Potential Opportunities Associated with the Development of Mineral Processing Activities in South Asia and South East Asia

Prof. Zhuo Xiaojun(zhuoxj@minmetals.com) ● Myanmar ● Sep. 9th, 2019

Curriculum Vitae

Prof. Zhuo Xiaojun

- Deputy General Manager, Changsha Research Institute of Mining and Metallurgy Co., Ltd (CRIMM) of CMC;
- Responsible for Deep Sea Mining, Sci-tec Innovation Projects, Intellectual Property, etc.;
- Ph.D of Metallurgical Engineering, University of Science and Technology Beijing, China in 2008;
- Major in Metallurgy and Material.

CONTENT

01 CMC & CRIMM Brief Introduction

1.1 China Minmetals Corporation History

China Minmetals Corporation was founded in 1950. CMC is a large-scale globally marketing enterprise with focus on production and development of metals and mineral products, logistics and comprehensive services and doing businesses concurrently in finance, real estate and miming and metallurgical science and technology.

1.2 CMC Operations

■As an internationalized mining company, corporation engages in exploration, mining, smelting, processing, trading of metal & mineral products, engineering contracting and construction, equipment manufacturing, as well as financial business, real estate, mining & metallurgical technologies, etc.

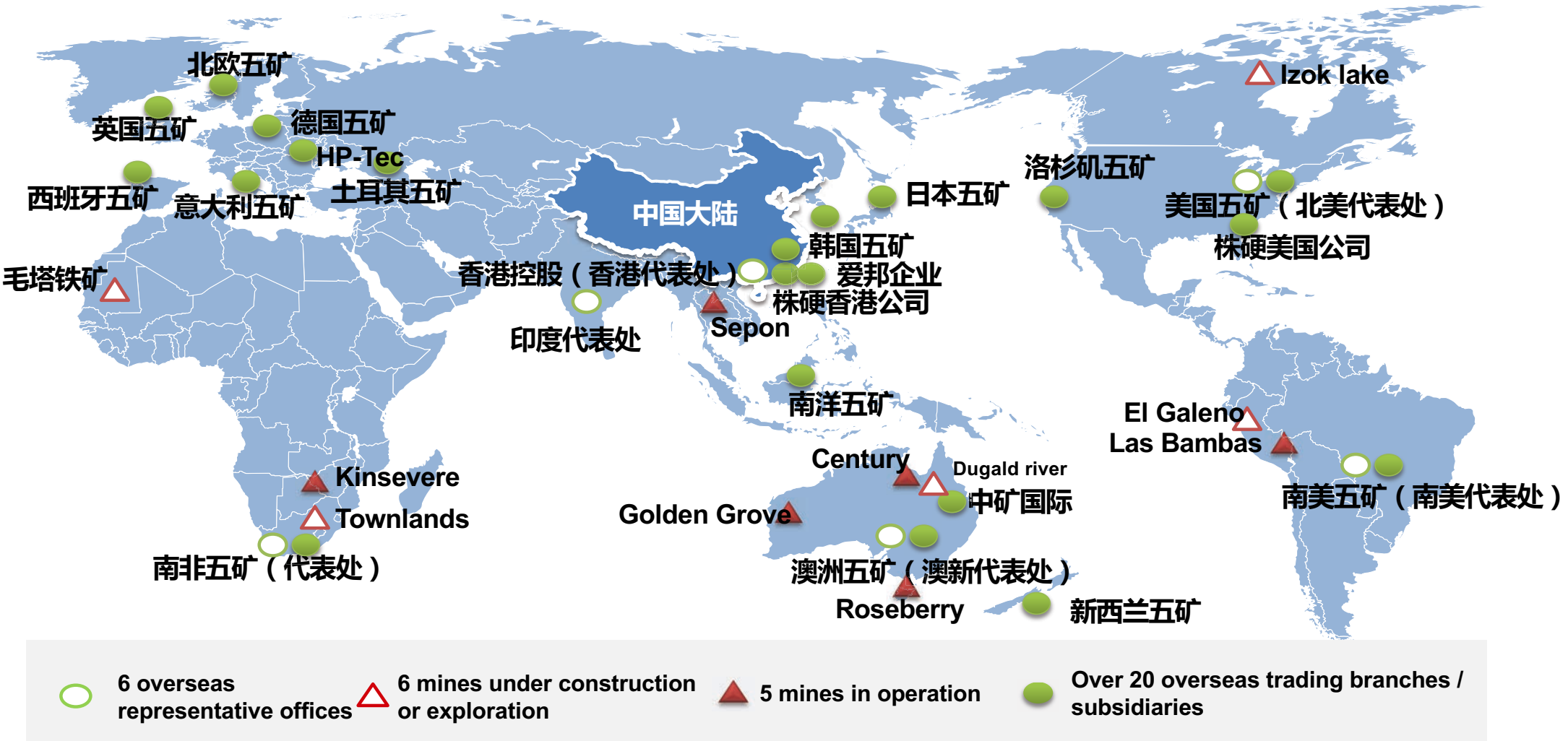
■It has overseas subsidiaries, engineering projects spreading over 60 countries and regions, with business spreading all over the world.

■CMC currently has a total asset up to 800 billion Yuan. After merging and reorganization, it was ranked 112th among the Fortune Global 500 companies in 2019 and 1st in the domestic metal and mining industry.

■With abundant mineral resources and reserves, CMC has owned a series of world-class mines with high quality at home and abroad, belonging to the first-tier companies in the world for resources of copper, zinc and nickel, as well as taking the top place in tungsten, antimony and bismuth resources globally.

■CMC is equipped with more than 60,000 professionals and 32 national sci-tech innovation platforms and key laboratories , as well as over 23,000 effective patents accumulatively, with professional skills and technical strength prominent among SOEs.

