Serviço Geológico do Brasil - CPRM

Economic Viability and Global Market Competitiveness of Specific Minerals

Cobalt Geoeconomic Profile

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Cobalt Geoeconomic Profile

Outline

- Description
- Origin
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- Mineral Rights
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- Resources and Reserves
- Brazilian Production and Foreign Trade
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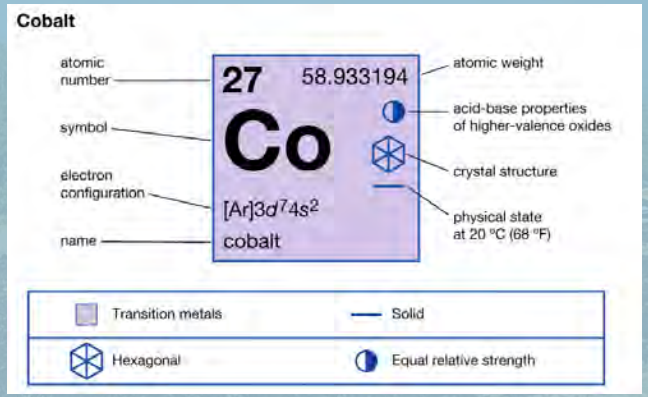
Cobalt

Description

It was not until the 1730s that Swedish chemist George Brandt purified and identified cobalt, then another 50 years until Torbern Bergman verified Brandt's new element.

Several centuries ago, miners in Germany struggled melting down certain ores for useful metals such as silver and copper. They were exposed to poisonous fumes released from the rock which they blamed on the kobolds - underground sprites of local folklore. Though the vapors actually arose from the arsenic also contained in the ores, when chemists later extracted cobalt from these minerals, the name stuck.

Source: Cobalt Institute; Encyclopedia Britannica



Cobalt

Origin

Cobalt can be found in many minerals.
The most famous of them is cobaltite.

Minerais de níquel		Minerais de cobalto	
Mineral	Fórmula química	Mineral	Fórmula química
Níquel-Ferro nativo	Ni_3Fe	Ahlfeldita	$(Ni,Co)[SeO_3]\cdot 2H_2O$
Pentlandita	$(Fe,Ni)_9S_8$	Alloclasita	$(Co,Fe)AsS$
Bravoita	$(Fe,Ni)S_2$	Aplowita	$CoSO_4\cdot 4H_2O$
Violarita	Ni_2FeS_4	Carrollita	$CuCo_2S_4$
Polydymita	Ni_3S_4	Cattierita	CoS_2
Millerita	NiS	Cobaltita	$CoAsS$
Heazlewoodita	Ni_3S_2	Cobaltoblodita	$Na_2Co(SO_4)2\cdot 4H_2O$
Siegenita	$(Ni,Co)_3S_4$	Erythrita	$Co_3(AsO_4)_2\cdot 8H_2O)$
Linnaeita	$(Co,Fe,Ni)_3S_4$	Glaucodot	$(Co,Fe)AsS$
Gersdorffita	$NiAsS$	Linnaeite	$(Co^{+2},Co^{+3})_2S_4$
Niccolita	$NiAs$	Moorhouseita	$CoSO_4\cdot 6H_2O$
Rammelsbergita	$NiAs_2$	Penroseita	$(Ni,Co,Cu)Se_2$
Chloantita	$(Ni,Co)As_{3-x}$	Roselita	$Ca_2(Co,Mg)[AsO_4]2\cdot H_2O$
Smaltita	$(Co,Ni)As_{3-x}$	Safflorita	$(Co,Fe)As_2$
Skutterudita	$(Co,Ni)As_3$	Skutterudita	$CoAs_3$
Maucherita	$Ni_{11}As_8$	Smaltita	$(Co,Fe,Ni)As_2$
Breithaupita	$NiSb$	Spherocobaltita	$CoCO_3$
Ullmannita	$NiSb_S$	Trogtalita	$CoSe_2$
Parkerita	$Ni_3Bi_2S_2$	Tyrrellita	$Cu(Co,Ni)_2Se_4$
Annabergita	$Ni_3(AsO_4)_2\cdot 8H_2O$		
Morenosita	$NiSO_4\cdot 7H_2O$		
Zaratita	$NiCo_3\cdot 2Ni(OH)_2\cdot 4H_2O$		

Source: Cornwall, 1966

Cobalt

Origin

Sediment Hosted: are primarily worked for copper with cobalt as a by-product. They account for over 50% of world cobalt mined production. These mineralized sediments are always found above oxidized terrestrial clastic sediments. Two of the largest and most well known deposits of this type are the European Kupferschiefer and the Central African Copperbelt.

Hydrothermal and Volcanogenic: This deposit type groups comprises a wide range of deposit styles and mineral assemblages. The key process is precipitation from hydrothermal fluids passing through the host rock often sourced from, or powered by, volcanic activity.

Magmatic Sulphide: If a mafic to ultramafic melt becomes saturated in sulphur (generally because of contamination from crustal-derived sulphur), an immiscible liquid sulphide phase will form, into which nickel, cobalt and platinum-group elements (PGE) preferentially partition. These elements are thus scavenged from the residual magma and are deposited in discrete sulphide-rich layers.

Source: Cobalt Institute

Cobalt

Origin

Laterite: In tropical and subtropical climates intense weathering of ultramafic rocks may cause significant cobalt and nickel enrichment in surficial residual deposits known as laterites. They are principally worked for nickel with cobalt as a by-product. The cobalt is contained within limonite and goethite as well as erythrite and asbolite. At deeper levels,weathering of ultramafic rocks is less intense and the nickeliferous mineral garnierite is formed.

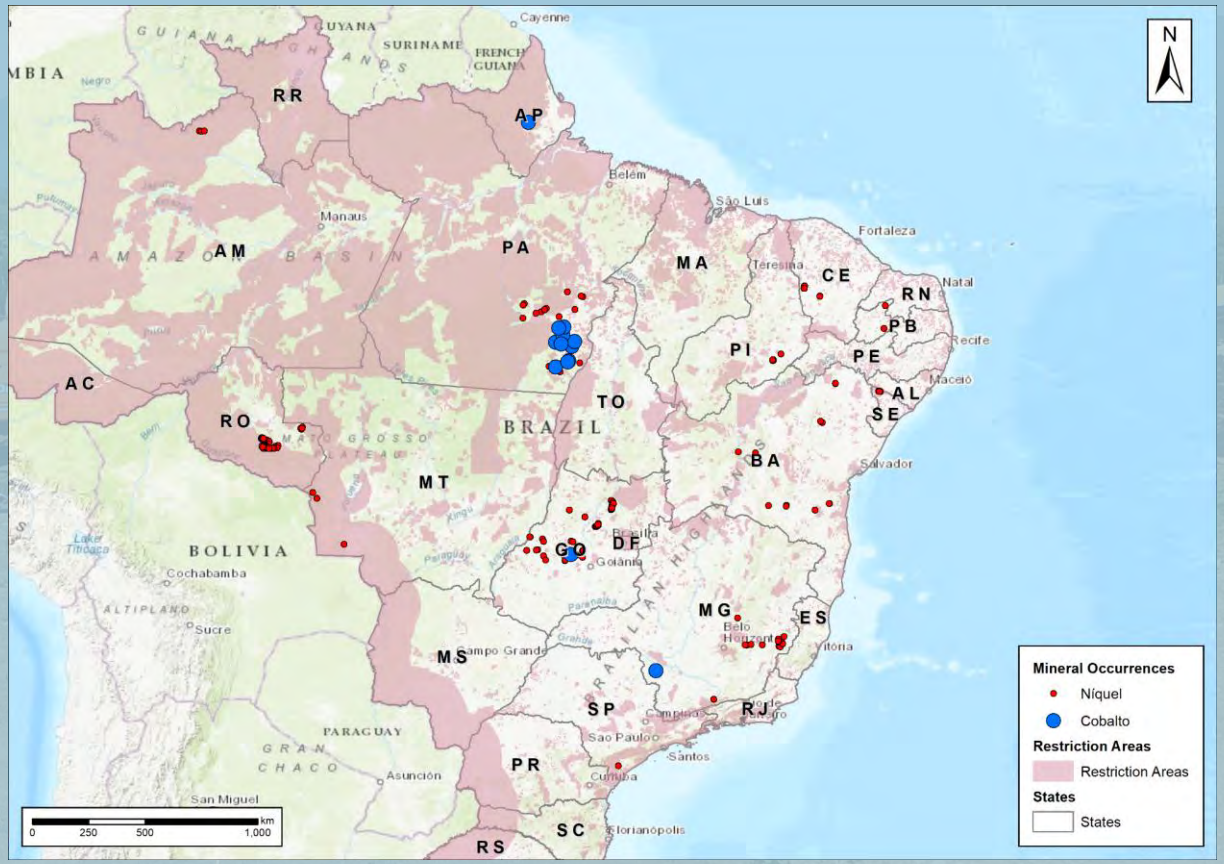
Manganese Nodules and Cobalt-rich Crusts: On sediment-starved deep cean floors, generally 4 to 5.5 kilometers deep, concretions rich in manganese, cobalt and nickel can form around small fragments of debris and organic material. The nodules concentrate minerals from siliceous oozes and from the water column. Their occurrence in proximity to mid-ocean ridges suggests a volcanogenic source for mineral enrichment. They may occur as densely packed sheets covering areas of hundreds of square kilometers with cobalt grades in the range of 1 to 2.5 per cent.

