Group Deep Blue

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Sustainable Seabed Mining:
Guidelines and a new concept for Atlantis II Deep

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Agenda

1. Motivation, Objectives and Research Framework
2. Online Survey and Expert Interviews
3. A New Concept for Atlantis II Deep
4. Conclusion and Outlook for Future Research

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Motivation and Objectives

Motivation

- Mineral resources deplete on land
- Seabed provides rich mineral and organism sources
- Seabed mining demands a multidisciplinary approach
- How can the seabed be mined sustainably?

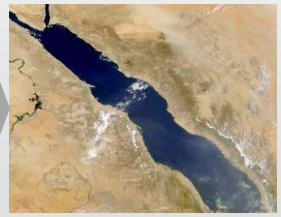
Research Focus

- Review of seabed resources → Selection of *Massive Sulphides* in *Inactive Hydrothermal Vents*

Massive Sulphides (Active Vents)	Massive Sulphides (Inactive Vents: Sediments)	Manganese Nodules	Benthos: Algae and Biofuel
Economics			
• Mineral rich deposits (e.g. Cu, Zn, Ag, Au) • Water depths: ~1000 – 4000m	• Mineral rich deposits (e.g. Cu, Zn, Ag, Au) • Water depths: ~1000 – 4000m	• Highly-concentrated polymetallic nodules (e.g. Mn, Co, Ni, Cu) • Water depths: ~4000 – 6000m	• Multiple uses of algae as biofuels, fertilisers and food • High production rate compared to land-based biofuels • Water depths: 0 – 50m
Environment			
• Chemosynthesis: High biodiversity	• Shut-off active chemosynthesis: lower biodiversity	• Growth and occurrence nucleus • Deep seawater biodiversity in early exploration state	• High biodiversity related to algae growth • Limited research and knowledge on mass algae cultivation on the seabed
Society / Legal			
• EEZ and High Seas (Intl. Waters)	• EEZ and High Seas (Intl. Waters)	• High seas, CCZ and Indian Ocean	• EEZ

- Review of potential mining sites → *Atlantis II Deep*

Potential Deposit Sites	Water Depth	Jurisdiction	Country
Atlantis II Deep	2,000-2,200 m	EEZ	Saudi Arabia; Sudan
Middle Valley Northeast Pacific	2,400-2,500 m	EEZ	Canada
Explorer Ridge Northeast Pacific	1,750-2,400 m	EEZ	Canada
Lau Basin Southwest Pacific	1,700-2,000 m	EEZ	Tonga
North Fiji Basin Southwest Pacific	1,900-2,000 m	EEZ	Fiji
Eastern Manus Basin Southwest Pacific	1,450-1,650 m	EEZ	Papua New Guinea
Central Manus Basin Southwest Pacific	2,450-2,500 m	EEZ	Papua New Guinea
Conical Seamount Southwest Pacific	1,050-1,650 m	EEZ	Papua New Guinea
Okinawa Trough West Pacific	1,250-1,610 m	EEZ	Japan
Galapagos Rift East Pacific	2,600-2,850 m	EEZ	Ecuador
EPR 13°N East Pacific	2,500-2,600 m	International	International
TAG Central Atlantic	3,650-3,700 m	International	International



Objectives

- Provide guidelines for sustainable seabed mining
- Development of a new concept for Atlantis II Deep in the Red Sea

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Research Approach

Focus: Broader View on Sustainable Seabed Mining

Focus: Atlantis II Deep/ Transfer of Lessons Learned

Survey

Expert Interviews

Case Study Nautilus

Engineering System

Economic Model

Environmental Assessment

Supply Chain Network

Legal Environment

Guidelines for Sustainable Seabed Mining

Concept for Atlantis II Deep

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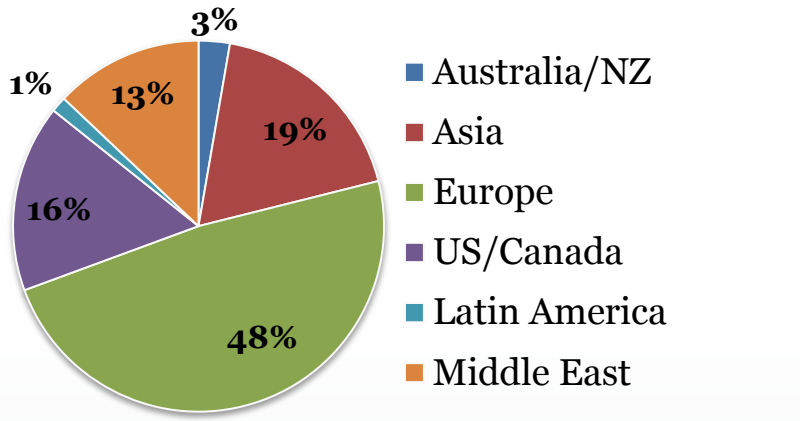
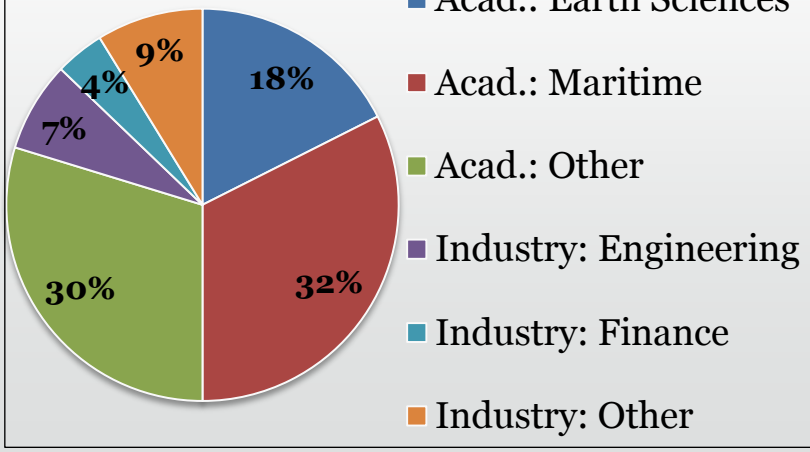
Online Survey

Sample (n = 147)





Drivers and Barriers

- **Major Drivers:**
  - Economic profit (80.5%),
  - Resource scarcity (69.5%)
  - Technological progress (64%)
- **Major Barriers:**
  - Environmental impacts (62.5%)
  - Economic challenges (57.8%)
  - Legal boundaries (46.1%)

Environmental Impacts

- 10.7% of the participants believe seabed mining should not be considered at all
- 55% think seabed mining is not environmentally friendlier or safer than land mining
- 53.4% think consequences can only fully be assessed when piloted

The percentages indicate the ratio of participants that agree or strongly agree with a statement based on a 5 point Likert-scale used.