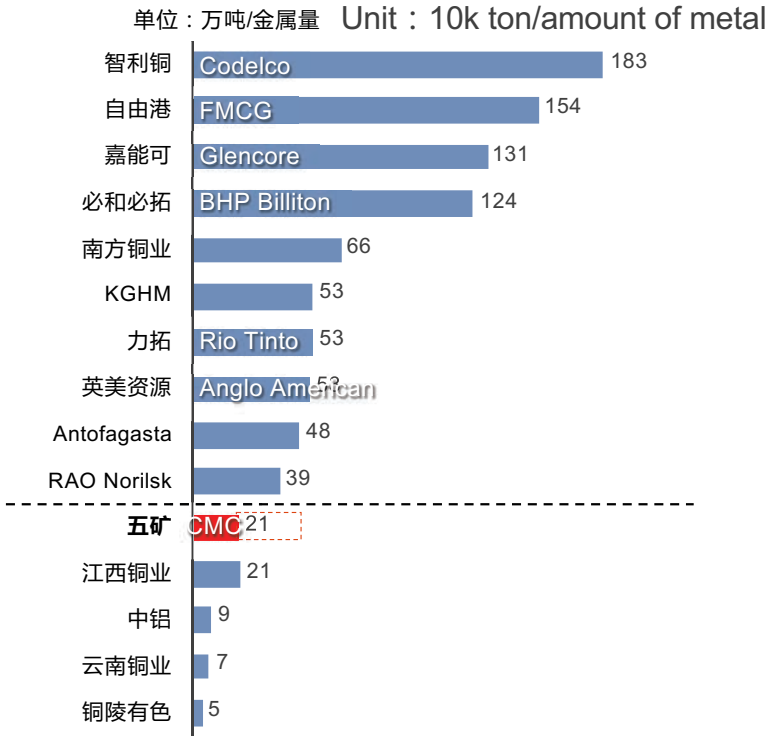
CMC Global Distribution



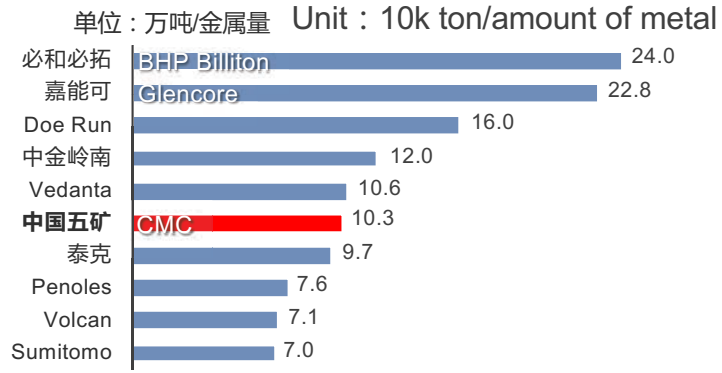
Basic Metals Business

Global copper reserves rankings

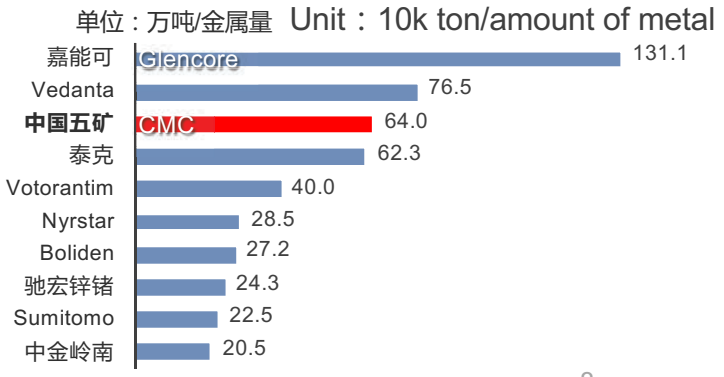
World's top 10 copper producers



World's top 10 Lead Concentrate Producer



World's top 10 Zinc Concentrate Producer



1.3 History of CRIMM

Changsha Research Institute of Mining and Metallurgy Co., Ltd (CRIMM) was Established in 1955, it was subordinate to the Chinese Academy of Sciences, National Defense Commission and the Ministry of Metallurgical Industry;

In 1999, CRIMM was transferred and subordinated to the Central Enterprise Work Committee and the State Council's SASAC;

In 2009, CRIMM was restructured and become a wholly-owned subsidiary of CMC.

1.3 History of CRIMM

- Main Business and Human Resources

Metallurgical and Mining Engineering Technology and Equipment

- Beneficiation and Metallurgical Engineering Technology and Equipment
- **Development and Utilization of Deep Sea Resources**
- Environmental Engineering Technology and Equipment
- Intelligent Mine

R&D and Industrialization of New Material

- New Energy Materials and Devices
- Power Battery Recycling
- Manganese-based New Materials
- Technology and Equipment

Employees: **1536** (2018)
Professional and Technical Personnels: **664** (**423** senior researchers)
Academicians: **1** (Chinese Academy of Engineering), **1**(foreign academician)
Postgraduate Supervisors: **49**
Experts enjoying special government allowances from the State Council: **108**

CRIMM Sci-tech Innovation Platform

National Level (7):

◆ International Joint Research Center for Seabed Mineral Resources Development

◆ State Key Laboratory for Development and Utilization of Deep Sea Mineral Resources

◆State Engineering Technology Research Center for Comprehensive Utilization of Metal Mineral Resources

◆State-Local Joint Engineering Laboratory for Efficient Clean Processing and Comprehensive Utilization of Ferromanganese Mineral Resources

◆Quality Control and Technology Evaluation Laboratory for Industrial Products (Ferrous Metal Beneficiation and Metallurgy Products)

◆State SME Public Service Demonstration Platform—Metal Mineral Resources Development and Utilization Service Platform

◆State Quality Inspection Center for Drilling Tools in Metallurgical Industry

Provincial Level (6):

◆Hunan Engineering Laboratory for Power Battery Cathode Material Preparation

◆ Guizhou Engineering Technology Research Center for Efficient Use of Manganese Resources

◆ Hunan Engineering Research Center for Metal Surface Cleaning Technology of High Pressure Water Jet

◆ Industrial Cluster Window Platform for Comprehensive Utilization of Non-ferrous Metal Mineral Resources

◆Hunan Demonstration Base for Public Entrepreneurship and Innovation

◆ Hunan Entrepreneurship and Innovation Base for Medium Small and Micro-sized Enterprises

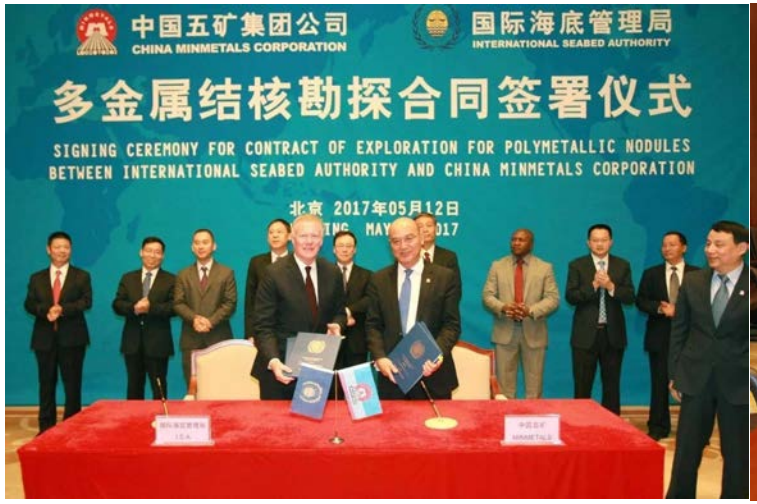
1.6 CMC/CRIMM Seabed Mineral Exploitation

- At May 12th, 2017, SG Michael Lodge of ISA and Chairman He Wenbo of MINMETALS signed the contract of exploration for Polymetallic Nodules in Beijing, China.