Source: Cobalt Institute

Nickel and Cobalt

Mineral Occurrences

Occurrences, Deposits and Mineral Production Units		
States	**Ni**	**Co**
Amapá	-	1
Amazonas	3	-
Bahia	12	-
Ceará	6	-
Goiás	45	1
Mato Grosso	4	-
Minas Gerais	19	1
Pará	24	10
Paraíba	2	-
Piauí	7	-
Rondônia	76	-
São Paulo	1	-
Sergipe	5	-
Total Geral	**204**	**13**



Source: Mineral Ocurrences: SGB GEOSGB – Jun, 2020; Processed by Platform P3M

Nickel and Cobalt - *Mineral Rights*

Mineral Rights								
States	Available		Exploitation		Exploration		Total	
	Units	Area (ha)	Units	Area (ha)	Units	Area (ha)	Units	Area (ha)
AL	-	-	-	-	2	90	2	90
AP	-	-	-	-	4	23,533	4	23,533
BA	37	53,347	7	5,220	264	386,165	308	444,732
CE	1	1,917	-	-	18	30,744	19	32,661
GO	31	45,466	56	43,094	198	263,774	285	352,334
MT	14	78,829	3	11,910	82	560,731	99	651,470
MS	2	2,936	-	-	-	-	2	2,936
MG	43	67,847	5	1,343	90	94,600	138	163,790
PA	23	126,609	22	76,143	83	366,120	128	568,871
PB	11	18,800	-	-	13	14,976	24	33,776
PE	1	1,533	-	-	128	230,970	129	232,503
PI	9	17,937	1	977	45	87,700	55	106,614
RN	1	1,831	-	-	38	52,532	39	54,363
RO	1	8,991	-	-	9	61,395	10	70,386
RR	-	-	-	-	7	69,931	7	69,931
SC	3	5,655	-	-	4	6,372	7	12,027
SP	-	-	-	-	7	5,791	7	5,791
SE	1	1,983	-	-	16	30,748	17	32,731
TO	5	15,261	-	-	22	52,260	27	67,522
Total	**180**	**448,943**	**94**	**138,687**	**1,012**	**2,338,432**	**1,286**	**2,926,062**

Source: ANM Open Data – 2019
Processed by Platform P3M

Nickel and Cobalt

Mineral Deposits

Nickel Brazil 2021 (Cu-Co-PGE)

- Lateritic nickel is the dominant resource (> 95%);
- Currently, nickel is mainly extracted from laterite deposits (>85%);
- Few small/medium size Ni-Cu-PGE sulfide deposits. Except for Santa Rita-BA;
- One large unconventional hydrothermal deposit in Carajás (Jaguar deposit);
- Most nickel laterite deposits have considerable cobalt contents.

Sources: Adapted from Ferreira Filho, 2021

Nickel - *Resources and Reserves (2020)*

Brazilian Reserves (in thousand tons)							
Municipality	**State**	**Measured**		**Indicated**		**Inferred**	
		Ore	**Ni**	**Ore**	**Ni**	**Ore**	**Ni**
Itagibá	BA	26,695	204	45,983	143	45,000	140
Americano do Brasil	GO	1,274	8	455	2	759	2
Barro Alto	GO	16,357	246	29,028	376	46,412	601
Goianésia	GO	127	1	213	1	190	1
Iporá	GO	25,368	346	4,090	68	1,107	15
Jussara	GO	51,322	781	29,028	405	55,856	582
Montes Claros de Goiás	GO	65,238	810	7,325	97	2,179	23
Niquelândia	GO	11,608	96	30,979	88	208	0
Comodoro	MT	39,117	669	0	0	0	0
Vila Bela da Santíssima Trindade	MT	9,053	158	5,253	92	0	0
Conceição das Pedras	MG	521	4	0	0	0	0
Fortaleza de Minas	MG	330	1	830	2	700	1
Ipanema	MG	22,301	484	4,616	98	1,053	24
Liberdade	MG	1,886	29	3,554	40	2,423	27
Pratápolis	MG	299	4	84	1	46	1
Água Azul do Norte	PA	5,306	30	12,234	61	37,098	152
Canaã dos Carajás	PA	205,046	1,671	46,813	244	69,944	467
Conceição do Araguaia	PA	0	0	21,170	356	0	0
Marabá	PA	5,198	47	15,124	127	32,204	245
Parauapebas	PA	10,191	187	8,636	150	0	0
Rio Maria	PA	12,469	158	17,359	177	6,962	66
São Félix do Xingu	PA	59,812	871	151,515	1,349	135,564	1,151
Sapucaia	PA	3,335	40	4,481	49	8,511	93
Tucumã	PA	4,438	59	9,450	124	16,751	214
Xinguara	PA	37,317	473	3,697	45	15,091	148
Capitão Gervásio Oliveira	PI	241	1	1,085	3	65	0
Total		**614,850**	**7,379**	**452,999**	**4,097**	**478,123**	**3,954**

Current brazilian Ni reserves:

- in the order of 16 M tons of Ni content, in 1.5 B tons of ore.

Source: ANM Open Data – 2020

Processed by Platform P3M

Cobalt

Resources and Reserves (2020)

Brazilian Reserves (in thousand tons)							
Municipality	**State**	**Measured**		**Indicated**		**Inferred**	
		Ore	**Co**	**Ore**	**Co**	**Ore**	**Co**
Americano do Brasil	GO	1,274	0.54	455	0.14	759	0.17
São Félix do Xingu	PA	111	0.14	203	0.26	0	0.00
Total		**1,385**	**0.69**	**658**	**0.40**	**759**	**0.17**

Source: ANM Open Data – 2020; Processed by Platform P3M

Current brazilian Co reserves:

- in the order of 1.3 thousand tons of Co content, in 2.7 M tons of ore.

Nickel and Cobalt

Resources and Reserves

The reserve and resource status, the average Ni (if known) and Co contents of the most important Ni-Co deposits:

Mines:

- **Onça Puma (Vale SA, PA): 107 Mt reserves and resources; 1.53% Ni, 0.1%Co**;
- Niquelândia (Nexa Resources, GO): 30 Mt reserves and resources; 1.3% Ni, 0.1% Co*;
- Barro Alto (Anglo American, GO): 105 Mt reserves and resources; 1.32% Ni, 0.05 – 0.08% Co.

Development stage:

- Piauí (Brazilian Nickel, PI): 72 Mt reserves and resources; 1 % Ni, 0.05 % Co;
- Projeto Araguaia (Serra do Tapa, Vale dos Sonhos e Pau Preto - Horizonte Mineral): 132 Mt reserves and resources; 1.27 % Ni, 0,06 % Co.

