Metallurgical Model Presentation

Maximizing metallurgical yields at minimal environmental cost

Processing Technologies, Metal Recoveries & Economic Feasibility of Deep Sea Mining

Monday, September 3 – Wednesday, September 5

Ministry of Environment, Warsaw, Poland

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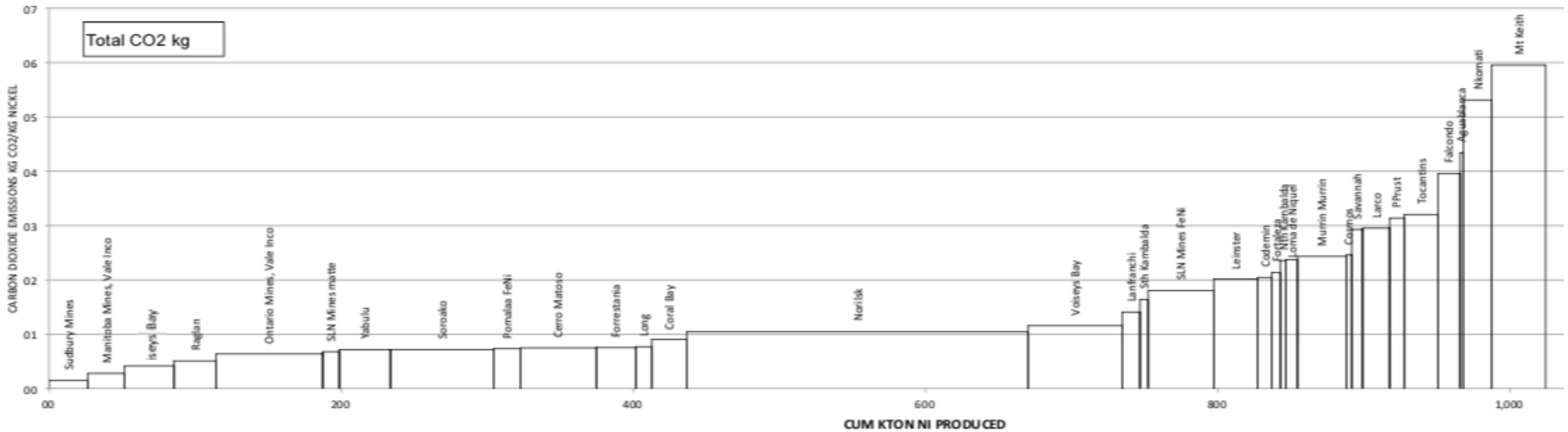
1. Base thought

- Mining – transport – processing should have lower impact than land-based alternatives
- Leading to an environmental impact optimisation − E.g The use of an environmental cost curve



2. Applied on nodule processing

- CO_2 impact (energy use)
- Toxicity reagents
- Waste produced
- Efficiency of process / irrevocable loss of metals

