The Influence of Metals Processing Economics on the Choice of a Financial Payment Mechanism for DSM Polymetallic Nodules

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Relationship between on-shore and off-shore economics

- ISA jurisdiction is limited to **Off-Shore** activities
- Revenues derived from ISA financial payment regime can only relate to off-shore activities
  - Ad valorem ($/metal value removed from sea)
  - Profit sharing ($/profit of the collectors only)
  - Licensing fees ($/year to allow collectors to operate)
  - Combinations

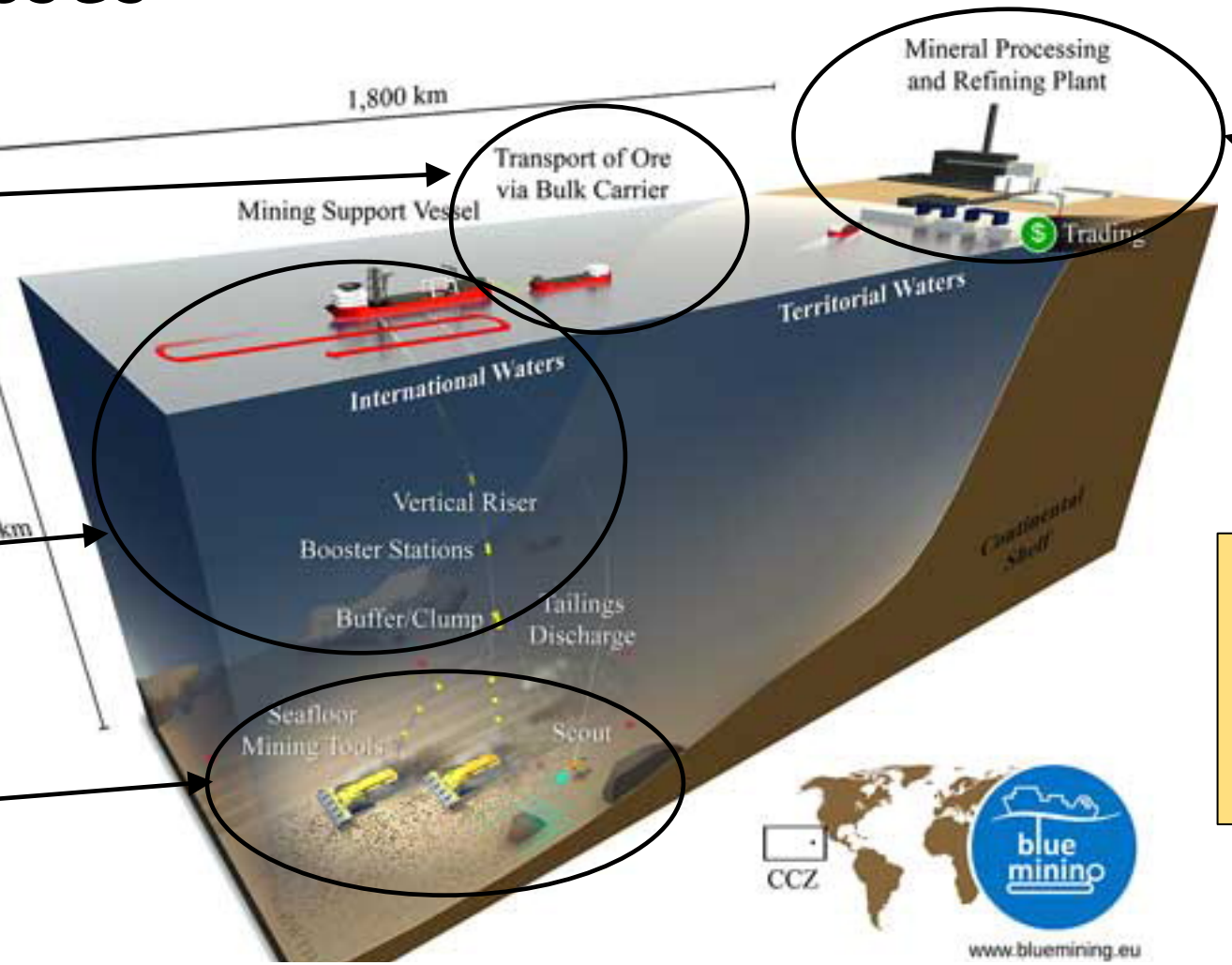
- These **appear to be independent** of the actions of the metals processor
- But they're linked through the profitability of the collectors which in turn depends on the **ability to sell the nodules** they collect from the sea.