Expert Interviews & Case Study

Expert Interviews

- 10 semi-structured in person and telephone interviews
- Experts in industry and academia

Case Study "Nautilus"

- Website Documentation
- Annual Reports
- News Feeds
- Technical Reports

Engineering Systems	▪ Criticality of Riser and Lift System ▪ Brine Environment, Fine Grain → Tracks System, Pre-processing
Economics	▪ Zinc concentration 2% ▪ Operation costs ▪ Fine grain sediments / Pre-processing
Environment	▪ Tailings disposal ▪ Sensitivity of Red Sea environment ▪ No standard for Impact Assessment
Logistics	▪ Multi-mineral processing facility ▪ Transportation and storage costs ▪ Oxidation of ores / dangerous goods
Legal	▪ Supportive Joint Development Agreement of Saudi-Arabia and Sudan

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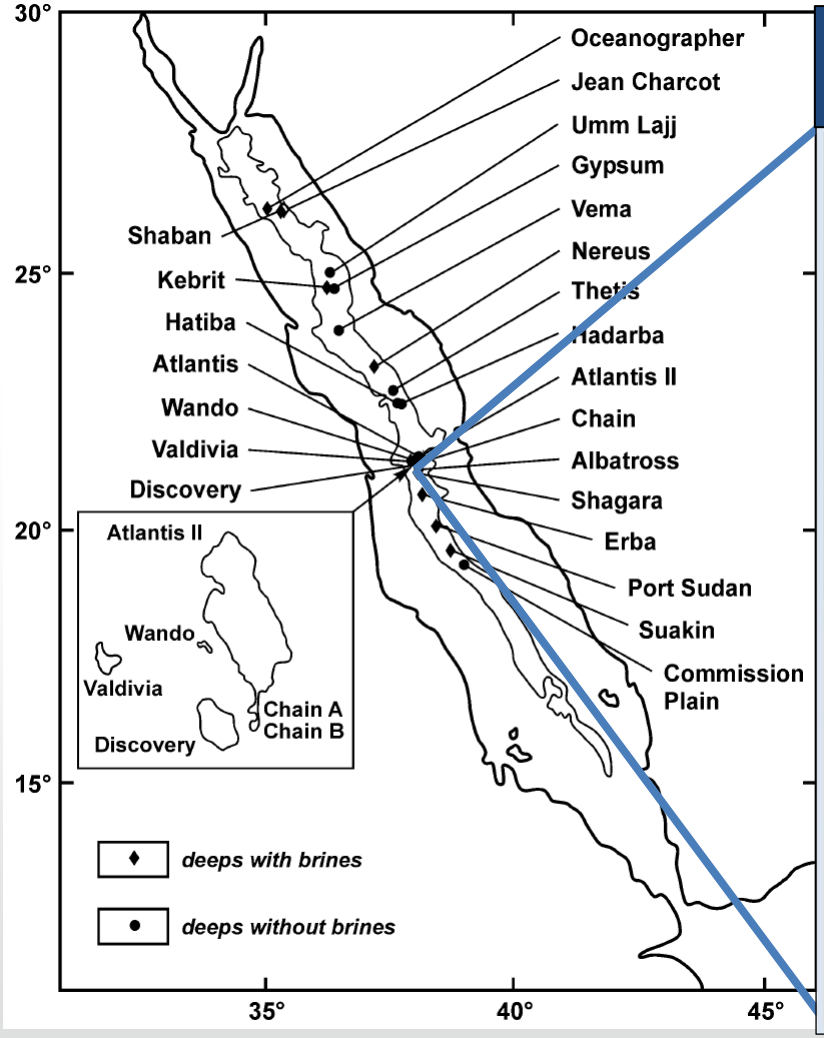
Overview



Red Sea, Atlantis II Deep

Environmental Conditions

- Depth: 2 km Brine water
- Wave: H_s = 1.2 m, T_{mean} = 9.26 sec
- Current = 0.3 m/s

Deposit Composition

- Zn>2%,
  Cu>0.5%,
  Ag>39 g/t
- Fine particle sizes (80%<2 μm)

Economic Analysis

Sensitivity Study

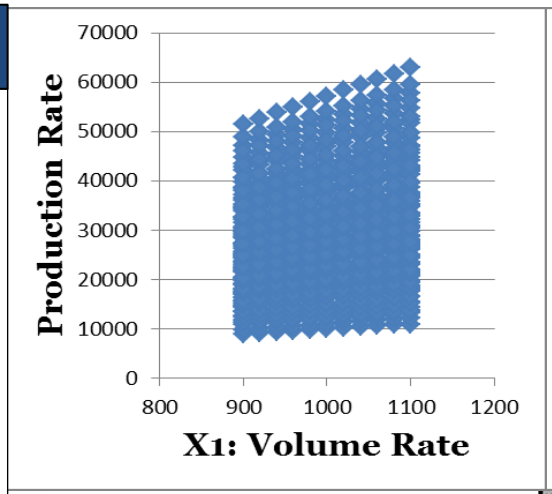
(Production) = *f*(X1,X2,X3)

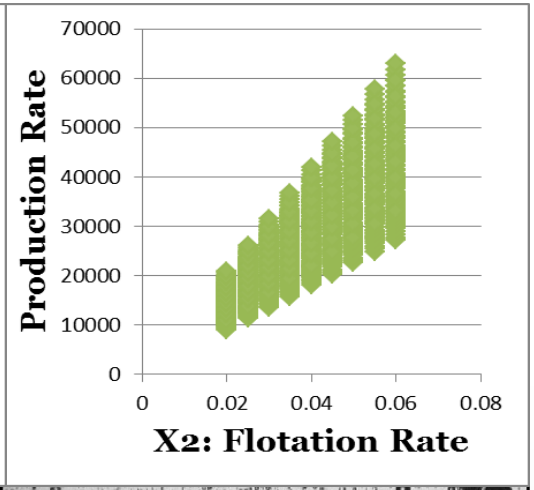
- X1: volume rate
- **X2: flotation rate**
- X3: recovery rate