Exploration projects:

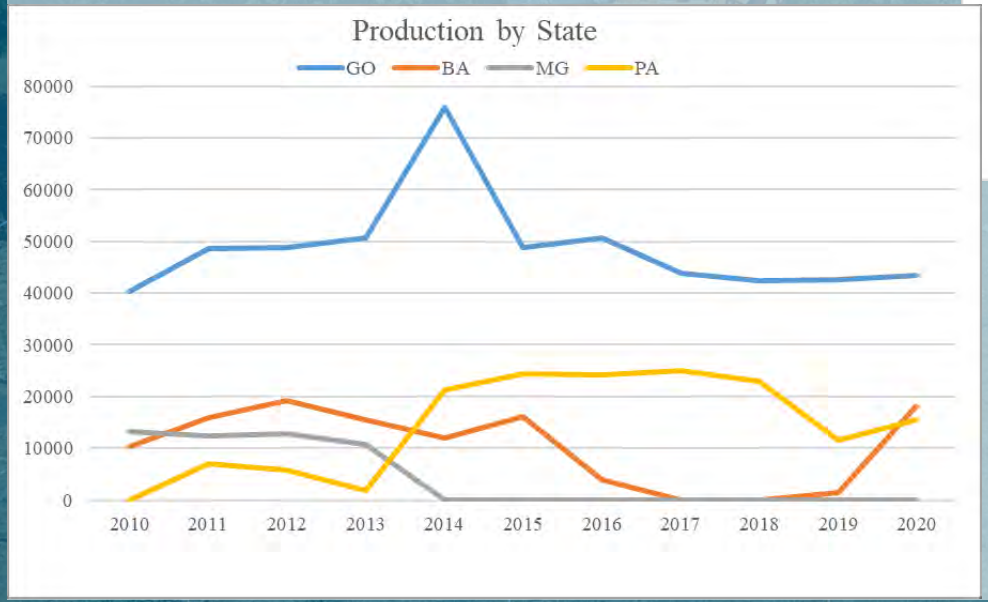
- **Jacaré (Anglo American, PA): 500 Mt reserves and resources; 1.3 % Ni, 0.15% Co**;
- Vermelho (Horizonte Minerals, PA): 171 Mt reserves and resources; 1 % Ni, 0.06% Co;
- Morro do Engenho/Santa Fé (CPRM, GO): 10 reserves and resources; 1.17% Ni, (Co – >0,08**);
- Projeto Noroeste (Morro Sem Boné e Morro do Leme - GK Resources Lt.): 57.7 kt reserves and resources; 1,75% Ni, (Co > 0,03.).

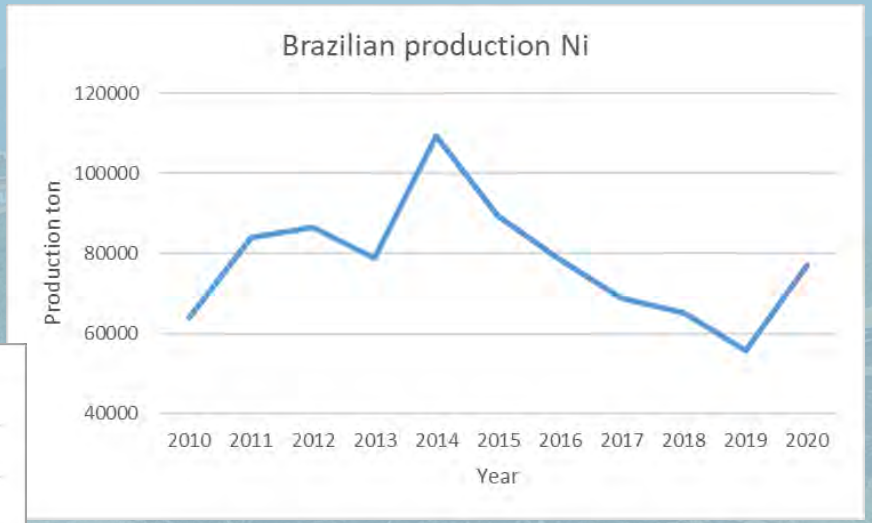
Sources: BioProLat Project and Platform P3M

Nickel

Brazilian Production and Foreign Trade

Production by State
Ni contained (2000 – 2020)





- Last cobalt production (2016): **407.98 ton**;
- Cobalt production average between (2010-2016): **2040.48 ton**

Source: ANM, June, 2021; Processed by Platform P3M

Nickel

Brazilian Production and Foreign Trade

Nickel Production (2019)

Production (in thousand)			
Municipality	**State**	**Tons**	**R$**
Niquelândia	GO	45	592,540
Barro Alto	GO	139	1,770,466
Parauapebas	PA	44	520,665
Total		**228**	**2,883,671**

CFEM (2020)

States	R$ thousand
Bahia	9,701
Goiás	15,648
Minas Gerais	2
Pará	3,744
Total	**29,095**

Counties	R$ thousand
Barro Alto	15,600
Itagibá	9,701
Liberdade	2
Niquelândia	48
Parauapebas	2,216
São Félix do Xingu	1,528
Total	**29,095**

Source: ANM Open Data – 2020; Processed by Platform P3M

Nickel and Cobalt

Brazilian Production and Foreign Trade (2020)

Brazilian Import (in thousand US$)

State	Cobalt	Nickel	Total
AL	3	253	256
AM	-	935	935
BA	2	3,939	3,942
CE	-	809	809
DF	-	49	49
ES	793	821	1,614
GO	0	110	110
MA	-	107	107
MG	19	18,282	18,301
MS	-	22	22
MT	155	57	212
PA	-	1	1
PB	-	11	11
PE	7	1,023	1,031
PR	527	1,377	1,903
RJ	1,334	73,032	74,366
RS	2,379	6,518	8,897
SC	19,881	37,491	57,372
SE	-	1	1
SP	4,303	105,343	109,646
Total	**29,403**	**250,182**	**279,585**

Brazilian Export (in thousand US$)

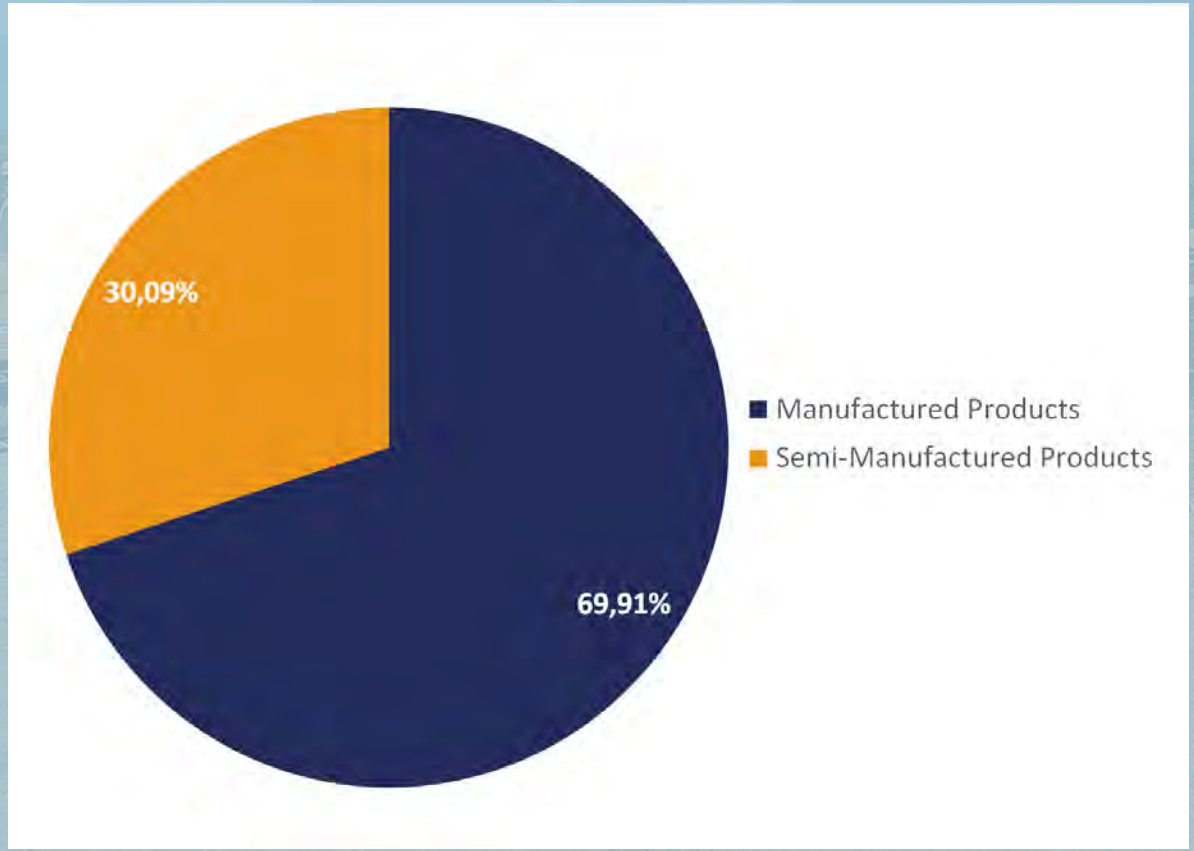
State	Cobalt	Nickel	Total
AM	-	2	2
BA	-	77,775	77,775
CE	-	-	-
ES	-	-	-
GO	-	506,345	506,345
MA	-	-	-
MG	-	2,000	2,000
PA	-	166,516	166,516
PR	20	150	171
RJ	419	26,494	26,913
RN	-	2	2
RR	-	-	-
RS	-	1,032	1,032
SC	638	200	838
SP	600	34,104	34,704
Total	**1,677**	**814,620**	**816,297**