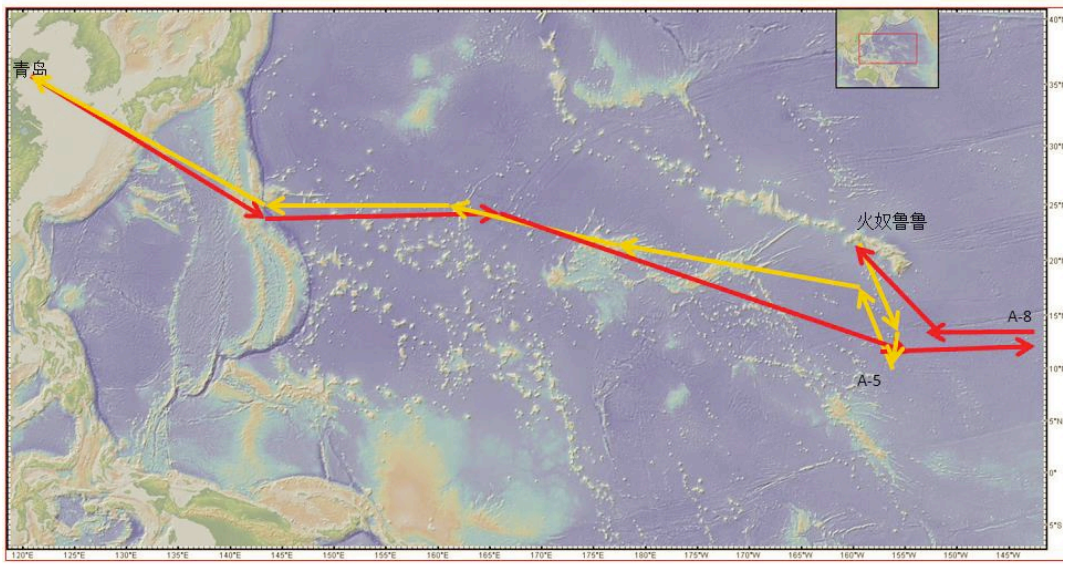
12th, May 2017
MINMETALS Tower

中国五矿集团公司
MINMETALS

国际海底管理局
ISA



Exploration cruise for CMC CCZ-2017



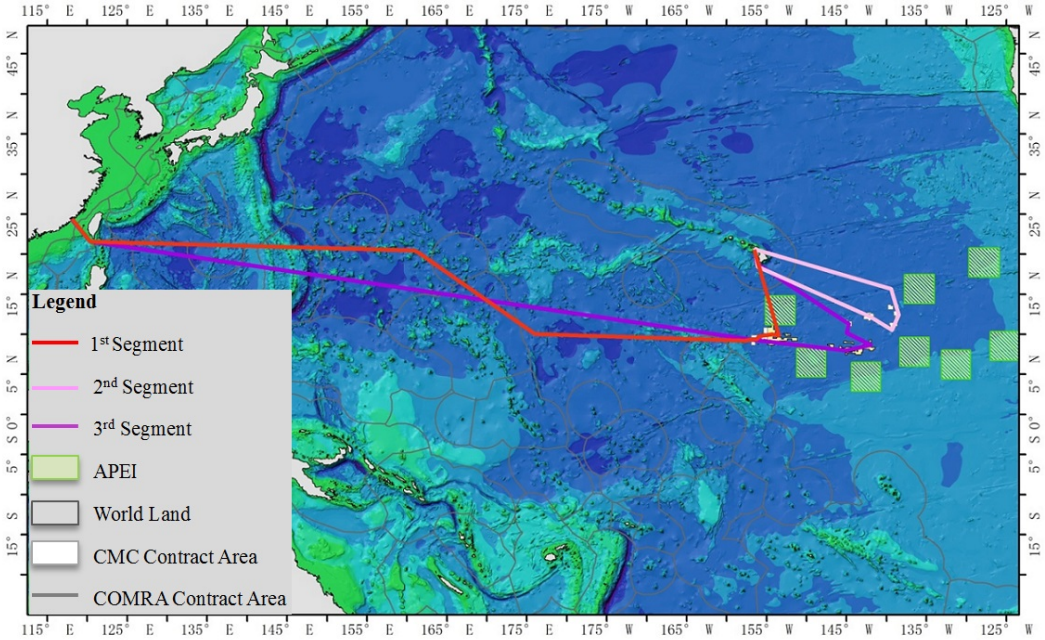
◆On August, 2017, CMC set sail for the first exploration cruise for maritime surveys in CMC Contract Area

◆Route: Qingdao->A-5->Hawaii->A-1，2，6，7，8->Qingdao

◆Time Period: 95 days

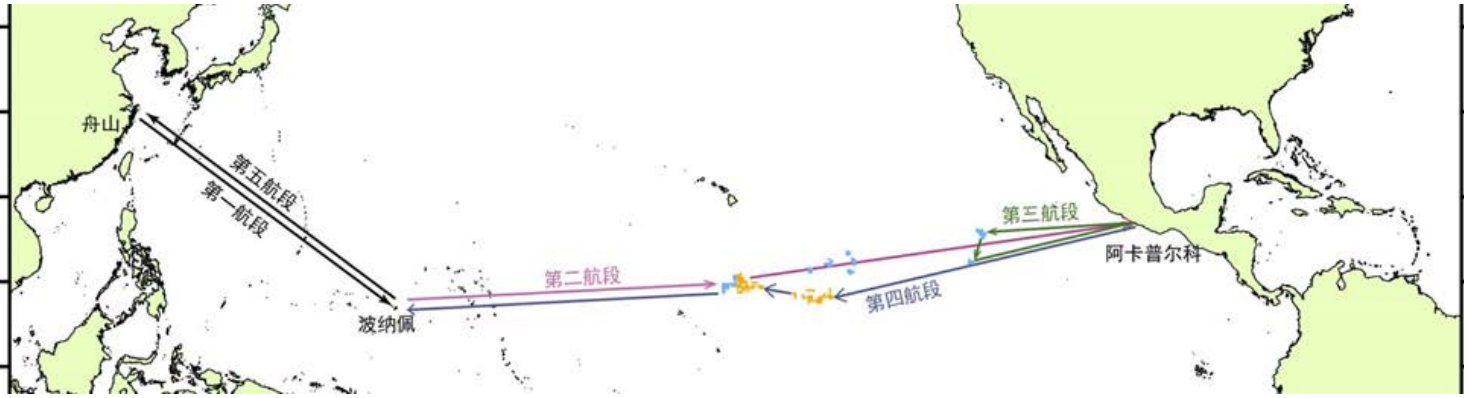
Exploration cruise for CMC CCZ-2018

Time: July to Nov., 2018
Day period: 100 days
Area: A-5、1、2、6、7 and 8 blocks
Target: further understand the distribution of polymetallic nodules in the area and estimate the amount of resources through submarine camera and geological sampling



The Environmental Survey: conducted mainly in A-8 block and the sea route was conducted by means of box-type, multi-tube, anchor line, CTD, and biological dredger to obtain hydrological, biological, chemical, and sedimentary samples and data, and to accumulate environmental baseline data.