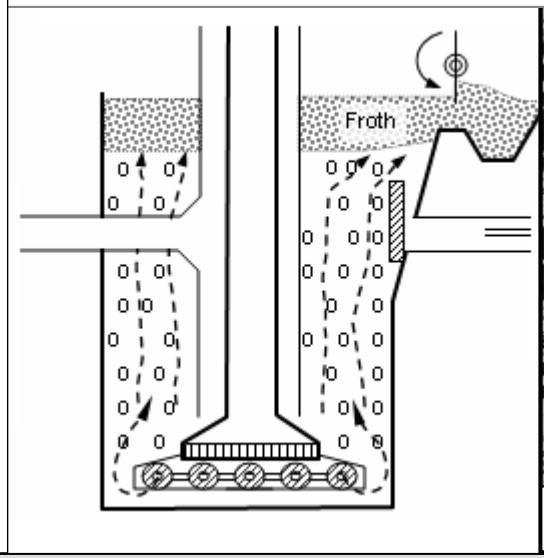
(PV) = *g*(X4,X5,X6,X7)

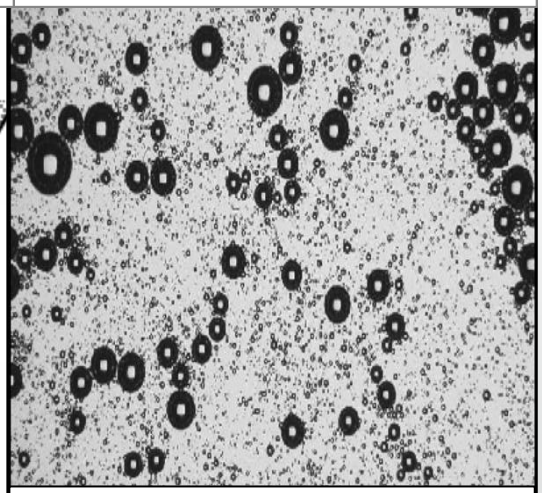
- X4: production rate
- X5: operating cost
- X6: capital expenditure
- X7: metal prices

- **Production rate**
  Flotation technique is critical to establish economic feasibility.





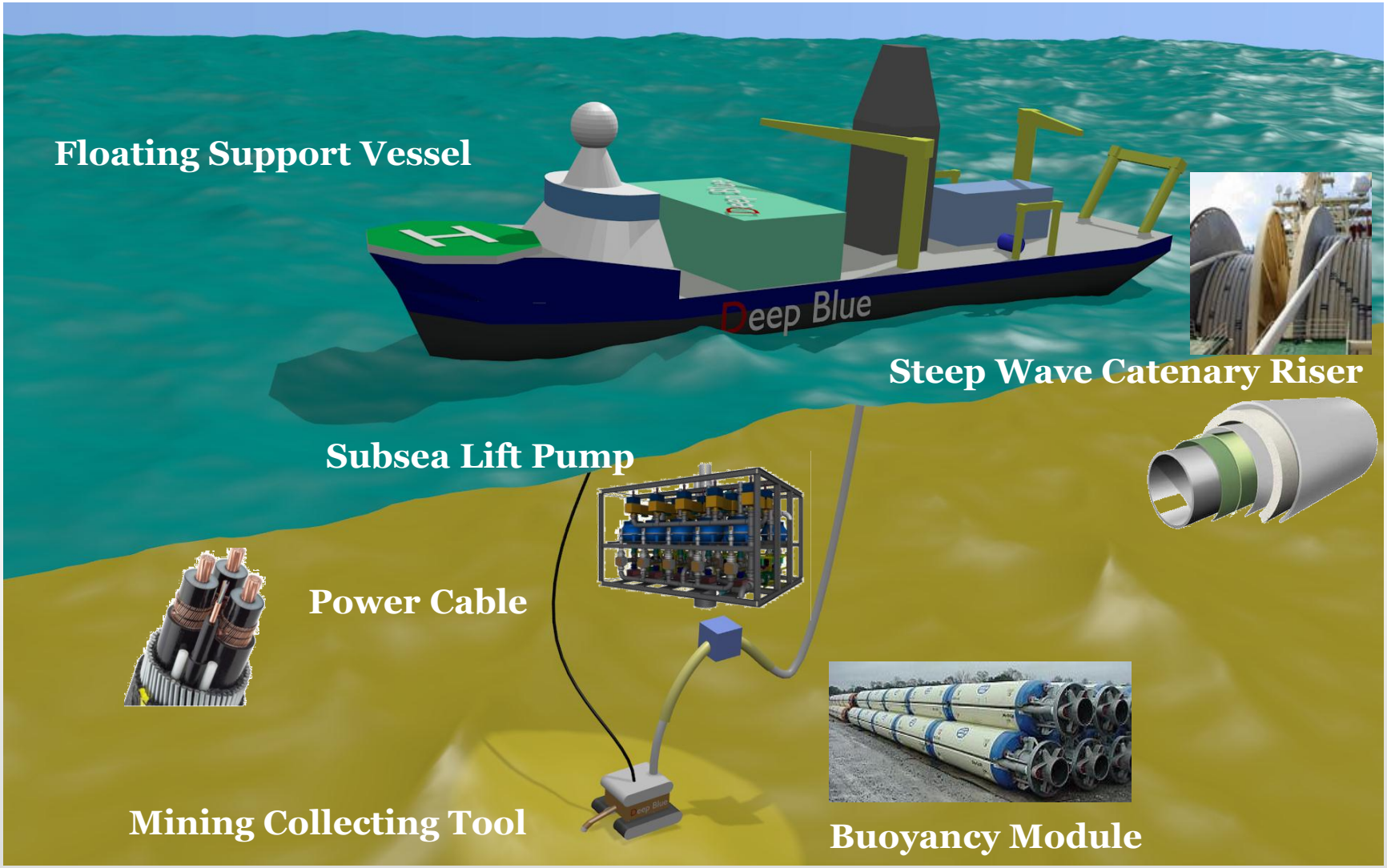




Rodrigues & Rubio (2007)