Assessment requires understanding the mining & refining processes

Transport

Lift/Platform/ Process Water

Nodule Collection



Metallurgical Processor
Separate the four metals

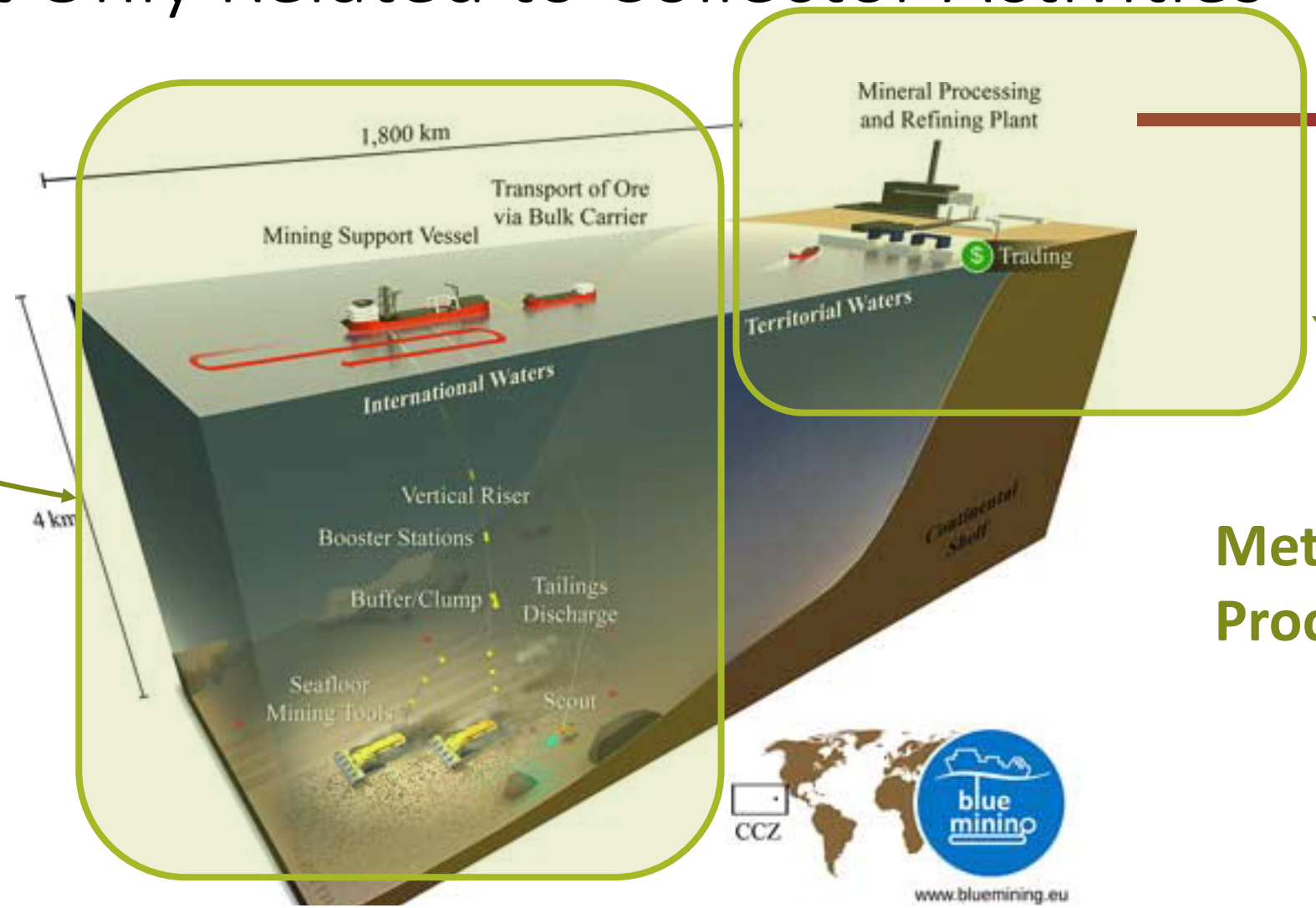
Each of these activities require:
-upfront investments
-ongoing operating …expenditures

Image from: Marvasti, A. Env. and Resource Econ (2000) 17: 395. https://doi.org/10.1023/A:1026566931709