Exploration cruise for CMC CCZ-2019



- **Conducting exploration and environmental investigation of polymetallic nodule resources in A-5, A-3 and A-4 blocks and adjacent areas of the contract areas of China Minmetals, and data such as topography, geomorphology, gravity, shallow stratum characteristics, nodule distribution, grade, abundance and coverage, as well as data of environmental baselines such as hydrology, chemistry and biology in the contract areas were obtained.**

Exploration cruise for CMC CCZ-2019

China, Myanmar, China, Somalia, Malaysia

Lecturer Ms. THET PAING KYAW WIN
From Dagon University, 50 days offshore

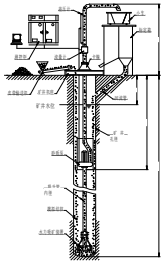
CRIMM Deep Sea Mining Development

2001

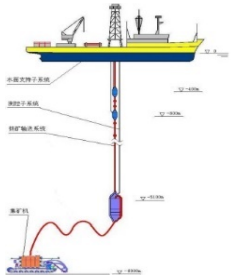
lake testing at the depth of 135m

2009

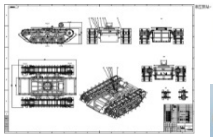
217m mine lifting test

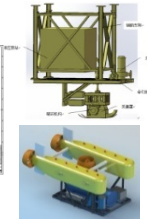


2010



Starting to develop Polymetallic Nodule and SMS mining key equipment





2011

1000m Polymetallic Nodule mining system design

2014

Starting to develop miner, sea trial testing was completed in 2018

2016

Test of lifting system at sea completed

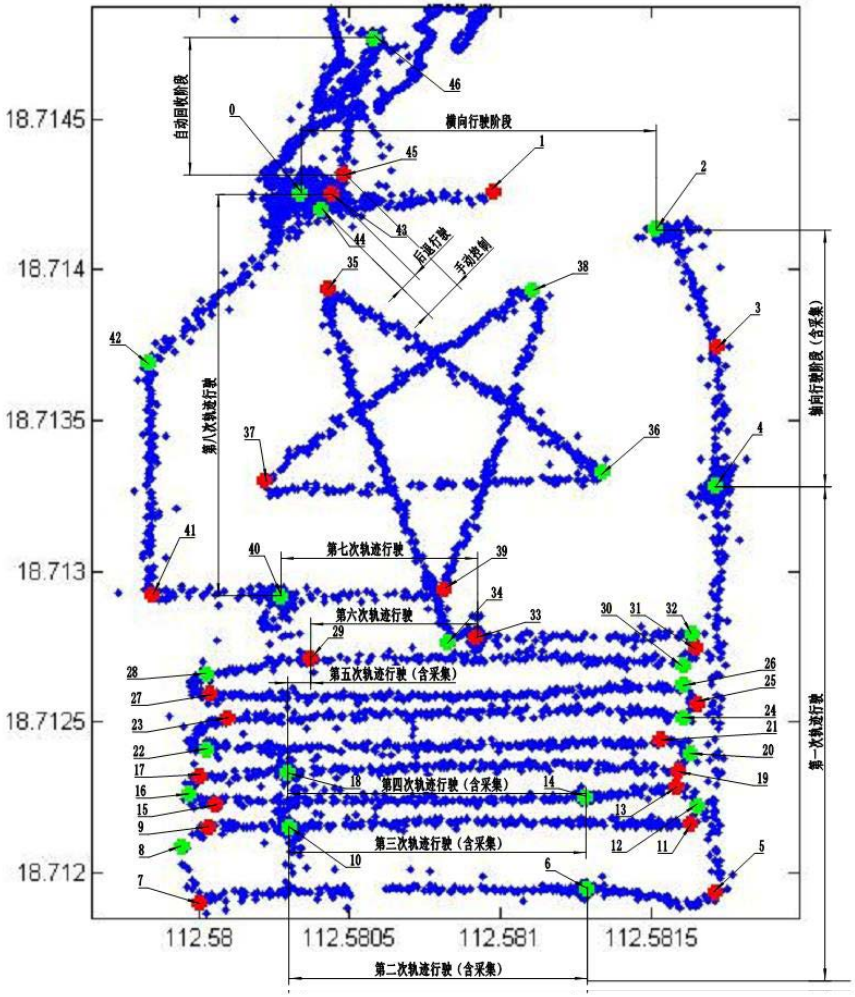
17

CRIMM Success for First Pipeline Transportation Sea-trial Testing

The first sea trial test of pipeline transportation system for deep-sea mining was completed at China in 2016. This test has been hold for 22 days in 304m depth with 5hrs system working time.

CRIMM Success for first collection Sea-trial testing system

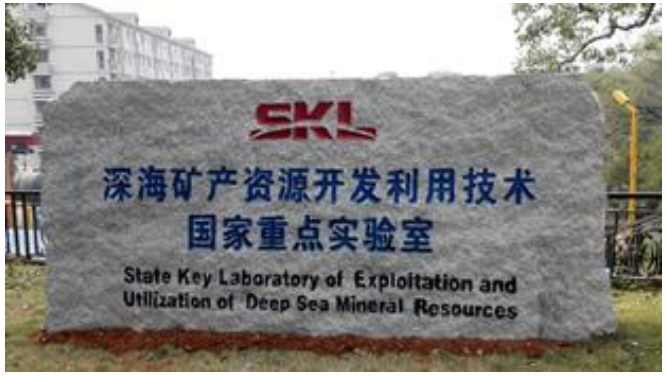
- June, 2018 in China South Sea.



The sea trial for the collection system at the water depth of 500m is expected to be completed on June, 2018.

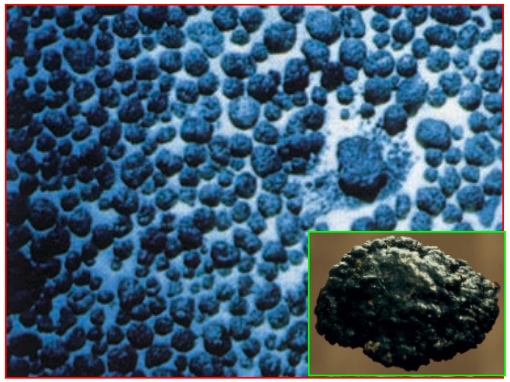
CRIMM Smelting and Processing Practice

CRIMM is one of the earliest working units in the beneficiation and metallurgy of oceanic polymetallic nodule in China. It has been the first in China to carry out the research on the pyrometallurgical and hydrometallurgical in China since September, 1983. So far, CRIMM has completed nearly 20 studies of oceanic polymetallic nodules beneficiation and metallurgy project, the main contents include: polymetallic nodules smelting process research, process mineralogy and beneficiation technology research, the mineral processing reagents research as well as direct usage research of nodules minerals, etc.

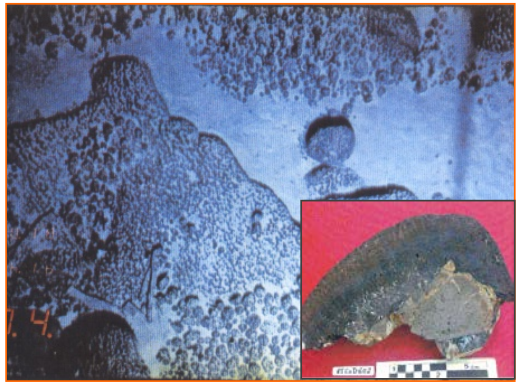


02 Seabed Mineral and Land Mineral in the World

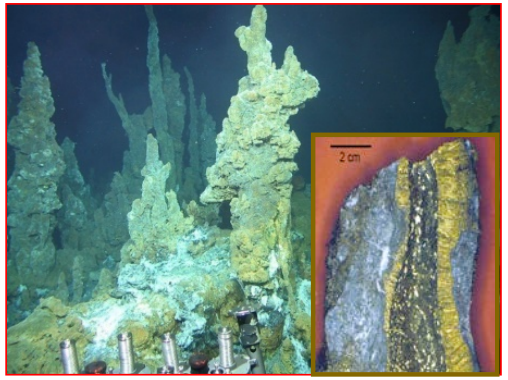
2.1 Seabed Resources Type, Reserves, Distribution