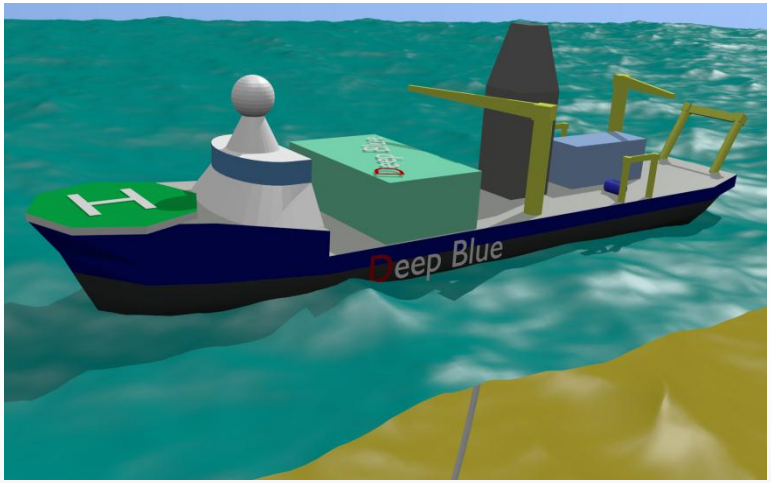
PV: Present Value
IRR: Internal Rate of Return

Offshore Production System



Mining System: Key Elements

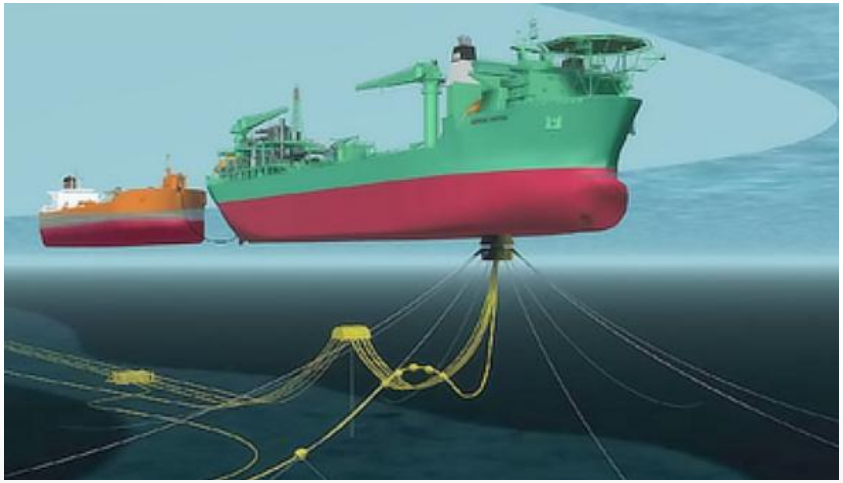
Floating Vessel (Ship-Shape)



Advantages of ship-shape structure for sea bed mining:

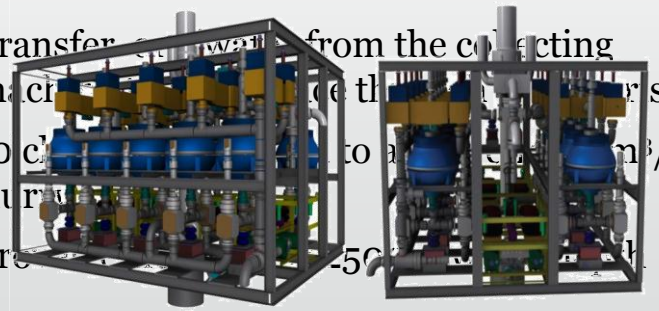
- Mobility
- Adequate deck space
- Accommodation for up to 140 persons
- Dynamic positioning reliability
- Adequate electrical power

Riser System: Compliant Riser

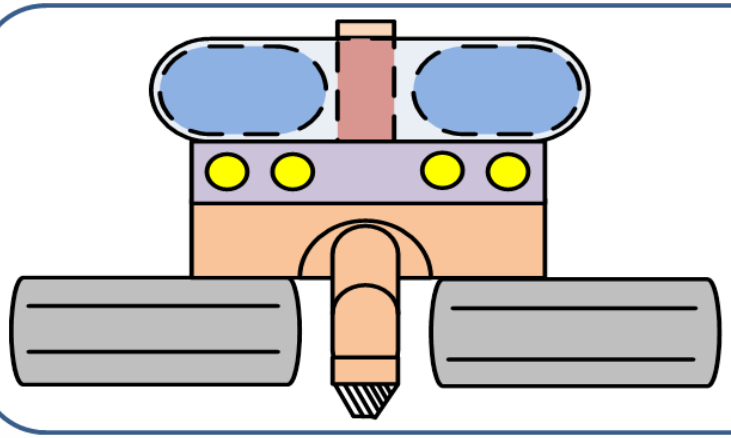


Subsea Lift Pump

- Transfer [illegible] from the collecting [illegible] ser
- 10 [illegible] /hr slurry
- Pr[illegible]