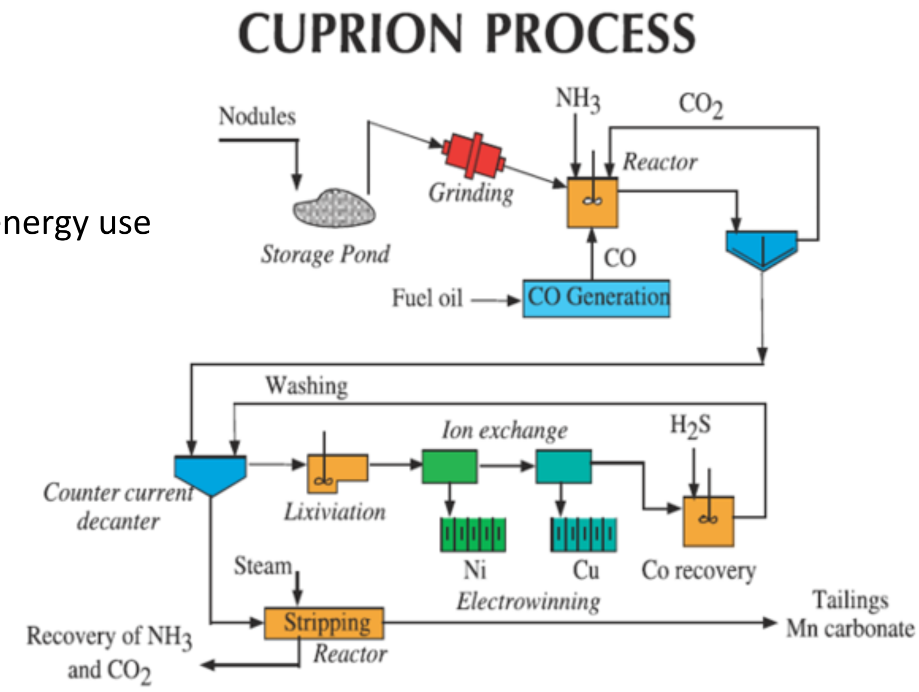
3. Choice of metallurgical route

1. Cuprion + EMM – process description
2. Overview energy & reagentia impact
3. Waste

3.1. Cuprion + EMM – Winning of Ni-Cu-Co

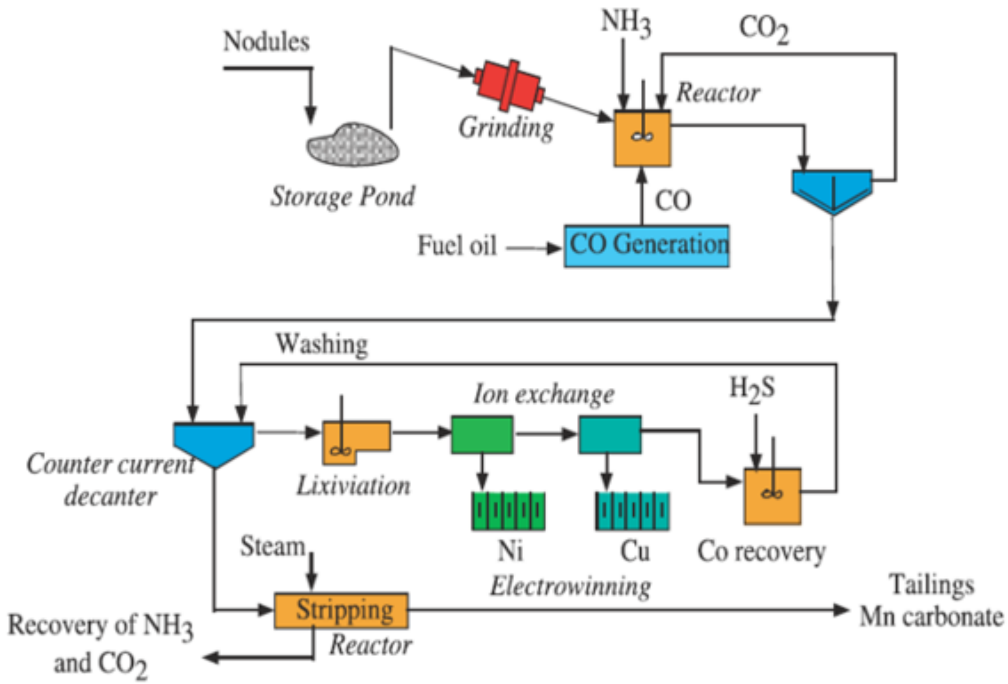
- Selective metal recovery
- No toxic reagentia
- Low pressure (p_{atm})
- Low temperature (40 °C)

Optimal energy use



3.1. Cuprion + EMM – Winning of Ni-Cu-Co

Selective picking of metals from poly-metallic inflow



3.1. Cuprion + EMM – Winning of Ni-Cu-Co

- Physical breakdown
- Chemical breakdown

  $MnO_{2\ (s)} + CO_{(g)} \rightarrow MnCO_{3\ (aq)}$

  Ni, Cu, Co: liberated from crystal structure

  Other trace elements

- Recovery of trace metals (SX/EW)

