Lloyd's Register Educational Trust

UNIVERSITY OF Southampton

Polymetallic nodule mining: Innovative concepts for commercialisation

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Polymetallic nodule mining: Innovative concepts for commercialisation





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Group *Eco*

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Topic: System engineering for Seabed Exploitation

Focus: Marine mineral exploitation; Polymetallic nodules (PMN)

Aims:

- Review the field of polymetallic nodule mining
- Identify the main areas for development
- Propose new concepts to address these areas.

Contents

- Introduction
- Barriers to commercialisation - RISK
- New engineering concepts for seabed mining
  - Concept selection & development
  - Conceptual design of nodule mining
- Mineral processing concept
  - Composition & techniques
  - REE processing
- Hazard identification of the concept design
  - Method & results
- Conclusions
- Q&A

Introduction

- What are polymetallic nodules?
- Resource assessment at the CCZ

What are polymetallic nodules?

Major and minor elements of potential economic interest

Mn, Fe, Ni, Cu, Co, Zn

Precious metals and radioactive elements

Au, Pt, Ra, U

REE

La, Ce, Nd, Tb, Dy

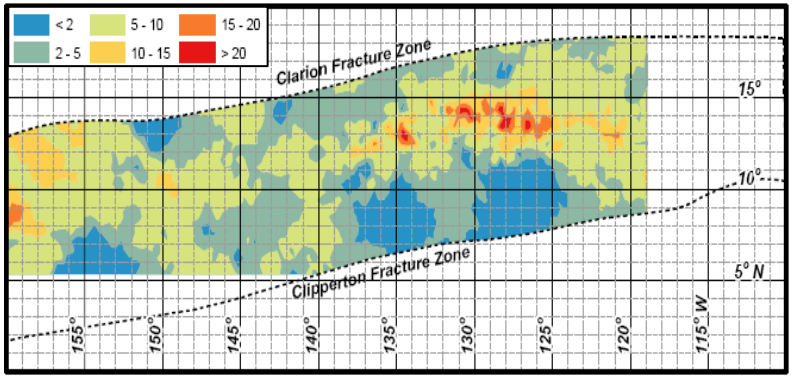
Elements of environmental interest

As, Ba, Cd, Pb, Hg, Se

Source: Cited from Science Photo Library

Resource assessment at the CCZ

Abundance of polymetallic nodule (kg/m^2)



(Morgan, 2012)

The inferred resources of CCZ

Source	Included area (km^2 × 10^6)	Estimated abundance (metric tons×10^6)				
		Nodule	Mn	Co	Ni	Cu
Reduced area	3.83	21,100	5,950	46	270	234

Resources assessment summary

Total Value $ 16 trillion

Materials	Abundance (M ton)	Production on land (M ton/year, 2010)	Year	Value trillion (98$*)
Manganese	5,950	14	425	8.9
Cobalt	46	0.17	280	1.3
Nickel	270	1	170	4.2
Copper	290	16	18	1.6

***Value in 1998 US dollars**

Source: Production data from www.USGS.com

Background

- Nodules
- Nodule economics
- Background for our engineering concept

Previous mining ventures

Organization/ Consortium name	Members	Year	Sampling Yield
India	NIOT, DOD	1974	
Ocean Mining Associates	US Steel, Union Miniere, Sun Company, Ente Nazionale, Idrocarburi	1974	**500 tons**
AFERNOD	CNEXO, Commissariat a I' Energie Atomique , Societe Metallurgique le Nickel, Chantiers de France-Dunkerque	1974	
Deep Ocean Resources Development	C. Itoh and Co., Marubeni Corporation, Mitsubishi Corporation, Mitsui and Co., Nichimen Co., Nissho Iwai Co., Sumitomo Co., Mitsubishi Metal Co., Sumitomo Metal Mining Co., National Institute for Resources and Environment , Deep Ocean Minerals Association, Technology Research Association of Ocean Mineral Resources Mining System.	1974	**7.25 tons**
Ocean Management Incorporated	INCO, Metallgesellschaft AG, Preussag AG, Salzgitter AG, SEDCO, Deep Ocean Mining Company	1975	**1000 tons**
Ocean Minerals Company	Amoco Ocean Minerals Co., Lockheed Systems Co., Ocean Minerals Inc., Billiton BV, BKW Ocean Minerals BV	1977	
Yuzhmorgeologiya	Russia		
Inter Ocean Metals	Bulgaria, Cuba, Czech Republic, Poland, Russian Federation, Slovakia		
COMRA	China		
KORDI	Korea		
NOR	Nauru		
Tonga Offshore Mining	**Nautilus Minerals**		
OceanflORE	IHC Merwede, DEME	2011	