Source: ANM and Comex Stat (MDIC) – 2020; Processed by Platform P3M

Nickel

Brazilian Production and Foreign Trade (2020)

Nickel - Import



Source: ANM and Comex Stat (MDIC) – 2020
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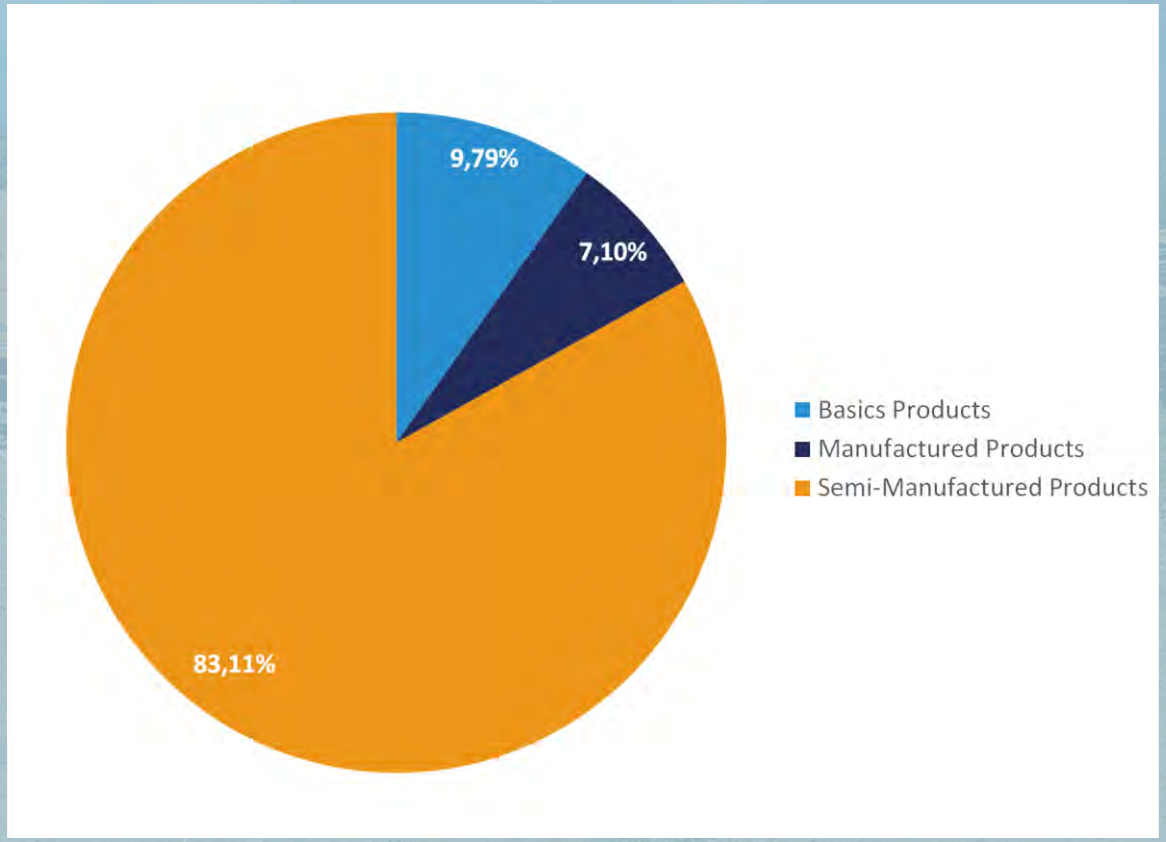
Nickel

Brazilian Production and Foreign Trade (2020)

Nickel - Export



Source: ANM and Comex Stat (MDIC) – 2020
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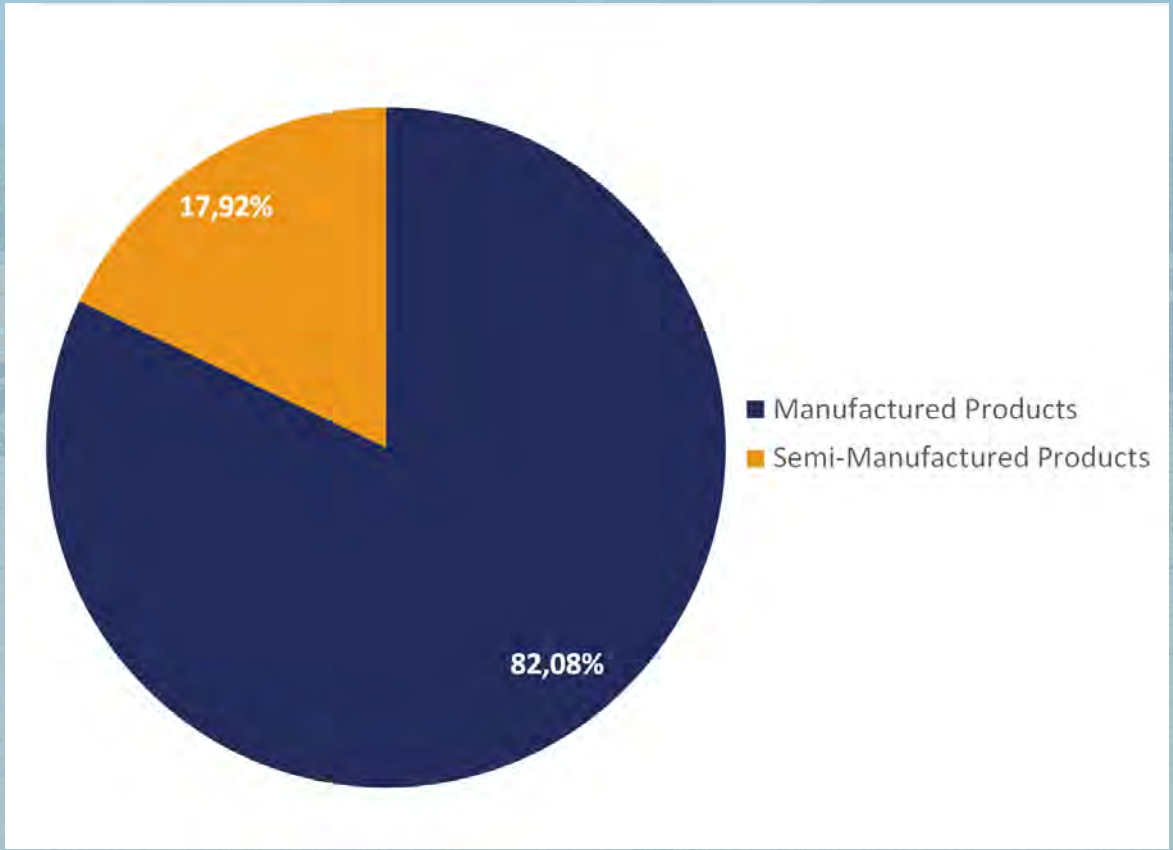
Cobalt

