Report[1] to the International Seabed Authority on the Development of an Economic Model and System of Payments for the Exploitation of Polymetallic Nodules in the Area

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Executive Summary

1. The MIT Materials Systems Laboratory was contracted by the ISA to explore the implications of alternative financial payment mechanisms upon the economics of both the ISA, on behalf of mankind, and of seabed mining contractors engaged in the mining of poly-metallic nodules (PMN) found in the deep ocean. The financial payment mechanism defines the rules and rates associated with payments from contractors to the ISA under future exploitation contracts concluded with the ISA. The goal of that payment mechanism would be to provide the best financial outcome (optimum revenues) to the ISA while still allowing the contractors mining the nodules a satisfactory return on their investment.

2. There is a set of competing challenges that have to be taken into consideration when trying to set payment mechanisms for any mining operation. On the one hand, the owners of the mineral resource will want to be compensated for the extraction of the resource. On the other hand, the mining operator will want to be compensated for the time, effort, and capital required to undertake the extraction. This work explores this balance by evaluating many different financial payment systems from several perspectives and using several metrics.

3. To address this, the research team developed a set of parametric models of the key mining-related operations – the collector (i.e., the mining only part of the operation) and the metals processor (i.e., the part of the operations that extracts metals from the nodules) – and of the market into which metals from these operations will be sold. Using these models, it is possible to explore how different payment systems lead to more or less funds coming to the ISA and more or less return to the contractor.

4. This report has three main objectives: (1) to present the basic economic issues that underlie the challenge of setting a payment mechanism for deep sea mining of mineral resources, (2) to present the methodologies that have been developed to explore these issues, and (3) to summarize the results that can be developed using these methods — all with the objective of presenting a working framework for the analysis, evaluation and negotiation of potential payment mechanisms and financial terms.

Operational Scope

5. The scope of the analysis reported on here is the direct costs and revenues arising from mining and processing the nodules. Such costs include the costs of environmental baseline studies, assessment and monitoring and other activities directly associated with mining operations but will not consider externality costs of environmental degradation. We model a mining operation that spans 35-45 years including pre-feasibility (exploration), feasibility, operation build up, and operation.

Payment System Scope

6. A variety of payment mechanisms have been proposed and implemented for mining activities around the globe. Here we evaluate extraction-related payment systems grounded in one of the following, or a combination thereof, namely:

- Value-based or Ad-valorem
    - Payment is proportional to the market value of the resources within the ore.
- Profit-based
    - Payment is proportional to the profit of the mining activity in a given time period.

Method

7. As with any resource owner, the goal of the ISA is to design a payment system that maximizes the capture of value from the mining of the deep sea. Mining at scale, and the revenues it would provide to the ISA, will only occur if firms expect to make sufficient revenues to more than offset the considerable expenditures that are required to create and operate a deep-sea mining operation. As such, to bound the inquiry to the set of practically-interesting payment systems, we **first** identify the systems that model results indicate would provide some target level of return (the minimum attractive rate of return (MARR)) to the contractor. Then from this limited set, we identify the systems that maximize the return to the ISA. This order of analysis is required to make the inquiry efficient. In this work, we assume that the MARR would need to exceed typical land-based rates (~15%) to account for novel technological, operational, and geological risk. Therefore, we analyze systems that would be expected to provide a return of 17. 17.5, and 18%.

8. Because there is such a long time period between the start of a mining project and its conclusion, we rely on a discounted cash-flow analysis (DCFA) approach to evaluate the economic merits of the payment mechanism outcomes. A DCFA assumes that future cash flows are of less value (are discounted) compared to cash flows today. This is a standard method for evaluating mining operations.

9. From the DCFA, it is possible to compute a number of performance metrics for the mining operation. These include net present value, internal rate of return, and the share of revenues among key actors – ISA, sponsoring States, and the collector. Selected systems were evaluated using Monte Carlo analysis – a statistical sampling method to estimate the uncertainty in model results based on uncertainty in model inputs.

10. The analysis and results presented in this document assume that any revenues collected by the ISA are based on characteristics of the operations taking place within ISA jurisdiction *only*. Practically, this means that ISA can only collect revenues directly from the collector. This is primarily relevant in defining the share of revenue that is split among the collector, the ISA, and the appropriate sponsoring State (assuming a mining entity would be subject to taxes in its sponsoring State).

Metal Processor Cost

11. Extracting metals or Mn-rich slag from the PMN requires a series of complex and highly capital-intensive processing involving very large upfront investments and ongoing operating expenditures. Currently no processing plants exist that extract metals from PMN and thus there is nosingle definitive approach for such extraction. In this report, we develop costs associated with three classes of processing routes, namely:

- Ammoniacal leaching processes ("Cuprion" and others);
- Pyrometallurgical extraction processes followed by Electrowinning refining; and
- Hydrometallurgical extraction processes followed by Electrowinning refining.

12. All three general approaches are explored in a cost model which considers both upfront capital requirements and ongoing operating costs. Because the Ammoniacal leaching process seemed to offer the most favorable cost position, its costs were used in analyzing the payment systems. The cost model was used to estimate both a baseline set of costs and the uncertainty in those costs. Specifically, the cost modeling effort suggests that a plant capable of processing three million dry tons of nodules per year

would likely (baseline result) cost more than two billion USD to develop and construct and more than two hundred USD per ton of nodule per year to operate.

Estimating metal revenue

13. Revenues to this mining system derive from the sale of metals extracted from the nodules. In a general sense, that value derives from the quantity of metal recovered and the price of those metals. All analyses were done at an assumed scale of 3 million dry tons of nodules per year, although the models allow analysis across a wide range of the scales of nodule collection. Three million dry tons was selected as the baseline since it is believed that this order of magnitude is needed to achieve economies of scale and thus minimize costs. Best available information was used to estimate collector and metals processor yields.

14. Metals prices were modeled using a combination of expert estimates of long-term prices and statistical models to simulate uncertainty around those estimates. For the manganese market, the research team considered an approximate reaction of the market to significant quantities of high purity manganese. Future work should develop a fully dynamic model to understand how the market might react.

Transfer price

15. Metals processors must purchase nodules from nodule collectors. In a mature market, a price would have settled out for such nodules. For the PMN context, no such price exists. The model applied here solves for a transfer price so that both the metals processor and nodule collector both earn the same rate of return.

Nodule Collector

16. A model was developed to estimate the cash flows associated with the mining contractor collecting nodules from the ocean floor. This model estimates the number of resources (capital, labor, and energy) needed to carry out mining operations on the ocean floor, the surface, and the transport of nodules for processing. Additionally, the research team developed a detailed environmental monitoring plan the estimated the cost of executing that plan. The cost model was used to estimate both a baseline set of costs and the uncertainty in those costs. These results suggest that a mining operation capable of collecting three million dry tons of nodules per year would likely (baseline results) cost more than 1.6 billion USD to develop and construct and just under 130 USD per ton of nodule per year to operate.

Uncertainty

17. There are many uncertain aspects of the analysis presented here. Deepsea mining operations are novel at scale and many technological risks still exists. From the perspective of cash flow economics, this technological risk could translate into delayed full scale mining, slower ramp up of mining, and additional downtime during regular operations. Because no facility currently extracts metals from nodules at scale, there is much technological uncertainty surrounding the processing facilities for nodules. This translates into uncertainty in processing cost and metal yield. As with any mining business there is significant uncertainty around future metal prices. Finally, there is uncertainty about the geological conditions of a future mine site. These manifest in terms of realized nodule density, topological challenges, and collecting yields. We have attempted to capture most of these aspects of uncertainty in the simulation analyses carried out as part of this work.

Results

18. At a high level the payment system is defined by three to four characteristics. These can be expressed as answers to the following questions:

- Rate basis: Will extraction-related payments be based on metal value (ad-valorem royalty) only or metal value anda share of contractor profit?
- Rate stability: Will the rate of payment be fixed or will (can) it change at pre-defined stages during the lifetime of the mining operation?
- Basis for rate change (if the rate will (can) change): What will trigger the change: time or some other metric of firm fiscal performance?
- Rate level: What will the rate of payment (per value or per unit of profit) be for the first stage of mine operations? If the rate level is staged, what will the level be for future stages?

19. To find the best system, the research team evaluated hundreds of system configurations using baseline conditions only. These results were used to identify several promising payment systems. These selected payment systems were then evaluated using Monte Carlo simulation to generate more detailed analyses and to get a sense of the uncertainty surrounding the estimates of economic performance.

20. Figure EX 1 shows the performance of the selected systems. Specifically, this figure plots the net present value of the expected revenues going to the ISA versus the expected return to the contractor (x-axis). These results show some expected results such as that as the contractors expected return declines, the expected ISA revenue increases. More interestingly, within each cluster of results we see systems that generate similar returns to the contractor, but significantly different value for the ISA. For example, compare two points near the center of the plot: 1) the blue circle labeled AV4%/AV4% which represents a system where extraction-related payments are 4% of the gross metal value[2] (GVM) collected and 2) the red X labeled AV2%+PB15% which represents a system where extraction-related payments are 2% of GVM for the first five years mining and then are 2% of GVM plus 15% of profit for the balance of mining operations. The latter system generates nearly 30% more NPV for the ISA than the former, even though they generated nearly the same expected contractor return.

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[2] Gross metal value here is defined as the value of the total content of four metals – manganese, cobalt, copper, nickel – contained in the nodules collected. Here gross refers to the fact that no real processing will recover all of this metal.

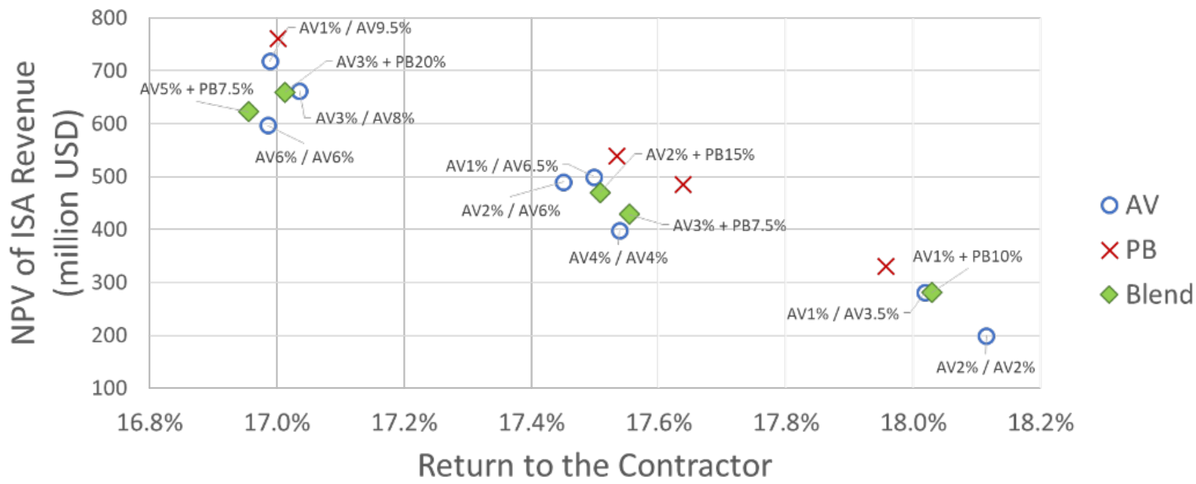

Figure EX 1. NPV of ISA Revenue vs return to the collector for each of the systems studied in detail. Note that within each cluster the return to the contractor is reasonably similar. Nevertheless, within each cluster there can be significant variation in the NPV

21. Based on consideration of the various characteristics of different payment systems, the authors have selected what appear to be the best options for implementation by the ISA. The table below provides the recommended financial payment options using either: a) a two-stage ad-valorem only system or b) a combined ad-valorem and profit-based system for each target Collector IRR. Recommended systems are presented for three levels of expected return to the contractor: 17%, 17.5%, and 18%. The results presented here all assumes an environmental liability fund collection rate of 1% of gross metal value collected up to a maximum of $500 million per mine site and an assumed sponsoring state tax rate of 25% of profit. The recommendations seek to maximize the NPV to the ISA while still ensuring that the ISA will receive a reasonable amount of the revenues in the early years.

Return to Contractor	System	ISA NPV (million USD)	Cumulative ISA Revenue (million USD)	Share of NOR_c to Collector
17%	AV3%→ AV8%	$660	$5,300	51%
	AV3% + PB20%	$640	$5,300	51%
17.5%	AV2%→ AV6%	$490	$4,000	56%
	AV2% + PB15%	$470	$3,850	57%
18%	AV1%→ AV3.5%	$280	$2,300	63%
	AV1% + PB10%	$285	$2,400	63%

22.