Polymetallic nodules 4000~6000m depth distribute in more than 70% seabed area



cobalt –rich crust distribute in seamount 800~3000 depth



polymetallic sulphide 3000~3500m Distribute in mid-ocean ridges and backarc basin

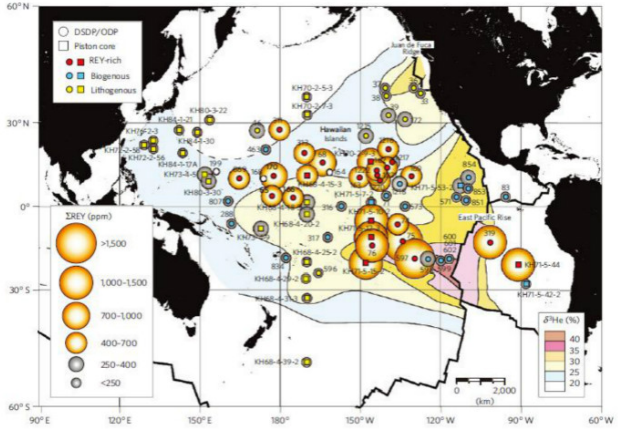
100 million tons	Polymetallic nodules	Mn	Ni	Cu
Allowable exploitation in the Pacific Ocean	425	86	3.9	3
Total reserves in land	-	6.3	0.8	6.9

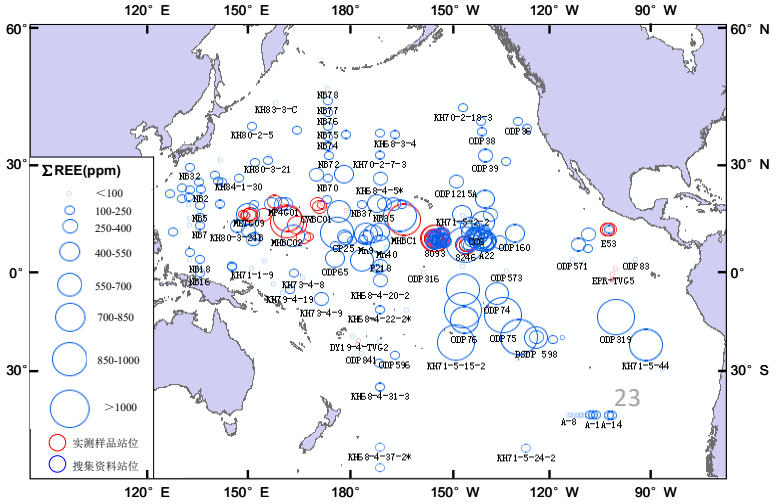
- Cobalt in cobalt –rich crust can meet global consumption at least 110 years.
- 34 polymetallic sulphide mining areas remain in mid-ocean ridges. There are a lot of resources in EEZ of South Pacific island countries .

※exploitation boundary conditions: abundance:10kilo/m2, total grade of copper, nickel and cobalt: 2.5%

2.1 Seabed Resources Type, Reserves, Distribution

- According to exploratory data, REO in Southeast Pacific and Central North Pacific can reach 90 billion tons, it is 800 times of currently known terrestrial resources amount, and grade can reach over 10 times of the land rare earth resources.
- Japan and the United States and other countries in the world are doing development research of rare earth resources. China is exploring rare earth resources too.





2.2 Land Mineral-COPPER

World Mine Production and Reserves

(Data in thousand metric tons of copper content)

Country	Mine production		Reserves
	2017	2018	
United States	1260	1200	48，000
Australia	860	950	88，000
Chile	5500	5800	170，000
China	1710	1600	26，000
Congo (Kinshasa)	1090	1200	20，000
Indonesia	**622**	**780**	**51，000**
Mexico	742	760	50，000
Peru	2450	2400	83，000
Russia	705	710	61，000
Zambia	794	870	19，000
Other countries	4250	4400	210，000
World total (rounded)	20000	21000	830，000

Resource : USGS

2.2 Land Mineral-NICKEL

World Mine Production and Reserves

(Data in thousand metric tons of nickel content)

Country	Mine production		Reserves
	2017	2018	
United States	22.1	19	110
Australia	179	170	19,000
Brazil	78.6	80	11,000
Canada	214	160	2,700
China	103	110	2,800
Colombia	45.5	43	440
Cuba	52.8	53	5,500
Finland	34.6	46	-
Guatemala	53.7	49	1,800
Indonesia	345	560	21,000
Madagascar	41.7	39	1,600
New Caledonia	215	210	-
Philippines	366	340	4,800
Russia	214	210	7,600
South Africa	48.4	44	3,700
Other countries	146	180	6,500
World total (rounded)	2160	2300	89,000

Resource : USGS

2.2 Land Mineral-COBALT

World Mine Production and Reserves

(Data in metric tons of cobalt content)

Country	Mine production		Reserves
	2017	2018	
United States	640	500	38,000
Australia	5030	4700	1,200,000
Canada	3870	3800	250,000
China	3100	3100	80,000
Congo (Kinshasa)	73000	9000	3,400,000
Cuba	5000	4900	500,000
Madagascar	3500	3500	140,000
Morocco	2200	2300	17,000
Papua New Guinea	3310	3200	56,000
Philippines	4600	4600	280,000
Russia	5900	5900	250,000
South Africa	2300	2200	24,000
Other countries	7650	7000	640,000
World total (rounded)	120000	140000	6,900,000

Resource : USGS

2.2 Land Mineral-MANGANES

World Mine Production and Reserves

(Data in thousand metric tons gross weight)

Country	Mine production		Reserves
	2017	2018	
Australia	2820	3100	99,000
Brazil	1160	1200	110,000
China	1700	1800	54,000
Gabon	2190	2300	65,000
Ghana	810	850	13,000
India	734	770	33,000
Kazakhstan, concentrate	168	170	5,000
Malaysia	478	510	-
Mexico	212	220	5,000
South Africa	5400	5500	230,000
Ukraine, concentrate	735	740	140,000
Other countries	898	940	-
World total (rounded)	17300	18000	760,000

Resource : USGS

2.2 Land Mineral-RARE EARTHS

World Mine Production and Reserves

(Data in metric tons of rare-earth oxide (REO) equivalent content)

Country	Mine production		Reserves
	2017	2018	
United States	-	15000	1,400,000
Australia	19000	20000	3,400,000
Brazil	1700	1000	22,000,000
Myanmar	-	5000	-
Burundi	-	1000	-
China	105000	120000	44,000,000
India	1800	1800	6,900,000
Malaysia	180	200	30,000
Russia	2600	2600	12,000,000
Thailand	1300	1000	-
Vietnam	200	400	22,000,000
Other countries	-	-	4,400,000
World total (rounded)	132000	170000	120,000,000

Resource : USGS

2.3 Rich Mineral Resources in South East Asia

- Rich Cu, Cr, Li, Bauxite, Tin Mineral Resources in South East Asia.