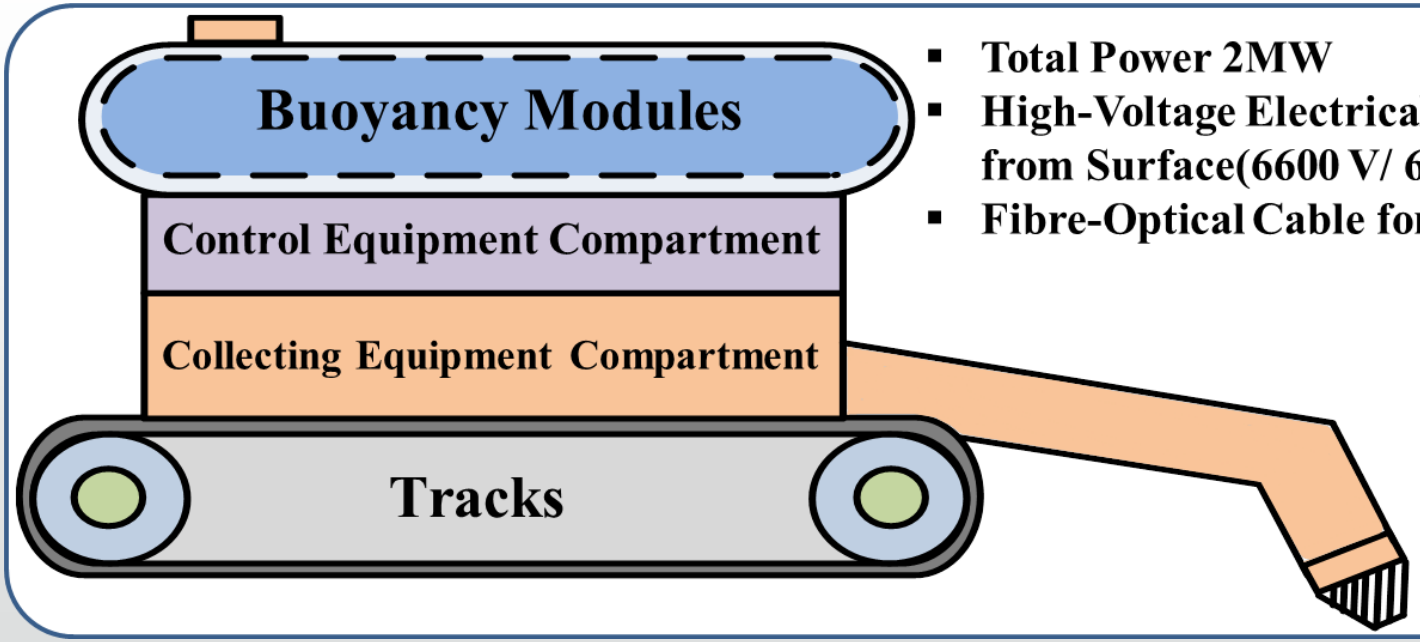


Seabed Mining Machine



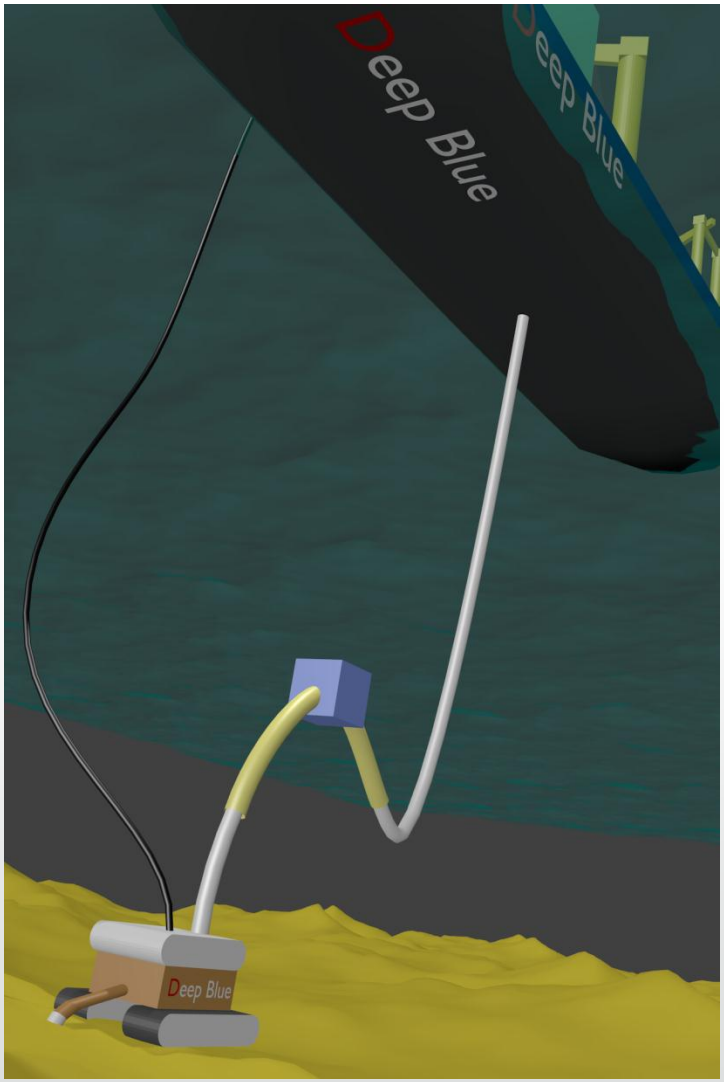
Requirements:

- **High Pressure Resistant (200 bars)**
- **High Temperature Resistant (66 °C)**
- **High Salinity Resistant (270 ‰)**
- **Adaptation to Cohesive Soils**
- **Long Maintenance-Free Time span**



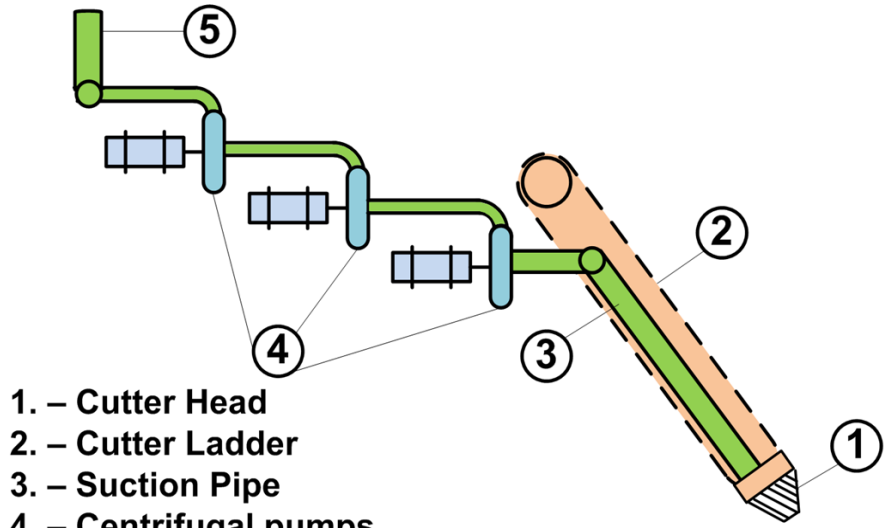
- **Total Power 2MW**
- **High-Voltage Electrical Cable from Surface(6600 V/ 60 Hz)**
- **Fibre-Optical Cable for control signals**

Seabed Mining Machine



Advantages of High Voltage

- Decreasing the full-load current
- Reducing power losses in the cable
- Decreasing cable cross-section
- Decreasing the size of the equipment