Introduction

23. Materials are the building blocks of the made world. As world population continues to grow, a core technological challenge for the 21st century is to secure a sustainable supply of those material building blocks. Achieving materials sustainability will require producers and consumers alike to make the most efficient use of materials resources wherever possible and, when necessary, to increase the stock of available materials through the careful development of new sources.

24. For much of human history, these sources have been land-based. An inevitable consequence of the finiteness of our planetary resources is that, over time, the effort required to extract from land-based sources has continued to increase. And so, just as the petroleum industry has expanded its scope to the floor of our oceans, there has been increasing interest in the mineral resources that have been discovered on the seafloor.

25. While many kinds of mineral resources have been discovered, polymetallic nodules (PMN) found in the deep ocean have become increasingly interesting. This interest stems from the type of constituent metals available (particularly nickel and cobalt), technological trends that are dependent upon a ready availability of these metals (renewable energy generation and electrical mobility), and the increasing difficulties associated with deriving these materials from land-based sources.

26. The viability of every ore body derives from the combination of techno-economic feasibility and appropriate legal framework. Because most polymetallic nodules are found outside of national jurisdiction and within the purview of the International Seabed Authority (ISA), it falls to the ISA and its member States to establish that framework.

27. Although, the mining of the seafloor beyond areas under national jurisdiction is governed by the United Nations Convention on the Law of the Sea (UNCLOS), which establishes a suite of rights and obligations for the recovery of mineral resources in such areas, managed and administered by the ISA, a number of details must be worked out to translate the provisions in the UNCLOS into operational regulations. A key component of those regulations is a financial payment mechanism (or system of payments) that determines what payments must be made by a mining operator to mankind, as the resource owner. This report deals with that single, albeit important aspect of the legal framework. Specifically, this report describes work carried out by the Materials Systems Laboratory at the Massachusetts Institute of Technology which was contracted by the ISA to explore the implications of alternative financial payment mechanisms upon the revenues that would be received by the ISA and the economic viability of seabed mining contractors.

28. There is a set of competing challenges that have to be taken into consideration when trying to set payment mechanisms for any mining operation. On the one hand, the owners of the mineral resource will want to be compensated for the extraction of the resource. On the other hand, the mining operator will want to be compensated for the time, effort, and capital required to undertake the extraction. In effect, a balance between the income to the owner and the extractor has to be struck, so that all participants have an economic incentive to undertake the resource extraction. This work explores this balance by evaluating many different financial payment systems from several perspectives and using several metrics.

Goals of the Report

29. The ISA faces a number of decisions when it comes to polymetallic nodule mining in the deep sea. One key decision centers on defining the financial payment mechanism and associated rates of payment.

30. The MIT Materials Systems Laboratory has been working with the ISA to quantify the economic implications of of alternative financial payment mechanisms for both the ISA, on behalf of mankind, and for seabed mining contractors (i.e., entities conducting mining operations under an exploitation contract with the ISA). The financial payment mechanism will define the basis and rates for the calculation of payments to be made by such contractors to the ISA under future exploitation contracts. The goal of that payment mechanism is to provide the best financial outcome (optimum revenues) to the ISA, while still allowing the contractors mining the nodules a satisfactory return on their investment.

31. To address this, the research team developed a set of parametric models of the key mining-related operations – the collector (i.e., the mining only part of the operation) and the metals processor (i.e., the part of the operations that extracts metals from the nodules) – and of the market into which metals from these operations will be sold. The models were used to simulate the physical and economic dimensions of the production system. Using these models, it is possible to explore how different payment systems lead to more or less funds coming to the ISA, and more or less return to the contractor.

32. This report has three main objectives: (1) to present the basic economic issues that underlie the challenge in setting a payment mechanism for deep sea mining of mineral resources; (2) to present the methodologies that have been developed to explore these issues, and (3) to summarize the results that can be developed using these methods — all with the objective of presenting a working framework for the analysis, evaluation and negotiation of potential payment mechanisms and financial terms under future exploitation contracts.

33. Like any such financial evaluations, it is vital to limit their scope in order to ensure that a credible analysis can be undertaken. In the present case, the scope of analysis is focused upon the direct financial conditions arising out of the costs and revenues of mining and processing the nodules. These costs include the costs of environmental monitoring and other activities directly associated with mining operations but will not consider externality costs of environmental degradation beyond those costs specifically enumerated in and accounted for by any ISA environmental fee structures under consideration. It is worth noting that at present direct costs do not consider any costs for environmental restoration at mine closure as there is currently no explicit obligation to do so.

34. The failure to include externality costs should not be construed as an assertion that these costs are unimportant. Instead, the authors hope that the information on expected direct costs (and revenues) presented here will ultimately be compared to estimates of externality costs.

35. There are two complementary questions which are not answered in this report, but which should be considered. Given the acknowledged risks of a deep-sea mining venture, what is the minimum return on investment needed by the contractors to secure financing and, therefore, to operate? Does the payment mechanism that provides this return generate sufficient revenue to the ISA to offer fair compensation to mankind as the resource owner?

Resource Valuation and Transfer

36. Sovereign states around the globe face the challenge of designing payment regimes for the extraction of mineral resources. High royalty and tax payment obligations could bring in large revenues to the state, but if too high will dissuade investment and mining operation entirely. States thus face the continual question of what is the optimal level and form of payment regime that provides the highest total value to the nation.

37. Because the mined ore generally requires considerable processing and time before it is sold and, moreover, because market prices will vary not only according to the nature and extent of product refinement but also in response to the vagaries of market supply and demand, resource owners are confronted with a delicate balancing act when setting these payment mechanisms. Essentially, there is the question of achieving fair compensation for the resources being extracted and the complementary problem of establishing a level of compensation that leaves the operator sufficient profit to support the investment in and operation of a mining enterprise.

38. In the face of these questions, a variety of payment mechanisms have been proposed and implemented around the globe. Here we focus primarily on payments in the form of royalties, where we use the term royalty as used by Otto et al. in the World Bank publication “Mining Royalties”[3]. That is, we are referring to payments made to the resource owner with the intent to compensate the owner for transferring ownership of the resource or the right to sell the resource to the payment-maker. While the authors feel that all of the payment systems explored in this document fit the Otto et al. definition of royalties, we understand that some believe that this term should not be applied to a payment that scales with the profit level of the mining activity. To avoid any confusion, therefore, we will refer to the various systems as extraction-related payment systems.

39. The typical extraction-related payment systems under national fiscal regimes are grounded in one of the following or a combination thereof:

- Unit-based royalty
    - Payment is based on the mass of ore removed. Also called “specific” royalties and typically applied as specified amount per tonne. The advantages of this approach are its simplicity. However, unit-based payments do not respond to changes in value or mining economics. Application of unit-based payments are generally limited to low value resources and are, therefore, not considered further in this work.
- Value-based or Ad-valorem royalty
    - Payment is proportional to (being generally a percentage of) the market value of the resources within the ore. This approach requires regular ore assays to validate the ore composition as well as a set of benchmark resource prices, which may fluctuate over time. This approach requires considerably more monitoring and analysis than a specific royalty, but it also responds to changes in resource values.
- Profit-based

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[3] James Otto, Craig Andrews, Fred Cawood, Michael Doggett, Pietro Guj, Frank Stermole, John Stermole, and John Tilton, “Mining Royalties: A Global Study of Their Impact on Investors, Government, and Civil Society”, World Bank, 2006.

- Payment is proportional to the profit of the mining activity in a given time period. This system adjusts with both changes in resource value and changes in operational costs. However, profit-based systems are much more costly to administer – much more information about the paying entity is required – and are, therefore, more susceptible to accounting manipulation.

In this work we will look at extraction-related payment systems based only on ad-valorem (resource value), profit only, and a combination of the two.

40. Notably, there are two other forms of payment from mining contractors to the ISA which are currently planned or being considered. These are: 1) administrative fees that generally are not proportional to the scale of mining activity but occur for each mining contract; and 2) possible funds to cover environmental liability or other yet to be specified sustainability-related goals. ISA needs to settle on the specifics of both of these categories. In this report, we include both of these types of payments as assumptions in our modeling, we examine only limited scenarios in which fees and funds differ from baseline assumptions. Our focus is instead on various configuration of extraction-related payments.

Objectives and principles for financial terms under an exploitation contract

41. Under the UNCLOS, the resources of the deep-sea bed, beyond areas under national jurisdiction, belong to and must be developed for the benefit of mankind as a whole. The ISA acts on behalf of mankind in the administration and management of the international seabed area and the resources. The resources can only be recovered by mining entities in accordance with the UNCLOS and the rules, regulations and procedures put in place by the ISA. To date, contracts have been issued by the ISA under its rules to States, State enterprises and private investors for exploration only. Exploration operations will determine the technical and economic feasibility of recovering the resources, as well as assessing the potential effects on the marine environment of future mining projects. As noted above, the ISA is currently developing comprehensive rules to regulate future mining operations, including the payment mechanism under which contracted mining entities will make payments to the ISA as compensation for the extraction of and transfer of legal title to the resources.

42. In connection with a payment mechanism and the development of financial terms under future exploitation contracts concluded with the ISA, the UNCLOS and a 1994 Implementing Agreement set out a number of objectives and principles respectively.[4] Such objectives include: (1) to ensure optimum revenues for the Authority from the proceeds of commercial production; (2) to attract investments and technology to the exploration and exploitation of the Area, and (3) that contractors receive equal treatment and have comparable financial obligations. Principles for the development of a payment mechanism and rates of payment include, that: (1) the system of payments to the ISA be fair both to a mining contractor and to the ISA, and provides adequate means of determining compliance by the contractor; (2) any payment mechanism should not be complicated to administer for both the contractor and the ISA or impose major administration costs, and consideration to the adoption of a royalty system or a combination of a royalty and profit-sharing mechanism; (3) a periodic review be applied to the system

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[4] See ISA "A Discussion Paper on the Development and Implementation of a Payment Mechanism in the Area", March 2015 which discussed these objectives and principles and other considerations in the development of a payment mechanism.

of payments, and (4) the rates of any payments under the system shall be within the range of those prevailing in respect of land-based mining of the same or similar minerals, with .

43. The current ISA draft regulations on exploitation of mineral resources in the Area provide for a royalty liability based on the market value of the metals contained in the ore. The royalty mechanism anticipates an initial royalty (on an ad valorem basis) being set for the first period of commercial and a likely higher royalty rate for the second period of commercial production. At the end of the second period of commercial production, the royalty rate would be reviewed. To date, the ISA has neither determined the royalty rate nor the time periods for any change in such rate pending further discussion and analysis. While this report considers a number of payment instruments deployed by land-based resource owners, and the timing of and change in rates of payments, it does not provide a comparative analysis of the equivalent rates of payment under land-based regimes as it is understood that the ISA has already conducted this research.

44. This report is based on best available information collected by the authors during the course of their research. As the ISA continues its development of the draft exploitation regulations, and associated standards and guidelines, revised or additional regulatory requirements, particularly in connection with environmental obligations, will likely impact the underlying cost assumptions in the model.

Analytical Approach

46. To accomplish the goals of this report, the research team developed a set of parametric models of the key mining-related operations – the collector and the metals processor – and of the market into which metals from these operations will be sold. The models were used to simulate the physical and economic dimensions of the production system. This section details those models, but first describes several aspects of the mining context that must be captured by the models.

A Note of the Role of Contractor Return in the Analysis

47. As with any resource owner, the goal of the ISA is to design a payment system that maximizes the capture of value from the mining of the deep sea. By extension, this report attempts to provide the information needed by ISA decision-makers to accomplish that goal. Given that goal, several ISA stakeholders have raised the question as to why the analyses presented herein are often framed around the level of return that model results suggest that a mining contractor would be expected to achieve under a specific payment system. The question generally takes the form of "If we are trying to find a system that maximizes revenue to the ISA, why do we worry about the return that will be garnered by the contractor."

48. The answer to this question is that without consideration of the return to the contractor, the analysis is formally unbounded and practically meaningless. For example, one payment system that could provide immense revenues to the ISA would be one that collected a royalty of 100% of metal value. For a three million dry ton operation per year, 100% of metal value could easily exceed two billion USD per year. However, the expected net revenue to the ISA for such a system would be zero. Why zero? Zero revenue would be expected because no contractor would undertake a business in which 100% of revenues were paid to a regulatory body. There would be no opportunity for profit and no reason to engage in the business.

49. The ISA will only receive significant revenue if mining occurs albeit, contracts for exploration do generate a minimal amount of income to cover administrative tasks. Mining at scale will only occur if firms expect to make sufficient revenues to more than offset the considerable expenditures that are required to create and operate a deep sea mining operation.

