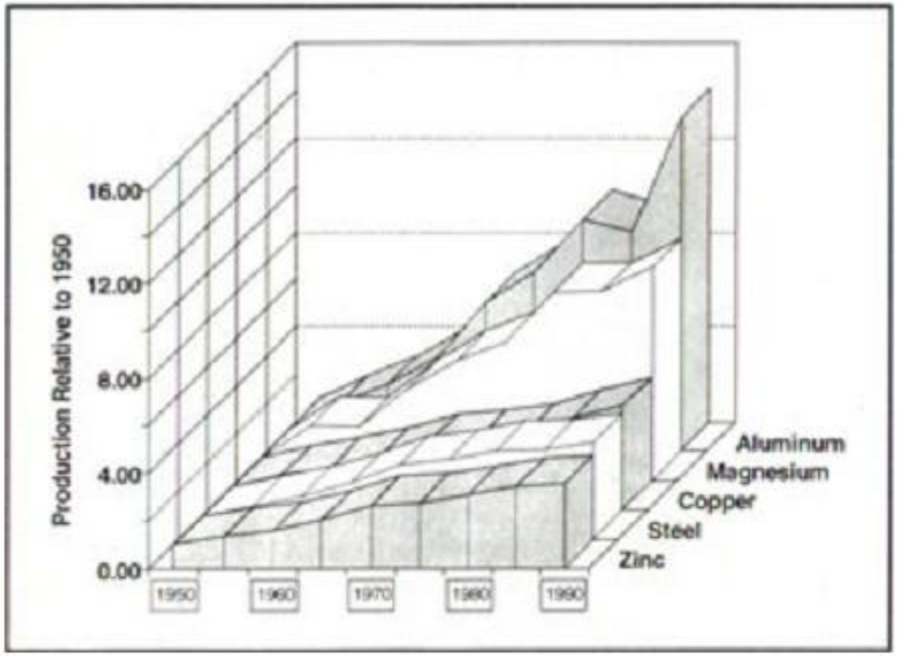
Source: Journal of Cleaner Production 18 (2010) 266–274

Energy and greenhouse gas results

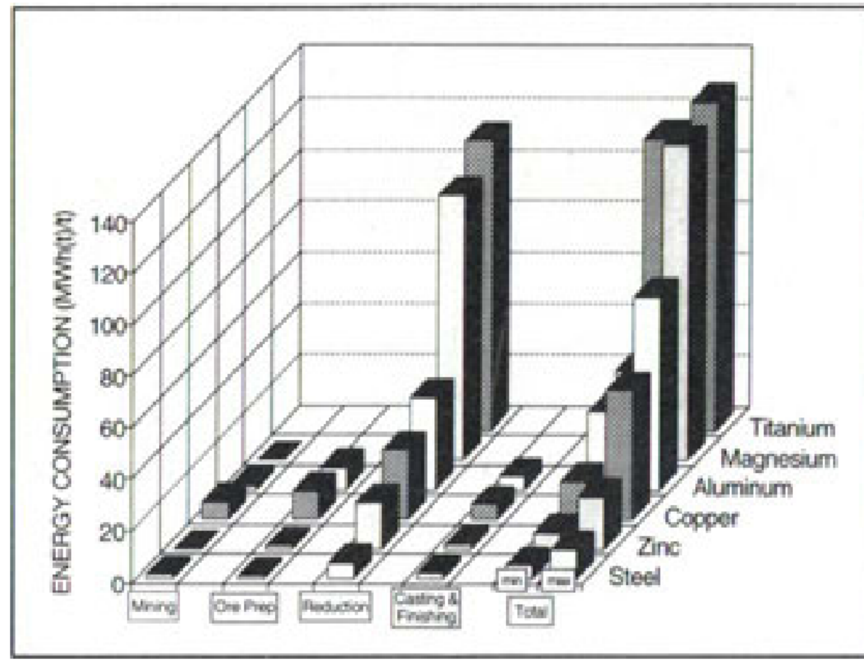
Metal ore	Energy (MJ/t ore[a] or conc.[b])	GWP (kg $CO2_e$/t ore[a] or conc.[b])
Iron ore	(%)	(%)
- Drilling	1.3 (0.9)	0.1 (0.8)
- Blasting	3.3 (2.2)	0.7 (5.9)
- Loading & hauling	92.1 (60.3)	6.0 (50.5)
- Crushing & screening	23.1 (15.1)	2.5 (21.0)
- Stacking & reclaiming	4.6 (3.0)	0.5 (4.2)
- Rail transport	20.9 (13.7)	1.3 (10.9)
- Port operations	7.4 (4.8)	0.8 (6.7)
- Total	152.7	11.9
Bauxite	(%)	(%)
- Drilling	1.2 (2.2)	0.1 (2.0)
- Blasting	2.0 (3.6)	0.4 (8.2)
- Loading & hauling	36.1 (65.8)	2.6 (53.1)
- Crushing & screening	14.7 (26.8)	1.7 (34.7)
- Beneficiation	0.9 (1.6)	0.1 (2.0)
- Total	54.9	4.9
Copper concentrate	(%)	(%)
- Drilling	720 (8.6)	30.8 (4.9)
- Blasting	43 (0.5)	9.1 (1.4)
- Loading & hauling	2059 (24.7)	88.1 (14.0)
- Ventilation	1417 (17.0)	127.0 (20.2)
- Dewatering	673 (8.1)	60.3 (9.6)
- Crushing & grinding	3277 (39.4)	293.7 (46.8)
- Concentrating	140 (1.7)	19.2 (3.1)
- Total	8329	628.2

1MJ/t = 0.27 kWh/t

Source: Journal of Cleaner Production 18 (2010) 266–274



Trends in Metal Production 1990-2000



Energy consumption by process in MWh (thermal)/t

Table II. Energy Consumption in the Production of Various Metals

	Energy Consumption (kWh [thermal]/tonne of primary metal)*					
	Aluminum	**Steel**	**Copper**	**Zinc**	**Magnesium**†	**Titanium**
Mining	1,668	1,711	6,500	139	0	NEA
Ore Preparation	8,507	922	10,920	1,101	NEA	NEA
Smelting	35,384	6,055	26,520	17,560	103,000	113,000
Casting & Finishing	4,937	2,452	5,970	1,492	NEA	NEA
Total						
Minimum	30,000‡	5,321	14,370	6,125	35,000‡	113,700
Maximum	75,000	11,140	49,910	20,300	123,000	127,900

Table III. The Gibbs Free-Energy and Smelting Fuel Requirements for the Major Metals

Metal	Gibbs Free Energy, ΔG (GJ/t)	Direct Fuel (GJ/t)	Direct Efficiency (%)	Smelting (GJ/t)	Overall Efficiency (%)
Aluminum	29.2	54	54	228	13
Iron	6.6	15.1	44	25	26
Copper	0.68	7.6	9	47	1.4
Zinc	3.04	25.3	12	55	5.5
Magnesium	24.2	50	48	393	6.1
Titanium	17.8	177	10	430	4.1