Nodule economics – Project finance

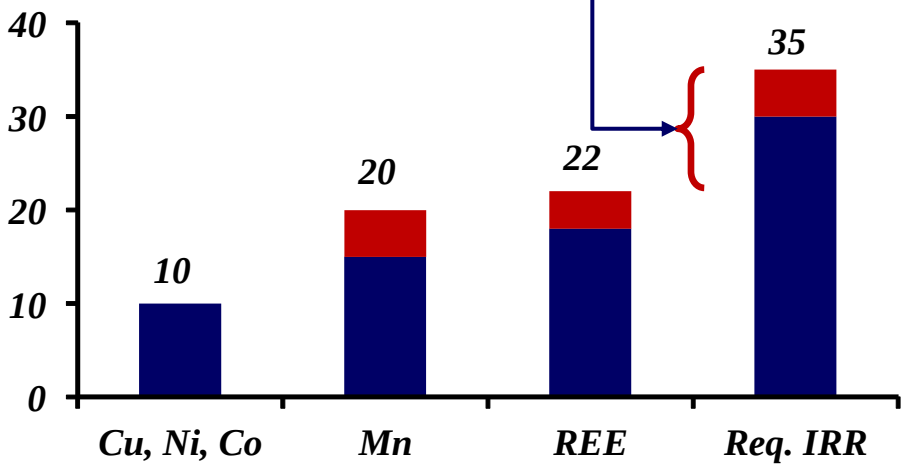
Required IRR = Market Rate + Req. Return + Risk Premium = 30-35%

(Arthur D. Little, 1979)

- Market Risk
- 3rd Party Risk
- Regulatory Risk
- Environmental Risk
- Technology Risk

Research	Material	IRR*
Yamazaki(2008)	Co, Ni, Cu	~10%
Martino(2012)	+ Mn	15-20%
Group E	+ REE	18-22%

***IRR** (Internal Rate of Return)



- Market-Product Technology (MPT) index imposes a risk premium on the required return for an investment using new or unproven technology.
- PMN mining has been assessed at very high risk, partly due to poor yields and unproven technology
- Poor yields are largely the result of inadequate performance from engineered components

Background for our engineering concept

Nodule mining system

Main challenges:

Downtime, production cost

***Our approach*:**

Simpler design based on proven concepts

Collector

***Main challenges*:**

Downtime, reduced efficiency due to interaction with the seabed

***Our approach*:**

Robust & reliable design

Lifting system

***Main challenges*:**

Cost, size, maintenance of riser systems

***Our approach*:**

Simplified shuttle concept

Processing

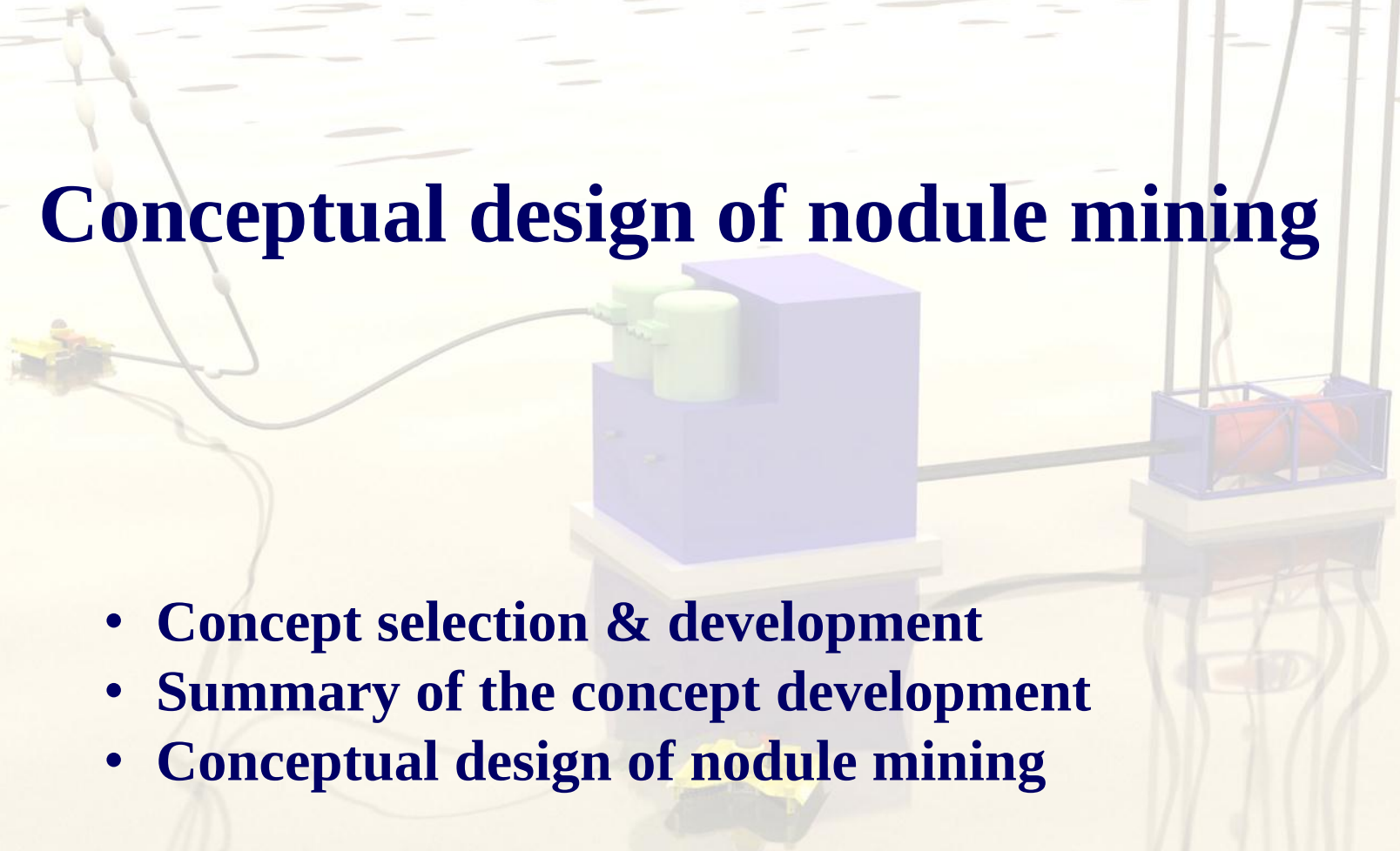
***Main challenges*:**

Dependence on marine mining, multiple products

***Our approach*:**

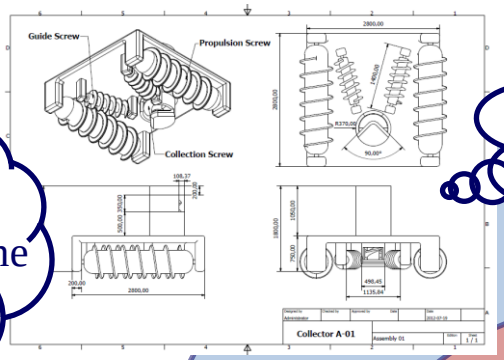
Processing route for combined marine and laterite ores

Conceptual design of nodule mining



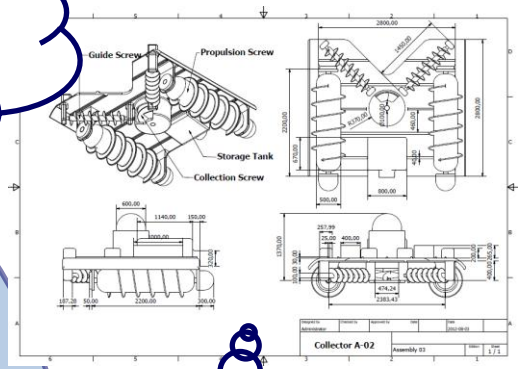
- Concept selection & development
- Summary of the concept development
- Conceptual design of nodule mining

Concept selection & development(1/2)



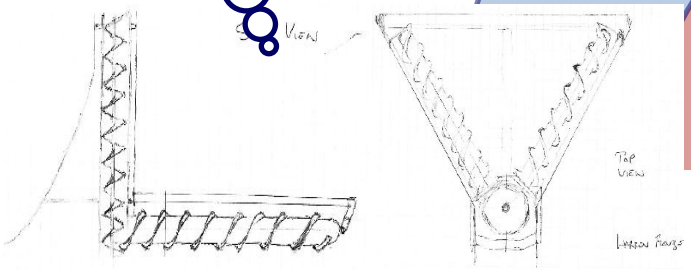
Phase I
Realization of the sketch drawing

Phase II
Reduce weight (thickness) & increase production rate

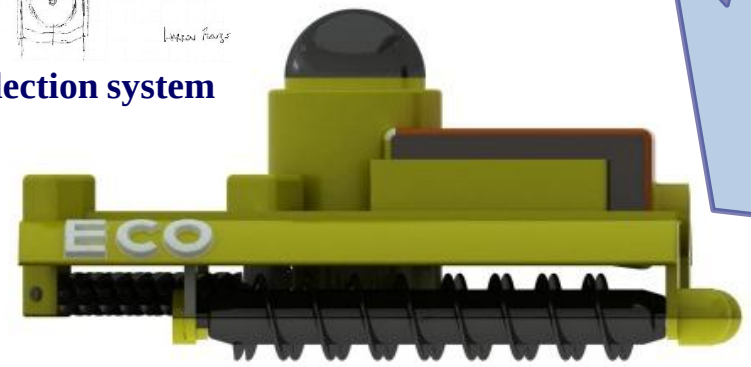


Design Loop

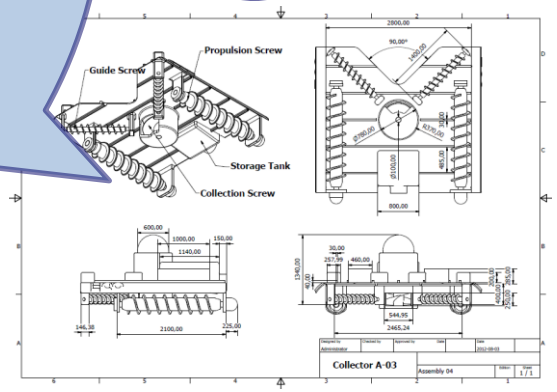
Phase III
Reduce weight (material) & Screw design limits