50. As such, to bound the inquiry to the set of practically-interesting payment systems, we **first** identify the systems that model results indicate would provide some target level of return to the contractor. **Then** from this limited set, we identify the systems that maximize the return to the ISA. This order of analysis is required to make the inquiry efficient.

51. As will be discussed more later in the report, for the purposes of the analyses presented here we assume that contractors will aim for a threshold rate of return that is higher than for typical land-based mines. We assume this because the uniqueness of seabed mining creates technological and operational risks beyond those of land-based mines.

Basics of Seabed Mining Project

52. It is important to start the analysis by taking the viewpoint of a mining operator who is considering undertaking a deep-sea mining operation. Mining companies regularly consider a wide range of mining properties, each with its own set of characteristics and challenges. Variations among sites include:

- the nature of the ore body;

- its physical location;
- the kinds of technologies that will be required to extract the ore;
- the equipment and manpower required to conduct mining operations;
- the logistics of both bringing resources to the site and bringing the ore out;
- the necessary processing of the ore required to extract material suitable for market; and
- the market for the material itself.

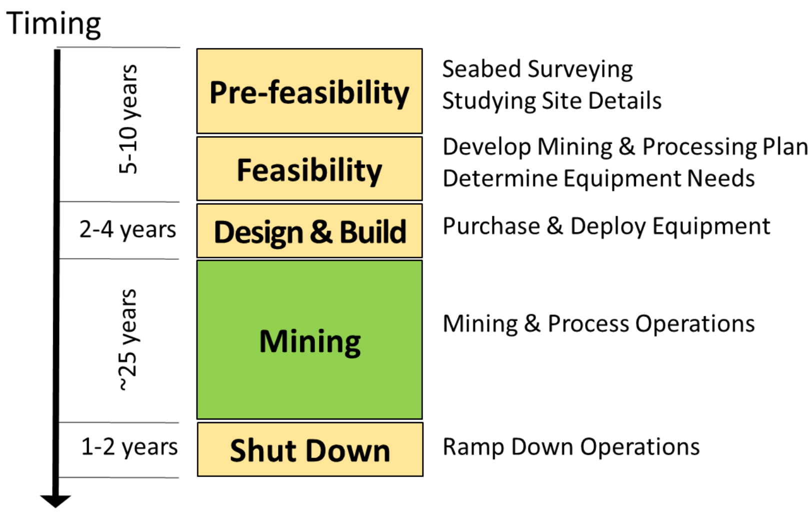


Figure 1. Modeled progression of seabed mining activities

53. Because of the amount of resources required for such an undertaking, considerable planning and analysis are undertaken long before the first day a mine actually operates. The typical timeline assumed for a PMN mining operation is diagrammed in Figure 1 and includes:

a. Pre-Feasibility phase: The mine site is surveyed, using a variety of sampling and mapping methods. The objective of this stage in the operation is to quite literally get the “lay of the land” — what evidence can be collected to survey the possible site, not only to develop a preliminary assessment of the size and nature of the ore body, but also to assess the physical layout of the operating site so as to begin to develop an understanding of the scale and scope of equipment and physical plant that will be required to conduct a mining operation.
b. Feasibility phase: Assuming the pre-feasibility analysis gives the mining firm confidence to continue, the firm will start into the feasibility stage of site planning. Armed with the evidence from the pre-feasibility stage, the mining operators will start developing engineering plans for the mining and operations to be conducted at a prospective mine site. While pre-feasibility is about ensuring that there is reason to consider opening a mine, the feasibility stage is centered on developing detailed plans for the mine, including bills of equipment, operating plans, production schedules, operating costs, and other detailed assessments of what will actually be required to extract the mine’s resources. Market assessments will also be required at this stage in order to be able to devise an estimate of the potential revenues that can be expected, and to compare those revenues with the costs of building, operating, and shutting down the mine.

c. Should the feasibility stage yield results encouraging enough to convince the mining firm to go forward with their project, then the project enters the Investment stage, which typically takes about two to four years to complete. During this stage, capital is disbursed to acquire and install the equipment necessary to conduct operations at the mine site, as well as the supplemental investments required to set up the necessary operating logistics for the site — i.e., how to move men and material both into and out of the mine site. Other investments will include setting up contracts for services.
d. After the build out years, the mine will go into operation. Mines typically operate 20-30 years, depending on the size and nature of the ore body, the difficulty of removal and extraction, and the vicissitudes of the markets for the resource in place.
e. Finally, once the decision is made to shut down the mine, there are usually one to two years of effort requires to close down the site, sell off equipment that still has value, and to conduct any necessary remediation before the mining company can leave the site.

54. Thus, a typical mining operation represents a 35 to 45-year commitment by a mining company. Such long-term commitments require careful consideration of the costs and investments that will be required over that time period, as well as the revenues that will be required to cover these costs and investments.

Cash Flow Analysis

Evaluating Cost Decisions Over Time

55. With such a long time period between the start of a mining project and its conclusion, the evaluation of the economic merit of any project vitally depends not only upon the amounts of money required and income generated, but also the timing of those cash outlays and incomes.

56. Figure 2 communicates something of the scale, duration, and complexity of the planning horizon and associated cash flows of a potential seabed mining project. The bars below the x-axis represent cash expenditures that are needed to acquire equipment and develop the mine site, as well as the costs of operation and shutdown. The green bars above the x-axis represent the income garnered by selling the commodity on the open market (where, in this figure, the prices are assumed stable and constant over the lifetime of the project).

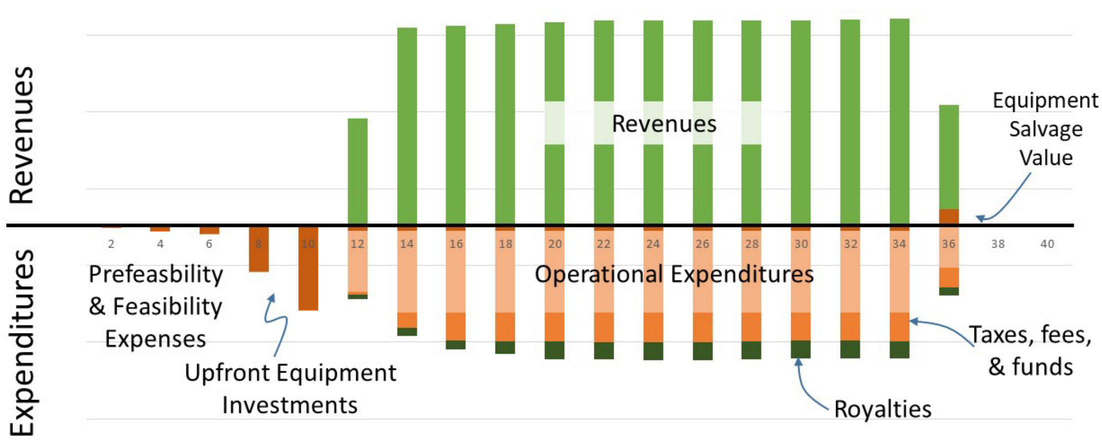


Figure 2. Types of capital and operattional cash flows considered in the modeling of the seabed operation

57. To understand why timing is so important, we have to consider a basic notion: the idea that money available today is more valuable than money available at a future date. The whole of finance is based upon the idea that the holders of cash are willing to exchange money today for money in the future. For example, a firm would invest in a factory today, in exchange for the potential to produce and sell goods and, therefore, receive funds for those goods in the future. Such an exchange, generally, will only take place if the money we give away today is replaced with more money in the future. This notion, known as the inter-temporal value of money, is captured in the following equation:

$$\text{Value of Money Today} = \frac{\text{Value of Money in Future}}{\text{Discount Factor}} \tag{1}$$

58. This discount factor is not a physical constant, unlike the values we use to convert imperial gallons to liters. Rather, this discount rate is determined by the financial context of the entity whose funds are in question. It is typically represented more formally as:

$$X_t = \frac{X_{t+n}}{(1+r)^n} \tag{2}$$

59. Where X_t is a monetary value at time t, X_{t+n} is a monetary value at some time n years in the future (n+t), and r is the rate of discount. The discount rate of any entity – private firm, public agency, or individual – is influenced by four factors: 1) inflation: the loss in purchasing power over time, 2) financing cost: the cost to acquire funds, 3) opportunity cost: the return possible by using funds elsewhere, and 4) risk: what might happen in an unknown future. In an analysis like this, inflation is dealt with by assuming that all cash flows are themselves already adjusted for inflation. This is referred to as a real dollars analysis and is the approach adopted here.

60. Why does the discount rate matter when considering a business project that takes many years? Because a firm has many ways in which it can allocate its resources, and the primary objective of any firm is to maximize the value it receives for its investments. Thus, a firm will only consider spending its money on a project that offers a greater risk-adjusted return on its expenditures. The discount rate is used by firms to make this assessment.

61. The follow example serves to communicate the power of discounting over a long period of time. Imagine an individual or firm with a discount rate of 10% (later in the document we will refer to rates as high as 18%). For that individual, the value of a cash flow 30 years hence can be found using equation (2)

$$Value_{Today} = \frac{Value_{Year=30}}{(1+r)^n} = \frac{Value_{Year=30}}{(1+10\%)^{30}} = 6\% \times Value_{Year=30} \tag{3}$$

62. This result indicates that the value today would only be 6% of the actual cash flow in thirty years – a loss of value of 94%. Given this potential impact, it is no wonder that the timing of cash flows is critical to determining the financial attractiveness of any project.

Tracking Cash Flows among Financial Actors

63. In addition to considering the impacts of time, determining the financial implication of any payment system requires an understanding of how the overall cash flows within the value chain are distributed among the various actors. While revenues are initially received by contractors, these need to be

distributed to the other three actors including any host or sponsoring States, environmental/sustainability funds, and the ISA.

64. The ways in which the revenues from the sale of nodules are distributed to the different actors are the main subject of analysis of this work. The financial payment system will set the method and rates for revenues paid from the contractors to the ISA and to any required environmental funds. National laws will determine the share of revenue under State fiscal regimes, including sponsoring States.

65. This analysis is further complicated by the fact that there will be at least two types of operations in the value chain to extract value from nodules. These operations are the nodule collectors and metals processors – operations, presumably on land, that purchase nodules, extract metals or other valuable refined products from those nodules, and sell those products. Even if nodule collectors and metals processors are part of the same vertically integrated firm, the distinction between the two is needed because the ISA can only regulate and collect payments for the activities occurring in international waters (I.e. on “activities in the Area”). This means that ISA can only collect payments from the nodule collectors since metals processing is assumed to occur on land within the jurisdiction of a sovereign State and thus subject to its national fiscal rules.

66. While analysis of metals processors is not directly related to an understanding of the financial implications of an ISA financial payment system, the cash flows of the metals processor will impact the price they are willing to pay to purchase nodules from the collectors. Anything that alters the revenue received by the nodule collector can, in turn, impact the revenue collected by the ISA. Monies paid to other parties such as the sponsoring State through taxes on the nodule collectors and the host nation for the metals processors are tracked and used to give a view of how the net revenues are split among the various actors.

67. Cash flow analysis is used as the basis for organizing all of the costs, revenues and transfer payments for each actor. Costs include all expenditures associated with the retrieval of nodules from the seabed and extraction of the metals from those nodules. Revenues include all of the funds coming into the value chain (i.e., operations of both collector and metals processor) from the sale of those extracted metals. Transfer payments include any movement of revenue from one actor to another. These include transfer payments for metals processors to acquire nodules from collectors as well as royalties, taxes and fees and any other funds that move between one actor and another. Table 1 below shows the ways in which funds flow between the different cash flows.

Table 1. Key cash flows and transfers for and among actors associated with seabed mining operations.

	ISA	Nodule Collector	Metals Processor	Sponsoring State & Host Nation
Costs	- Administration - Oversight	- Prefeasibility Studies - Feasibility Studies - Upfront Investments - Operating Expenses	- Prefeasibility Studies - Feasibility Studies - Upfront Investments - Operating Expenses	
Revenues *(including inbound transfers)*	- Fees - Royalties *(from collector)*	- Sale of Nodules *(to metals processors)*	- Sale of Metals	- Taxes to Sponsoring State *(from collector)* - *Taxes to Host Nation* *(from metals processor)*
Transfers *(outbound)*	- Equitable sharing of revenues received - Administrative costs	- Royalties *(to ISA)* - Corporate Tax *(to sponsoring State)*	- Nodule Purchases *(to collector)* - Taxes *(to host nation)*	

68. Costs generally include upfront investments in equipment and ongoing operating costs plus any prefeasibility and feasibility studies and administrative costs. System level revenues enter only from the final sale of metals to the metals processor (shown as the green cell). All other actors derive their revenues through the transfer of funds from other actors. For the nodule collectors, this derives from the sale of nodules to the metal's processor and for the governmental bodies (ISA and nations) this derives from royalties, taxes and other fees.