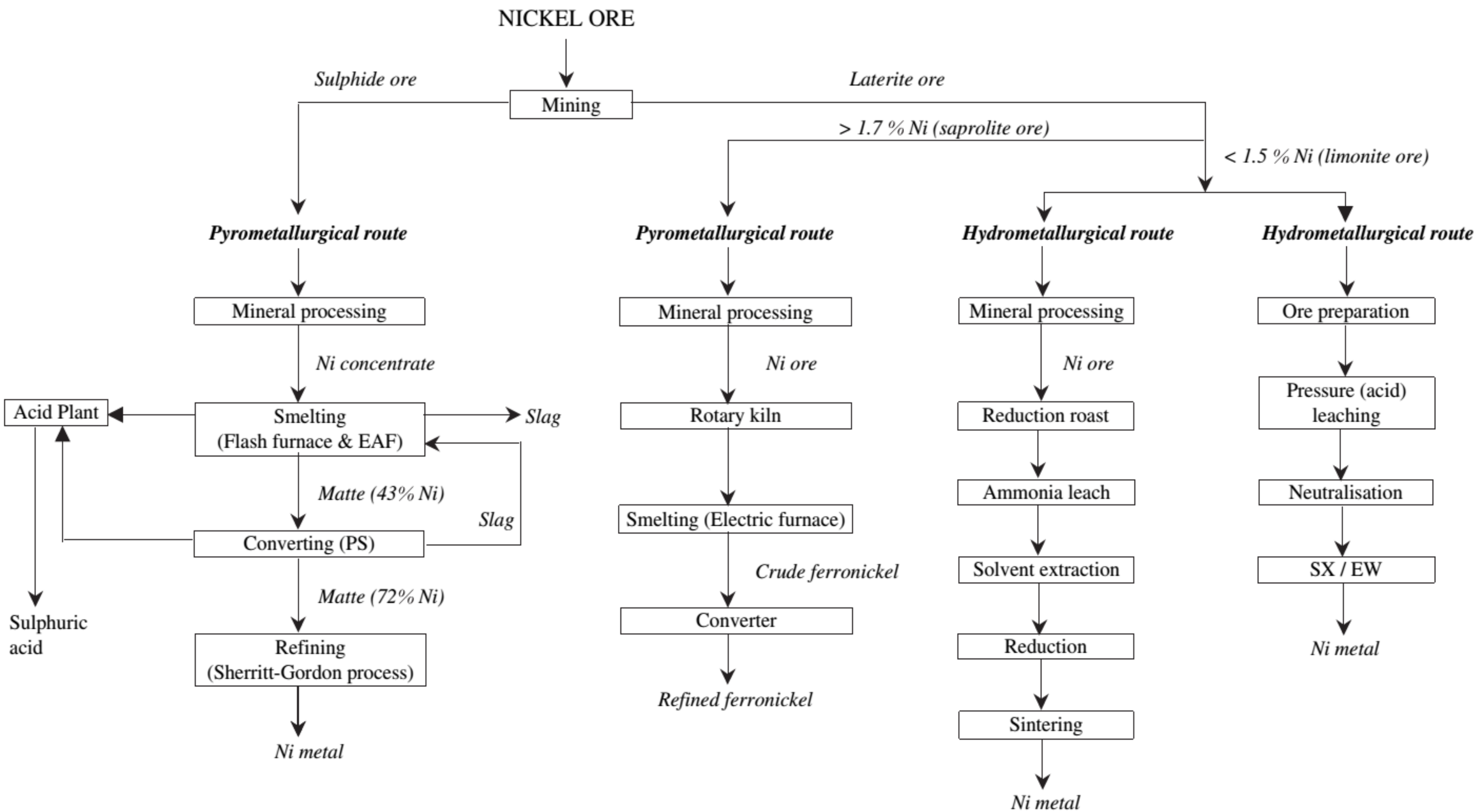
Source: JOM (1993) 45 (5) 15-20

Metal Production Processes and Production Rate

Metal	Raw Material	Process	World Production
Nickel	Sulphide ore (2.3% Ni) Laterite ore (1.0% Ni)	Flash furnace smelting and Sherritt-Gordon refining Pressure acid leaching and solvent extraction/ electrowinning (SX/EW)	2.1 million Mt (2013)
Copper	Sulphide ore (3.0% Cu) Sulphide ore (2.0% Cu)	Smelting/converting and electro-refining Heap leaching and SX/EW	17.0 million Mt (2013)
Lead	Sulphide ore (5.5% Pb, 8.6% Zn)	Lead blast furnace Imperial smelting process	5.2 million Mt (2013)
Zinc	Sulphide ore (5.5% Pb, 8.6% Zn)	Electrolytic process Imperial smelting process	13.0 million Mt (2013)
Aluminum	Bauxite ore (17.4% Al)	Bayer refining, HalleHeroult smelting	44.9 million Mt (2013)
Titanium	Ilmenite (36.0% Ti)	Becher and Kroll processes	0.2 million Mt (2013)
Steel	Iron ore (64% Fe)	Integrated route (blast furnace (BF) and basic oxygen furnace (BOF))	1.5 billion Mt (2013)
Stainless Steel	Pig iron (94% Fe), chromite ore (27.0% Cr, 17.4% Fe) laterite ore (2.4% Ni, 13.4% Fe)	Electric furnace and Argoneoxygen decarburisation (AOD)	35.4 million Mt (2012)

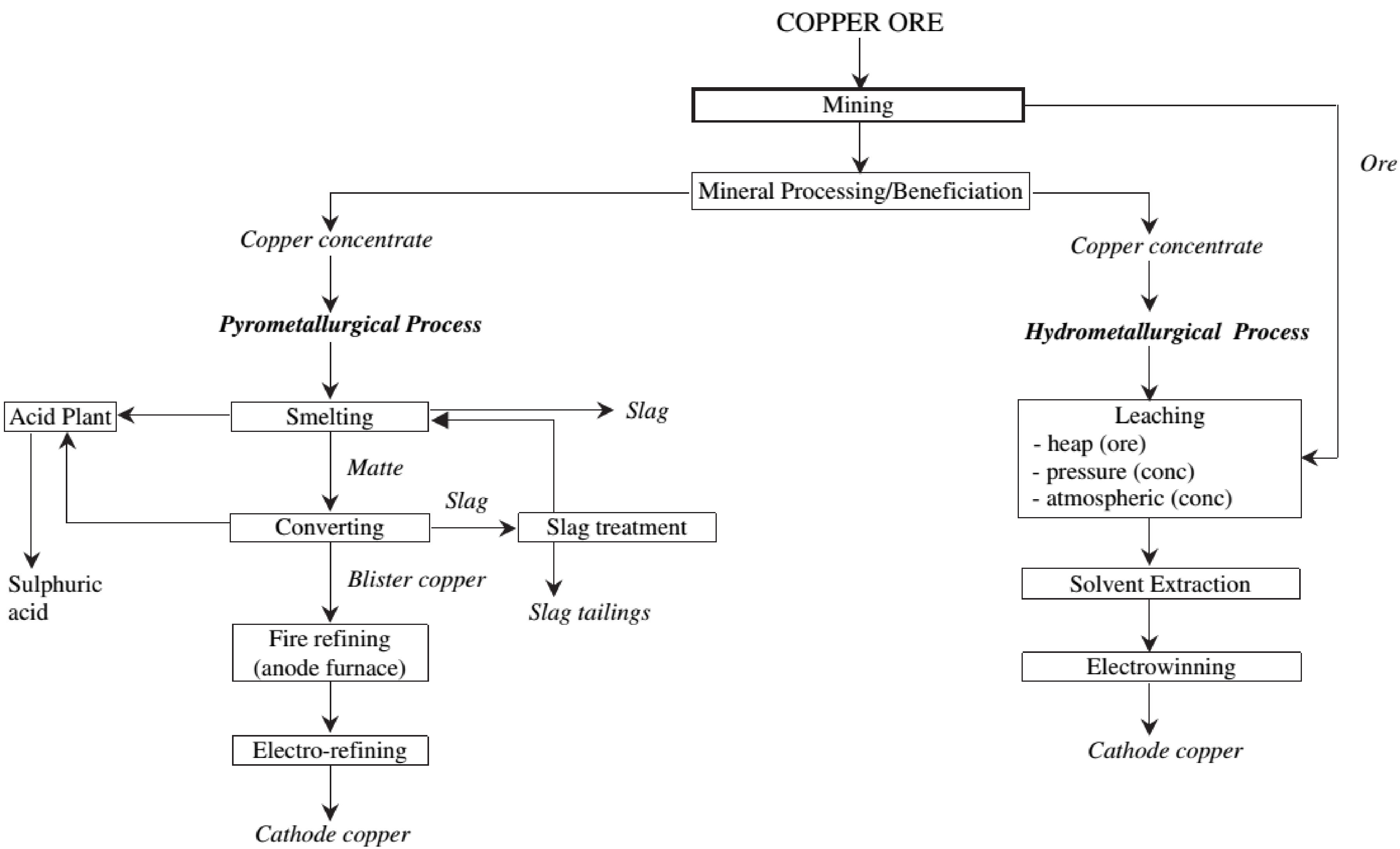
Source: Journal of Cleaner Production 15 (2007) 838-848