Brazilian Production and Foreign Trade (2020)

Cobalt - Import



Source: ANM and Comex Stat (MDIC) – 2020
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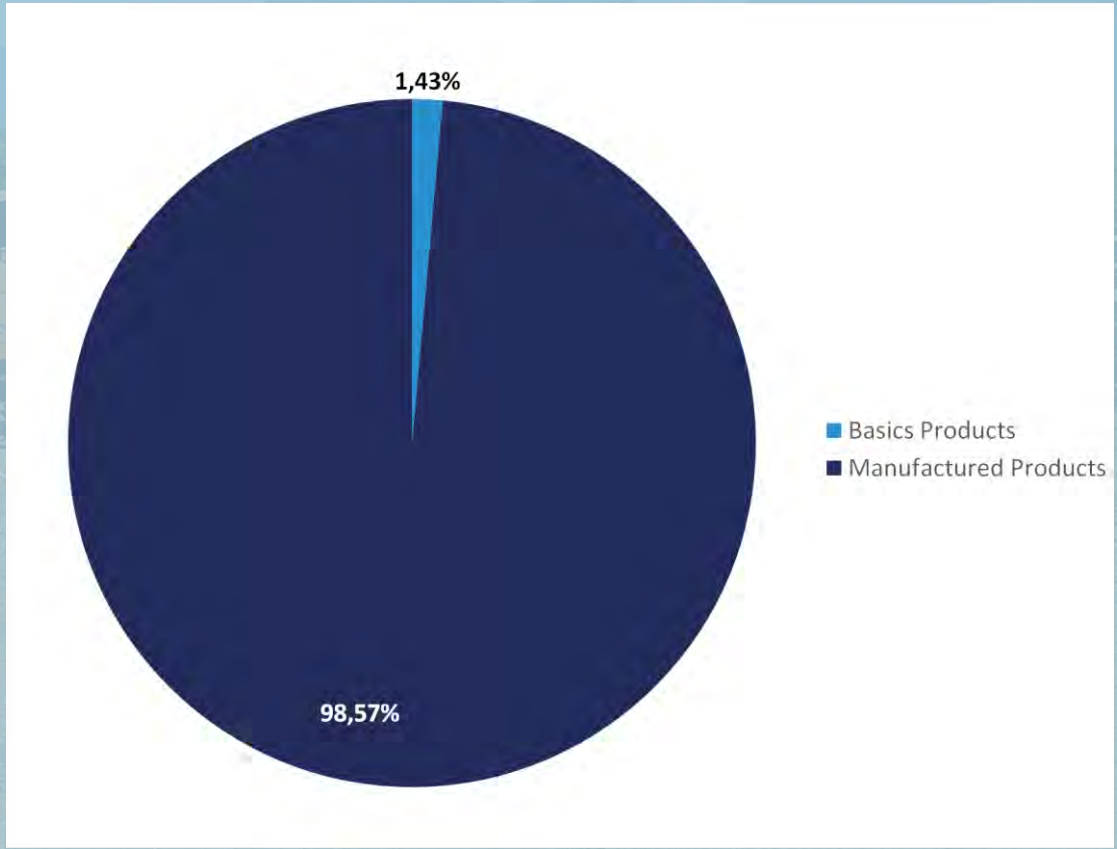
Cobalt

Brazilian Production and Foreign Trade (2020)

Cobalt - Export

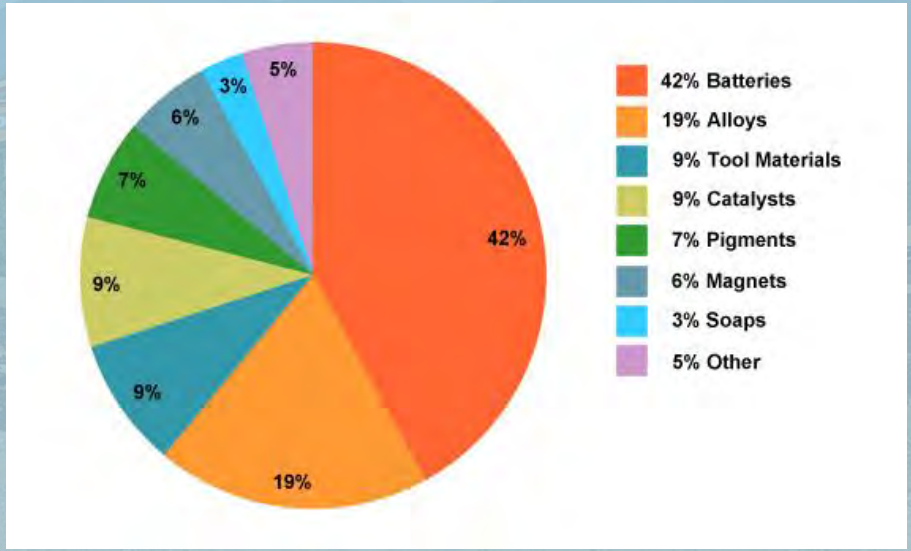


Source: ANM and Comex Stat (MDIC) – 2020
Processed by Platform P3M

Cobalt

Uses and Applications

- Cobalt (Co) is a metal used in numerous diverse commercial, industrial, and military applications, many of which are strategic and critical.
- On a global basis, the leading use of cobalt is in rechargeable battery electrodes. Superalloys, which are used to make parts for gas turbine engines, are another major use for cobalt.



- Cobalt is also used to make airbags in automobiles; catalysts for the petroleum and chemical industries; cemented carbides (also called hardmetals) and diamond tools; corrosion- and wear-resistant alloys; drying agents for paints, varnishes, and inks; dyes and pigments; ground coats for porcelain enamels; high-speed steels; magnetic recording media; magnets; and steel-belted radial tires.

Source: Cobalt Institute; USGS

Cobalt

World Market

Risk Assessment 2018:

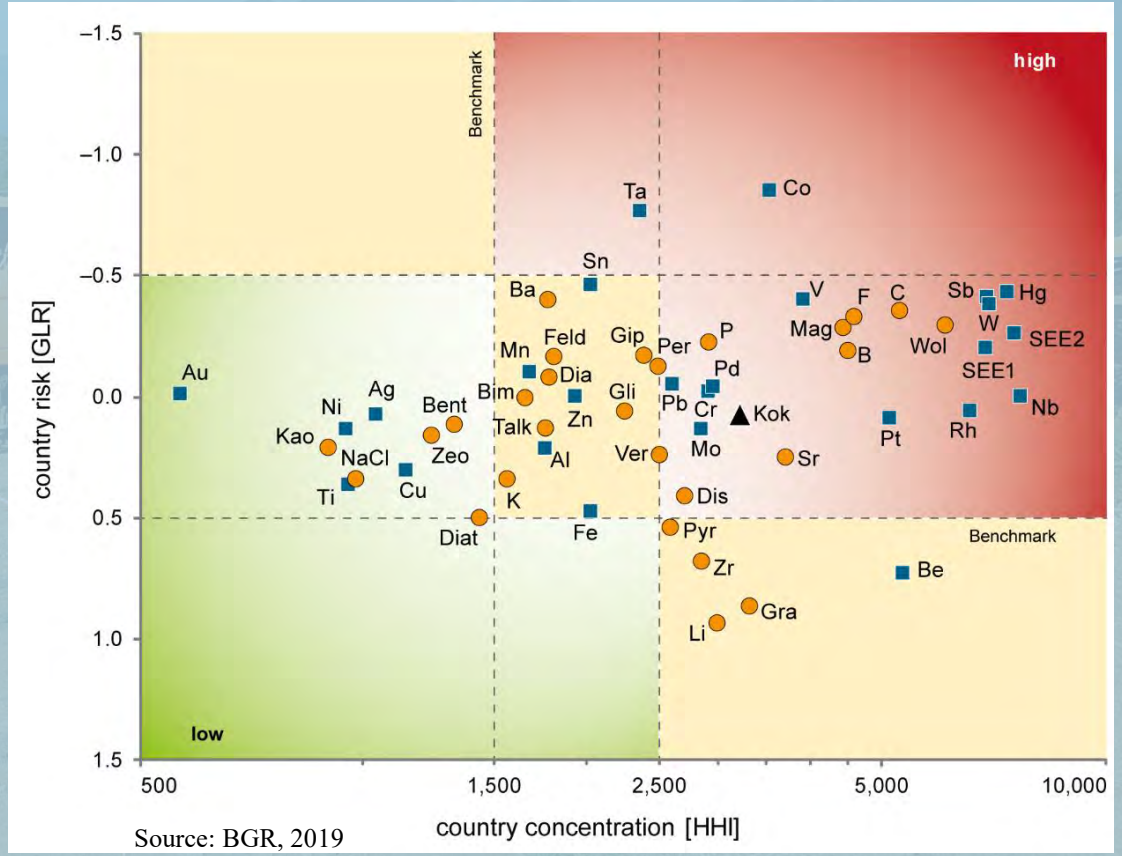
- 34 metals
- 27 industrial minerals + coking coal
- 213 commercial products