69. Considering all of these costs, revenues and transfers allows for the tracking of cash flows for each actor with the focus of this work being on the ISA and the nodule collectors. Nevertheless, as stated earlier, it's also necessary to understand the cash flows of the metals processor in order to estimate the revenues the nodule collectors will receive. Those revenues are derived from the quantity of nodules sold times a nodule transfer price. It is difficult to estimate the future price of nodules given that currently no market exists. However, the nodule transfer price can be estimated from the metals processor cash flows. This will be discussed in great detail in later sections of this report.

Metrics to Evaluate Payment Systems

70. There are several ways that investors or other financial decision makers evaluate a project's cash flow and decide on its attractiveness. In this report we will evaluate a number of different metrics including:

i. Net Present Value of Revenues received by the ISA (NPV_{ISA})
ii. Internal Rate of Return for the Collector (IRR_c)
iii. Net Operating Revenue for the Collector (NOR_c)
iv. Share (of cumulative NOR_c) to the ISA (Rev_{ISA})
v. Share to the sponsoring state (Rev_{SS})
vi. Share to Other (Rev_{oth})
vii. Share to the collector (NR_c)
viii. Percent share (of NOR_c) to the ISA ($Share_{ISA}$)
ix. Percent share to the sponsoring state ($Share_{SS}$)
x. Percent share to Other ($Share_{oth}$)
xi. Percent share to the collector ($Share_c$)

71. In the interest of parsimony, we do not report Net Operating Revenue for the Collector (NOR_c) in the results section as it is defined as the sum of the four shares (see equation (8)).

72. To be able to both scan a broad range of potential payment systems and yet examine some in detail, we apply a two stage analytical strategy. We evaluate two metrics NPV_{ISA} and IRR_c for many different systems, using baseline conditions online. Using this information, we select several specific systems that are evaluated using all metrics and across a broad range of uncertain conditions.

Discounted Cash Flow Metrics

73. The NPV represents the cumulative value of all future cash flows that occur over the life of the mine (LoM) expressed in today's dollars. For a project of N years, this can be expressed mathematically as

$$NPV = \sum_{k=0}^{N} \frac{(R_k - E_k)}{(1+MARR)^k} \tag{4}$$

where R_k is the net revenue in period k, E_k is the net expenses in period k, and MARR represents the minimum attractive rate of return. In an NPV approach, the MARR represents the lowest return provided by the project that would make it attractive to the entity undertaking that project. An NPV greater than zero indicates this project will exceed the minimally required rate of return (MARR) and thus the firm will invest (unless other even more attractive investments are available).

74. The IRR represents the rate of return that results in an NPV equal to zero. Mathematically the IRR is expressed implicitly as

$$NPV = \sum_{k=0}^{N} \frac{(R_k - E_k)}{(1+IRR)^k} = 0 \tag{5}$$

If the IRR is greater than the required return (MARR), presumably the firm will invest.

75. For this work, IRR's will be calculated for all contractor investment scenarios. NPV will be calculated and used to evaluate ISA cash flows. (Note: An IRR only exists if NPV can be zero. This can only happen is and actor experiences both positive and negative cash flows. In this analysis, we only assess revenues – positive cash flows – for the ISA due to administrative fees and extraction-related payments. Therefore, it is not possible to compute and IRR for the ISA and an NPV analysis is used to understand those revenues, while still incorporating the concept of time value of money through discounting.)

A Note of the Required Return of the Contractor (MARR)

76. The MARR represents the rate of return at or above which an investment opportunity is attractive. As note earlier, this threshold rate is a key parameter in the analysis presented here. Analyses carried out here first identifies payment systems that are expected to provide some threshold level of return and then, from that set, identify the payment systems that provide the largest revenue to the ISA.

77. Given the central role of the MARR, it is useful to understand what values of MARR would be typical for a deep-sea mining operation. This is a tricky question because there are no extant full-scale deep-sea mining operations with which to compare. Instead, our best estimates of MARR come from three sources of data. First, what are typical MARR values for land-based mines. Second, what risk premium might be expected above a land-based mine return because deep sea mining is unprecedented. Third, what do contractors claim are their MARR.

78. Regarding the first topic, there are relatively few studies in the recent academic literature, but Runge in 1998[5] reported a typical MARR of 15%. The level of the risk premium that should be associated with

15%.[7] Because of this, it is difficult to assign pick the appropriate MARR for seabed mining. Interviews with the contractors currently involved with the ISA suggest an MARR of 18%. Because we cannot confirm this number specifically, here we identify systems for detailed analysis that model results suggest would provide 17%, 17.5%, and 18% return to the contractor.

Undiscounted Cash Flow Metrics

79. A key metric that has been raised in the LTC is the share of net revenues that remains with the contractor and how much is collected by various governing bodies – the ISA and sponsoring state. To evaluate these metrics, we first define the cash flows that are available to be divided up. This is referred to as Net Operating Revenue for the Collector (NOR_c) and is computed for a given year *t* as:

$$NOR_{c,t} = Rev_{c,t} - OpCost_{c,t} \tag{6}$$

where $Rev_{c,t}$ is the revenues received by collector for sale of nodules in year *t* and $OpCost_{c,t}$ is all operating costs excluding fees, taxes, levies, and royalties in the year *t*.

80. We define the revenue to the ISA (Rev_{ISA})as the sum of administrative fees (fee_t), royalties (roy_t), and profit-based payments (pb_t)

$$Rev_{ISA,t} = fee_t + roy_t + pb_t \tag{7}$$

81. Revenue to the sponsoring state comprises the taxes they collect ($Rev_{SS,t}$) in a given year.

82. Finally, there is one other “actor”, the possible environmental or sustainability fund that may be collected. As the fate of these funds is unclear, we have tracked them separately ($Rev_{Oth,t}$).

83. Considering these together, we can compute the net revenues (NR) that are held by the collector as

$$NR_{c,t} = NOR_{c,t} - Rev_{ISA,t} - Rev_{SS,t} - Rev_{Oth,t} \tag{8}$$

84. Using these definitions, it is possible to compute four shares to understand how net revenues are allocated across actors. Because cash flows can vary significantly from year to year, these shares are computed from cash flows aggregated across the N year analysis period (that is LoM). For these metrics, cash flows are aggregated without discounting. The definitions of each of these shares, in either dollar terms or percent of NOR_c are shown in Table 2.

1.

[5] Ian Charles Runge (1998) *Mining Economics and Strategy*. Society for Mining, Metallurgy, and Exploration.

[7] Taheri, Mohsen; Irannajad, Mehdi and Ataee-Pour, Majid. Risk-adjusted discount rate estimation for evaluating mining projects. JASSA, No. 4, 2009: 36-42. ISSN: 0313-5934

Table 2. Definition of financial actor shares, both in dollars and percent

Financial Actor	Share in Dollars	Percent Share
ISA	$S_{ISA} = \sum_{t=1}^{N} Rev_{ISA,t}$ (9)	$PS_{ISA} = \frac{\sum_{t=1}^{N} Rev_{ISA,t}}{\sum_{t=1}^{N} NOR_{c,t}} \times 100\%$ (10)
Sponsoring State	$S_{ss} = \sum_{t=1}^{N} Rev_{SS,t}$ (11)	$\frac{\sum_{t=1}^{N} Rev_{SS,t}}{\sum_{t=1}^{N} NOR_{c,t}} \times 100\%$ (12)
Other	$S_{Oth} = \sum_{t=1}^{N} Rev_{Oth,t}$ (13)	$PS_{Oth} = \frac{\sum_{t=1}^{N} Rev_{Oth,t}}{\sum_{t=1}^{N} NOR_{c,t}} \times 100\%$ (14)
Contractor	$S_c = \sum_{t=1}^{N} NR_{c,t}$ (15)	$PS_c = \frac{\sum_{t=1}^{N} NR_{c,t}}{\sum_{t=1}^{N} NOR_{c,t}} \times 100\%$ (16)
Effective Tax Rate	n/a	$ETR = \left(1 - \frac{\sum_{t=1}^{N} NR_{c,t}}{\sum_{t=1}^{N} NOR_{c,t}}\right) \times 100\% = (1 - PS_c) \times 100\%$ (17)

85. Also in the last row of Table 2 we include the definition of Effective Tax Rate (ETR) as proposed by Otto et al.[8] ETR is the share of NOR_c that is not retained by the contractor but rather is paid to various governing bodies. Notably, the ETR is one minus the percent share of NOR_c retained by the contractor.

A Note on the Social Discount Rate – the Discount Rate Applied to Cash Flows to the ISA

86. As indicated in the preceding section, a key metric applied here is the sum of the discounted cash flows received by the ISA – the NPV_{ISA}. For the analyses presented here, we have selected a discount rate of 10%. Several stakeholders have asked why this value and, in particular, why did we chose such a high value.

87. The authors chose 10% because we have assumed that most of the revenues taken in by the ISA will be redistributed to developing countries whose land-based mining sectors are impacted by seabed

1.

[8] James Otto, Craig Andrews, Fred Cawood, Michael Doggett, Pietro Guj, Frank Stermole, John Stermole, and John Tilton, "Mining Royalties: A Global Study of Their Impact on Investors, Government, and Civil Society", World Bank, 2006.

mining. That is, most benefits will accrue to developing countries. Based on this assumption, we relied on a report by Warusawitharana that noted "leading development banks, such as the World Bank and the Asian Development Bank, typically apply a real discount rate in the range of 10 percent to 12 percent when evaluating projects in developing countries".[9] Notably, that same author advocates for a rate of 5% plus an appropriate project risk premium which is not specified. If we assume the same as for the private firms this would be an additional 3% or 8% total. The Authors chose 10% because it is a round figure that balances these two recommendations, though recognize that different stakeholders will advocate for differences in the discount rate to be used

88. Indeed, it is worth noting that developed countries typically use much lower discount rates (e.g., 1-3%) at this time to evaluate public projects.

Two Stage Approach to Identify Recommended Solution

89. To reach a recommendation on payment system design, it is necessary both to examine many different payment system configurations and to understand in detail how systems will perform under a broad range of scenarios. This need for both breadth and depth in the analysis presents a computational challenge. To overcome this challenge, we adopt a two-stage approach to the analysis.

90. To satisfy the first goal, we analyzed hundreds of system configurations using baseline assumptions *only*. Analysis based on one set of assumptions can be done quickly, so it is possible to analyze many payment system configurations. This kind of approach is referred to as a screening analysis as it is used to filter (i.e. screen) out the less promising systems and identify the more promising alternatives.

91. Using the screening analysis, several promising payment systems were identified and were analyzed across a broad range of assumptions. This analysis across a broad range of assumptions was done probabilistically and is referred to as a Monte Carlo analysis. More details on the Monte Carlo analysis are provided in the next section. The results from this Monte Carlo analyses were used to make a more conclusive assessment of the expected performance of for the selected payment systems. Our recommendations are based on this assessment.

Screening Analyses

92. To identify financial payment schemes that met specific economic goals, a screening analysis was conducted across a large sweep of rates for systems where mining activity-based rates were computed based on:

1) Ad-valorem only;
2) Profit-based only; or
3) Combination (blend) of ad-valorem and profit-based rates.

93. In all cases, we analyzed systems that involved two stages. The first stage commenced with the beginning of mining and continues for five years. The second stage extends from the end of the fifth year until the end of mining operations. Rates could go only go up in the second stage. (As described in more detail in the section "Extraction-related Payments to the ISA", five years was selected because across the majority of simulated scenarios, the collector begins to generate an annual net profit (breakeven) after

1.

[9] Warusawitharana, M. (2014) 'The Social Discount Rate in Developing Countries', *FEDS Notes*, 2014(0029). doi: 10.17016/2380-7172.0029.

three to seven years. Five years sits at the midpoint of three to seven years.) These screening analyses were conducted using baseline model values (i.e., without consideration of uncertainty) including the baseline projected metal prices and baseline cost model results.

Selection of Promising System Configurations

94. Results from the screening analyses were then used to identify a limited set of payment systems to explore in greater detail. These systems were selected for several reasons:

1) Model results suggest that they would provide an IRR to the collector of 18%, 17.5% or 17%;
2) They represented a wide range of system configurations; and
3) Strong preference was given to systems defined by round, whole-number percent values (That is systems defined by a 3% ad valorem rate was selected over either 2.9% or 3.1% even if one of the latter provided a return closer to one of the target levels (17%, 17.5%, or 18%). A few systems with rates ending in 0.5% were selected for evaluation because the authors felt that the nearest whole number percent rates generated expected returns too far from the target.)