Main Processing Routes for Nickel Production



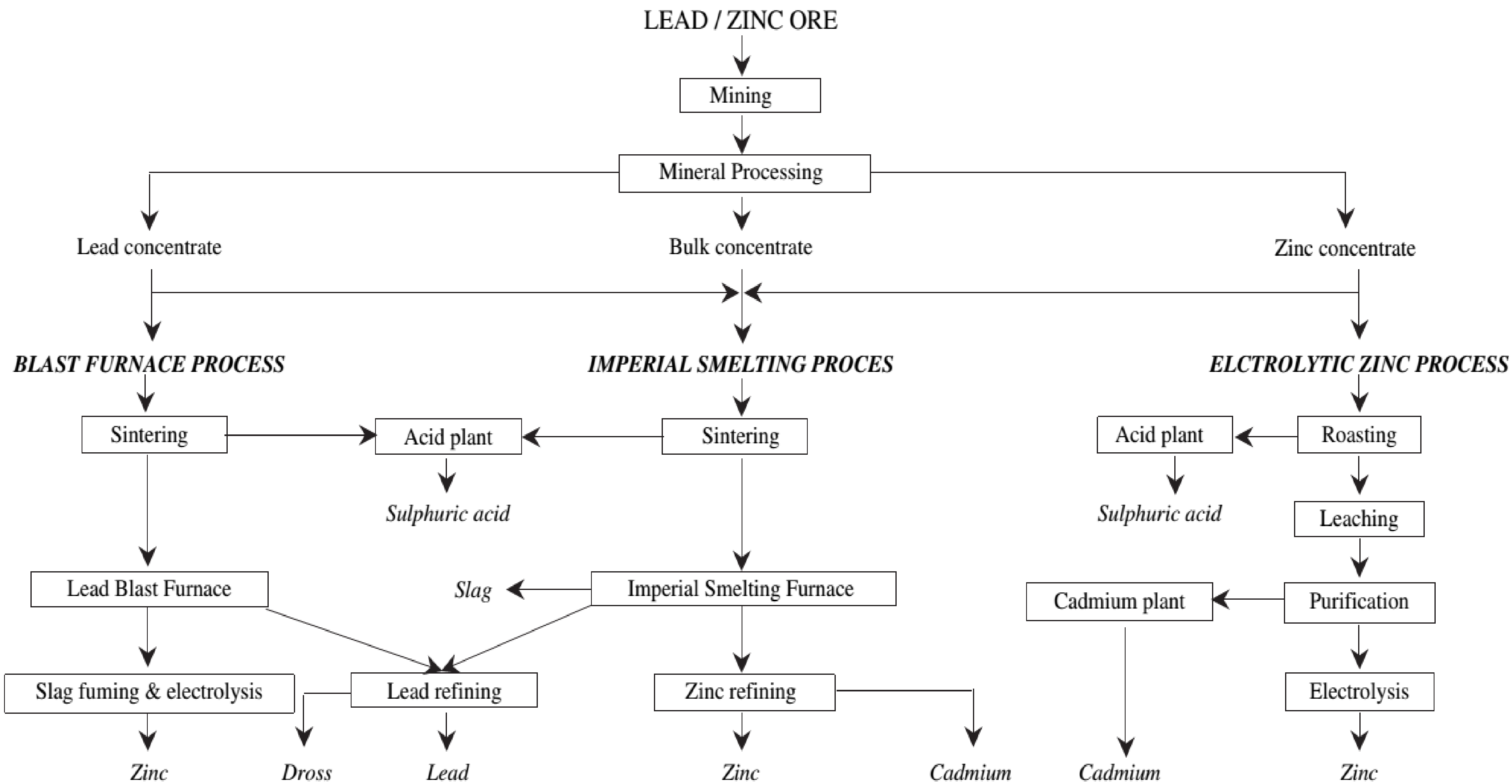
Source: Journal of Cleaner Production 15 (2007) 838-848

Main Processing Routes for Copper Production



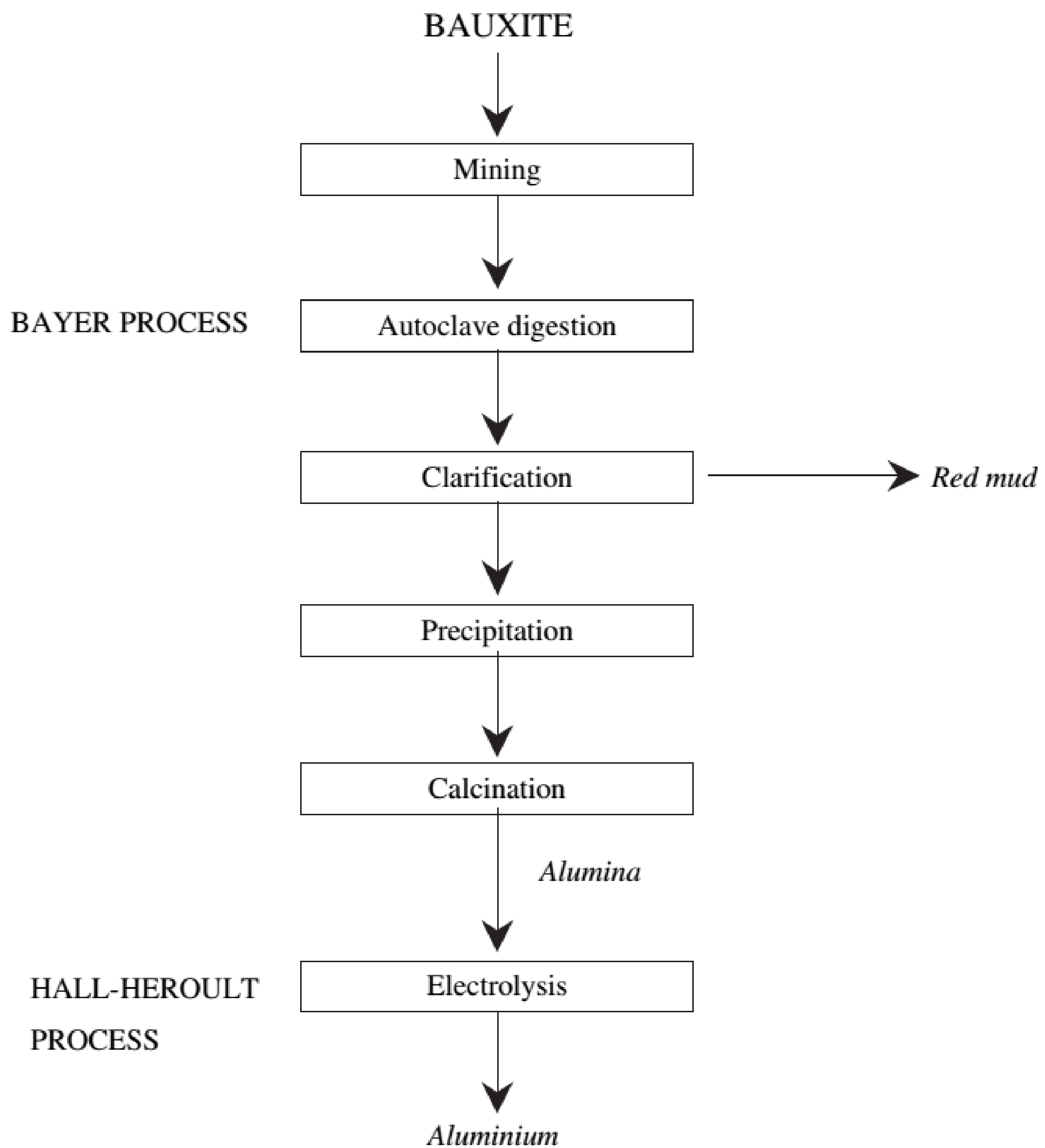
Source: Journal of Cleaner Production 15 (2007) 838-848

Main Processing Routes for Lead and Zinc Productions



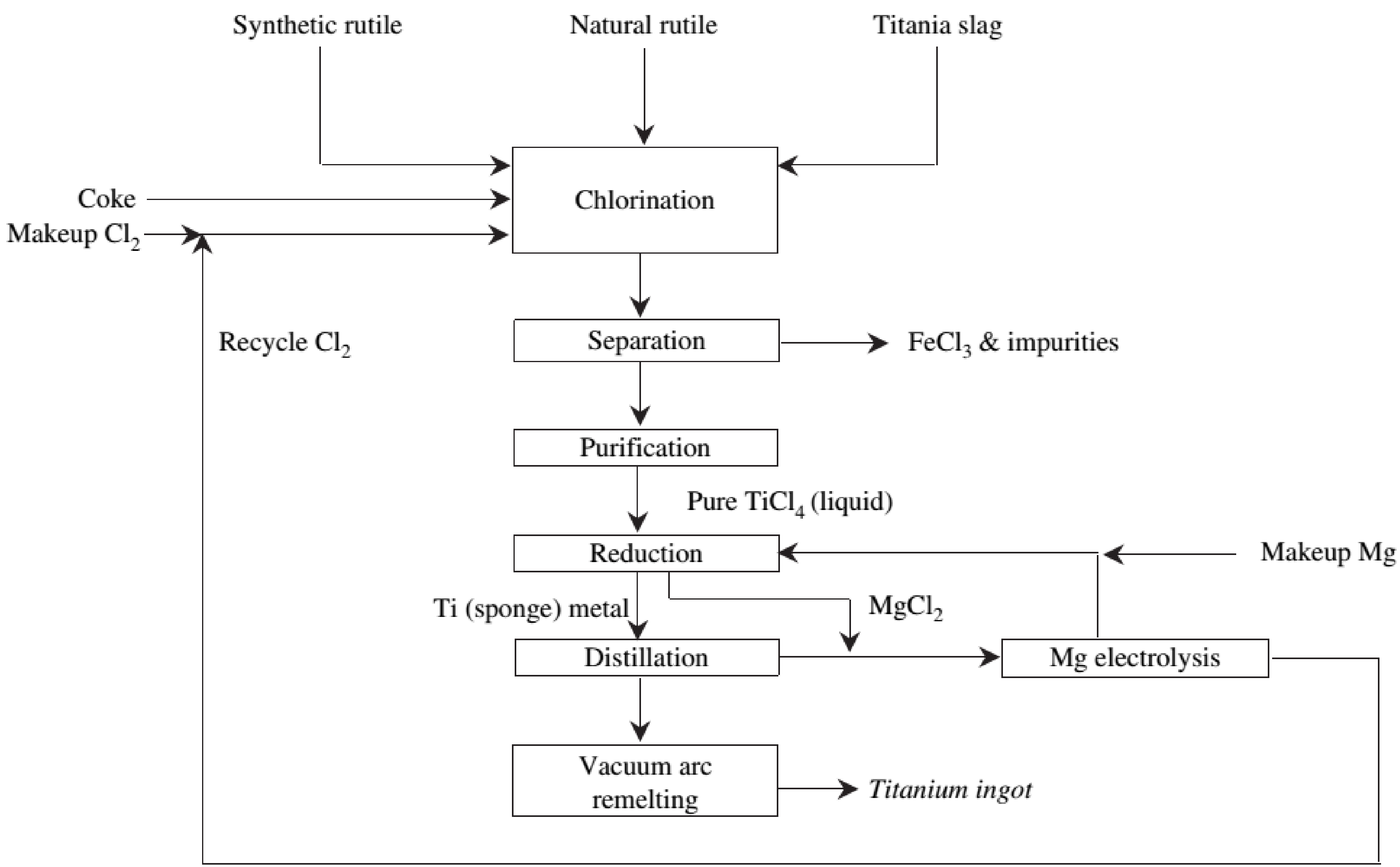
Source: Journal of Cleaner Production 15 (2007) 838-848