ISA Oversight Only Related to Collector Activities

Collector

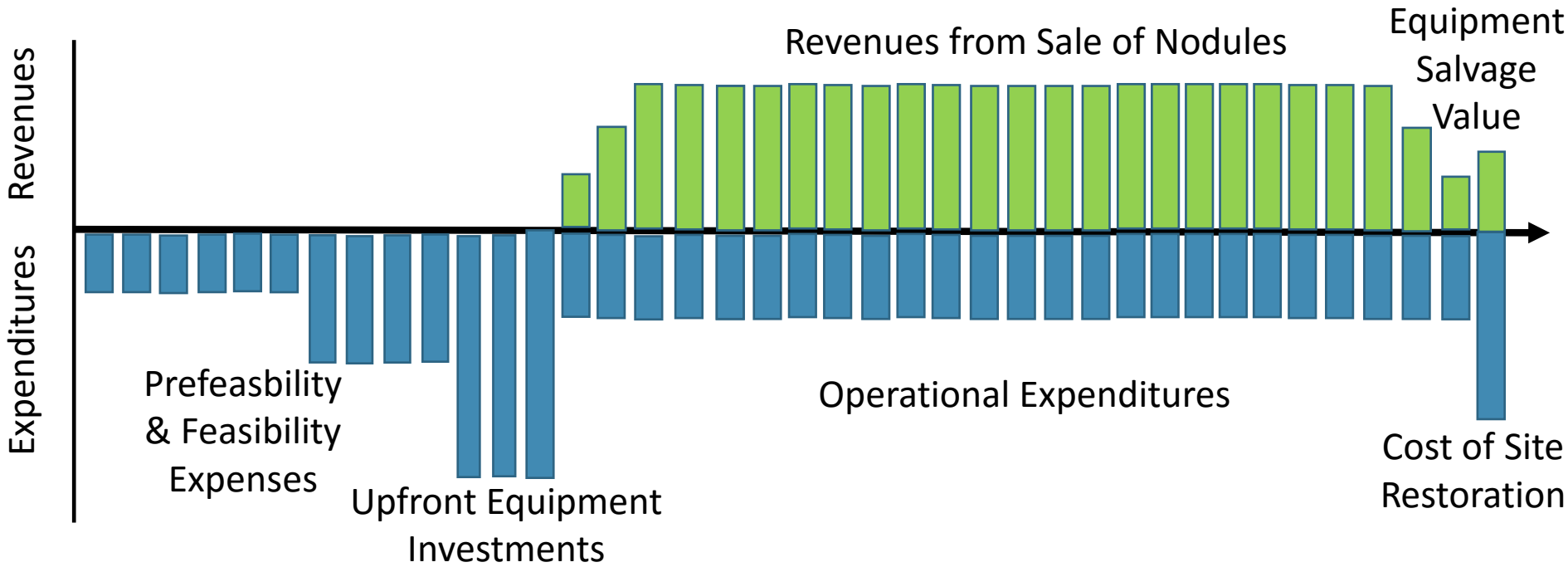
Modelling assumes that ISA royalties are only based on activities at the collector



Metals Processor

Image from: Marvasti, A. Env. and Resource Econ (2000) 17: 395. https://doi.org/10.1023/A:1026566931709