  Organic acid: selective binding of Ni and Cu

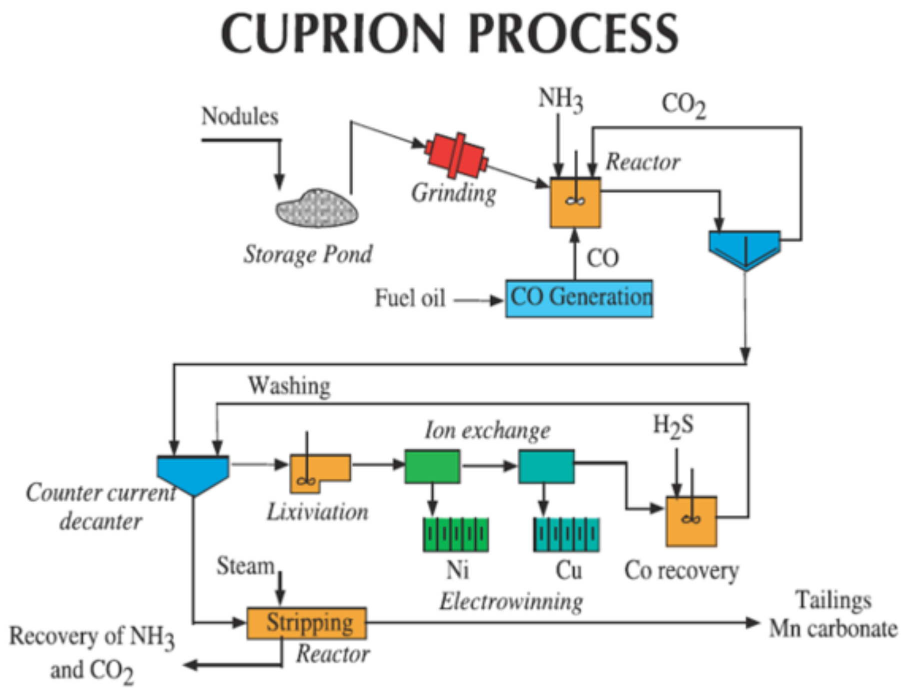
  Stripping: H_2SO_4 / recovery R

  $R_2Cu_{org} + H_2SO_4 \rightarrow 2R\text{-}H_{org} + CuSO_{4\ (aq)}$

  EW → Ni metal & Cu metal

  $Cu^{2+} + 2^{e-} \rightarrow Cu$

  Remaining: Mn, Co, trace elements



3.1. Cuprion + EMM – Winning of Ni-Cu-Co

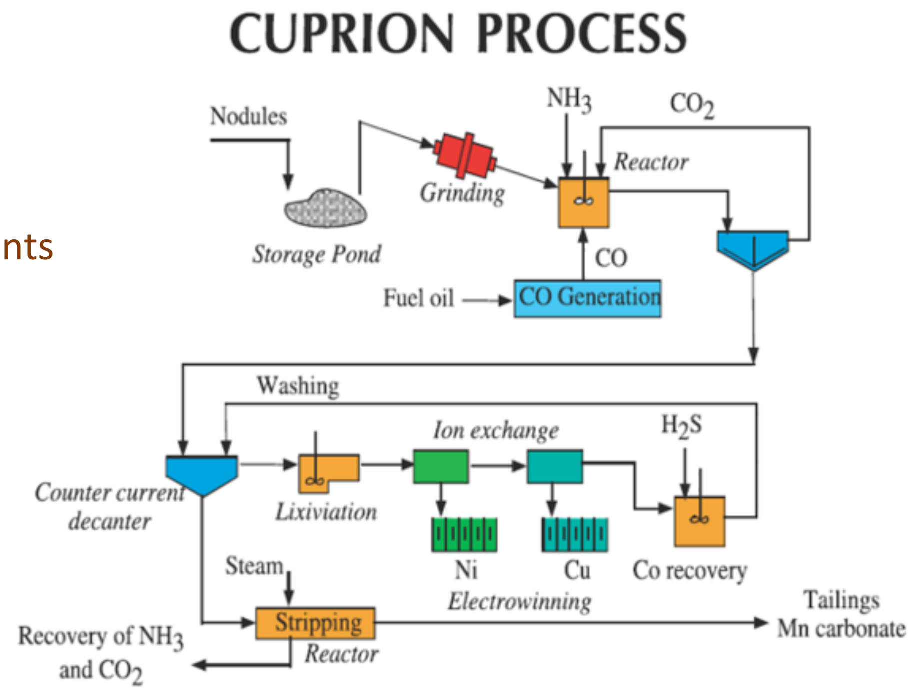
- Recovery of Co