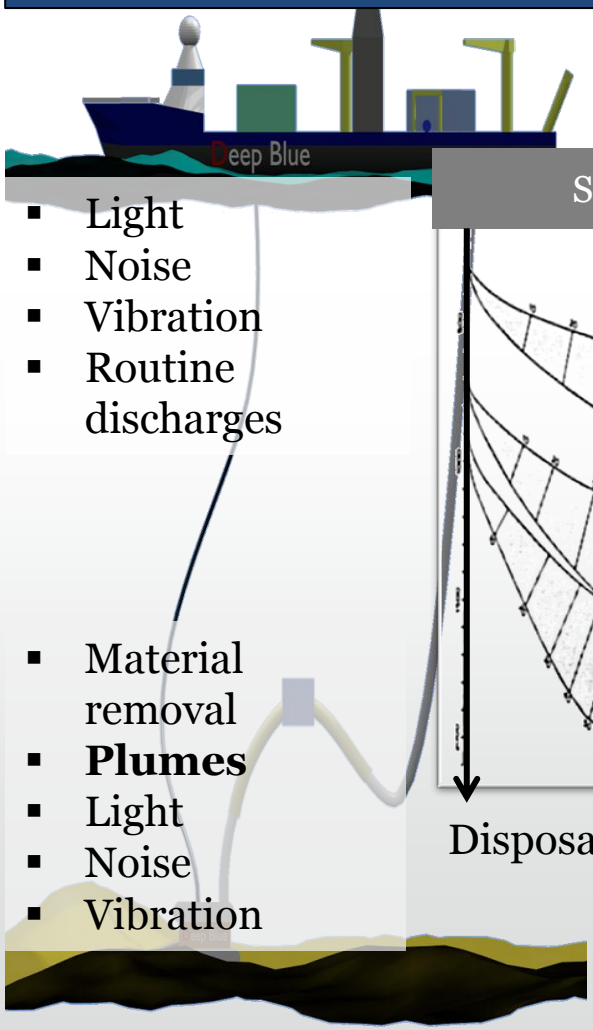


1. – Cutter Head
2. – Cutter Ladder
3. – Suction Pipe
4. – Centrifugal pumps
5. – Flexible Riser Connector

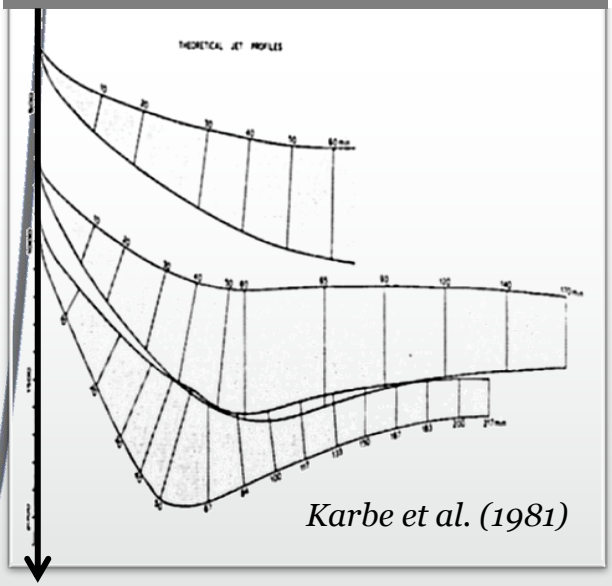
Collecting System

Environmental Impact and Mitigation Strategies

Environmental Impacts



Spreading of Plume



Disposal Depth

Mitigation Strategies

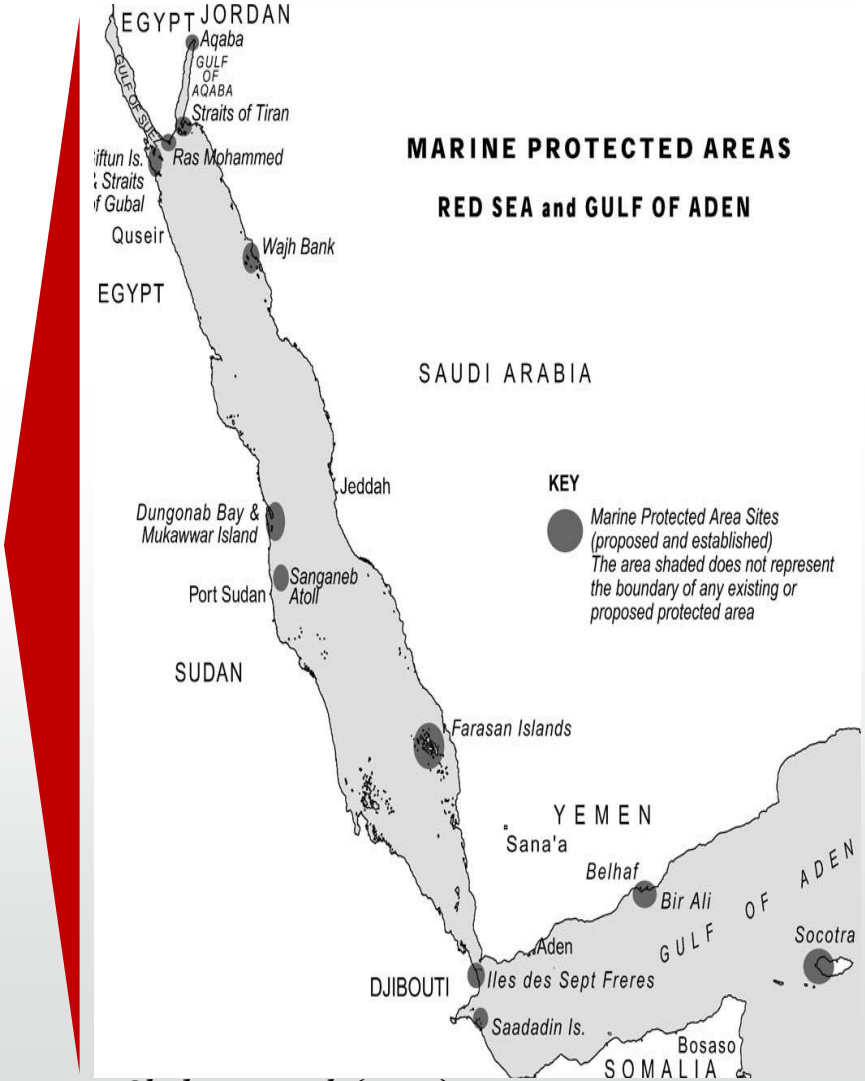
1. Following standard offshore regulations
2. Fully-enclosed riser and lift system
3. Wastewater discharge near the seafloor to prevent plume spreading
4. Select an unmined reference area to provide parent stock for repopulation
5. Monitoring throughout and beyond the life of the project

Environmental Regulations

Application Process for Environmental Permits for Seabed Mining (Level 3)

- **Environment Inception Report**
- **Environment Impact Statement**
- **Governmental Approval in Principle**
- **Environment Permit Application**
- **Environment Permit Approval**

Adapted from S. Smith (2010)



Gladstone et al. (2003)