Monte Carlo Analyses

95. The analysis described here is of processes that have never been executed at least at the scale being considered. Furthermore, the processes will be carried out in future that cannot be known with certainty. Together, these facts mean that the economics of polymetallic nodules is fraught with uncertainty. As such, it is critical that our analysis of those economics consider the impact of that future uncertainty.

96. Here we examine the implications of uncertainty using a method called Monte Carlo analysis (MCA). MCA is widely applied in every field of engineering and economics today and has been applied to mining related analyses for at least three decades. [10]

97. MCA allows us to estimate the uncertainty in some model output (e.g., in our case that might be NPV or IRR) based solely on information about the uncertainty in model inputs (e.g., metal prices or process efficiencies). We do this by taking samples from distributions that represent the characteristics of uncertainty model inputs and using these samples in our model to compute the corresponding output. If we repeat this process enough times, each time storing the model output, we will be able to estimate the distribution of model outputs associated with our model.

98. To better understand this, consider this example. Imagine our model has only two inputs, X and Y, and that the output, Z, is computed as the product of the two inputs. That is:

$$Z = XY \qquad (18)$$

99. We would like to know the distribution of outcomes Z, but we only know about the distribution of the two input variables X and Y. Specifically, let us assume that we know that X and Y are independent, random variables with X being uniformly distributed between 1 and 6 (this means that there is equal probability that X can be any value between 1 and 6) and Y uniformly distributed between 3 and 7.

100. To estimate the distribution of Z, we would sample values from the X and Y distributions, use these sample values to compute Z, and record that Z value. We would repeat this process (sample,

1.

[10] Root, D. H., Menzie, W. D. and Scott, W. A. (1992) 'Computer Monte Carlo simulation in quantitative resource estimation', *Nonrenewable Resources*. Kluwer Academic Publishers, 1(2), pp. 125–138. doi: 10.1007/BF01782266.

compute, record) over and over again until we had a population of Z values that we could use to describe the distribution of Z. Table 3 shows an excerpt of this kind of sampling and computation. Notice in the first row, the first samples are X = 4 and Y = 7. This yields Z = 28. This value is recorded and the process is repeated again and again. In this example, samples of X and Y are drawn, Z computed, and Z recorded 10,000 times.

Table 3. Example of Monte Carlo sampling and computation.

Sample #	X Value	Y Value	Z Value
Sample 1	4	7	28
Sample 2	1.64	4.61	7.56
Sample 3	1.23	4.71	5.79
…	…	…	…
Sample 9,999	3.91	6.56	25.65
Sample 10,0000	3.14	3.36	10.55

101. Figure 3 provides a visual representation of the Monte Carlo process described here. X and Y are sampled from the blue distributions (left hand of figure). The model maps those inputs to the corresponding output Z. This Z value is recorded and the process repeated until there are sufficient observations of Z to get a reasonable representation of the distribution of Z.

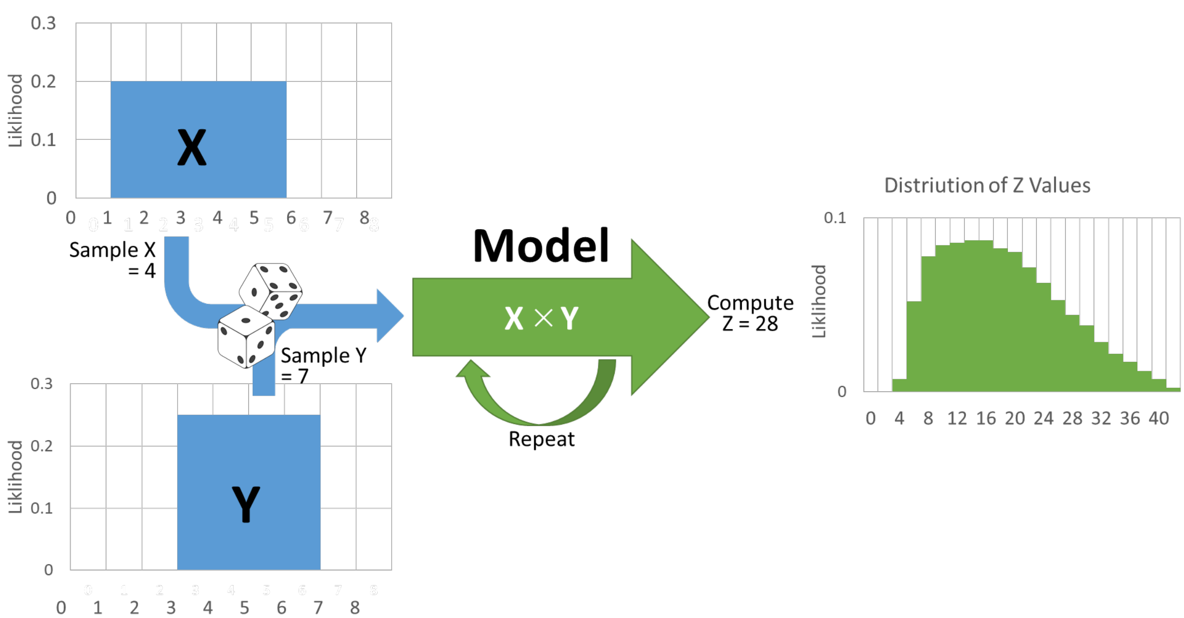


Figure 3. Schematic of the Monte Carlo modeling process. Values are samples from the ditributions describing all inputs (Here the inputs are X and Y.). The model is used to ocmpute the output of interest (Z) using those sampled values. This result is recorded and the process repeated. For this example, the model is very simple Z=XY. For the analysis presented in this document the model is complex and has many more inputs. Nevertheless, the basic Monte Carlo process is the same.

Focus on the Collector Perspective

102. The authors would like to reiterate that the analysis and results presented in this document are predicated on a framing assumption that differs from any previous study identified by the authors. Specifically, we have assumed that any revenues collected by the ISA are based on characteristics of the operations taking place within ISA jurisdiction *only*. Practically, this means that ISA can only collect revenues directly from the collector.

103. Previous studies[11,12,13,14] have either explicitly or implicitly assumed that there was a single contractor comprising both nodule collection and metals processing. To be clear, the present study does model both the collector and the processor. However, as is mentioned in the previous section, we assume the two are distinct businesses with the collector selling the nodules to the processor for some transfer price. This sale of nodules provides the *only* source of income for the collector (the operation under ISA purview).

104. For most calculations of economic consequence this distinction is irrelevant. However, there are two contexts in which the partitioning of activities between collector and processor will alter our economic calculations.

105. First, in this work, we have assumed that any profit-based revenue collection on the part of the ISA is only based on the profits made by the operation at sea (i.e. the collector within ISA jurisdiction). To be clear, that means that the profit that is made at the metals processor is not available for any profit-based revenue collection by the ISA.

1.

[11] Model and analysis described in "Request for consideration by the Council of the African Group's proposal on the Economic Model/Payment Regime and Other Financial Matters in the Draft Exploitation Regulations under review" that was submitted to the ISA on September 7, 2018.

[12] Model and analysis described in "Financial model and economic evaluation of polymetallic nodules development in the Area" that was submitted to the ISA by Prof. Shaojun Liu from China Southern University.

[13] "Analysis of the Economic Benefits of Developing Commercial Deep Sea Mining Operations in Regions where Germany has Exploration Licences of the International Seabed Authority, as well as Compilation and Evaluation of Implementation Options with a Focus on the Performance of a Pilot Mining Test" a report for the Federal Ministry for Economic Affairs and Energy (BMWi) issued on September 30, 2016.

[14] Van Nijen, K., Van Passel, S. and Squires, D. (2018) 'A stochastic techno-economic assessment of seabed mining of polymetallic nodules in the Clarion Clipperton Fracture Zone', *Marine Policy*. Pergamon, 95, pp. 133–141. doi: 10.1016/J.MARPOL.2018.02.027.

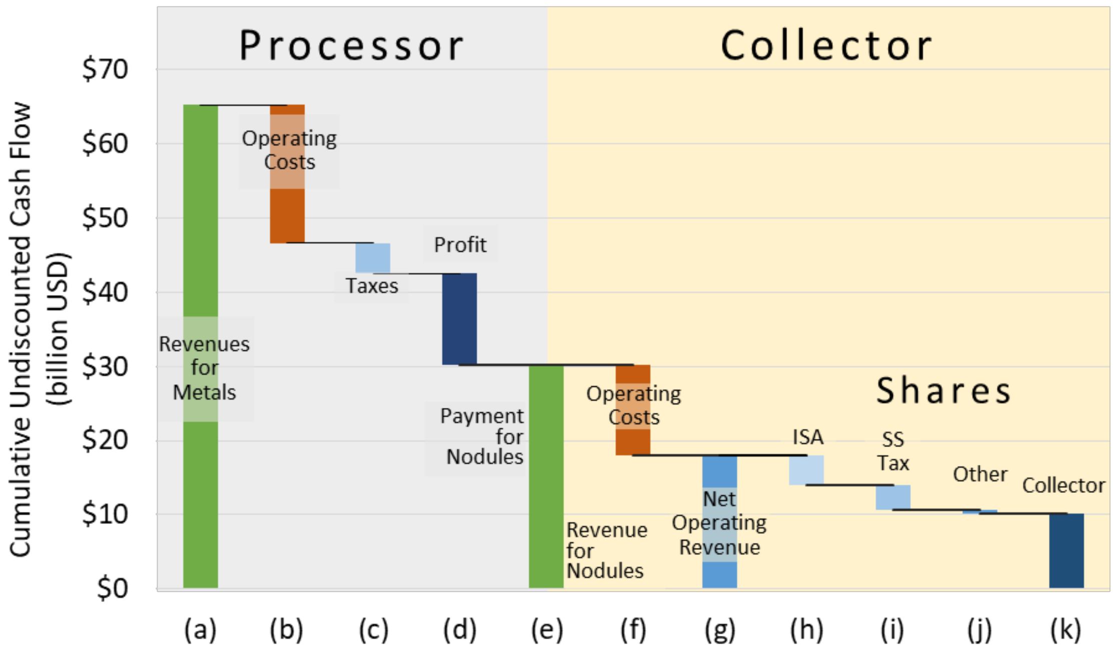


Figure 4 A schematic of how major categories of cash flows are divided among the key actors in the polymetallic nodule mining supply chain. The ISA has jurisdiction over only the activities of the collector. As such, in this report, ISA revenues(h), revenues to the sponsoring state (i), and net revenues to the collector(k) are all compared to the cash flow available at the collector: the Net Operating Revenue of the Collector (g). All figures are representative, but do not reflect the distrubtion of any particular payment system.

106. Second, because the operation under ISA jurisdiction is the collector, when we assess the fraction of net operating revenues that are shared among the actors (collector, ISA, and sponsoring state) we compare that to the net operating revenues of the collector only. Figure 4 aims to add clarity to this issue by plotting the major categories of aggregate cash flows that occur among actors in the supply chain. (Here aggregate cash flow represents the undiscounted sum of the cash flows to that actor over the entirety of the analysis period.) Specifically, Figure 4 provides a schematic representation of how aggregated cash flows are divided up among actors. Beginning at the far left in Figure 4, the large green bar (a) represents the total revenues received by the metal's processor for the sale of metals recovered from the nodules processed. These revenues are allocated to four categories of aggregate cash flows. These are: (b) the operating costs incurred by the processor to extract the metals; (c) taxes paid to the state in which the processor entity is tax resident; (e) (the smaller green bar) the payment made by the processor to purchase the nodules from the collector, and (d) the remainder reflecting the profit for the processor. The fifth bar (e) represents both the monies paid by the processor and those received by the collector in exchange for nodules. These revenues to the collector are then allocated out to five categories. First, the collector must spend revenues on the operating costs (f) that are required to recover the nodules. The difference between the revenues (e) and operating costs (f) is referred to in this document as the net operating revenues of the collector (g) in the diagram and NOR_c in later equations). NOR_c is shared among four actors. These are (h) the ISA, (i) the sponsoring State, (j) any environmental or sustainability funds – here labeled as other, and the remainder (i.e. profit) to the collector entity (k).

107. Subsequent assessments of revenue shares are made against NORc (i.e., (g)) not total revenues to the processor (a), because the latter includes activities and funds outside of the ISA's jurisdiction.