  Co^{2+} + impurities$_{(aq)}$ + H_2S → $CoS_{(s)}$ ↓

  $CoS + H_2SO_4$ → $CoSO_{4\,(aq)}$

  EW → Co metal

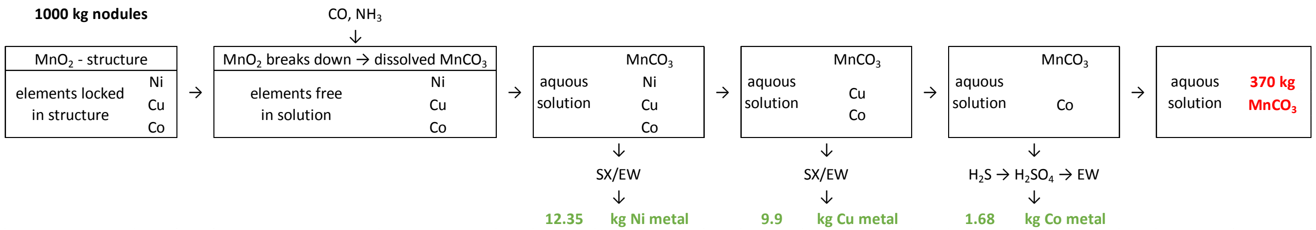
  Remaining: $MnCO_3$ (major fraction!) & trace elements



3.1. Cuprion + EMM – EMM substitution

- Mass balance

  Bulk of inflow: waste stockpile / low-grade product ($MnCO_3$: 6-7 USD/DMTU)



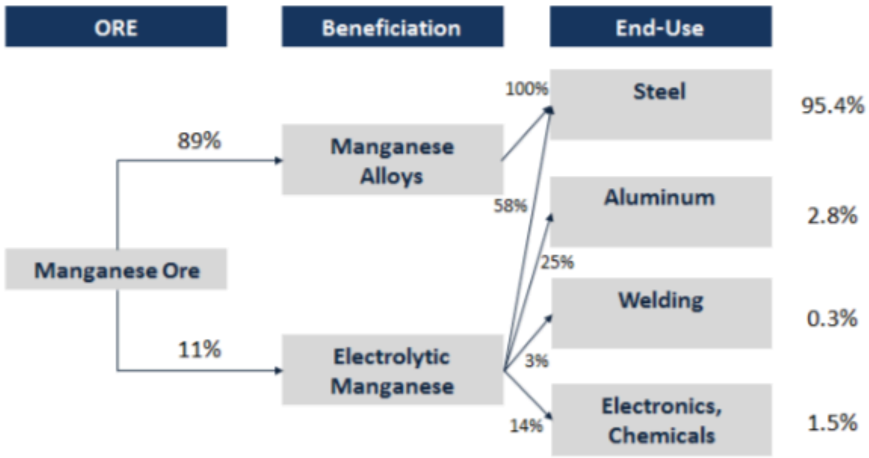
  Need for further processing of $MnCO_3$