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Legal Regulations

Saudi-Sudanese Red Sea Commission

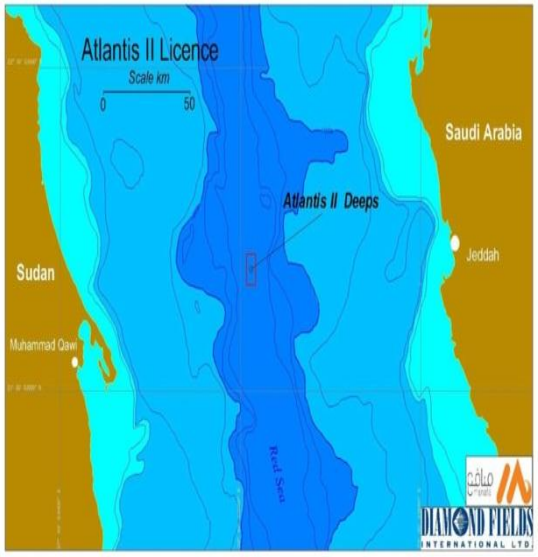
- Equal rights to the common zone where the depth exceeds 1000 m

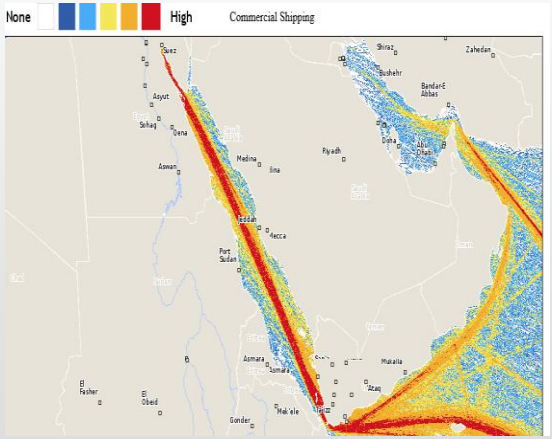
Environmental Legislation

- Possible use of Madang Guidelines and Code for Environmental Management of Marine Mining (IMMS, 2001)
- Jeddah Convention (1982)

Further Regulations of Interest

- Potentially permits from the transportation departments of Saudi Arabia and Sudan are needed





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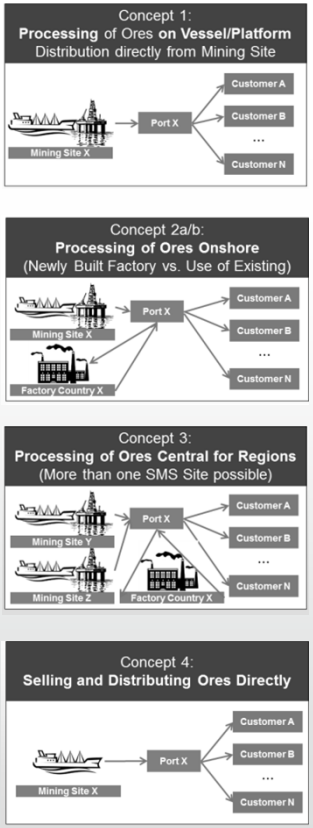
Atlantis II Deep Supply Chain

Development of Supply Chain Scenarios



Selection of Atlantis II Deep Scenario

- Selection of supply chain scenario based on SWOT analysis (processing onshore)
- Identification of a multi-mineral processing facility

Specification for Future Network Optimisation

- Atlantis II Deep maintenance and logistics (e.g. food and water supply)
- Handling sediments offshore (~ 380t/d)
- Barge transport mining site – Port of Gizan (~620km)
- Handling sediments in port
- Road transport Port of Gizan – Al Masane (~420km)
- Storage / Stockpiling

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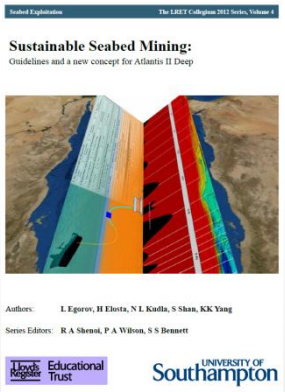
Conclusion & Outlook

Contributions of the Study

- **Guidelines and recommendations** for decision-makers in the seabed mining industry
  - Economics
  - Environmental impact assessments
  - Engineering system and supply chain design
  - Mining site selection



- **Concept for Atlantis II Deep**:
  - Collection machine
  - Specification riser and lift systems
  - Energy supply and vessel positioning systems
- **Online Survey**:
  - Drivers and barriers
  - Insights into public and single-discipline expert perceptions on seabed mining

Outlook

- Application of the engineering system to other potential seabed mining sites
- Further development of all concept aspects, validation and testing with real-world data
- Analysis of other resources based on the proposed research framework

Thank you for your support!