“At-Sea” Cash Flows Basis for Understanding ISA Decisions

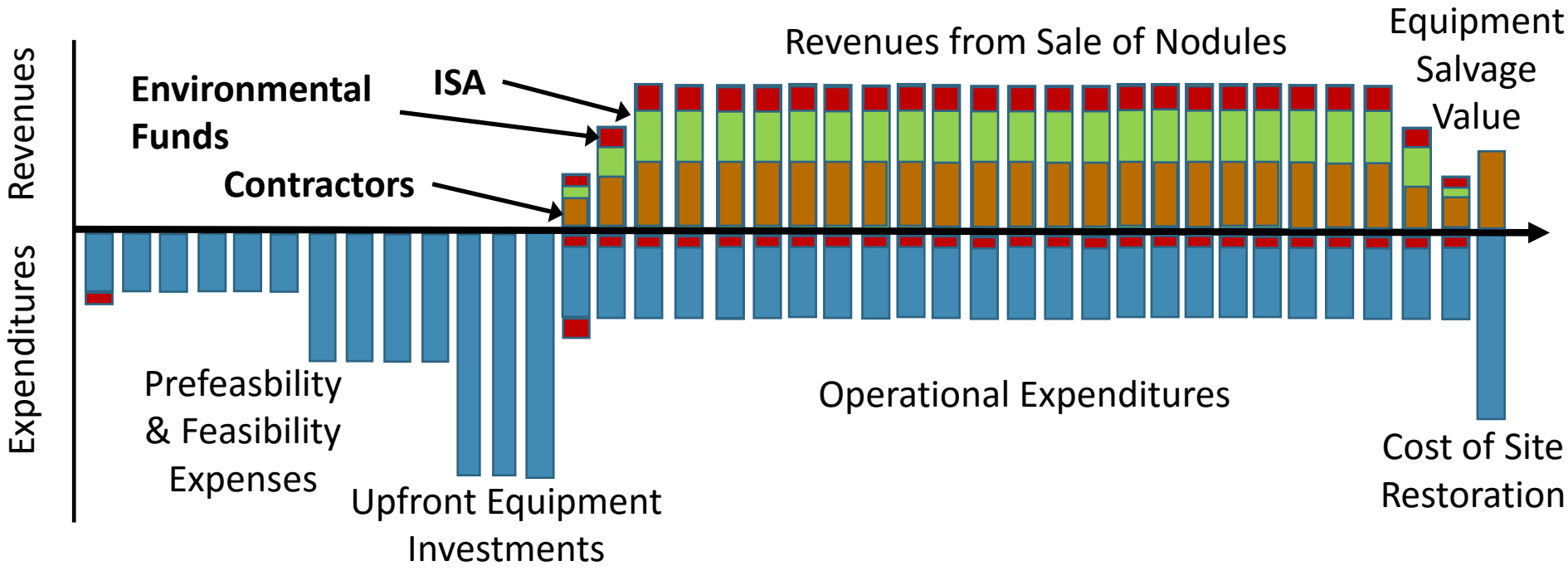


Calculate the Internal Rate of Return for the system

IRR is defined as the rate of return that gives a NPV = 0.

Collectors investment money upfront on feasibility studies and equipment investments
They pay annual operating costs and receive revenues from the sale of nodules to an on-shore processor

Funds to be shared depends directly on revenue from the sale of nodules



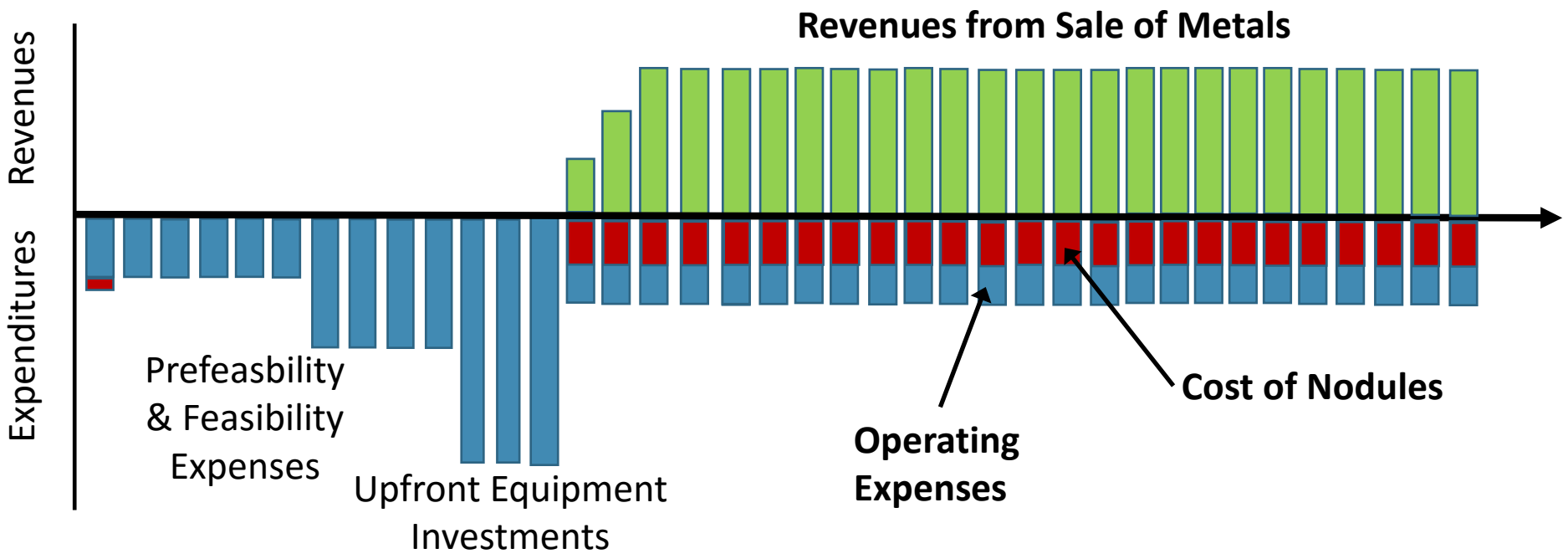
Revenues from sale of nodules derives from the quantity sold and the price metals processors are willing to pay for nodules in the future