Bayer and Hall-Heroult Processes for Aluminum Production



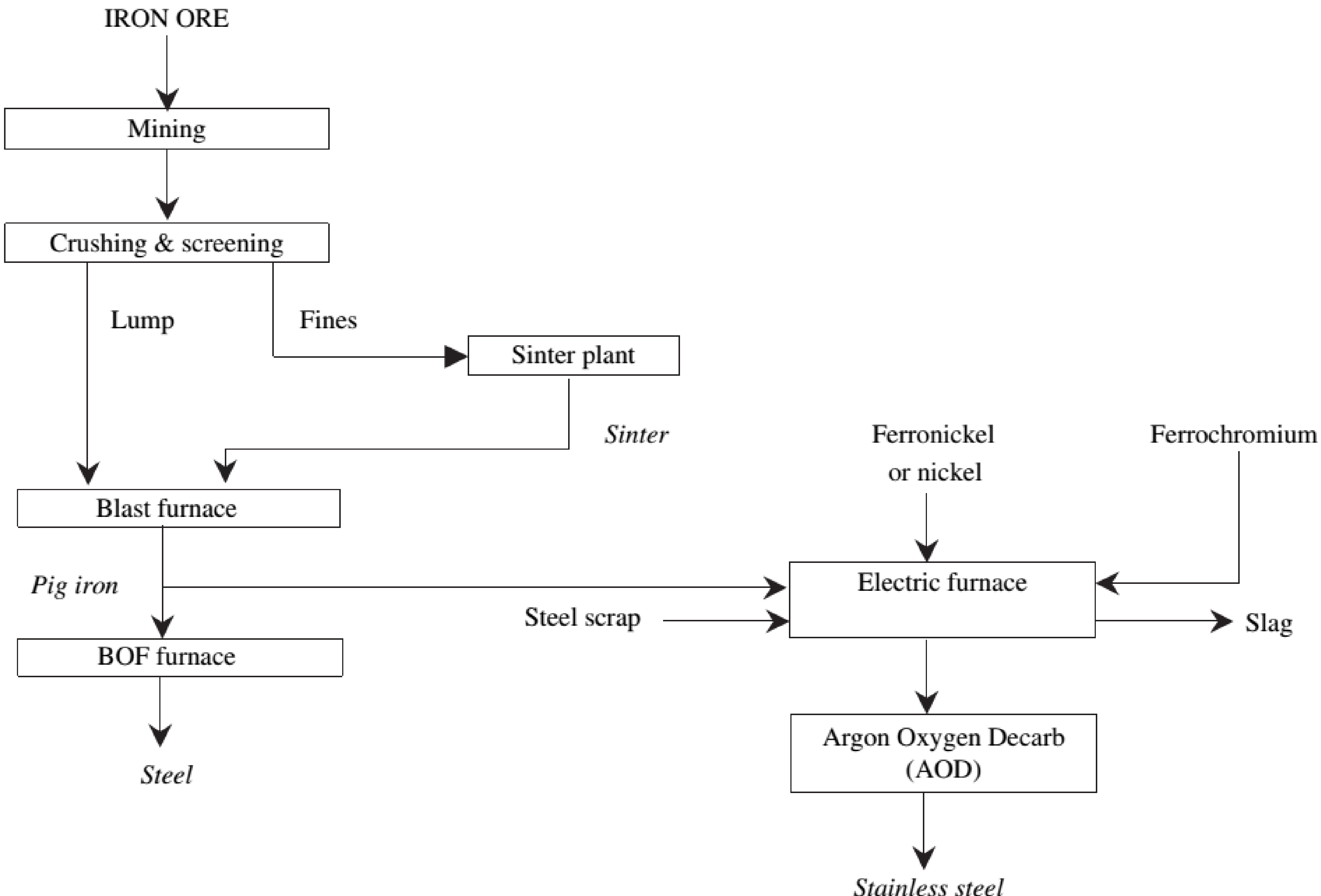
Source: Journal of Cleaner Production 15 (2007) 838-848