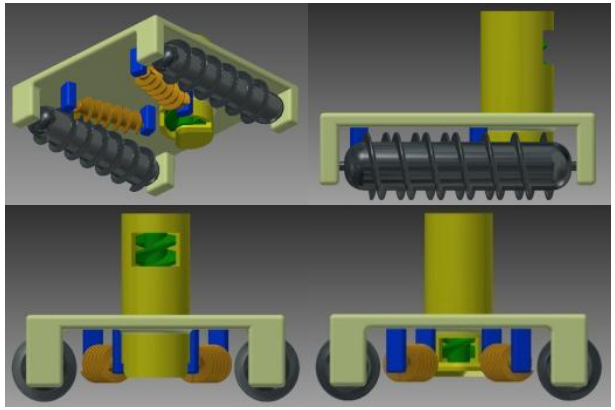
Hand-drawn sketch of collection system



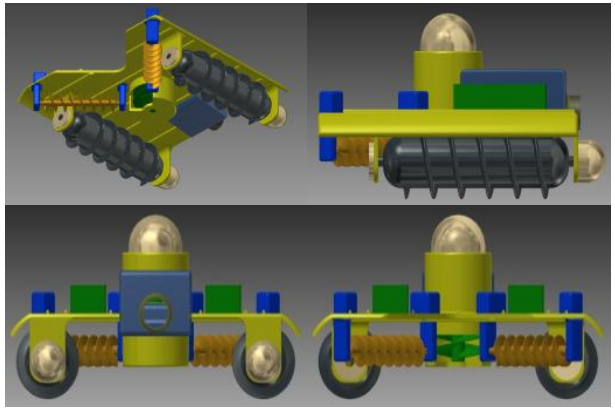
The Nodule Collector- *Eco*



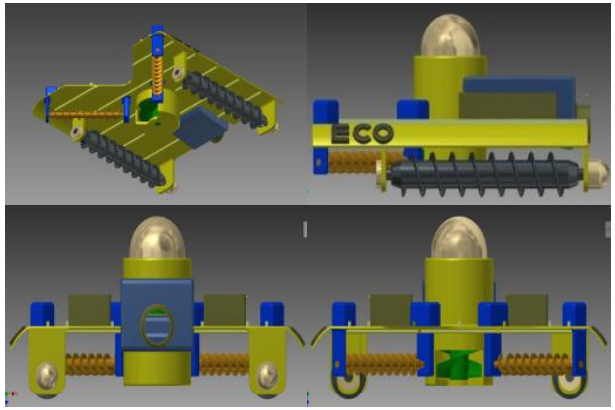
Concept selection & development(2/2)