The revenues from nodule sales needs to be shared among different stakeholders
Some goes to the ISA to pay for expenses, support environmental funds and to be divided among member states
Some remains with the collectors to compensate for their costs and risk they incur with the upfront investments

Understanding collector cash flows therefore requires a forecast for nodule price

- No market currently exists for nodules
- However, nodule price should be related to:
  - Value of the metals to be extracted
  - Costs for metals processing (upfront & operational expenses)
  - Processor margins
- Metals processors have their own cash flow which depends on price they pay for nodules
- They will only invest if they believe they can achieve a sufficient return on their initial investment

Metals Processor Cash Flows



Metals processors economics will only work if they can get nodules at a low enough price

Metals processors will only invest if they believe that their future revenues from the sale of metals minus their annual operating expenses provides them with sufficient returns on their upfront investment considering risk

Nodule market prices will be set by negotiation between buyers (processors) & sellers (collectors)

- Collectors will attempt to get **highest price** possible for nodules
- Metals processors will attempt to obtain nodules for the **lowest cost**

- Cleared price will depend on the balance between available supply of nodules from collectors and demand from suppliers at each point in time

- Noduel demand will likely be determined by their scale of operation.
  - If operating at full utilization, demand for additional nodules is low
  - However, if processing plants are underutilized, demand will be high
  - Similar to situation with TC/RC margins in copper industry

Assume collectors & processors will each accept same return on investment

- Impossible to predict day-to-day market balance and price
- We can determine nodule price that gives the same returns for both the metals processors & the collectors
- Requires complete cash flow information for both

How will this be done?

1. Calculate Overall System IRR
   using all costs to both collectors & processors (including royalties) and all metals revenues
2. Calculate Nodule Transfer Price
   by finding value that gives makes the Metals Processor IRR equal to the overall system IRR

Note: ISA royalties still only apply to the Collectors, but the recommended levels will depend on the nodule price which also depends on the Metals Processors

Many approaches to metals processing
Some modeling choices need to be made

Metals Systems

- 3 metal (Co, Cu, Ni)
- 4 metal (Co, Cu, Ni, Mn)
  - But there are several Mn markets?
- 3 metal + Mn ore
  - Assume Mn tailing sell for similar price to Mn ore
- 3 metal + Mn ore + REE-Y
  - Possibly sell rare earths and yttrium
- 4 metal + REE-Y

Processing Routes

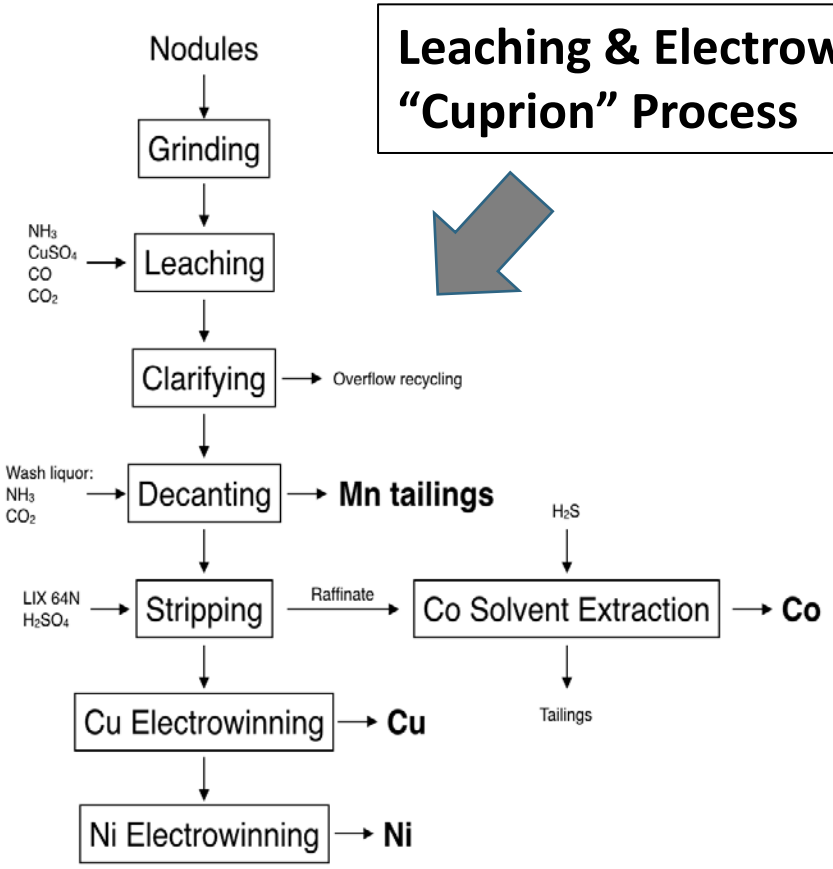
- Leaching + Electrowinning
- Smelting + Leaching
- All Leach
- Others