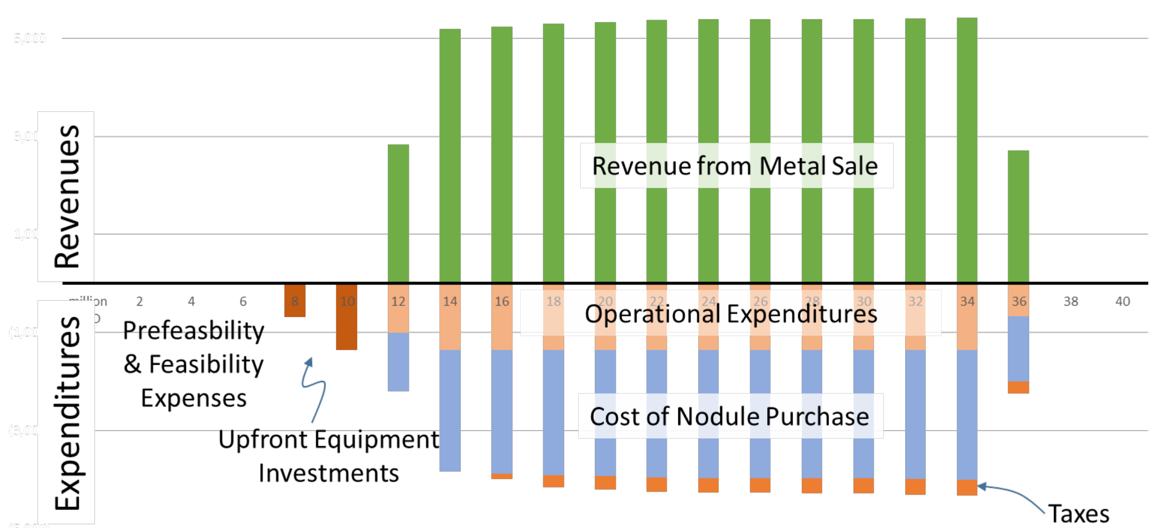
Metals Processor Cash Flow Analysis Overview

108. The economics of the metals processors have an indirect, but very important impact on the ISA revenues and therefore ultimately need to be taken into consideration in the decision-making process concerning a financial payment system. This impact is realized through a nodule transfer price that metals processors will need to pay to nodule collectors.

109. Currently no market for polymetallic nodules exist, but presumably one will exist in the future. If a market did exist, one could look at historical prices for nodules and attempt to derive a future nodule price forecast. This would obviate the need for a full metals processor cash flow analysis. Future nodule prices will be set through a negotiation between the metals processors and nodule collectors, each of which will aim to set the price in a way that's most favorable for that actor.[15] The resulting nodule price will derive from a combination of the cash flows for the two actors and each of their abilities to move the price in their favor, much in the same way mining firms and refiners negotiate TC/RC margins in the copper industry. However, as the relative negotiating strength of each actor in the future is impossible to know, the analysis carried out for this study assumes that each would agree to a nodule price that gives them the same return on their investment.

110. Other approaches to setting the nodule price are also possible including choosing an industry average profit margin for the metals processors and using the cash flow analysis to calculate the nodule transfer price that leads to this margin. This is reasonable but puts all of the financial risk of the system on the nodule collector by assuming that the metals processor will achieve its profits.

111. Metals processor cash flows can be broadly categorized as revenues from the sale of processed metals (and by-products), ore processing costs required for the metal's extraction (upfront capital investments and ongoing operational expenditures), expenditures on the purchase of nodules, and taxes and related payments to the host nation. Figure 5 below shows the cash flows specific to the metal's processors.



1.

[15] The metals processor and nodule collector may be housed in entities under common control (vertically integrated operations) or operated independently with no common control.

Figure 5. Key cash flows associated with the metals processor.

112. Because the cash flow model will calculate the transfer price at which nodules are sold to the metals processor, the expenditures on nodules (i.e. purchased by the metals processor) are not specified in the model. All other cash flows will be estimated through a variety of techniques described below and the nodule price will then be calculated.

General Approach to Metals Revenue Estimation

113. At the highest level, revenues from metals are simply the product of the amount of metal sold and the price of each metal, summed over all of the metals. Estimating the quantity of each metal sold can be done from the scale of the collection of the nodules, the composition of the nodules and the recovery rates from the extraction processes for each metal. While the scale of the nodule collection process may vary, all analyses are done at a scale of 3 million dry tons of nodules per year, although the models allow analysis across a wide range of the scales of nodule collection. Three million dry tons was selected as the baseline since it is believed that this order of magnitude is needed to achieve economies of scale and thus minimize costs.

114. The quantity of each metal sold is also impacted by the recovery rate in the extraction process. These rates differ by metal and by the process used for extraction. Table 4 below shows the annual quantities expected to be retrieved for each metal assuming collection of three million dry tons of nodules per year and industry average metals recovery rates. More discussion of metals recovery rates will be provided in a later section about the different metallurgical processes.

Table 4. Rough estimate of metals recoverable from an operation collecting 3 million dry tonnes of nodules per year.

	Composition	Recovery Rate	Amount Recoverable (tonnes per annum (tpa))
Cobalt	0.2%	85%	5,100 tpa
Nickel	1.3%	95%	37,050 tpa
Copper	1.1%	90%	29,700 tpa
Manganese	28.4%	90%	766,800 tpa

115. Estimating future metals prices is challenging because they are unlikely to remain constant and may not even change according to historical patterns. Changing supply and availability issues will impact prices. Technological improvements in traditional mining and extraction methods may lower costs and put downward pressure on prices.

116. Changing demand patterns will also impact prices. In particular, cobalt and nickel may experience large demand growth rates due to the need for these materials in batteries for electric vehicles and other applications. Some of this expected demand growth may already be incorporated into the metals prices which may actually fall if negative substitution occurs or additional sources of traditional supply expand to meet the demand. This is of particular concern for cobalt where recent price spikes have caused battery producers to expend considerable effort on finding technical solutions that use far less cobalt.

117. Broadly speaking there are three classes of approaches to price forecasting, (1) statistical/econometric approaches based on historical price data, (2) structural models of supply and demand that employ economic theory to solve for prices that create equilibrium between these two

aspects of the market and (3) surveying of expert opinions which likely base their estimates on some understanding of past prices and future supply and demand levels combined with other knowledge of the industry.

118. The challenge of the first method is that it is inherently retrospective and therefore does not consider structural changes to the market such as those anticipated in the cobalt and nickel markets as the number of electric vehicles produced grows dramatically.

119. The authors of this report strongly advocate the structural modeling approach informed with statistical price and other data when available and appropriate. These models not only allow for a greater understanding of market changes, but also provide the basis for addressing how metals prices might be impacted by specific external factors such as changes in production levels from traditional land-based mining operations. This is an important issue for the ISA and many member states. However, structural market models can be very data intensive and time consuming to develop. Many industry experts have developed these types of models (including the authors of this report) and thus some of the insights to be gained from these models have already been internalized into expert opinions. For this reason, an expert opinion approach has been employed in this work with additional analysis around uncertainty incorporated into the forecasts. Future work should be conducted to get a better understanding of future prices through the development of structural market models at least for cobalt and manganese as the large uncertainty in these forecasts can have a significant impact on revenues and the overall financial results.

120. Baseline analysis were developed around external price forecasts for each metal. Uncertainty was added in the form of an autoregressive (AR) model that will produce random price walks trending toward and around the future expert prediction. One thousand variations on future price streams using the AR model were developed for each metal and used in a series of simulation analyses. The parameters of the AR models were derived from variations in the historical price data.

121. The combined expert forecast with AR modeling approach was applied in the cases of cobalt, nickel and copper. The values of the long-term expert forecast, the average current price and the historical variation parameter are provided in Table 5. The situation for manganese is more complicated as there are multiple markets for different forms of manganese each with their own price. This will be addressed in more detail in the next section.

Table 5. Cobalt, Nickel and Copper Price Forecast Parameters

	Initial Price	Long Term Price	Uncertainty Parameter
Cobalt	$38,000/ton	$55,000/ton	$3,000/ton
Nickel	$10,800/ton	$24,717/ton	$800/ton
Copper	$5,600/ton	$7,000/ton	$500/ton

A Note on the Autoregressive Model

122. An autoregressive (AR) model is a mathematical representation of a random process where some amount of future behavior can be explained by the present or past state (this dependence on ones own past state is where the name autoregressive comes from) and some amount of future behavior is attributable to unknowns (uncertainty). Given that we are applying this to estimate future prices the autoregressive aspect is that the level of future prices is a function of past prices. Here we make use of

the simplest version of the AR model where future values are assumed to be a function of only the immediately preceding value (referred to as AR(1)). So, if we are estimating the value of Price at time t (Pt), this means that

$$P_t = f\left(P_{t-1}\right) \tag{19}$$

123. This means that if prices were high last year, they will likely be high this year. However, we know that prices are also influenced by both random events and the long term trends in the balance between supply and demand. To account for these, we apply the complete version of an AR(1) model:

$$P_t = \alpha\left(P_{t-1} - \beta\right) + \beta + \varepsilon_t \tag{20}$$

where β represents the long-term trend (average) for price, α represents the rate at which price converges back to that trend when it is perturbed away, and ε captures the random movements that any price can incur in a given year. ε is modeled to be normally distributed with a mean of zero and a standard deviation of σ.

Consideration of Multiple Manganese Markets

124. There is an added complexity in the case of manganese in that there are numerous markets for manganese, each with its own price dynamics. Manganese can be sold as a nearly pure metal in the form of Electrolytic Manganese Metal (EMM). Extracting EMM requires large investments in the metallurgical plants and equipment and high operational costs, but the final product is able to command a significantly higher price than other forms. The current EMM market is quite small and there are concerns that seabed mining would yield far more EMM than current market demands.

125. Currently, manganese is largely sold as an alloy since some applications make use of the additional elements present in the alloy and this reduces the metallurgical extraction costs. The largest market for manganese is steelmaking which is generally uses a variety ferromanganese alloys each characterized by the level of carbon contained in the alloy. Low carbon ferromanganese commands a higher price per manganese content than medium and high carbon ferromanganese which have progressively lower concentrations of manganese. Other forms of manganese also exist such as silicon manganese, but these are unlikely destinations for the metal in polymetallic nodules due to compositional and demand issues.

126. Selling the manganese from the nodules into the EMM market would command the highest price and thus generate the greatest revenues. However, additional processes beyond those needed to extract the cobalt, nickel and copper are required for EMM. These extra processes require very high capital expenses and operating costs thus negating some of the benefits. Alternatively, the residue that results from the cobalt, nickel and copper extraction processes is a manganese rich slag which can be sold into the various ferromanganese markets. This slag is very similar in grade to the manganese ore from land-based mines as such, little to no additional expenditures are needed, but the resulting revenue stream is significantly lower.

127. Metals processors are considering both of these markets and the final choice will depend on the details of the additional processing costs, the differences in prices for the markets and most importantly the demand for manganese in these markets. Cost estimations for each process will be presented in later sections of this report. Market sizes are particularly concerning for EMM and will be presented in a later section of this report on the specifics of EMM price forecasts.

Manganese Rich Slag Price Forecasting

128. Future manganese rich slag prices were modeled based on prices for manganese ore derived from land-based sources. This was done using the same methods as were applied to cobalt, nickel and copper involving an expert price forecast combined with an autoregressive model. Ore prices are generally quoted on a per manganese content basis for a reference concentration. This same system was employed for the manganese rich slag from polymetallic nodules since the manganese concentration in the slag remaining after nodule processing is very similar to this reference concentration. Historical price variations for manganese ore were used for the uncertainty parameter in the AR model. The current average price, expert price forecast and uncertainty parameter are presented in the table below.

Table 6. Manganese Ore Price Forecast Parameters

	Initial Price	Long Term Price	Uncertainty Parameter
Mn ore	$450/ton	$450/ton	$50/ton

Price Forecasting for EMM Considering Market Substitution

129. If the manganese in all of the nodules processed are used to produce EMM in an attempt to capture the currently high metals prices, one would expect significant price drops due to oversupply. Therefore, it is not reasonable to simply use today's EMM prices or even a current expert forecast for EMM prices in the analysis unless that forecast explicitly considers the impact of the large increase in supply on price. Numerous approaches have been proposed to address this problem. In this work, a supply curve impact approach is employed.

130. According to supply theory, nodule suppliers will offer their EMM at their marginal cost, but the price will be set by the overall marginal player on the supply curve. Cost analysis suggests that the supply from nodules will be relatively low cost and will thus insert into the low end of the supply curve shifting all other players to the right. The new marginal player will be a lower cost supplier thus causing the price to drop to that level. High cost suppliers will be forced to exit the market. This will continue until the price for EMM drops to the same level as the price for the next highest priced market, Low Carbon Ferromanganese. At this point, suppliers will choose which market to sell into and the equilibrium price will be set by the combined supply and demand intersection.