Nickel Laterite Mine Project in Tagaung Taung , Myanma

Tong Cong Cu Smelt Plant in Vietnam

Dong-Tai Potash Mine Mining and Beneficiation Project in Laos

OBI Island Ni-Ferro Project in Indonesia

Ramu Nickel Project in PNG

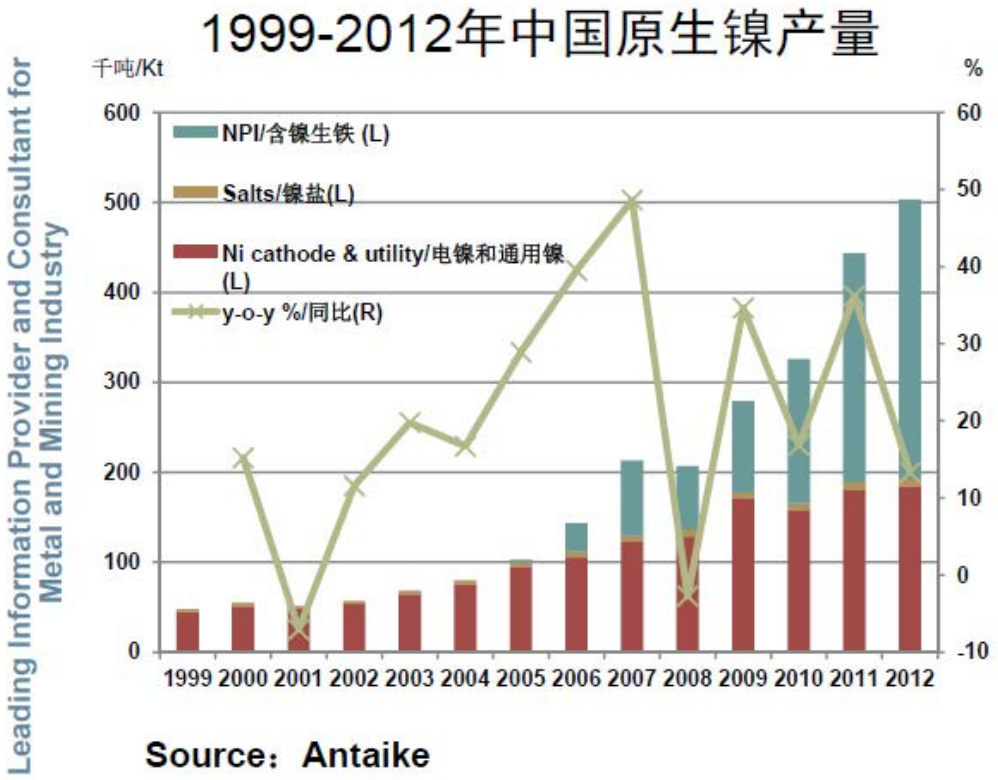
2.4 Metal Market-Nickel

Global Market Condition

- About 80 percent of global nickel supply is used in the production of stainless steel.
- Since 2018, with the economy around the globe weakening, the market demand for the stainless steel is also in downturn.

The consumption growth for the nickel is slow.

2.4 Metal Market-Nickel



China Market Condition

- In recent years, China becomes the major impetus for the increase of the global stainless steel production, and accounts for 45% of global raw stainless steel production.

2.4 Metal Market-Cobalt

Global Market Condition

- Since 2009, the oversupply situation for the global cobalt market comes again.
- The global consumption growth rate of cobalt will be stable in coming years, but the supply growth rate will be faster.

Continued oversupply situation of global cobalt market.

2.4 Metal Market-Cobalt

China Market Condition

- Since 2011, China has become the world's largest cobalt consumption country, and will account for 33% of the world's total consumption in 2016.
- The batteries used in mobile phone, laptop and electromobile may lead to an increase in cobalt demand in battery industry, but some other battery materials without cobalt or with low cobalt content may also reduce the use of cobalt.

2.4 Metal Market-Copper

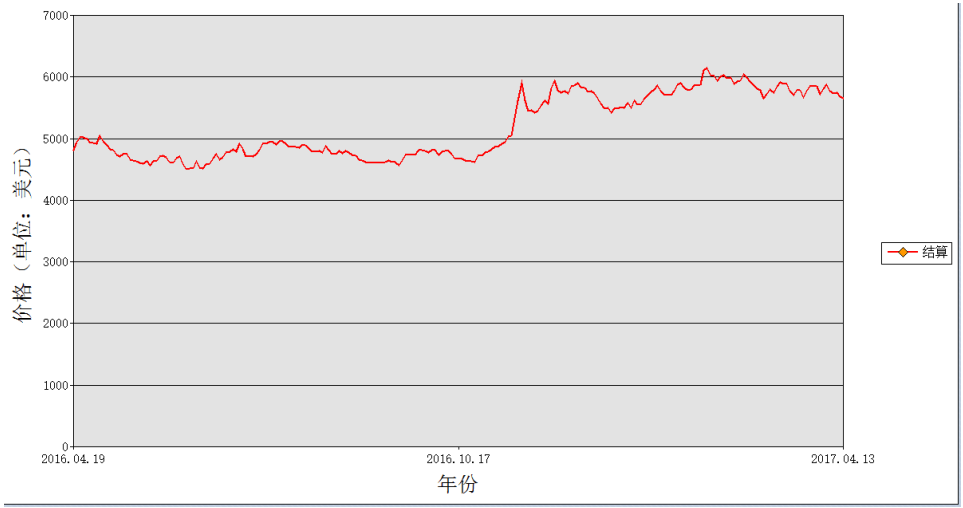
Global Market Condition

- In 2013, the global copper market was from supply shortage to oversupply.
- In July 2013, Mongolia began to export copper concentrates to China, with the annual productivity is up to 0.45 million tons.

2.4 Metal Market-Copper

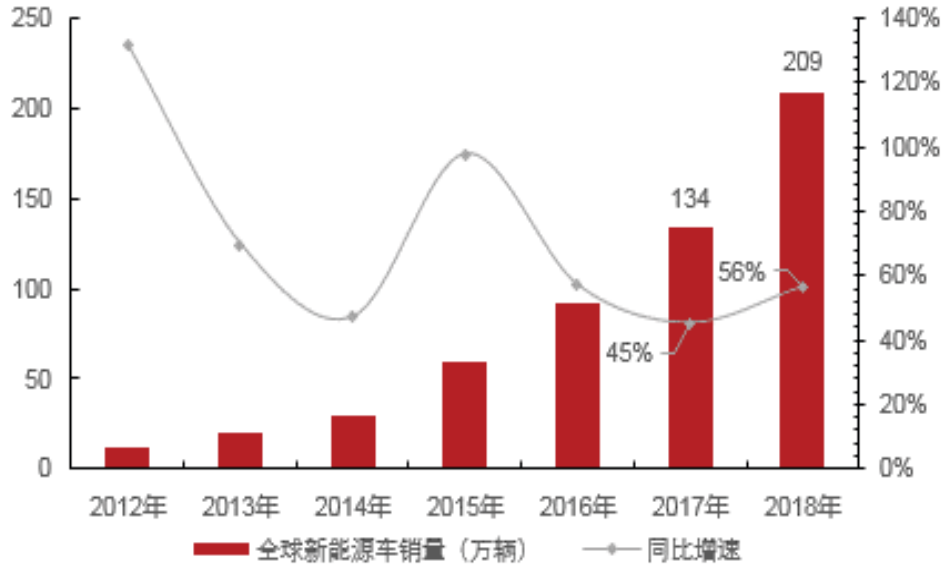
China Market Condition

- As the world's largest copper consumption (account for 40%) country, China's demand growth for copper is declining, as the investment on power grid construction and demands for household electrical appliances are declining.
- The growth rate of copper consumption has been slow down for many years.