Kroll Process for Titanium Production

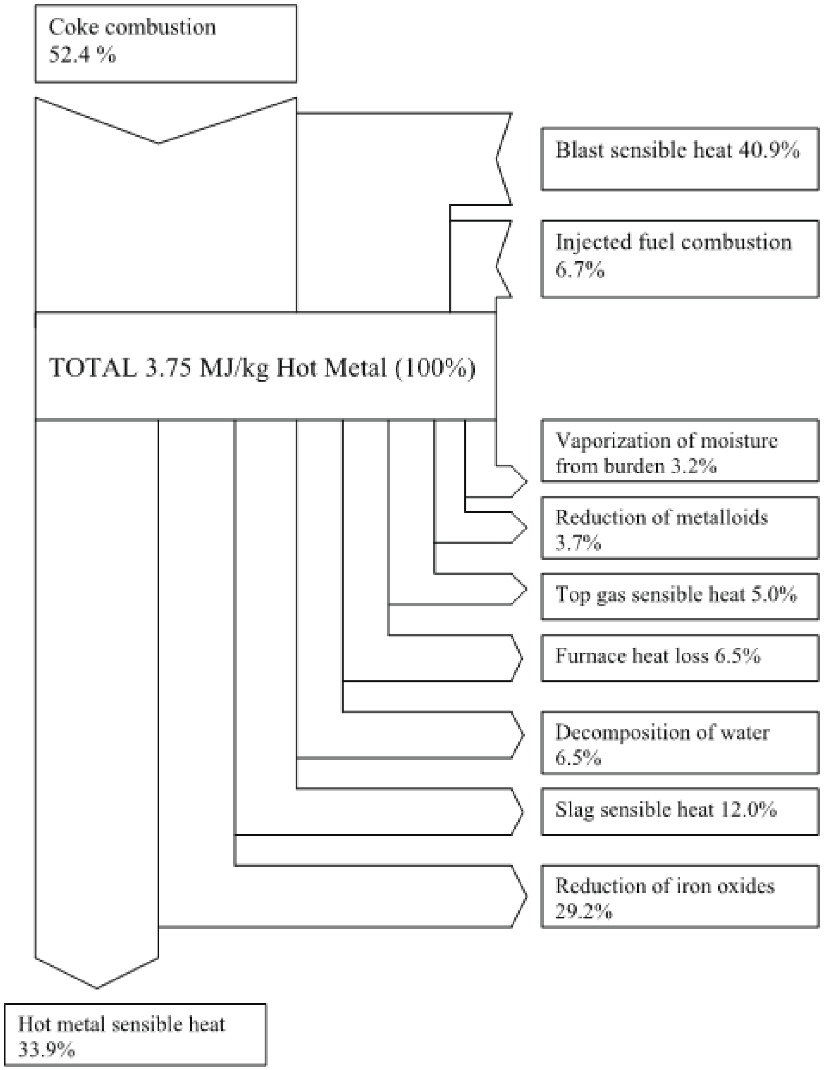


Source: Journal of Cleaner Production 15 (2007) 838-848

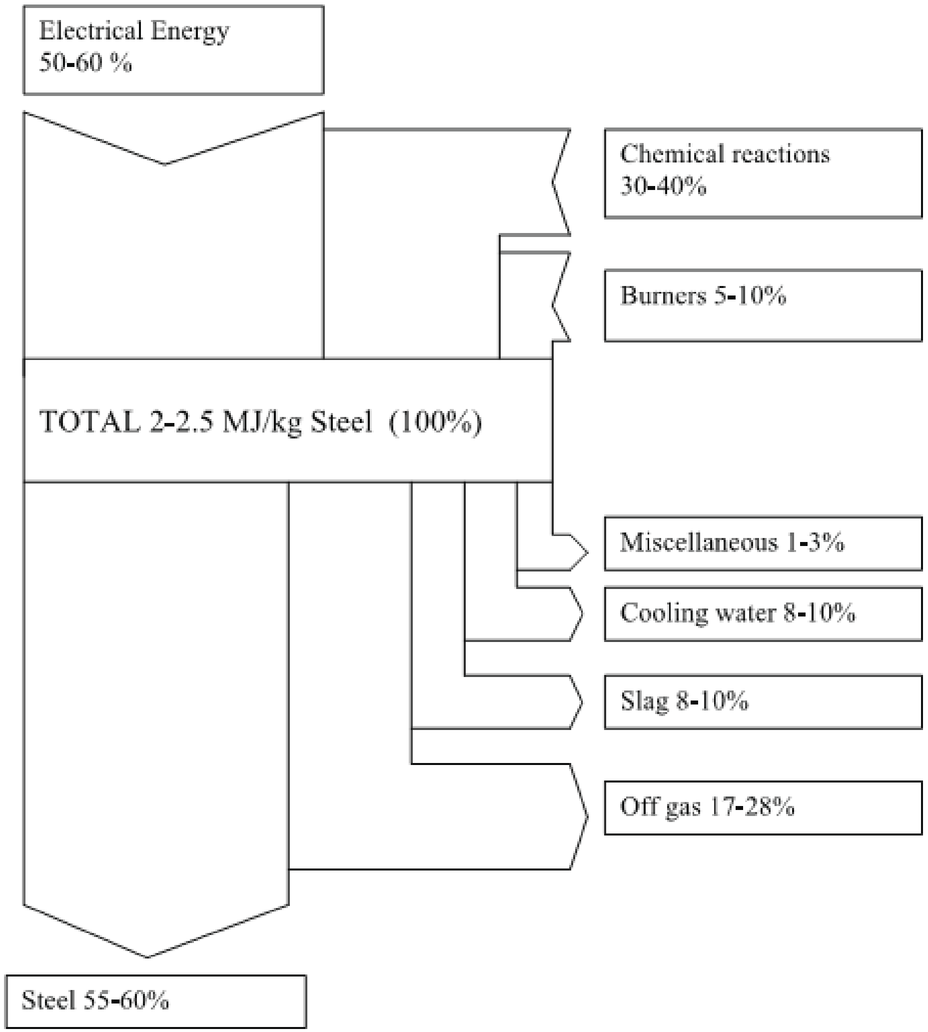
Main Processing Routes for Steel and Stainless Steel Productions



Source: Journal of Cleaner Production 15 (2007) 838-848



Blast Furnace Energy Balance



Typical energy balance for electric arc furnace

Source: Green Processing Conference, 281-286

Energy Requirement of Metal Production Processes

Metal	Process	Gross Energy Requirement (kWh/kg)	Global Warming Potential (kg CO_2e/kg)	Acidification Potential (kg SO_2e/kg)	Solid Waste Burden (kg/kg)
Nickel	Flash furnace smelting and Sherritt-Gordon refining	31.667	11.4	0.130	65.0
	Pressure acid leaching and SX/EW	53.889	16.1	-	351.0
Copper	Smelting/converting and electro-refining	9.167	3.3	0.040	64.0
	Heap leaching and SX/EW	17.778	6.2	-	125.0
Lead	Lead blast furnace	5.556	2.1	0.022	14.8
	Imperial smelting process	8.889	3.2	0.035	15.9
Zinc	Electrolytic process	13.333	4.6	0.055	29.3
	Imperial smelting process	10.000	3.3	0.036	15.4
Aluminum	Bayer refining, HalleHeroult smelting	58.611	22.4	0.131	4.5
Titanium	Becher and Kroll processes	100.278	35.7	0.230	16.9
Steel	Integrated route (BF and BOF)	6.389	2.3	0.020	2.4
Stainless Steel	Electric furnace and Argon-Oxygen decarburisation	20.833	6.8	0.051	6.4

Source: Journal of Cleaner Production 15 (2007) 838-848

Processing routes and energy analysis of five major industrial metals processed from ores

Metal	Prod MT/y	Principal mineral(s)	Ore dressing[c]	Dominant reduction route(s)[c]	Dominant refining route(s)[c]	H°$_f$ MJ/kg[d]	Energy MJ/kg[e,f]
Steel	790[a]	Fe_20_3 Fe_30_4 50 - 70 % Fe[c]	Crushing <30 mm	Pyrometallurgical (Blast Furnace, DRI)	Pyrometallurgical (BOF and EAF)	7.30 (Fe_20_3)	20 - 50
Aluminium	22.8[b]	$Al_20_3.xH_2O$ 26 - 32 % Al[c]	Grinding <500 µm	Hydrometallurgical (Bayer Process)	Electrowinning (Hall-Heroult)	31.2 (Al_20_3)	227 - 342
Copper	13.6[b]	Cu_2S $CuFeS_2$ 0.5 - 2 % Cu[c]	Grinding <300 µm flotation	1. Pyrometallurgical (Flash and Bath Smelting) 2. Hydrometallurgical	1. Electrorefining 2. Electrowinning	1.82 (Cu_2S)	60 - 125
Zinc	7.65[b]	ZnS (ZnFe)S 1 - 19 % Zn[g]	Grinding <300 µm flotation	1. Hydrometallurgical 2. Pyrometallurgical (ISP)	1. Electrowinning 2. Pyrometallurgical	4.25 (ZnS)	60 - 70
Lead	5.80[b]	PbS 0.5 - 9 % Pb[g]	Grinding <300 µm flotation	Pyrometallurgical (Blast Furnace, ISP and Bath Smelting)	1. Pyrometallurgical 2. Electrorefining (Bett's Process)	0.788 (PbS)	30 - 50

Typical operating conditions of electrometallurgical operations

Metal	Zn Electrowinning[a]	Al Electrowinning[b]	Cu Electrowinning[c]	Cu Electrorefining[a]
Temperature °C	35	950 - 1000	< 60	60 - 65
Current Density A/m^2	500 - 1200	8000 - 8500	150 - 300	200 - 300
Cell Voltage V	3.5	4.1	1.9 - 2.0	0.2 - 0.28
Current Efficiency	90 %	92 - 95 %	86 - 93 %	92 - 98 %
Energy MJ/kg	11.3	46.8	7.2	0.81