risk group 1
risk group 2
risk group 3

metals
coking coal
industrial minerals

SEE[1] excl. illegal production
SEE[2] incl. illegal production

Market concentration of raw materials



Source: BGR, 2019

Cobalt

World Market

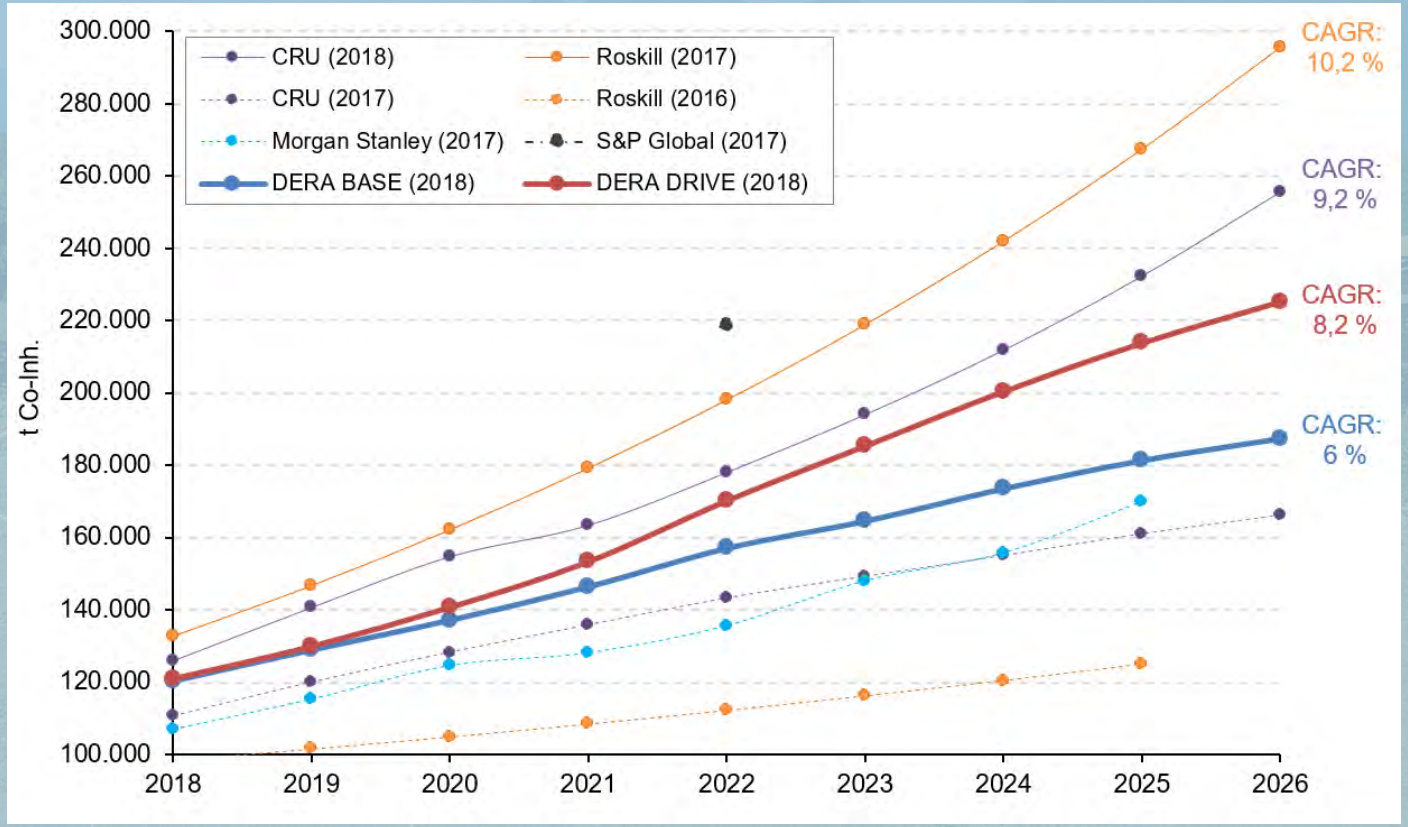
Future Demand

Co Demand 2026:

DERA DRIVE
→ 225.360 t Co

DERA BASE
→ 187.500 t Co

How much Cobalt do we need?

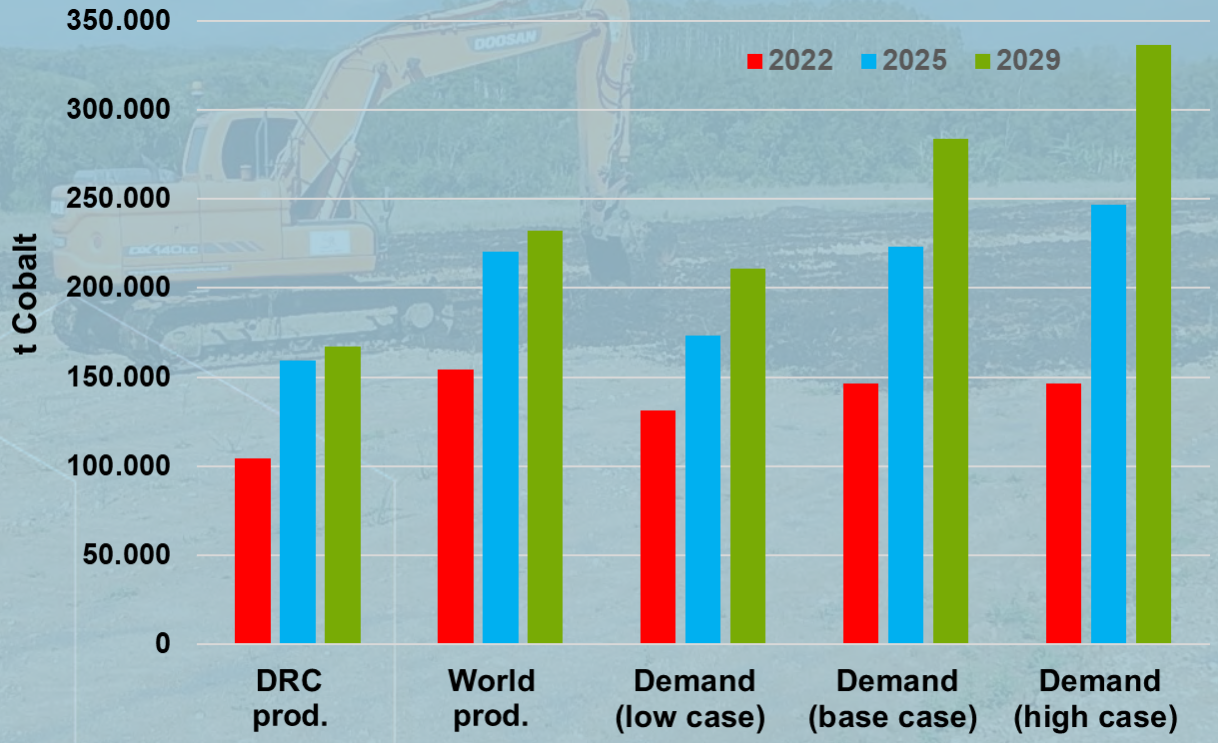


Source: DERA, 2020

Cobalt

World Market

Forecast: global mine production from existing producers and demand for 2022, 2025 and 2029