- Exact choice of processing route depends on the metals to be extraction and available technology

Let’s look at 3 metal system + Mn ore

- Why this system?
  - Most analyses show the need to generate revenue from 4 metals to justify investments
  - However, Mn market is very complex
    - High value Electrolytic Mn Metal market (EMM) is too small to absorb all of the Mn content in the nodules
    - Do not want incur all of the expenses required to obtain high value Mn, but then have to sell into the lower value Ferromanganese markets
  - Get around this issue by assuming Mn tailings from Leach/Electrowin process are similar to currently mined Mn ore
  - Fortunately there is historical data on Mn ore prices for grades similar to Mn tailings

Analyzing Cost of Leaching/Electrowinning Process



Leaching & Electrowinning "Cuprion" Process

Estimate capital investments & operating expenses for each process step *(excluding nodule costs, to be calculated later)*

General		
Annual production	3,000,000	tdn
Operating days	330	days/year
Wage including benefits	18	$/hr
Electricity cost	0.15	$/kWh
Land cost	27	$/m2
Infrastructure and facilities cost	13.5	$/m2
Power plant electricity supply	67	%
Purchased electricity supply	33	%

Nodules metal content	
Copper content	1.10%
Cobalt content	0.21%
Nickel content	1.30%
Manganese content	27.00%

Yields	
Copper	90%
Cobalt	80%
Nickel	95%

CAPEX	**$969M**
OPEX	**$285M/yr**

CAPEX Results: Cuprion Process

	Installed Equipment	Auxiliary Equipment	Land & Infrastructure	TOTAL
Grinding	$31M	$16M	$1M	$48M
Leaching	$75M	$38M	$5M	$118M
Stripping	$66M	$33M	$3M	$102M
Co Solvent Extraction	$16M	$8M	$1M	$25M
Cu Electrowinning	$74M	$37M	$2M	$113M
Ni Electrowinning	$74M	$37M	$2M	$113M
Reagents Recovery	$67M	$33M	$2M	$102M
Materials H&S	$113M	$56M	$8M	$177M
Plant Services*	$109M	$54M	$8M	$171M
TOTAL	$625M	$312M	$32M	**$969M**

* Includes power generation, CO generation plant, Water treatment & Administration

Consumables Unit Costs & Results: Cuprion Process

Consumables		
NH3	9.50E-02	tonne/tdn/year
Limestone	7.80E-03	tonne/tdn/year
Lime	1.20E-02	tonne/tdn/year
LIX 64N	1.90E-05	tonne/tdn/year
Kerosene	7.70E-05	tonne/tdn/year
H2SO4	2.40E-01	tonne/tdn/year
H2S	1.63E-03	tonne/tdn/year
Na2SO4	4.50E-04	tonne/tdn/year
H3BO3	6.70E-05	tonne/tdn/year
NaCl	7.70E-05	tonne/tdn/year
Cl2	3.30E-04	tonne/tdn/year
Coal	2.30E-01	tonne/tdn/year
Steam	1.84E+00	mmbtu/tdn/yer
Water	2.00E+00	m3/tdn/year