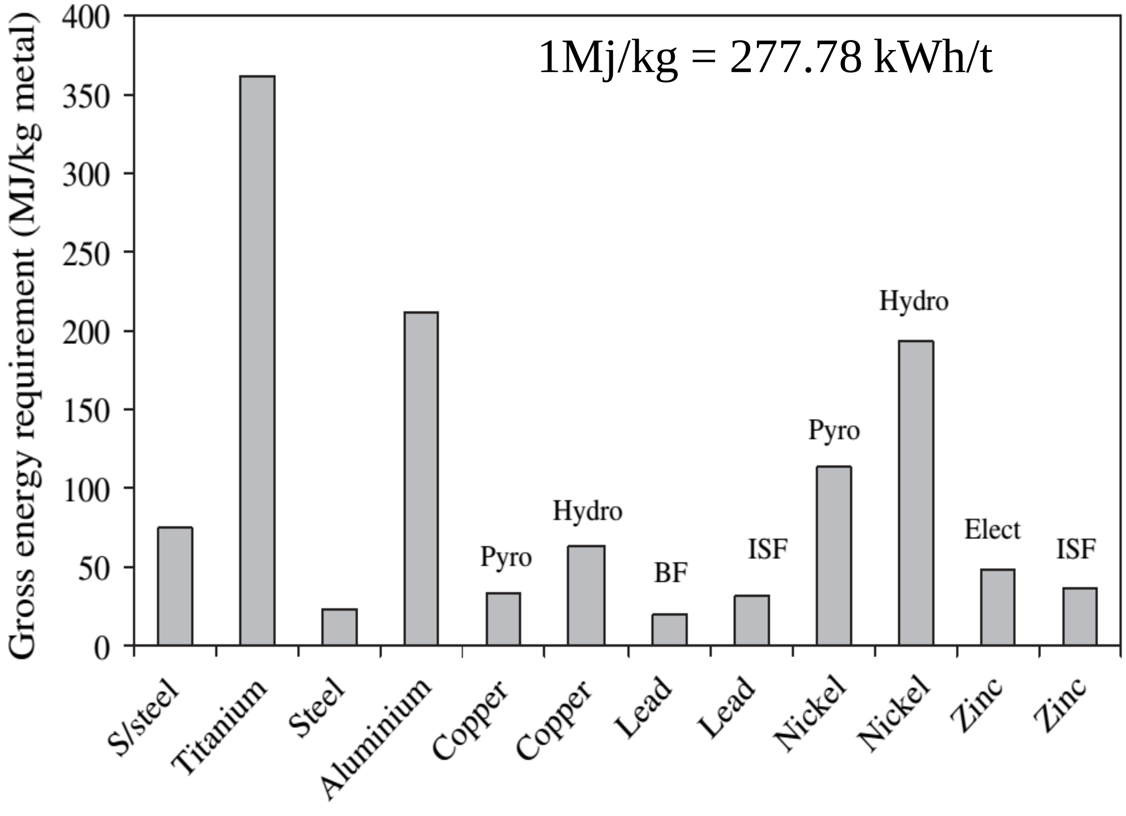
Source: Green Processing Conference, 281-286

Energy Requirement of Metal Production Processes

It can be seen from these results that the light metals, titanium and aluminium had the greatest ‘‘cradle-to-gate’’ environmental impacts in terms of GER (Gross Energy Requirement) followed by nickel. Steel and lead (by the blast furnace process) had the lowest ‘‘cradle-to-gate’’ environmental impacts in these terms.

The hydrometallurgical processing routes for copper and nickel have greater environmental impacts in these terms, than the pyrometallurgical routes.

Apart from differences in ore grade, this is largely due to the large amounts of electricity consumed in the electrowinning stage of these processes and the inefficiencies associated with the generation of this electricity.



GER for ‘‘cradle-to-gate’’ production of various metals.

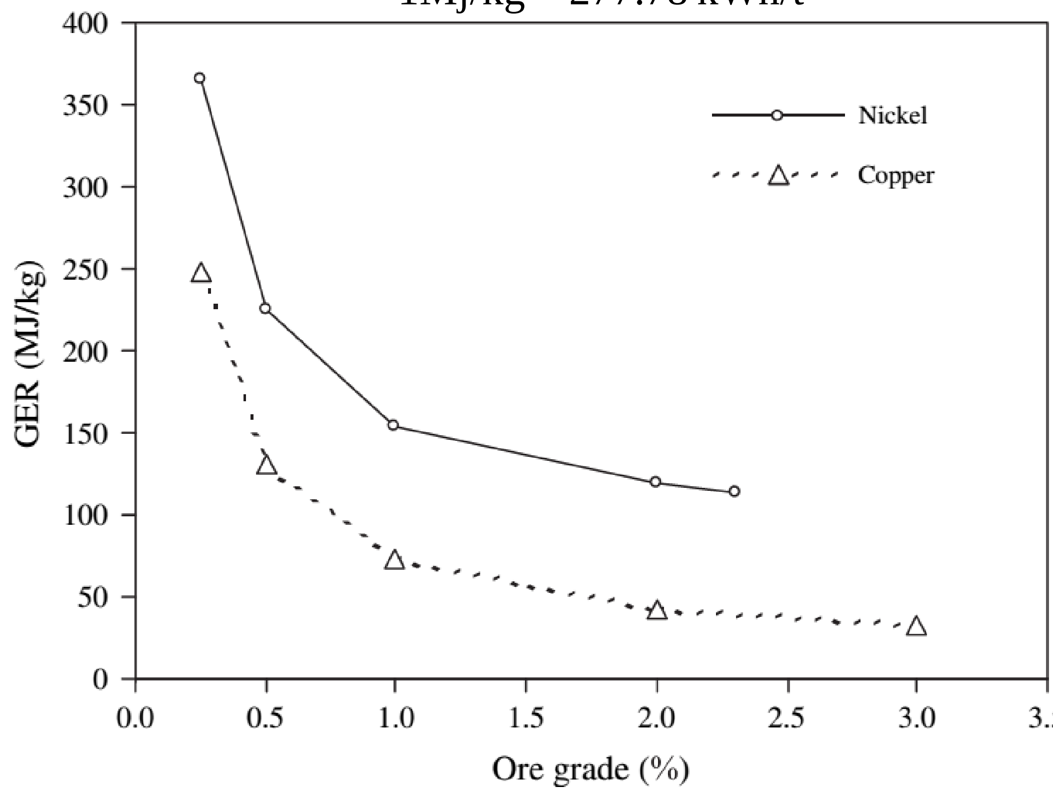
Source: Journal of Cleaner Production 15 (2007) 838-848

Factors influencing environmental impacts – Ore Grade

There are many factors or parameters associated with a particular metal production process that influence the ‘‘cradle-to-gate’’ environmental impacts of the process. These include ore grade, electricity energy source, fuel types, and material transport as well as process technology.

The impact of declining ore grade on GER comes about largely because of the additional energy that must be consumed in the mining and mineral processing stages to move and treat the additional gangue material.
Once a concentrate or mineral product of a specified grade has been produced, emissions from downstream processing (e.g. smelting and refining) are not significantly affected by the original ore grade.

1Mj/kg = 277.78 kWh/t



Effect of ore grade on GER for copper and nickel productions.

Source: Journal of Cleaner Production 15 (2007) 838-848

Factors influencing environmental impacts – Energy Source

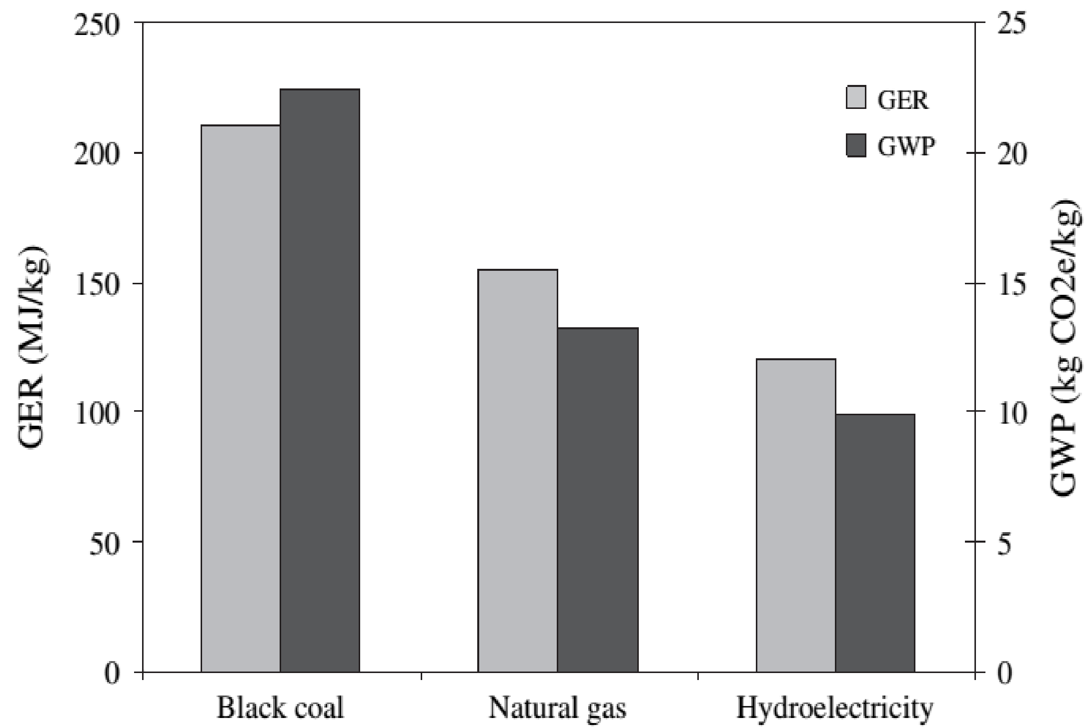
The energy source used to generate the electricity consumed in a particular metal production process also influences the ''cradle-to-gate'' environmental impact of that process. This may be illustrated by considering primary aluminium production

The three main energy sources used for generating electrical power for aluminum production worldwide in 2003 were coal 36%, hydroelectricity 49% and natural gas 9%.

The effect of these three electricity energy sources on the GER and GWP for primary aluminum production is shown in this Figure.