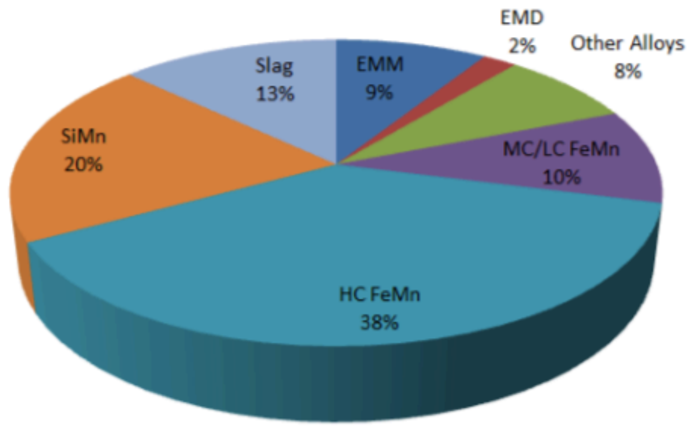
- EMM: high value, known process
  - EW→ Electrolytic Manganese Metal (EMM)
  - At 3 Mtpa nodules: 729 000 t EMM
  - Annual EMM market: 1 400 000 t EMM

  } Marketing strategy required

3.1. Cuprion + EMM – Processing of $MnCO_3$

- Substitution theory
  - Selling EMM into other Mn markets
  - Thereby avoiding disruption of Mn prices





3.2. Overview energy & reagents impact

- Energy use

Electricity consumption Cuprion + EMM Process

	kWh / tonne **metal**		kWh / tonne **nodules**		Reference
Nickel electrowinning	3,000	4,000	40	50	1 - 2 - 10
Copper electrowinning	2,000	3,000	20	30	1 - 2
Cobalt electrowinning	3,000	4,500	5	8	3 - 4 - 10
EMM electrowinning	10,000		40		1 - 5 - 10
Auxiliary processes	x		40	80	1 - 2
Total	x		*145*	*208*	

3.2. Overview energy & reagents impact

- Impact of energy use

Impact of electricity generation

	Coal	Oil & Gas	Renewable	Nuclear	Overall (kg CO2/kWh)	Reference
CO2 emissions generation (kg CO2/kWh)	1.1	0.35	0.025	0.115	-	6
Generation distribution Canada	10%	10%	65%	15%	0.17	7
Generation distribution Mexico	10%	70%	20%	0%	0.35	8
Generation distribtution China	65%	5%	25%	5%	0.71	9

Electricity impact Cuprion + EMM Process

	kg CO2/tonne **nodules**	
Processing in Canada	25	36
Processing in Mexico	51	73
Processing in China	103	148

1 kg CO2 emitted = driving 10 km by car

3.2. Overview energy & reagents impact

- Impact of energy use

Impact of electricity generation

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1 kg CO2 emitted = driving 10 km by car

Relatively easy optimisation by relocation

3.2. Overview energy & reagents impact

- Consumption of main reagents

Main reagentia consumption Cuprion + EMM Process

	kg / tonne **nodules**		Reference
NH_3	90	100	2 - 5
CaO	12	13	2
H_2SO_4	240	550	2 - 5 - 11
CO	148		stoichiometry
Steam	**500**		1 - 2

Cross-checked with atmospheric sulphuric acid leaching of limonitic laterite ore

3.2. Overview energy & reagents impact

- Impact of reagents consumption

Impact of main reagentia Cuprion + EMM Process

	kg CO_2 / kg reagens	Reference
NH_3	2.1	12 - 13 - 14
CaO	1.2	13 - 14
H_2SO_4	0.14	13 - 14
CO	1.57	stoichiometry
Steam	0.61	

Impact of main reagentia consumption Cuprion + EMM Process

	kg CO_2 / tonne **nodules**	
NH_3	189	210
CaO	14	14
H_2SO_4	34	77
CO	233	
Steam	**305**	
Total	774	839

3.2. Overview energy & reagents impact

- Impact of reagents consumption

Impact of main reagentia Cuprion + EMM Process

	kg CO2 / kg reagens	Reference
NH3	2.1	12 - 13 - 14
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H2SO4	0.14	[illegible]4
CO	1.57	[illegible]chiometry
Steam	[illegible]	