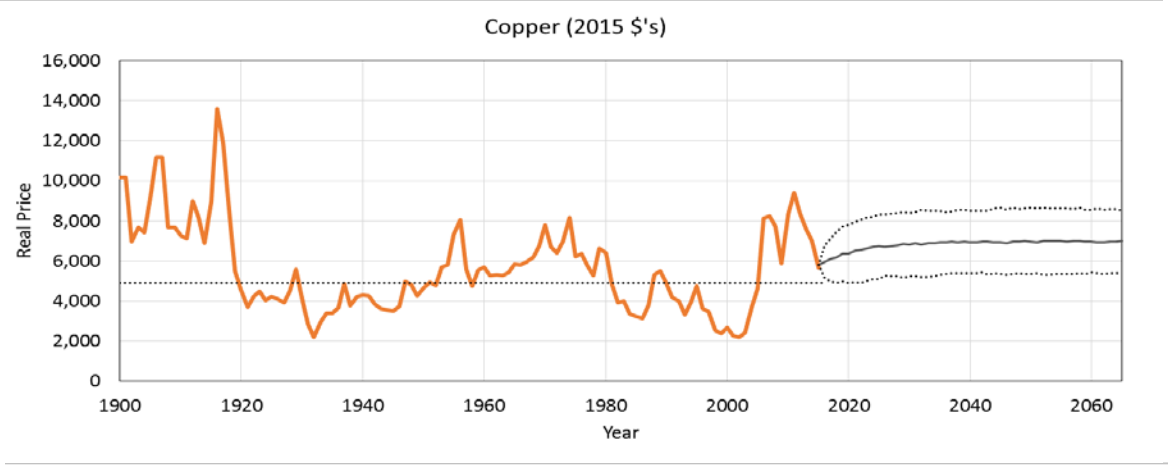
Consumables Cost		
	$/tdn	$/year
NH3	$28.50	$85,500,000
Limestone	$0.12	$351,000
Lime	$0.08	$252,000
LIX 64N	$0.16	$484,500
Kerosene	$0.04	$131,157
H2SO4	$24.00	$72,000,000
H2S	$0.73	$2,200,500
Na2SO4	$0.07	$202,500
H3BO3	$0.05	$142,710
NaCl	$0.00	$11,550
Cl2	$0.12	$346,500
Coal	$9.20	$27,600,000
Water	$1.00	$3,000,000
Total	**$64.07**	**$189,222,417**

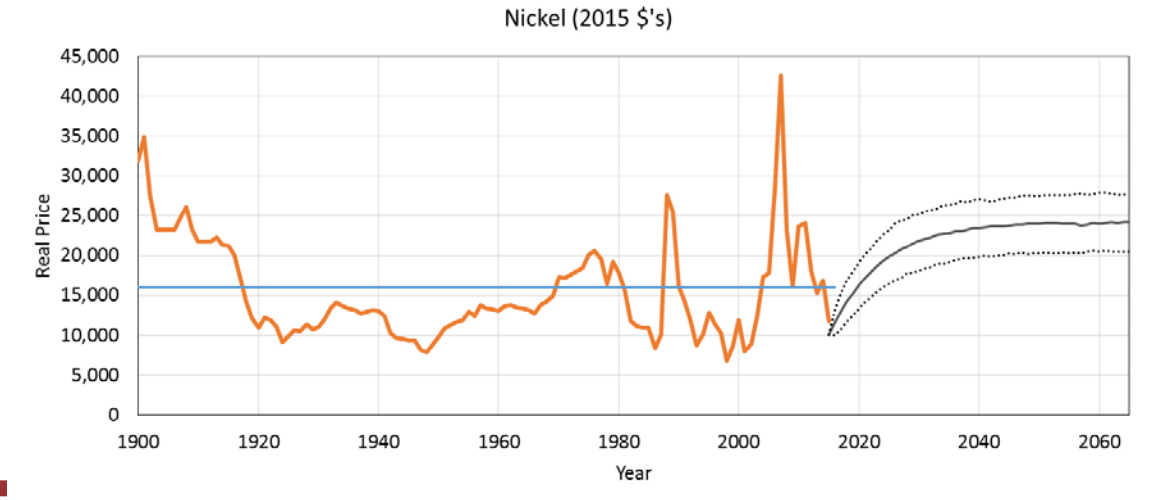
Energy & Labor Costs: Cuprion Process

Energy Consumption	
	kWh/tdn
Grinding	8.48
Leaching	12.88
Stripping	2.25
Co solvent extraction	2.25
Cu electrowin	23.75
Ni electrowin	39.5
Reagents recovery	2.88
Material H&S	2.5
Plant Services	2.88
Total	**94.49**