Sorce; Roskill, 2020

Cobalt

World Market

Global future demand of Co (tons)
CAGR for individual sectors

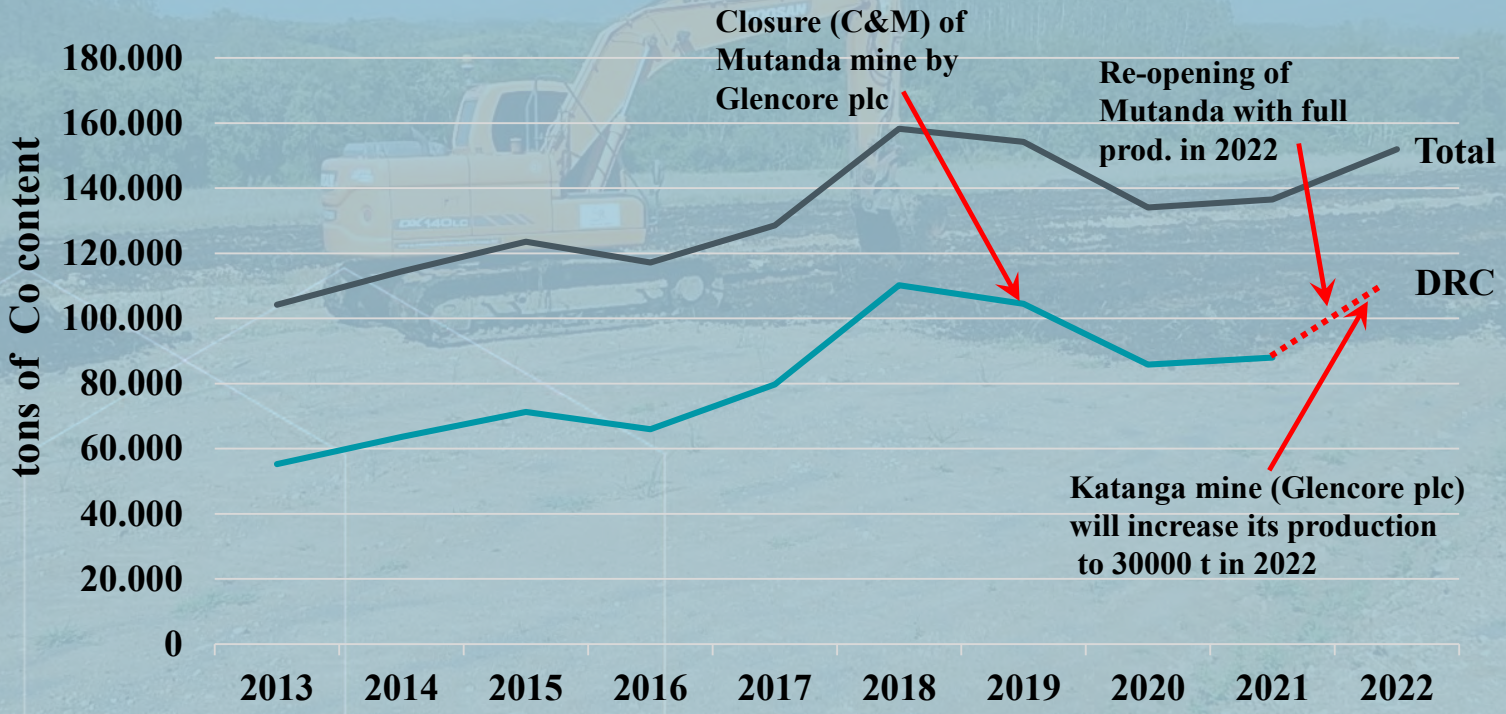
	2019	2024	2029	CAGR
Batteries	**86.740**	**154.410**	**204.760**	**9,0%**
Nickel-base alloys	20.930	25.250	27.670	2,8%
Tool materials	12.480	11.940	13.150	0,5%
Pigments	6.470	8.060	10.090	4,5%
Catalysts	6.180	7.520	9.230	4,1%
Magnets	5.670	7.690	10.100	5,9%
Soaps and dryers	2.720	3.220	3.850	3,5%
Total	**146.190**	**223.090**	**283.850**	**6,9%**

Source: Roskill 2020

Cobalt

World Market

Global mine production of Co



Souce: BGR 2021

Cobalt

World Market

Openings in 2022:

- Shayong (Hunan Hongjie, China)
- Kalongwe (Nzuri Copper , DRC)
- Kipushi Tailings Project (Paragon Mining, DRC)
- Enterprise (First Quantum, Zambia)
- Kitwe Tailings Project (Horizon Corp., Zambia)
- Idaho Cobalt **Project (Jervois, USA)**

Additional openings from 2026:

- Sunrise (Clean Teq Hold., Australia)
- Sconi (Australian Mines Ltd, Aus.)
- Goongarrie (Ardea Res., Australia)
- Wingellina (Metals X, Australia)
- Turagain (Giga Metals, Canada)
- Dumont (Royal Nickel Corp. Can.)
- Piauí (Brazilian Nickel, Brazil)

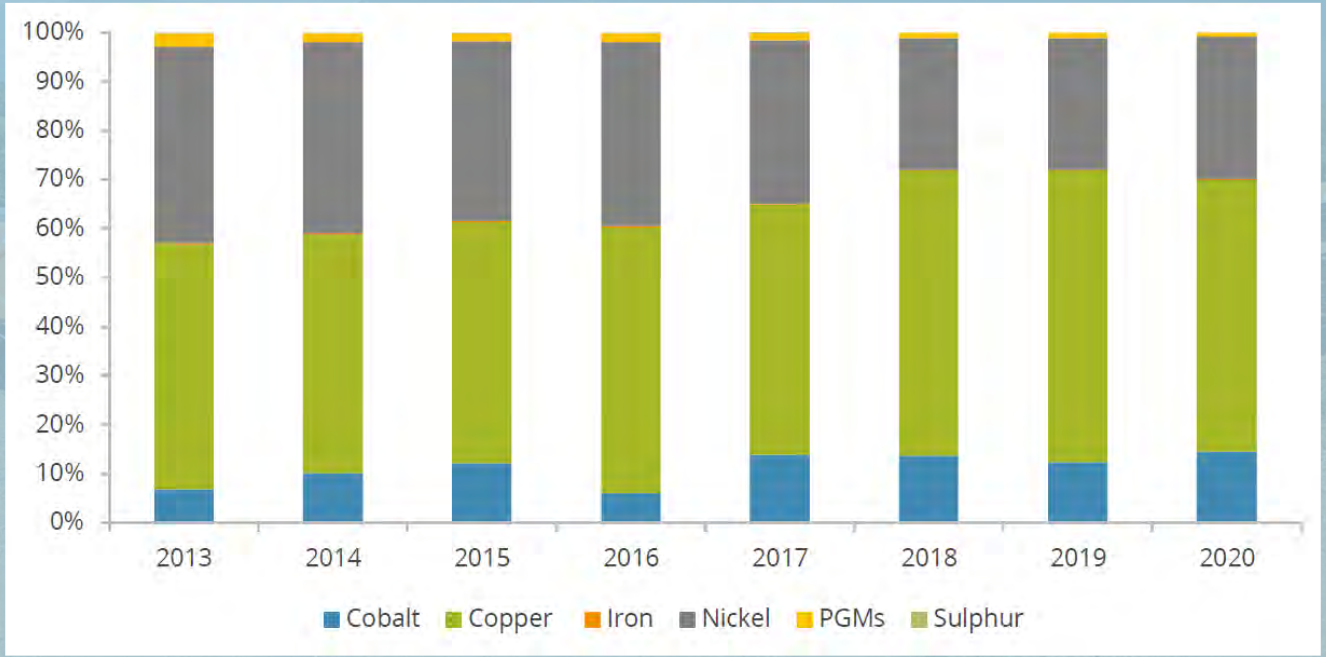
Sorce; Roskill 2020

Cobalt

World Market

Cobalt is predominantly mined as a by-product of copper (55% in 2020) and nickel (29% in 2020).

Cobalt supply is dependent on demand and production of copper and nickel.