131. The price of the combined market will fall to the level of the price of the next highest priced market, Medium Carbon Ferromanganese, after which suppliers will choose to sell into any of these three markets and the equilibrium price will be determined by the new set. This process will continue until all of the supply is sold.

132. This approach assumes that all higher value metal can be readily sold into lower value markets. While not strictly accurate, it is mostly reasonable to assume that this can occur since markets are ordered by manganese purity. This method is a variation on a substitution approach proposed by van Nijen[16] in which pre-specified quantities or percentages of global market sizes dictate the amount of manganese that can be sold into each market. However, in their approach, prices for each market are held constant, only the quantities sold into each are impacted. While this may be a reasonable approximation, it is

1.

[16] Van Nijen, K., Van Passel, S. and Squires, D. (2018) 'A stochastic techno-economic assessment of seabed mining of polymetallic nodules in the Clarion Clipperton Fracture Zone', *Marine Policy*. Pergamon, 95, pp. 133–141. doi: 10.1016/J.MARPOL.2018.02.027.

expected that prices would in fact change in response to new supply of such significant levels. Furthermore, that method provides an arbitrage situation where nodule metals processors sell a percent of their product into lower priced markets only to see a secondary market for EMM develop where that same metal is resold into the EMM market putting downward pressure on prices anyway.

133. Important factors in the price impact approach used in this work is the total quantity of manganese added to the market from all seabed polymetallic nodules sources and new land-based sources as well as the growth rates in global demand for each manganese sub-market. Most of the analysis in this work has been done on a per contractor basis at a given production rate, usually three million dry tons of nodules per year. However, for this analysis an additional assumption about the total number of contractors must also be made. The model treats this as a variable. The baseline analysis was conducted assuming two nodules suppliers operating at three million dry tons of nodules per year. A full list of assumptions and the resulting long-time price for EMM are shown in Table 7 below. As before, an AR model was developed to address uncertainty in the long-term forecast for use in the simulations. The uncertainty parameter is based on historical uncertainty in the manganese markets.

Table 7. Electrolytic Manganese Metal Price Forecasting Parameters

2015 Electrolytic Manganese Metal (EMM) Supply Curve	
90th Percentile Cost	\$2,150/ton
10th Percentile Cost	\$800/ton
Total Market Size	1400 kt

2015 Ferro-Manganese (Fe-Mn) Markets		
	Market Size (kt)	Price (\$/ton)
High Carbon Fe-Mn	4,200	\$875
Medium Carbon Fe-Mn	1,450	\$1,507
Low Carbon Fe-Mn	120	\$1,641

Future (2025) EMM Supply & Demand Assumptions	
Mine Sites	2
EMM Supply per Mine Site	767 kt
EMM Annual Demand Growth Rate	2.4%/year

134. The long term EMM price resulting from this analysis is \$1,561/t. Additional work is recommended in this area to better understand the impact of EMM price on the system economics and to determine if the financial model should be based on processing and selling the manganese into the EMM market or should be sold directly as Mn-rich slag into the lower value ferromanganese markets without further processing.

Estimating Metals Processing Costs

135. Evaluating metals processor cash flows to determine nodule transfer prices also requires understanding the costs associated with the metals extraction plants. Extracting metals or Mn-rich slag from the nodules requires a series of complex and highly capital-intensive processing involving very large upfront investments and ongoing expenditures on consumables, energy, labor, etc. Currently no processing plants exist that extract these four elements and thus there is not a single definitive approach to the extraction. A large number of process routes have been proposed, each with different resulting products and expenses. However, these can be roughly assigned to three classes of processing routes.

- Ammoniacal leaching processes (“Cuprion” and others)
- Pyrometallurgical extraction processes followed by Electrowinning refining
- Hydrometallurgical extraction processes followed by Electrowinning refining

136. There’s a great deal of uncertainty around the technical feasibility and economic viability of each approach. Furthermore, there is only limited data. Fortunately, modern day copper and nickel extraction plants employ many similar methods and can be used to inform the costs and recovery rates for each of these process routes.

137. All three general approaches are explored in a cost model which considers both upfront capital requirements and ongoing operating costs. Each process has a different baseline production level, size scaling factor and capital intensity reflective of the different needs of each process. Operating expenses are estimated on a per ton of material processed basis and are also estimated separately for each process. Different approaches to data collection were taken for each process depending on availability.

Ammoniacal Leach/”Cuprion” Processes

138. An approach first proposed in the 1970s involves a Nitric Acid or ammoniacal leach to create a leachate from which cobalt, nickel and copper can be recovered by electrowinning. The resulting slag can be further processed to retrieve electrolytic manganese metal or sold as a manganese rich slag. While unproved at commercial scale, this approach has received a great deal of attention and is often the basis for the cost analysis of nodule processing. A more complete process flow is show in Figure 6 below.

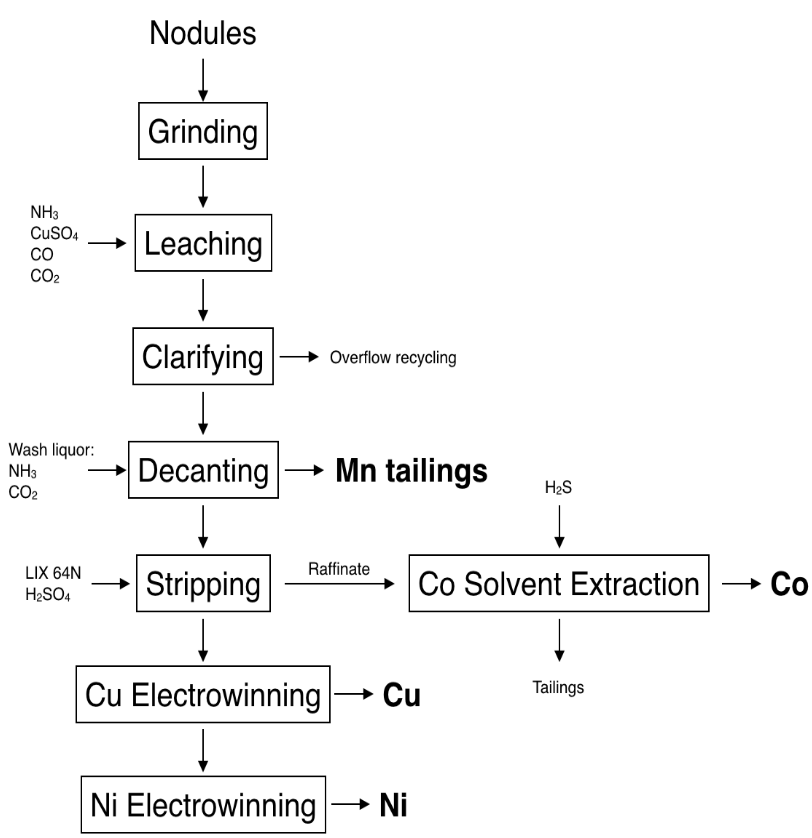


Figure 6. Cuprion Process Flow Diagram

139. The detailed process-based cost model considered the following unit process steps:

- *Grinding*
- *Leaching*
- *Stripping*
- *Cobalt Solvent Extraction*
- *Copper Electrowinning*
- *Nickel Electrowinning*
- *Reagents Recovery, Materials Storage & Handling and Plant Services*

140. Key cost model input data was obtained from a variety of literature sources[17,18,19,,20] and discussions with numerous contractors and metallurgy experts. The baseline production scale was assumed to be three million dry tons per year in line with the consensus view of contractors that this is the minimally efficient production scale for the metals processing. General production inputs for the cost model are provided in Table 8.

Table 8. Cuprion Process General Inputs

Wage	$18/hr
Electricity Price	$0.15/kWhr
Land Cost	$27/m2
Infrastructure Costs	50% additional investment
Power Plant Costs	67% additional investment

141. A considerable number and quantity of consumables are required for the Cuprion process. The quantities and prices of the feedstocks are provided in Table 9.

Table 9. Quantity and prices of consumables assumed in the modeling of the cuprion proecess.

Feedstock	Price	Quantity (per ton dry nodules)	Process Step
NH_3	$300/ton	0.095 tons	Leaching
Fuel (LNG)	$4.5/mmbtu	2.16 mmbtu	Power & Steam
Limestone ($CaCO_3$)	$15/ton	0.0078 tons	CO & CO_2 Generation
Lime (CaO)	$7/ton	0.012 tons	Ammonia Recovery
LIX 64N	$8500/m3	1.90E-05 m3	Stripping
Kerosene	$570/m3	7.67E-05 m3	Stripping
Sulfuric Acid (H_2SO_4)	$100/ton	0.24 tons	Stripping
Hydrogen Sulfide (H_2S)	$450/ton	0.00163 tons	CO Recovery
Na_2SO_4	$150/ton	4,50E-04 tons	Ni Electrowinning

1.

[17] Agarwal, J. C., Barner, H. E., Beecher, N., Davies, D. S. and Kust, R. N. (1979) 'Kennecott Process for Recovery of Copper , Nickel , Cobalt and Molybdenum from Ocean Nodules', *Mining Engineering*, (December 1979).

[18] Dames and Moore and EIC Corporation (1977) *Description of Manganese Nodule Processing Activities for Environmental Studies: Volume III. Processing Systems Technical Analyses*. National Oceanic and Atmospheric Administration, Office of Marine Minerals

[19] Nyhart, J. D. and Triantafyllou, M. S. (1983) *A Pioneer Deep Ocean Mining Venture*. Massachusetts Institute of Technology.

[20] Flipse, J. E. (1982) *An Economic Analysis of a Pioneer Deep Ocean Mining Venture*. Sea Gran College Program. Texas A&M University.

H_3BO_3	$710/ton	6.70E-05 tons	Ni Electrowinning
NaCl	$50/ton	7.70E-05 tons	Water Treatment
Chlorine Gas (Cl_2)	$350/ton	0.00033 tons	Water Treatment
Coal	$40/ton	0.23 tons	CO Generation
Water	$0.50/m3	2 m3	

142. Each process step is evaluated based on its capital investment requirements for equipment and land plus its operating costs for power, labor and consumables. Inputs are specified for a baseline capacity, set at three million tons and can be scaled for other production levels. Yields are incorporated into each process step to complete a mass balance for the resulting metals recovered from the process. Table 10 shows the inputs for each process step.

Table 10. Cuprion Process Specific Cost Model Inputs

	Yield	Equipment Cost	Land Required	Power Required	Workers Required
Grinding	100%	$31.1 M	20,235 m2	4.24 kW	2.5
Leaching	100%	$75.4 M	121,406 m2	12.88 kW	20.0
Stripping	100%	$65.9 M	80,937 m2	2.25 kW	15.0
Co Extraction	80%	$15.6 M	40,469 m2	2.25 kW	10.0
Cu Electrowinning	90%	$74.2 M	40,469 m2	23.75 kW	10.0
Ni Electrowinning	95%	$74.2 M	40,469 m2	39.50 kW	10.0
Other	---	$288.1 M	445,165 m2	8.26 kW	80.0

143. The cost model was then used to estimate the investment requirements and operation expenses associated with the Cuprion process under the baseline conditions given by the inputs described above. In addition, the cost of a dock located at the metals processor to receive the incoming nodules was added. Table 11 shows the resulting investments and expenses assuming a three million dry ton of nodules production level. Also provided are the recovery rates for each metal used in this cost analysis. These same levels are used in the subsequent cash flow analysis.

Table 11. CAPEX and OPEX Results for Cuprion Process with Baseline Metals Recovery Rates

Ammoniacal Leach/Cuprion Process Capital Requirements (CAPEX)	
Baseline Production Volume (tons/year)	3,000,000
Primary Extraction Process Investment	$969 million
Refining Investment	$1,050 million
Dock Cost	$52.5 million
Production Volume Scaling Factor	0.6

Ammoniacal Leach/Cuprion Operating Expenses (OPEX) including Dock Operating Costs	
Energy	$130 /ton
Consumables	$77 /ton
Labor	$10 /ton
Other	$1 /ton

Metallurgical Recovery Rates	
Cobalt	85%
Nickel	95%
Copper	90%
Manganese	90%

Pyrometallurgical and Hydrometallurgical Process Routes

144. A variety of pyrometallurgical and hydrometallurgical approaches have been proposed for the primary metals extraction. The scope of this work did not allow explicit detailed modeling of each variant. Instead, generic process flow charts for a single pyrometallurgy approach and a single hydrometallurgy approach were analyzed. Figure 7 below provides an overview of the main processes involved in a pyrometallurgy process.