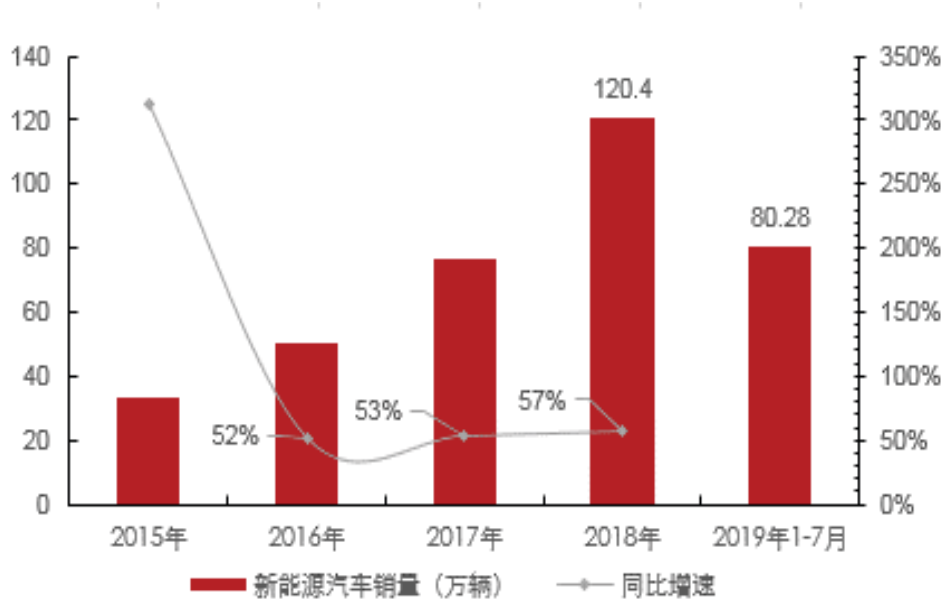


2.5 New Energy Automobile Increased Rapidly

New Energy Automobile Production in World and China



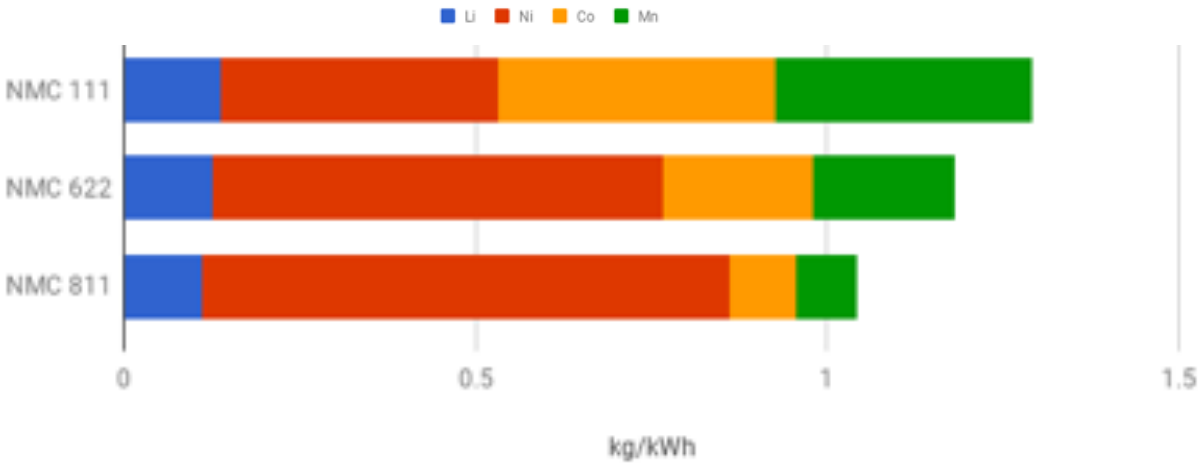
World(ten thousand)



China(ten thousand)

2.5 New Energy Automobile Increased Rapidly

Tendency for High Ni battery——2025 for NMC 811

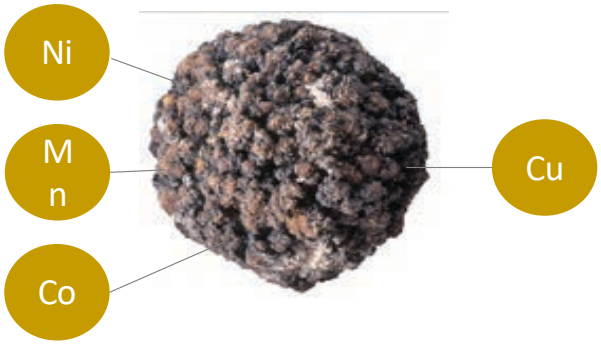


A single 75KWh EV battery with NMC 811 chemistry contains:

- 56 kg of Ni
- 7.1 kg of Co
- 6.6 kg of Mn

To electrify 1.2 billion ICE cars, the world would need:

- 67 million tonnes of Ni
- 9 million tonnes of Co
- 8 million tonnes of Mn



Polymetallic nodules is the good raw material for NMC 811. Every high Ni battery will consume 35kg Ni, Co and Mn.

03 Smelting and Processing of Oceanic Manganese Nodules

3.1 Resources and Characteristics of manganese nodules

Manganese nodules is a unique and complex oxidized ore with the following characteristics:

- Main minerals phase are the oxides crystallite of various manganese and iron without independent copper, nickel and cobalt minerals;
- Copper, nickel and cobalt are deposited in manganese and iron oxide lattice in the form of adsorption or isomorphism;
- Manganese nodules are porous with poor crystallization degree. With tunnel structure and layered structure, the gap diameter is between 1 ~ 12 nm and the porosity is as high as 50% ~ 60%, and the surface area is 200 ~ 300m^2/ g.

It's difficult to adopt the flotation or other physical methods to enrich it, the direct metallurgy process is needed, such as chemical treatment to destroy the ferromanganese oxide phase, the valent metals such as Cu, Ni, Co in the nodules can be released and recycled.

3.2 Manganese nodules smelting processing method

Direct leaching

- Selective leaching
  - Cuprous ion Ammonia leaching
  - High temp and high pressure acid leaching
- Non-selective leaching
  - High temp and normal pressure acid leaching
  - Hydrochloric acid leaching
  - Reduction leaching

Combined methods

- Roasting leaching
  - Reduction roasting-ammonia leaching
  - Sulphation roasting – water leaching
  - Chlorination roasting – water leaching
- Smelting leaching
  - Smelting sulfurization- leaching
  - Reduction alloy- leaching

3.2 Manganese nodules smelting processing method

➢ Cuprous ion Ammonia leaching

Nodules are mixed with copper ammonia solution absorbing CO after fine grinding, copper, nickel, and cobalt are leached from polymetallic nodules at 50 ℃ with iron and manganese slag left. The leaching liquid was extracted, nickel and copper are recovered through electrolysis, and cobalt is recovered from the liquid with hydrogen sulfide. Recovery rate (%) : Ni 92, Cu 92, Co 65.