Phase I



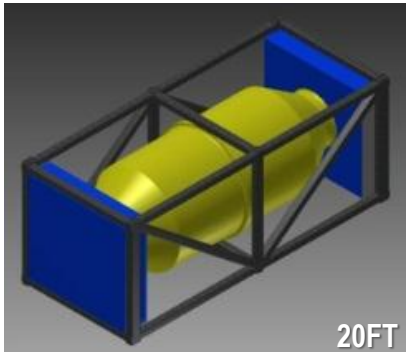
Phase II



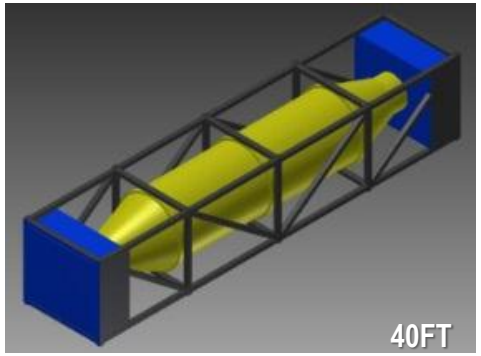
Phase III

Capacity 150ton/hour, Weight 30ton

The separation system



Capacity 30ton, Weight 23ton



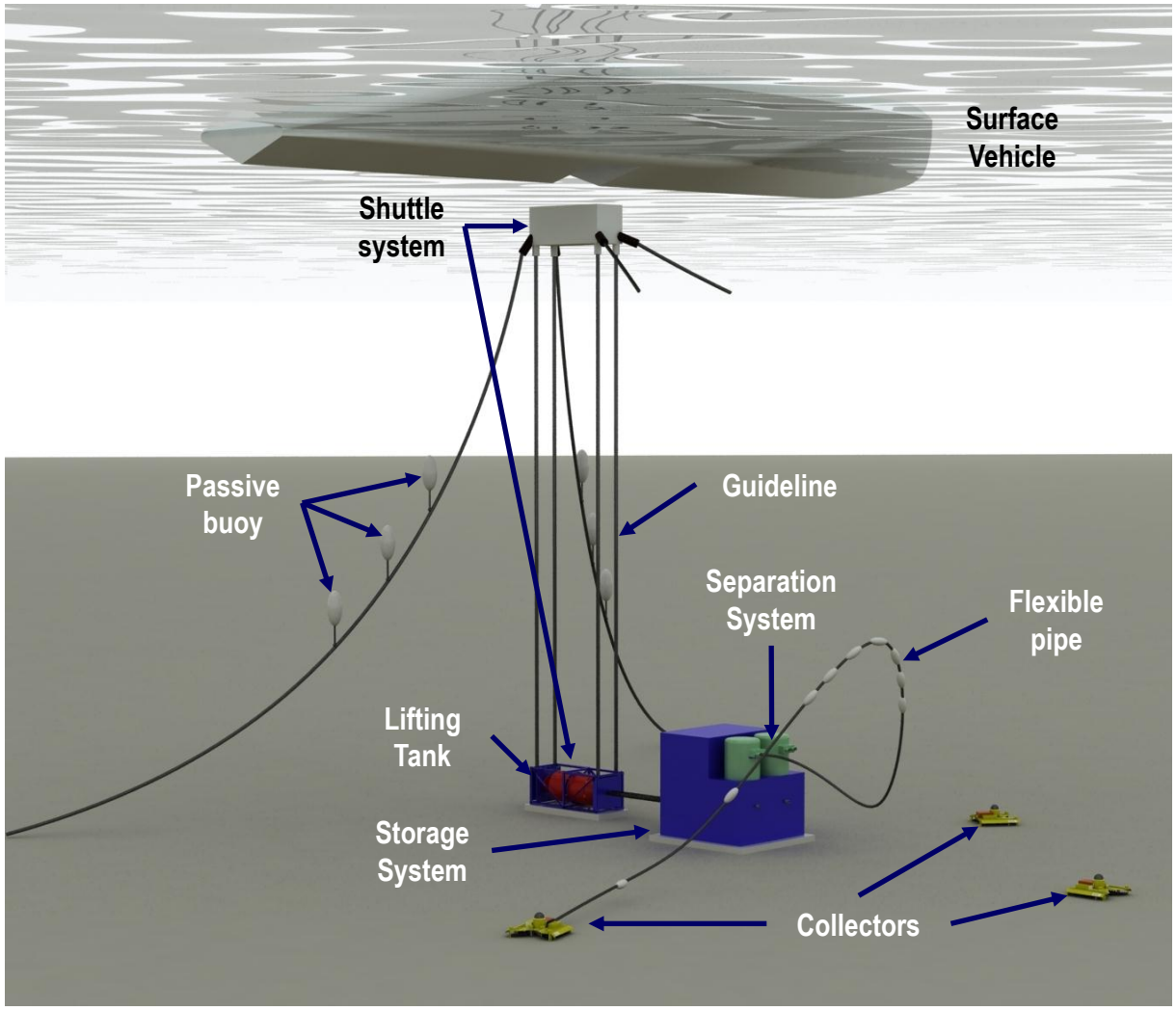
Capacity 50ton, Weight 60ton

The storage system

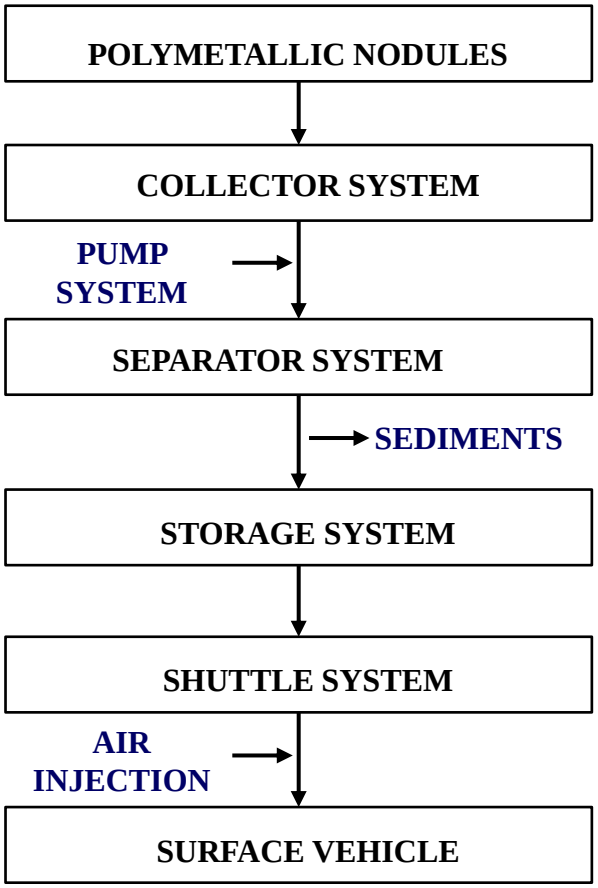
Summary of the concept development

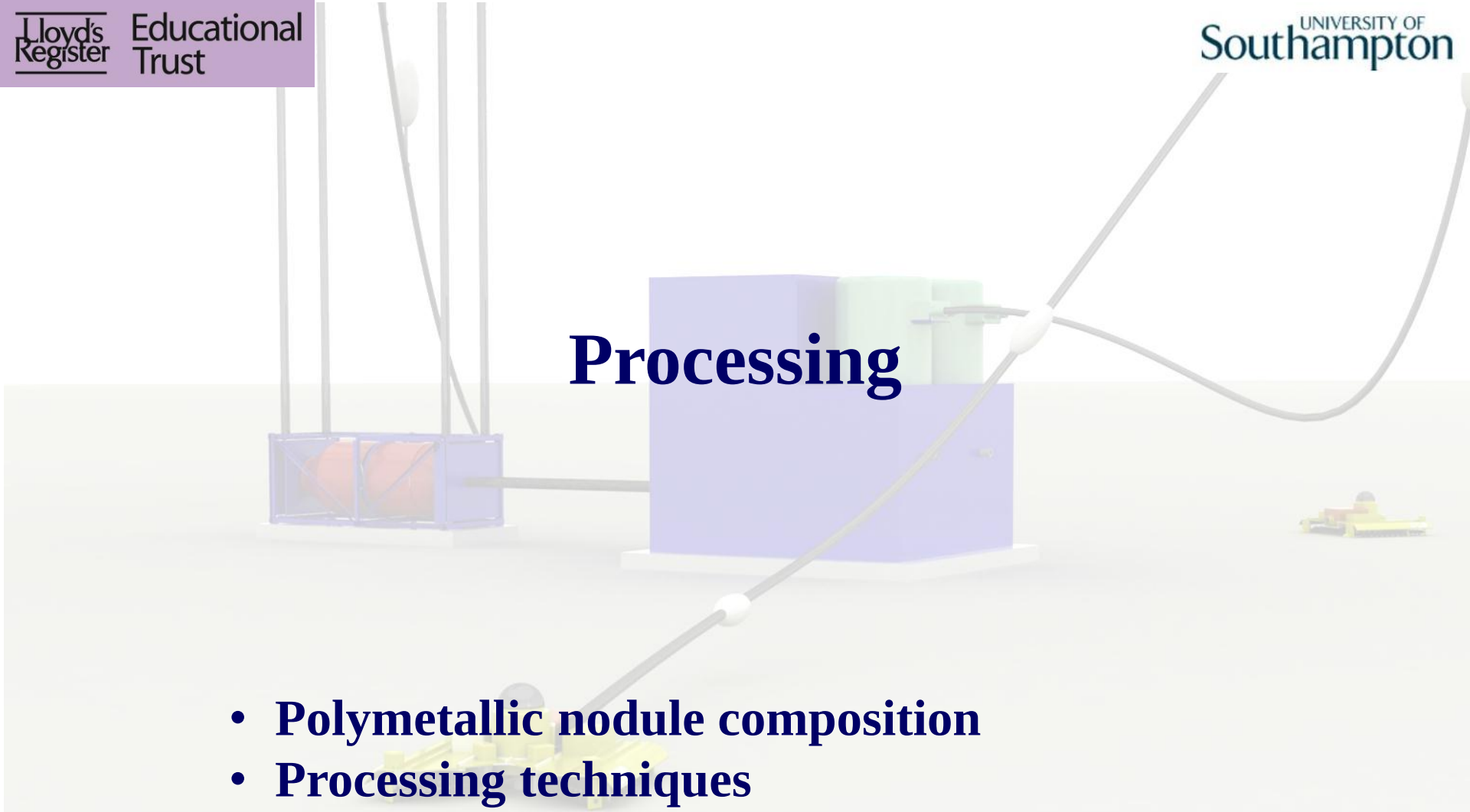
Model Number			Phase I	Phase II	Phase III
Angle (degree)			30	**90**	**90**
Hor. Screw	Inlet	Width (mm)	1,140	2,400	2,500
	Outlet		500	470	550
Ver. Screw	RPM		10	32	18
Production Rate	1 Day (ton)		200	430	450
	1 Mon (ton)		5,000	10,750	11,250
	1 Year (ton)		**60,000**	**130,000**	**135,000**
Weight	Main Pro. Screw (ton)		1.30	0.67	0.45
	Hor. Screw (ton)		0.22	0.08	0.06
	Ver. Screw (ton)		0.73	0.24	0.26
	Main Frame (ton)		13.00	6.72	4.50
	Total (ton)		**16.77**	**8.46**	**5.78**