The generation efficiencies in the latter two cases were assumed to be best current efficiencies of 80% and 54%, respectively, compared to 35% for black coal.

1Mj/kg = 277.78 kWh/t



Effect of electricity energy source on GER and GWP for aluminium.

Source: Journal of Cleaner Production 15 (2007) 838-848

Global CO_2 production for primary production of metals

Metal		% of total global metal production	Global annual production (Mt)	Embodied Energy (GJ per tonne)	Tonnes CO_2 per tonne metal	Global annual energy consumption (GJ)	Global annual CO_2 (tonnes)	% Global greenhouse gas production*
Copper	pyro	80	15.6	33.0	3.25	6.13×10^8	6.0×10^7	0.21
	hydro	20		64.5	6.16			
Nickel	pyro	60	1.66	113.5	11.45	2.42×10^8	2.2×10^7	0.08
	hydro	40		193.8	16.08			
Lead	BF	89	3.55	19.6	2.07	7.5×10^7	7.8×10^6	0.03
	ISP	11		32.5	3.18			
Zinc	electrolytic	90	10.5	48.4	4.61	4.95×10^8	4.7×10^7	0.16
	ISP	10		35.8	3.34			
Aluminium		100	38	211.5	21.81	8.0×10^9	8.3×10^8	2.9
Steel	BF/BOF	70	924	22.7	2.19	2.1×10^{10}	2.0×10^9	7.0
Cement			2 600	5.6	~0.9	1.46×10^{10}	2.3×10^9	8.1

*Global annual production of CO_2 from fossil fuel sources = 28 962 Mt (IEA, 2009)

The energy required to recycle metals is a relatively small fraction of the energy required to produce metals from their ores since energy is required largely only for melting and not chemical transformation

However, when the energy required for collection and separation of scrap is included, the embodied energy of recycled metals increases as the fraction of scrap collected increases since transportation and separation costs progressively increase.

Energy for recycling metals after collection and sorting

Commodity		Embodied energy (GJ/tonne)	
		Secondary Production*	Primary production
Plastic			
Paper			
Glass			
Aluminium	alloy	17.5	212
	cans	10.1	
Copper	no. 1 scrap	4.4	33
	no. 2 scrap	20.1	
	low-grade scrap	49.3	
Steel	billets	9.7	23
Lead – soft	batteries	9.4	20
Lead – hard	batteries	11.2	
Nickel	alloy scrap	12.9	114
Zinc	new scrap	3.8	48
	slab	22.0	

Source: High Temperature Processing Symposium 2012, Presentation-1, 7-9

Table II. Environmental Impact of Electricity Generation[39]

Power Source	Emissions (kg/kWh) CO_2	CO	SO_x	NO_x	Liquid	Solid
Coal	1.0	0.00025	0.0075	0.0027	0.00294	0.53
Oil	1.0	0.0013	0.008	0.007	1.9	0.0097
Gas	1.1	0.00013	0.007	0.0025	0.0039	0.0016
Nuclear	0.000025	Negligible	Negligible	0.000001	NEA	0.01

Table III. Total Emissions in Metal Processing (kg/t of Metal)

Emission	Al	Steel	Cu	Zn (Electrol.)	Mg (Electrol.)	Ti
Carbon Dioxide						
Ancillary	7,814	486	5,124	3,589	13,289	9,624
Excl. Electricity*	4,500	1,085	2,051	NEA	5,000	1,837
Carbon Monoxide						
Ancillary	2	0.1	2.54	1.78	4	4.78
Excl. Electricity*	340	54.9	NEA	P	0	P
Sulfur Oxides						
Ancillary	58	3.5	37	26	98	70
Excl. Electricity*	25	5.5	3,500	P	1	NEA
Nitrogen Oxides						
Ancillary	21	1.9	20	14	38	37
Excl. Electricity*	2	1.1	NEA	NEA	NEA	NEA
Hydrogen Fluorides						
Ancillary	NEA	NEA	NEA	NEA	NEA	NEA
Excl. Electricity*	5	NEA	NEA	NEA	0	NEA
Liquid Effluents						
Ancillary	833	267	2,820	1,974	1,417	5,294
Excl. Electricity*	8,001	39,285	1,350,000	442	P	P
Solid Waste						
Ancillary	3,401	103	1,100	765	5,783	2,052
Excl. Electricity*	2,000	484	138,000	P	500	1,500

Source: JOM (1993) 45 (8) 23-29

Because of the significant carbon intensity of steelmaking (approximately 1.8 tons of CO_2 emitted per ton of steel produced) and the high production rate of steel (more than 1.4 billion tonnes per annum), steelmaking is responsible for a large percentage, approximately 6.7%, of world anthropogenic CO_2 emissions [1]. By far the largest input of the carbon into conventional steelmaking is as coke, which is essential to blast furnace ironmaking. A typical fuel rate for blast furnace ironmaking is 450 kg of fuel per tonne of hot metal (THM). ("Fuel" includes coke and injectants which partially replace coke; pulverized coal and natural gas are typical injectants.) Assuming the fuels to contain 90% carbon on average, and since nearly all of this carbon exits the steel plant as CO_2, a fuel rate of 450 kg is equivalent to a CO_2 intensity of 1485 kg/THM – by far the largest part of the total CO_2 intensity of steelmaking.

Blast furnace ironmaking is expected to remain the main source of new iron units; this paper gives some estimates of the extents to which further reductions in carbon intensity from blast furnace ironmaking is possible. A recent European assessment suggested that blast furnace process intensification options such as increased pulverized-coal injection or natural gas injection would yield only modest energy savings [2]. However, if the focus is on CO_2 emissions rather than on total energy use, there would be an advantage to using fuels – such as natural gas – which have lower carbon contents relative to energy content.

Ironmaking and steelmaking process from iron ore through blast furnace and BOF is an essential steel production route for Japanese steel industries to supply high quality steel products in large quantity to society stably. Blast furnace – BOF process requires huge amount of fossil fuels such as mainly coal, resulting the emission of considerable amount of CO_2 gas. Since the emission of CO_2 gas from steel industries, about 147 Mt (FY2011), accounts for approximately 12 % of domestic CO_2 gas emission in Japan (FY2011),[1] it is an urgent issue for steel industries to develop environmental-friendly ironmaking and steelmaking process and reduce CO_2 emission.

Various kinds of gases and by-products generated from ironmaking and steelmaking processes have been recycled as much as possible at present. Enormous thermal energy is also generated from processes and released to surrounding atmosphere as various forms such as sensible heats of gases, molten steels or by-products, and as heat losses. However, these energies are not utilized before final dissipation to atmosphere. Although various technologies to utilize thermal energy from ironmaking and steelmaking processes have been attempted to develop, practical application of these technologies has not been achieved because the thermal energy is not always useful as an energy source.

In steelmaking process by BOF, fluxing agent such as CaO is added during reefing and thus about 100 kg/t-steel of steelmaking slag are generated. Since the steelmaking slag is discharged at temperature range between 1873 and 1923 K after discharge of refined molten steel, it also has large thermal energy. Amount of generated BOF slag is 11.0 Mt/y (FY2012) in Japan.[2] Assuming the amount of steelmaking slag is 10 Mt/y and its average heat capacity from room temperature to 1923 K is 1 kJ/kg·K,[3] unutilized heat is estimated to be 16 PJ/y, which is equal to annual energy consumption of 420 thousand families in Japan.[4]

Technology of aluminum electrolysis is a mature and efficient process of aluminum production. Due to the huge demand on aluminum worldwide, so resource consumption, energy consumption and pollutant emissions in the process of aluminum production are still large. The global output of aluminum reached 45193 kt in 2012. A large amount of CO_2 and PFCs are produced in the process of aluminum production, and the greenhouse effect and environmental pollution caused by emissions of them is a concern. PFCs belong to a powerful greenhouse gas, thus emission reduction of PFCs is very important for aluminum electrolysis industry. At present, China's aluminum production accounts for about 33% of the world's aluminum production, and controlling PFCs emission has become the key point of pollution control of aluminum electrolysis industry in China [1].

Taking the case of a typical electrolytic aluminum plant of a China’s northwest province, this paper studies the list analysis of GHG emissions of aluminum industry in China. GHG emissions of a China’s northwest province were calculated through investigating existing situation of aluminum electrolysis industry in the province, knowing capacity, output, main production technology and equipment level of aluminum electrolysis industry, and using the calculation framework and methods of GHG emissions of aluminum electrolysis industry, which were put forward by the intergovernmental panel on climate change (IPCC), the international aluminum association and other organizations at home and abroad. The list analysis of GHG emissions of aluminum electrolysis industry will offer useful information in promoting emission reduction of GHG in aluminum electrolysis industry, improve the efficiency of energy utilization.