Intrinsic to process – optimization much harder

Impact of main rea[illegible]ion Cuprion + EMM Process

	kg CO2 / tonne **nodules**	
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C[illegible]	14	14
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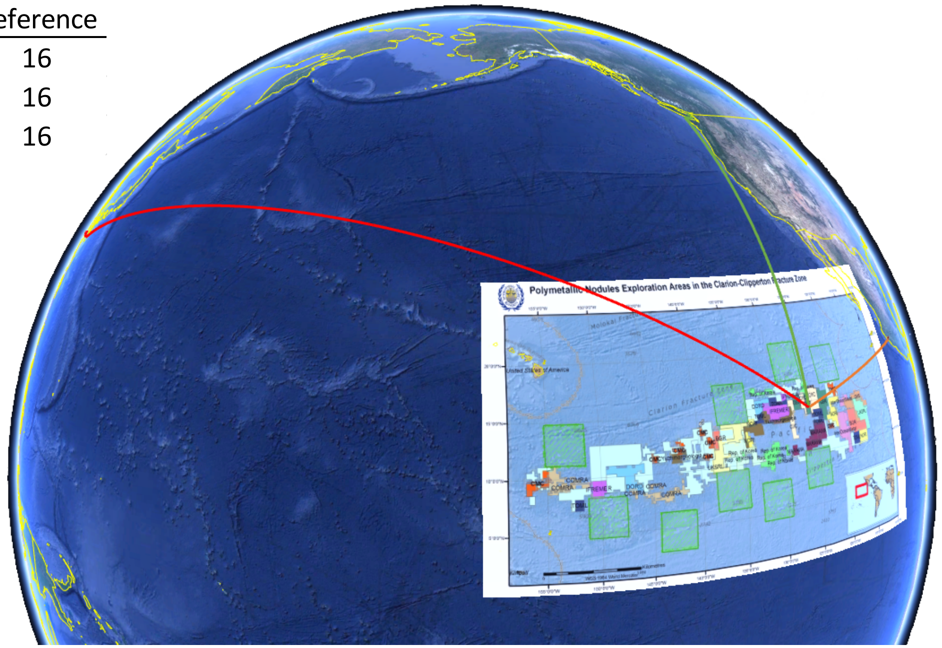
3.2. Overview energy & reagents impact

- Impact of transport

Impact of transport by bulk carrier

	sailing distance	g CO_2/(tonne x km)	kg CO_2/tonne **nodules**	Reference
Vancouver, CA	4100	5	21	16
Manzanillo, MX	2400	5	12	16
Shanghai, CN	11400	5	57	16



3.2. Overview energy & reagents impact

- Overall impact
  - Main driver: chemical reagents – defined by laws of nature
  - Secondary driver: electricity – CO_2 optimization by choice of location
  - Transport: small impact – longer routes justified by greener electricity
  - Conservative figures

Impact of chain "Mining ship to Metal"

	Transport impact	Cuprion + EMM				Processing impact		Mining ship to Metal	
		Electricity impact		Main reagentia impact					
	kg CO2 / tonne **nodules**	kg CO2 / tonne **nodules**		kg CO2 / tonne **nodules**		kg CO2 / tonne **nodules**		kg CO2 / tonne **nodules**	
Destination: Canada	21	25	36	774	839	799	875	820	895
Destination: Mexico	12	51	73	774	839	825	912	837	924
Destination: China	57	103	148	774	839	877	987	934	1044

3.2. Overview energy & reagents impact

- Discussion / outstanding issues
  - Consumption of minor reagents
  - Consumption steam: Dames & Moore (1977): 1600 kg / tonne nodules – CO_2 !

3.3. Waste

- Major metals recovered
  - Very little amounts
  - Closed loop process
  - Possibility of Mo recovery
- Efficient process
  - Very high recovery rate of metals

4. Alternative routes (Blue Nodules)

- EU Horizon 2020 programme
- RWTH Aachen: pyrometallurgical route
- Under examination
- www.blue-nodules.eu

bluenodules

Horizon 2020

European Commission

Questions?

Thank you

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