Conceptual design of nodule mining



Nodule mining process





Processing

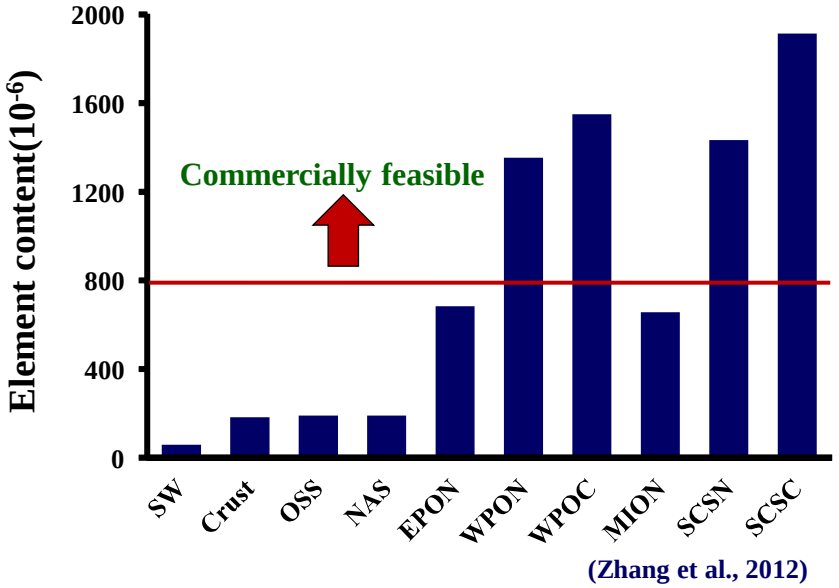
- Polymetallic nodule composition
- Processing techniques
- New concept of REE processing

Polymetallic nodules

Composition

Origin	Chemical Composition (mass%)						References
	Mn	Fe	Ni	Co	Cu	Zn	
Pacific Ocean	31.3	5.62	1.61	0.14	1.75	-	Hsiaohong (1992, 1996)
South-West Pacific Basin	16.6	22.8	0.35	0.44	0.21	-	Sen (2010)
Indian Ocean	10	11.4	0.26	0.14	0.23	-	Kanungo (1988, 1999)
South China Sea	27.7	8.92	1.62	0.02	0.1	0.08	Shen et al. (2007)

REE concentration



(Zhang et al., 2012)

Note:
In this figure, SW=REE of Sea Water, Crust-=REE of the Crust, OSS=REE of Offshore Surface Sediments, NAS=North American shale, EPON=Eastern Pacific Ocean Nodules, WPON=Western Pacific Ocean Nodules,WPOC= Western Pacific Ocean Crust, MION=Mid-Indian Ocean Nodules, SCSN=South China Sea Nodules, SCSC=South China Sea Crust

The composition varies widely depending on the location.

The pacific-wide REE concentration of polymetallic nodules is ~1400 ppm

Processing techniques

Available feasible techniques for PMN processing:

1. Gas reduction and ammoniacal leach
2. Cuprion ammoniacal leach
3. High temperature and high pressure sulphuric acid leach
4. Reduction and hydrochloric acid leach
5. **Smelting and sulphuric acid leach**