Labor Cost		
	Number of workers	$/year
Grinding	5	$755,550
Leaching	20	$3,022,200
Stripping	15	$2,266,650
Co solvent extraction	10	$1,511,100
Cu electrowin	10	$1,511,100
Ni electrowin	10	$1,511,100
Reagents recovery	10	$1,511,100
Material H&S	20	$3,022,200
Plant Services	50	$7,555,500
Total	**150**	**$22,666,500**

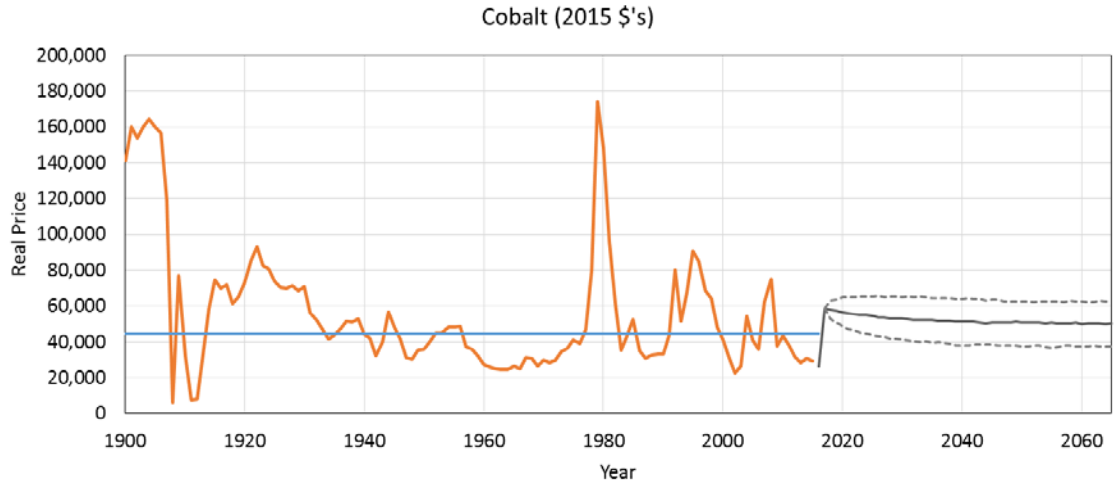
Expert Price Forecasts with Uncertainty





Still need to obtain forecasts for Mn-ore

Recommend a more detailed treatment with structural modeling in the future



What's next?

- Mn-ore price forecasts
- Review all revenue models including estimations of uncertainty
- Refine cost analysis for metallurgical processes
- Consideration of uncertainty and technical risks
  - For collection
  - For various metallurgical processes

Thoughts for economics working session

Metals Processing/Costs

- How to decide among the various process approaches
- Cost competitive position of each process
  - Capital costs/required investment
  - Energy requirements
  - Consumables
- Technical risk & uncertainty for each process
  - Which processes are most likely to succeed?
  - Which are most suspectible to cost overruns?

Metals Price Forecasts

- Will Cobalt prices remain high or are we currently experiencing a temporary peak?
- Will Nickel prices rise as battery manufacturers replace Co with Ni?
- Will electric vehicle markets grow as fast as expected?
  - Faster, slower?
  - How will this impact Co & Ni prices?
- Are there sufficient land based mining operations to meet future metals needs?

Economics Workshop Topic #1: Relative costs for each metallurgical process

- Discuss the relative cost position of the major metals processing routes
  - Leach/Electrowinning
  - Pyrometallurgy
  - Hydrometallurgy
- How do these compare in terms of:
  - CAPEX & OPEX
  - Energy requirements
  - Consumables
  - Water
- Are some processes better suited for some locations?

Economics Workshop Topic #2: Uncertainty associated with each metals process

- Discuss the technical risks associated with each major metal processing route
  - Which technologies are closest to full development?
  - Which have the most risk of not being ready?

- Discuss cost uncertainties associated with each technologies
  - Which technologies are most likely to have major cost overruns?
  - Which might have potential savings due to similarities to existing processes?

Economics Workshop Topic #3: Future of Cobalt & Nickel Prices

- Is Cobalt currently experiencing a price spike or will high prices endure?
- As battery manufacturers attempt to substitute Nickel for Cobalt, will Nickel prices rise?
- Future of electric vehicles
  - Will growth rates meet aggressive expectations?
  - Will other mobility systems replace battery electric vehicles?

Economics Workshop Topic #4: Impact on Terrestrial Mining

- Discuss potential impacts of seabed nodule mining on terrestrial mining for each metal
- Different impact on existing mines vs incentive mines
- Impact on sovereign nations vs. firms vs individual mine sites