➢ High temp and high pressure acid leaching

Wet nodules, after fine grinding, is mixed with sulfuric acid and leached under 180 ℃ and 12 atm, copper, nickel, and cobalt are dissolved, manganese and iron are left in slag, manganese silicon alloy is produced from leaching, pilot test recovery (%), respectively: manganese 85, nickel 96, copper 95 and cobalt 94.

➢ Smelting sulfurization leaching

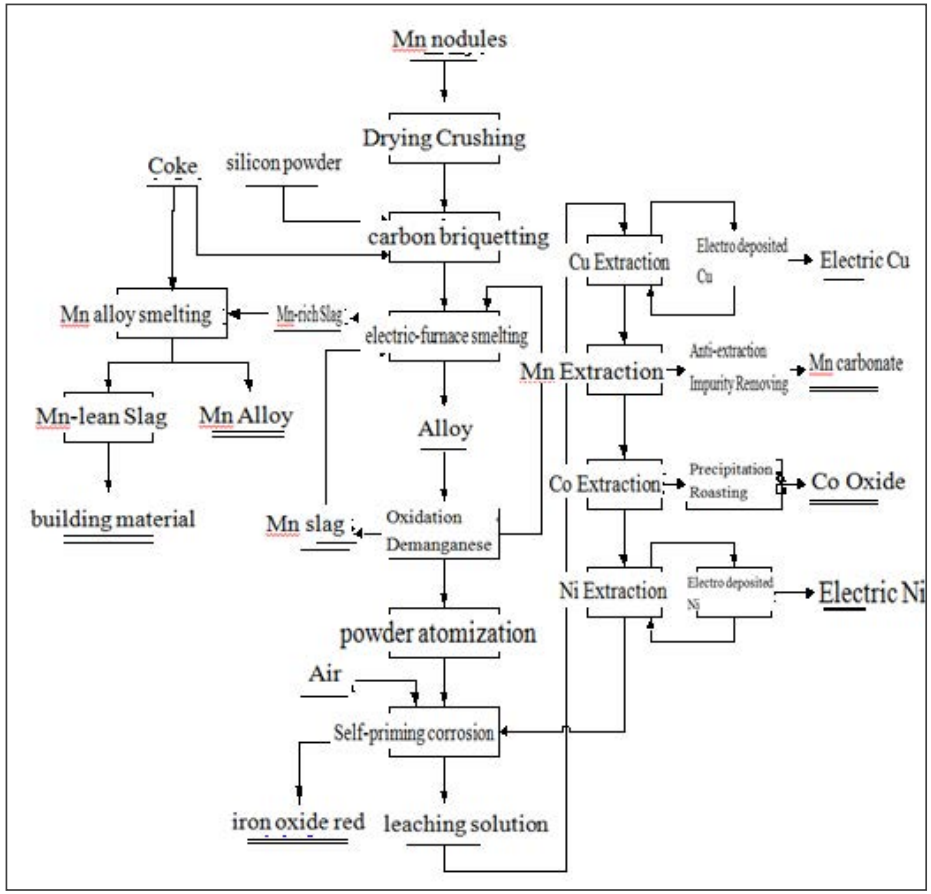
Nodules are reduced with carbon after crushing and drying at around 1000 ℃, melted and separated at 1400 ℃ to obtain Mn-rich slag and the smelting alloy of Fe, Ni, Cu and Co, 95% Mn into the Mn-rich slag, Mn-rich slag is used for smelting Mn alloy. nickel and cobalt matte is produced through sulfurization-re-oxidation-blowing smelting-deironing on smelting alloy at 1370 ℃, after oxygen pressure acid leaching on matte, the Ni and Cu are recovered through extraction separation, cobalt is recovered through sulfurization, recovery rate are : Ni 94、Cu 85、Co85、Mn75

3.3 CRIMM Smelting- corrosion- extraction process

Smelting- corrosion- extraction process

In the 1980s, CRIMM began to study on smelting- corrosion- extraction process based on improved innovation of foreign process of smelting-sulfurization blowing refining-oxidation pressure acid leaching. The full process expanded test of 100 kg scale was completed in 2005.

Recovery rate %:Cu94.33、 Mn82.69、 Co90.14 、Ni92.50 、Fe91.79。



smelting- corrosion- extraction process

CRIMM Smelting- corrosion- extraction process

I. Reduction smelting

Direct furnace smelting Mn nodules

DC arc Furnace smelting Mn Nodules

Manganese-rich slag

Nodules with Carbon pellets

CRIMM Smelting- corrosion- extraction process

II. Smelting alloy oxidation blowing demanganese and atomizing powder

Top and bottom blowing combined furnace

Smelting alloy high-pressure water atomization

CRIMM Smelting- corrosion- extraction process

III. Smelting alloy powder corrosion leaching equipment

Self-priming rust leaching tank

Self-priming rust leaching tank

CRIMM Smelting- corrosion- extraction process

IV. extraction separation of Copper ,cobalt ,nickel

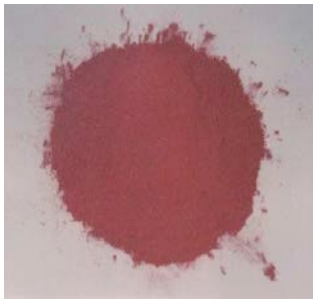
Mixed clarification extraction separation equipment

V. production

Mn-Si alloy

ECu

ENi



iron red

cobalt oxide

$MnCO_3$ Mn carbonate

04 Potential Opportunities and Suggestions

4.1 International Cooperation

- CMC conducted in-depth discussions and reached consensus on strategic cooperation with DeepGreen.
- CMC is strengthen cooperation with GSR, UK Resource, IOM, OMS etc in exploration and exploitation.
- CRIMM reached consensus on STP sea test.
- CRIMM signed Strategic Framework Agreement with 2H Offshore.

4.2 Contribute to ISA and public society

- Participate in deep sea mining code and payment regime actively.
- Provide constructive advice for ISA about deep sea mining area resource database.
- Share experience of production, operation, marketing and trading in land mines, contribute to the development of the common heritage of humankind.

- The 3rd ISA Contractors' Meeting will be held at Changsha, China hosted by CMC/CRIMM during 10-14th Oct., 2019.
- The main topics will be focused on regulation, payment regime, standards & guidelines etc.
- The output will contribute to ISA.

4.3 Suggestions

- With Chairman Xi’ the Belt and Road initiative, CMC/CRIMM likes to invest projects from resource acquisition and exploration to project design, construction, operation, distribution, and further processing in South Asia and South East Asia, and contribute to local economy and environment friendly;
- With ISA’ support, CMC/CRIMM will cooperate with local countries to improve science and technology within seabed resources, and share the benefit from Blue Economy, for example to select more trainees from local countries.

State Key Laboratory for Development and Utilization of Deep Sea Mineral Resources

International Joint Research Center for Seabed Mineral Resources Development

We’re looking forward to more extensive cooperation.


Thanks