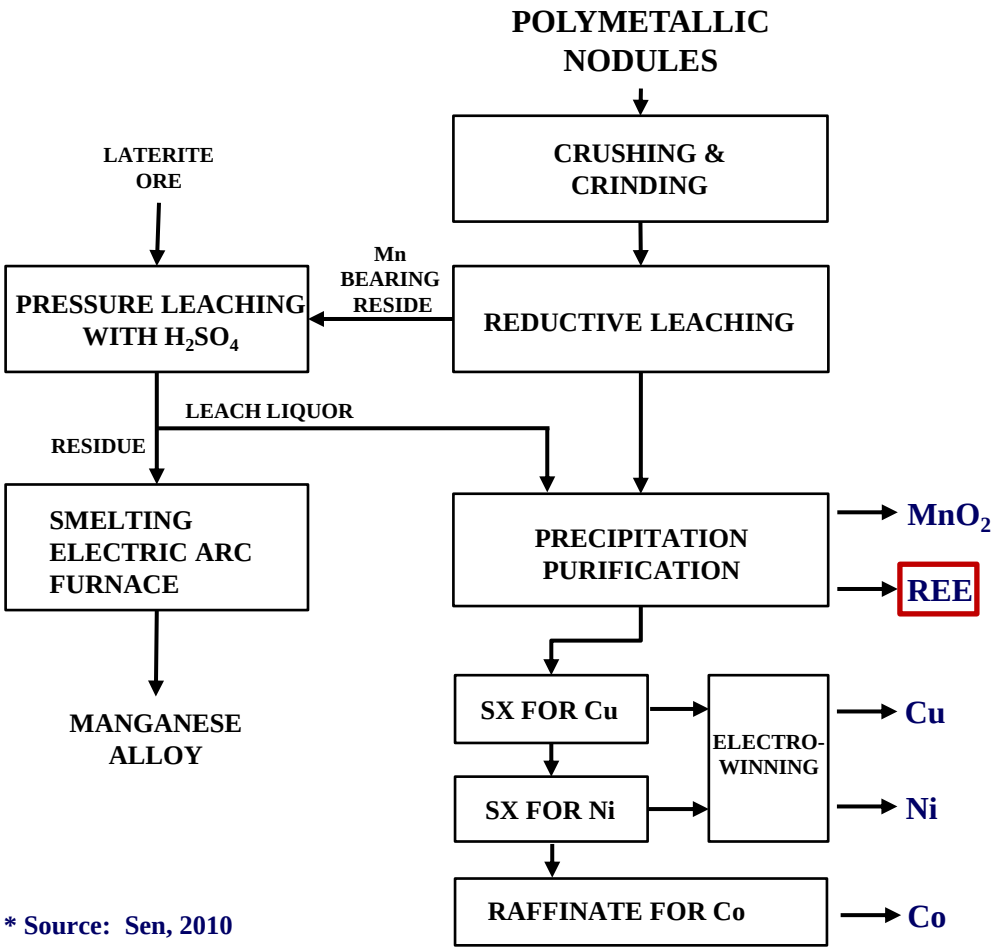
	Andrews et al. (1983)	**Hillman (1985)**	**Charles (1990)**	**Lenoble (1990)**	**Lenoble (1990)**	**Ham (1996)**	**Soreide et al. (2001)**
IRR (%)	6.4	7.4	12	**15.4**	15.7	11.9	9.6
Capacity (DMTPA)	1.5 four metal	3.0 three metal	1.5 four metal	1.5 four metal	1.5 four metal	3.0 four metal	0.7 three metal
Process route	Reduction smelting & Cuprion processes	Cuprion	Reduction HCl leach	Sulphuric acid leach	Smelt reduction	Reduction roast ammonia leach	Sulphuric acid pressure leach

Sulphuric acid leach gives four metal recovery with **15% IRR**.

IRR needs to be increased to 30-35% to make the PMN exploitation feasible.

Processing concept

Multi-feed and multi-product based PMN processing concept



* Source: Sen, 2010

1. 4 metal (Cu, Ni, Co & Mn) recovery process increases **IRR to 15%**.
2. Hybrid processing unit to combine lateritic ore with PMN to **reduce financial risk** and **increase IRR**
3. Final products are Cu, Ni, Co, MnO_2, Mn alloy and REE
4. No established processing technique is available for REE extraction from PMN, however, Scandium and Thorium are extractable using H_2SO_4 leaching.

Hazard identification (HAZID)

- HAZID- method
- HAZID- results

Hazard identification - method

Hazard identification:

- Brainstorming session
- Guidewords
- Participants:
  The 5 Group E members

Focus:

- Major hazards
- Environmental impact
- Proposed concepts

Systems:

- Screw based collector
- Shuttle system
- Combined processing
- PMN mining system as a whole (briefly)

Classification	Description of hazard or environmental impact
1	None identified.
2	Known from similar concepts.
3	Can be estimated from similar concepts.
4	Unique to this concept. Further studies required to conclude whether it is acceptable.

Hazard identification - results

System	No. of findings			
	1	2	3	4
Collector	4	-	3	**2**
Shuttle	4	-	2	**10**
Processing	-	7	1	**1**
Overall	-	-	1	**1**

Findings unique (4) to the proposed concepts

System	Major hazards	Environmental impact
Collector	-	- Seabed disturbance - Plume generation
Shuttle	- Collision with the surface ship - Collision with basket collection vessel - "Runaway" baskets - Toxic gasses in the buoyancy system	- Collision with sea animals - Waste into seawater from the buoyancy system
Processing	-	- Large amount of waste from nodules processing
Overall	-	- At-sea dewatering and drying

Concluding remarks

Concluding remarks

- Review the field of polymetallic nodule mining and identify the main areas for development.
- High investment risk prevents commercialisation of polymetallic nodules mining. Technical barriers are one of the contributors to the high investment risk. These include:
  - Downtime of the collector
  - High operating & maintenance cost
  - High processing cost & dependence on nodule supply
- The new conceptual engineering systems of polymetallic nodule mining and processing have been proposed.
  - The screw based new concept of the collector system
  - The new concept of the shuttle system
  - The storage systems, 20FT & 40FT
  - Processing routes for combined marine and laterite ores
- Hazard identification of proposed conceptual systems has been carried out.

Thank you for listening