Metal (*ΔH, ΔG* at 1000°C)	Aluminum	Magnesium	Neodymium	Lanthanum
Oxide *ΔH, ΔG*, kWh/kg metal	8.70, 6.22 [6]	6.95, 5.27 [6]	1.73, 1.40 [7]	1.80, 1.43 [7]
C reduction *ΔH, ΔG*, kWh/kg	5.73, 3.32	4.75, 2.88	1.18, 0.79	1.22, 0.81
CH_4 reduction *ΔH, ΔG*	5.61, 3.56	4.66, 3.05	1.16, 0.82	1.20, 0.83
Current industrial practice energy usage, kWh/kg	15.6 electric 5.7 anode 21.3 total [2]	100 Pidgeon/ 40 $MgCl_2$ e^-, 91 avg [3]	No data	No data
Direct GHG, kg CO_2e/kg	1.83	26/6, 23 avg	No data	No data
Electricity GHG 0.35 kg/kWh	5.42 [2]	1/12, 2.5 avg	No data	No data
Pure Oxygen Anodes est. electrical energy, kWh/kg	10.5-13 O_2, 8-10 CH_4	11-14 O_2 8-10 CH_4	No model	No model
POA direct GHG, O_2/CH_4	0/0.45	0/0.5	0-0.1	0-0.1

Table 1: Metal production energy and GHG emissions, changes using Pure Oxygen Anodes.

Table 1 Life cycle inventory of product 1t gold

Process	CIP process	Roasting pretreatment process	Bio-oxidation pretreatment process
Mining	Crude ore 273,224t Power 4.07*10^6kwh	Crude ore 218,723t Power 3.26*10^6kwh	Crude ore 208,307t Power 3.1*10^6kwh
Beneficiation	Concentrate 13,649t Power 7.4*10^6kwh Water consumption 1.5*10^6t New water 2.2*10^5t Sodium butyl xanthate 20.6t Butylamine aerofloat 10.9t No. 2 oil 13.1t Calcium oxide 2,732t	Concentrate 16,388t Sodium butyl xanthate 20.8t Butylamine aerofloat 11t No. 2 oil 13.3t Calcium oxide 2187t Total water 1.52*10^6t Power 5.9*10^6kwh	Concentrate 13,658t Total water1.45*10^6t Sodium butyl xanthate 19.8t Butylamine aerofloat 10.5t No. 2 oil 12.7t Calcium oxide 2,083t Power 5.64*10^6kwh
Pretreatment	——	Coal 6,293t Diesel 3.9t	Power 1.25*10^5kwh Medium 33.4t Flocculant 0.95t Calcium oxide 341t
cyanide leaching	Sodium cyanide 10^9t Calcium oxide 341t Activated carbon 1.64t Power 3.52*10^5kwh	Sodium cyanide 50.9t Calcium oxide 44.5t Activated carbon 1.5t Power 3.28*10^5kwh Calcine 12717t	Power 2.46*10^5kwh Sodium cyanide 38.1t Calcium oxide 33.4t Defoamers 1.43t Activated carbon1.14t Oxide slag 9533t

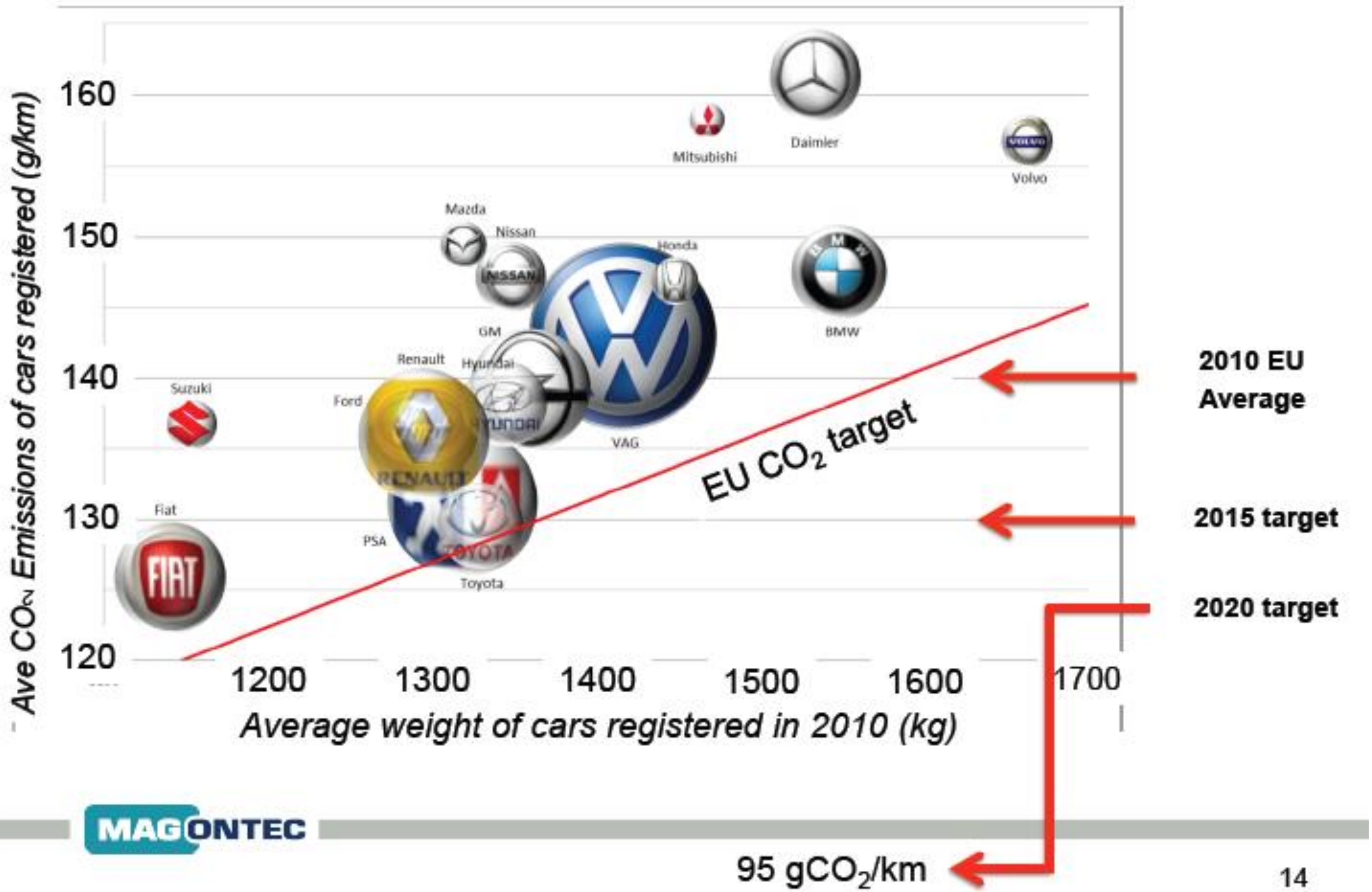
Results of Inventory Analysis

Table 2 Material and energy consumption of 3 processes

	Crude ore(t)	Power (10^6kwh)	Water (10^6t)	Calcium oxide(t)	Sodium cyanide(t)	Activated carbon(t)
CIP process	273,224	11.8	1.72	3,073	109	1.64
Roasting oxidation pretreatment process	218,723	9.5	1.52	2,231.5	50.9	1.5
Bio-oxidation pretreatment process	208,307	9.11	1.66	2,457.4	38.1	1.14

Gold recovery rate in the order of high to low: bio-oxidation pretreatment process > roasting pretreatment process > CIP process. Material and energy consumption in beneficiation stage increased the burden on the environment because grinding and mixing requires a large amount of water. The lower water recycling rate of gold extraction production causes greater water consumption. It also increases power consumption. Acidic waste water produced in biological oxidation and adsorption and desorption process in CIP gold extraction both require a lot of lime to adjust pH and has indirectly led to increased environment effects.

Incentives for EU Vehicle CO_2 Emission Reduction*



*EU Federation of Transport & Environment 2010; published 09.2011

The costs of being over weight

- **The EU intends to fine excess emissions at a rate of €95** per gCO_2/km
- **If 140.3 gCO_2/km** (the current average fleet level) is maintained in 2020 the financial **penalty would be = €4300/vehicle**
- Magontec has calculated that inclusive of CO_2 penalties, generic Mg is more than 25% cheaper than Aluminium.
- Even Rare Earth rich alloys like AE44 are cheaper than Aluminium (assuming primary Mg is 10% > Al)
- Similar advantages may apply over steel but comparison is more complex: not a comparison of die cast components
- For carbon fibre high material costs and non-recyclability outweigh any saving from penalty reduction