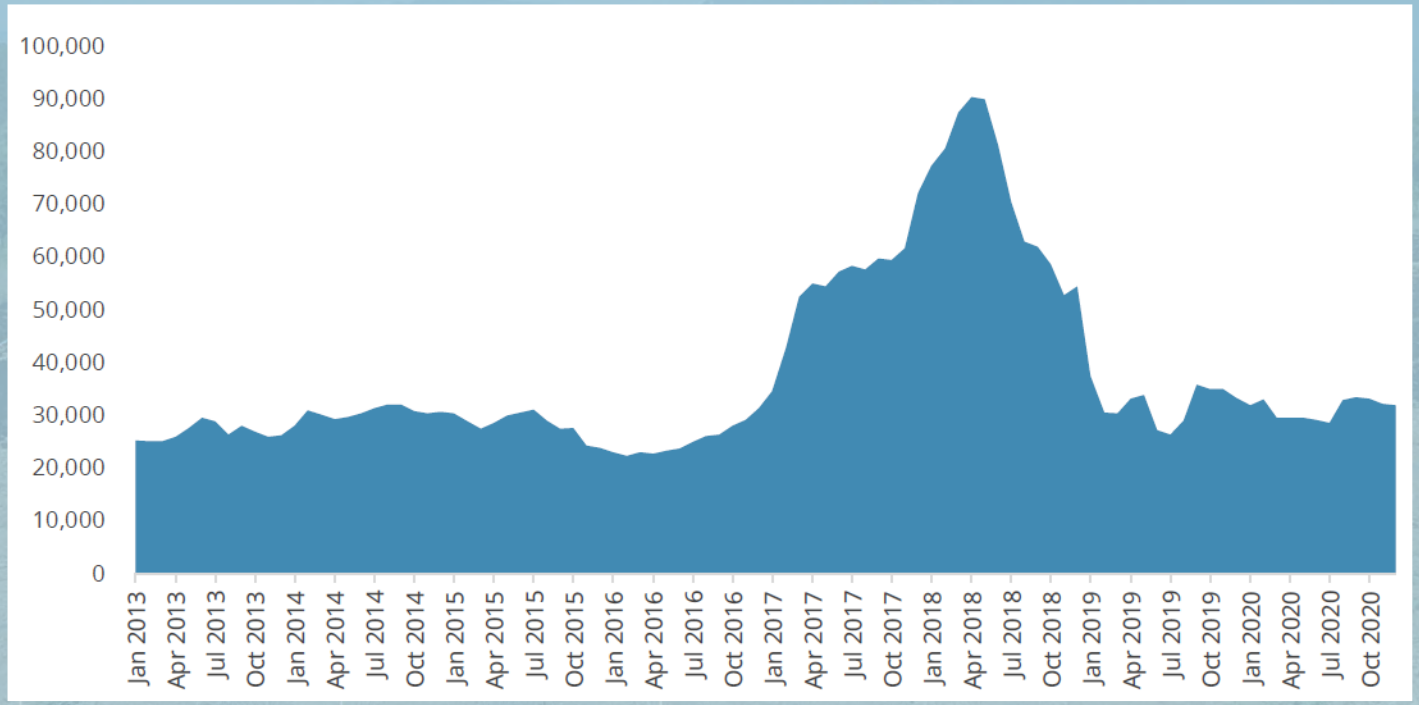


In Brazil, until 2016, all cobalt produced came from the production of sulphide nickel.

Roskill 2020

Cobalt

World Market



Cobalt prices have a history of volatility, although they remained in a narrow range of US$22,000-US$32,000/t between 2013 and 2016.

Cobalt

World Market

The effect of cobalt production on the profitability of Ni mines

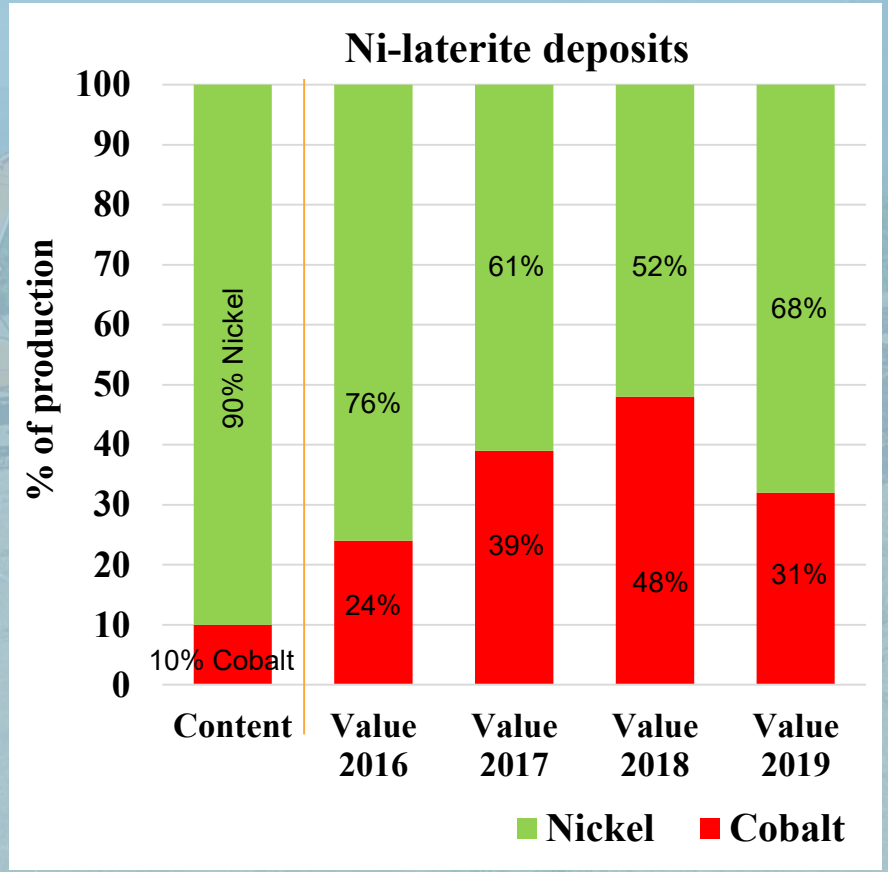
Average Co prices:

(Cobalt Metal 99.8% min. delivered China)

- **2016:** 31 US$/kg (low benchmark prize)
- **2017:** 62 US$/kg
- **2018:** 83 US$/kg (high benchmark prize)
- **2019:** 38 US$/kg

Nickel laterites contribute
~30% of the global Co supply!

Source: BGR 2020



Cobalt

Brazilian Perspective

Projects under implementation in laterites

Vermelho:

- 171 Mt reserves and resources
- CAPEX = 652.2 US$ M
- LOM = 38 years with 30,000/year;
- Process: High Pressure Acid Leaching
- 0.06 % Co

Araguaia:

- 132 Mt reserves and resources;
- CAPEX = 443.07 US$ M
- LOM = 28 years with 14,500/year;
- Process: Rotary Kiln Electric Furnace
- 0,06 % Co

Source: Centauro Mining

Piauí Nickel

- 72 Mt reserves and resources
- CAPEX= 465 US$ M
- LOM = 8 years with 25,000/year
- Process: Heap Leaching
- 0.048% Co

Source: Brazilian Nickel

Cobalt

Brazilian Government Policies

- The Cobalt Project is an initiative of the Geological Survey of Brazil (CPRM), together with the BGR (Federal Institute of Geosciences and Natural Resources of Germany), the CETEM (Mineral Technology Center) that seek to use cobalt contained in deposits of lateritic profiles in Brazil through the development of mineral processing technology based on bioleaching.

- The Geological Survey of Brazil - CPRM, through the Mineral Resources project of the Brazilian Continental Shelf, has been carrying out research seeking to map polymetallic sulphides in the Mid-oceanic Cordillera of the South Atlantic and Equatorial.

- **Pro-Strategic Minerals:** Decree 10,657, of March 24th, 2021 - Institutes the Policy to Support the Environmental Licensing of Investment Projects for the Production of Strategic Minerals - Pro-Strategic Minerals, provides for its qualification under the Investment Partnership Program and creates the Interministerial Committee for the Analysis of Strategic Minerals Projects.

SERVIÇO GEOLÓGICO DO BRASIL
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