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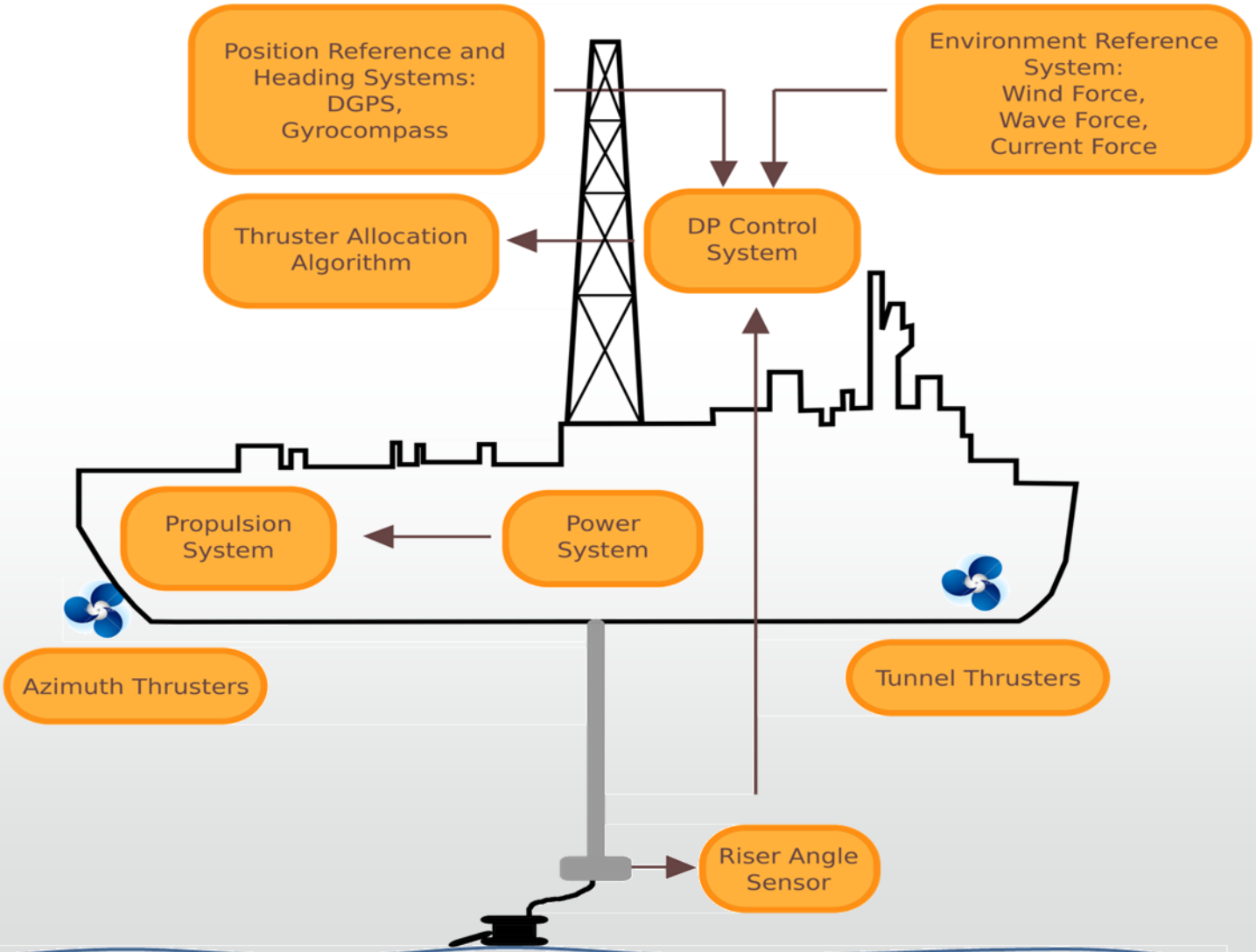
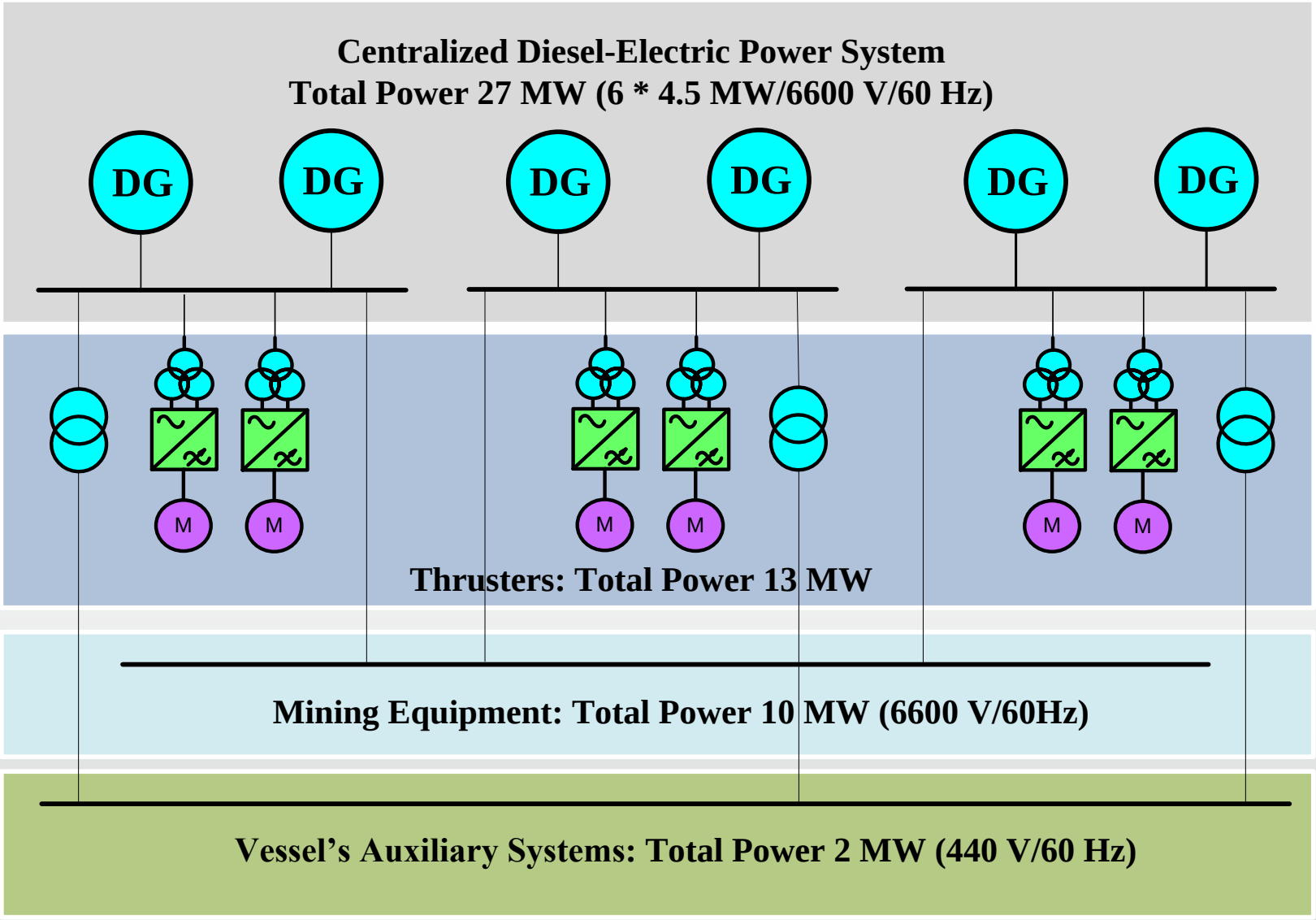
Vessel Positioning System



Energy Supply System



Floating Platform Selection for A2D

Characteristics	TLP	Spar	Semisub	FPSO
Water depth	More sensitive (up to 1500m)	Less sensitive (no practical limit)		
Platform motions	Very low vertical motions (i.e. heave, roll and pitch)	Low vertical motions and sensitive to long period waves	Motions limit applications	Motions limit applications
Heave natural period	< 10s	20-24s	~20s	>20s
Storage capability	No	No	No	Yes
TTRs	No constraints	No constraints	No	No
SCRs	No constraints	No constraints	Yes	In mild environment