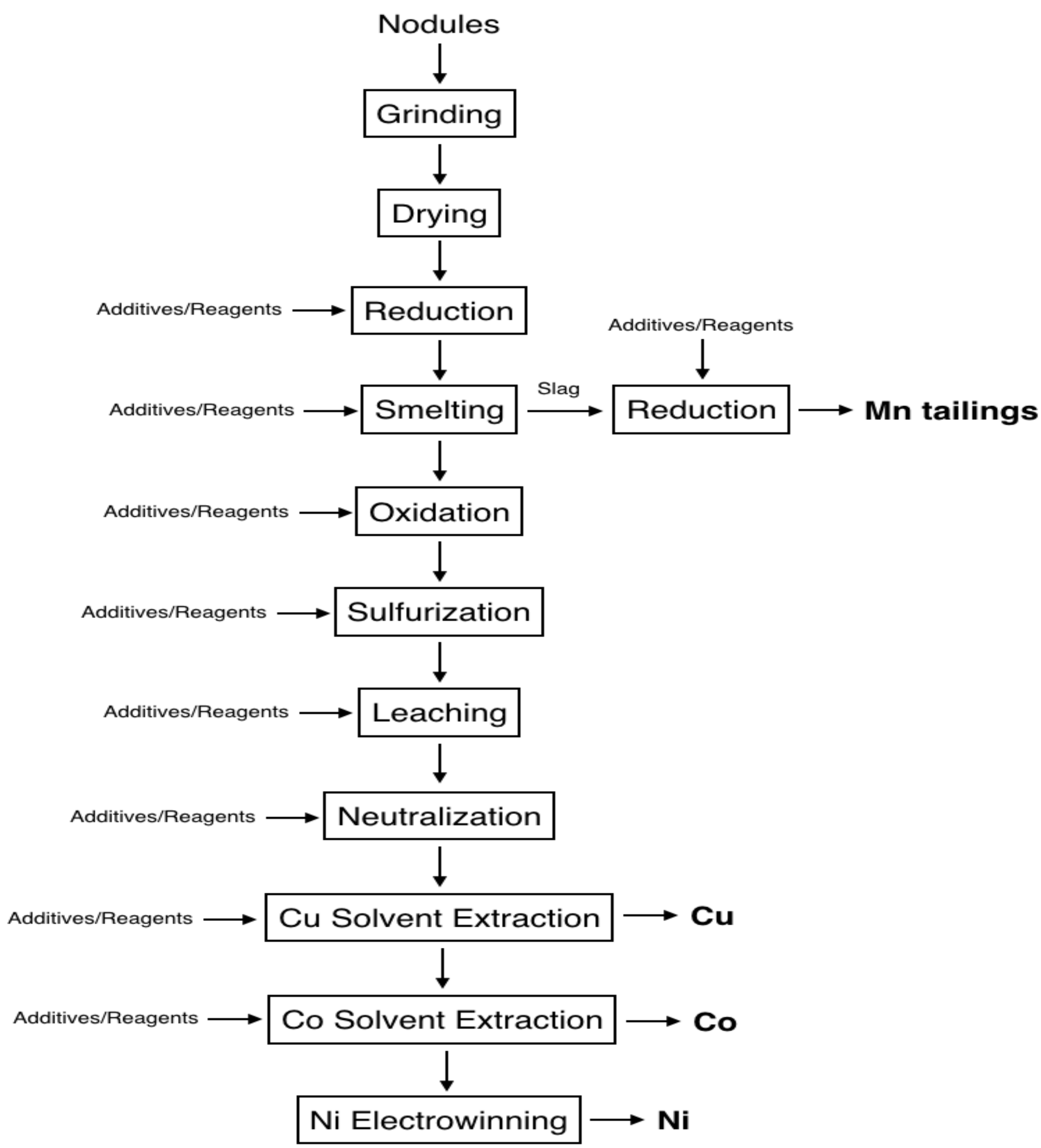


Figure 7. Pyrometallurgy Process Flow Chart

145. The pyrometallurgy approach involves using reduction and smelting processes to separate the nodules into an iron-nickel-copper-cobalt alloy and a manganese rich slag. The manganese rich slag can

be further processed to a manganese metal (EMM) or sold directly as a slag. The metal alloy then undergoes a series of solvent extraction and electrowinning operations to progressively extract the copper, cobalt and nickel metals. The basics of this operation are very similar to nickel smelting plants already widely in use.

146. Figure 8 provides a process flow chart for a typical hydrometallurgical approach.

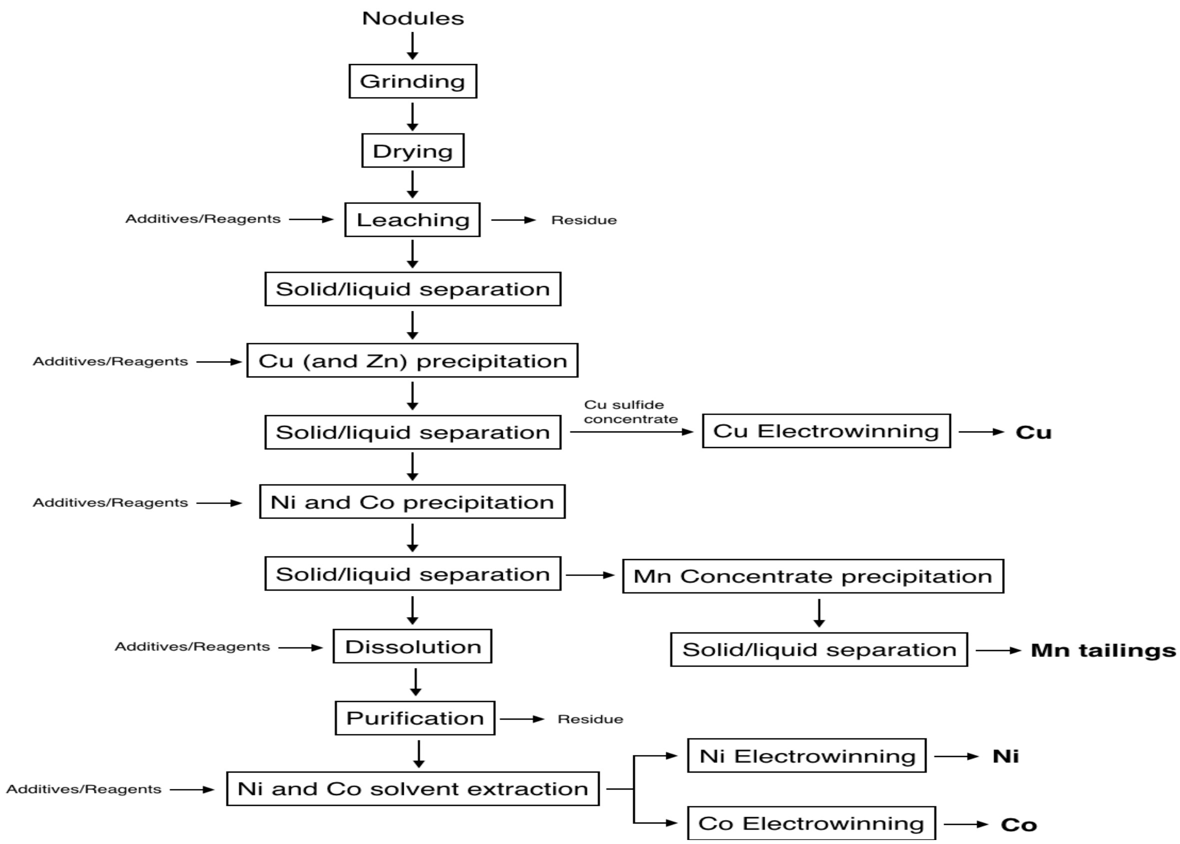


Figure 8. Hydrometallurgical Process Flow Chart

147. The hydrometallurgical approach is similar to the High Pressure Acid Leach processes (HPAL) often seen in nickel extraction plants.

148. Rather than construct a full unit process-based cost model for all of the individual activities in the pyro and hydro metallurgical approach, costs were instead estimated through an examination of cost benchmarking data with existing nickel extraction facilities of each type. Many examples of metals processing plants already exist that use variations on pyro and hydro metallurgical processes to extract nickel including several recently opened facilities. The investments needed in these plants and their operating expenses are known and were provided in the form of a benchmarking analysis and report by DeepGreen Metals and SNC Lavalin[21].

1.

[21] SNC-Lavalin for DeepGreen Metals, “Polymetallic Nodule Process Plant Benchmarks Cost Study”. October 2018.

149. That benchmarking study looked at numerous recently constructed nickel plants and aggregated the information into a single consensus view for a pyrometallurgy and hydrometallurgy system. In each case modifications were made to account for the extra requirements associated with the extraction of additional metals (cobalt and copper). In both of these analyses, no further processing of manganese is considered and thus the resulting product is a manganese rich slag to be used in ferromanganese applications, not EMM.

150. The investments and operating expenses in this benchmarking study were then incorporated into the cost models to allow for production scaling and other cost factors

151. The key inputs to the cost model, largely derived from the benchmarking study, are provided in Table 12. CAPEX and OPEX Results for Pyro & Hydro Metallurgy Process with Baseline Metals Recovery Rates

Table 12. CAPEX and OPEX Results for Pyro & Hydro Metallurgy Process with Baseline Metals Recovery Rates

Process Capital Requirements (CAPEX)		
	Pyrometallurgy	Hydrometallurgy
Baseline Production Volume (tons/year)	2,400,000	4,880,000
Primary Extraction Process Investment	$1,855 million	$5,136 million
Refining Investment	$529 million	$1,840 million
Dock Costs	$52.5 million	$52.5 million
Production Volume Scaling Factor	0.6	0.6

Operating Expenses (OPEX)		
	Pyrometallurgy	Hydrometallurgy
Energy	$28 /ton	$14 /ton
Consumables	$90 /ton	$104 /ton
Labor	$7 /ton	$7 /ton
Other	$14 /ton	$14 /ton

Metallurgical Recovery Rates		
	Pyrometallurgy	Hydrometallurgy
Cobalt	92%	89%
Nickel	94%	97%
Copper	95%	92%
Manganese	95%	96%

Metals Processor Cost Model Results

152. Production volume scaling factors were applied to each process to obtain the CAPEX requirements for a three-million-ton process. For all metallurgical processes, pre-feasibility and feasibility study costs were estimated based on general industry norms. Prefeasibility costs were estimated as 1% of CAPEX and feasibility costs were estimates as 5% of CAPEX. The scaled CAPEX, prefeasibility and feasibility costs associated with a three million ton processing plant are provided for each metallurgical approach in Table 13.

Table 13. OPEX, Scaled CAPEX, Prefeasibility and Feasibility Costs for Each Metallurgical Process

	Cuprion	Pyrometallurgy	Hydrometallurgy
OPEX	$218/ton	$139/ton	$139/ton
CAPEX	$2,072 million	$1,750 million	$2,742 million
Prefeasibility Cost	$20.7 million	$17.5 million	$27.4 million
Feasibility Cost	$95.1 million	$87.5 million	$137.2 million

Using Metals Processor Cash Flows to Determine Nodule Transfer Prices

153. As stated earlier, the goal of understanding metals processor cash flows is to inform the revenues to the nodule collector given that no market exists currently for nodules against which to reference a market price. Typically, cash flow analyses include all costs and revenues which are then used to compute financial metrics such as actor net present values (NPVs) and internal rates of return (IRRs). In this case the costs are specified, but the revenues needed to achieve a specific IRR are determined from the cash flow model. These revenues are then used to calculate the nodule transfer price

154. Nodule transfer prices are not expected to be constant over time, so an additional assumption that the price is always the same fraction of the total value of the metal in the nodules is needed. Instead of solving for the nodule price in each year, this enables the calculation of a single fraction that is then applied to the total metal value in nodules which will change over time as determined in the price forecast models. The metals processor IRR is not a set quantity, but rather is assumed to equal the nodule collector IRR as was already discussed. In reality, these two actors will negotiate nodule prices based on their relative strength in the market much as miners and refiners negotiate TC/RC margins in the copper industry. At this point, there is no way to know which player will have great negotiating power at each point in the future and thus an equitable system is assumed.

155. Since nodule transfer prices depend on metals processor IRRs which in turn depend on nodule collector IRRs, themselves a function of the nodule transfer price, the solution can only be determined through an iterative process. Consequently, results for nodule transfer prices will only be presented after the nodule collector cash flows are explored.

Nodule Collector Cash Flows

156. Nodule collector cash flows consist of revenues from the sale of nodules, costs including upfront investments and ongoing operational expenditures, as well as payments to the ISA and any host nation. Payments to the ISA may include annual and other administrative fees, required contributions to environmental funds, and royalties and profit share payments designed to compensate for the transfer of ownership of the nodules. . Figure 3 below shows the split of cash flows among the different actors specifically for the collector – note that collector revenues derive from selling nodules not metals.

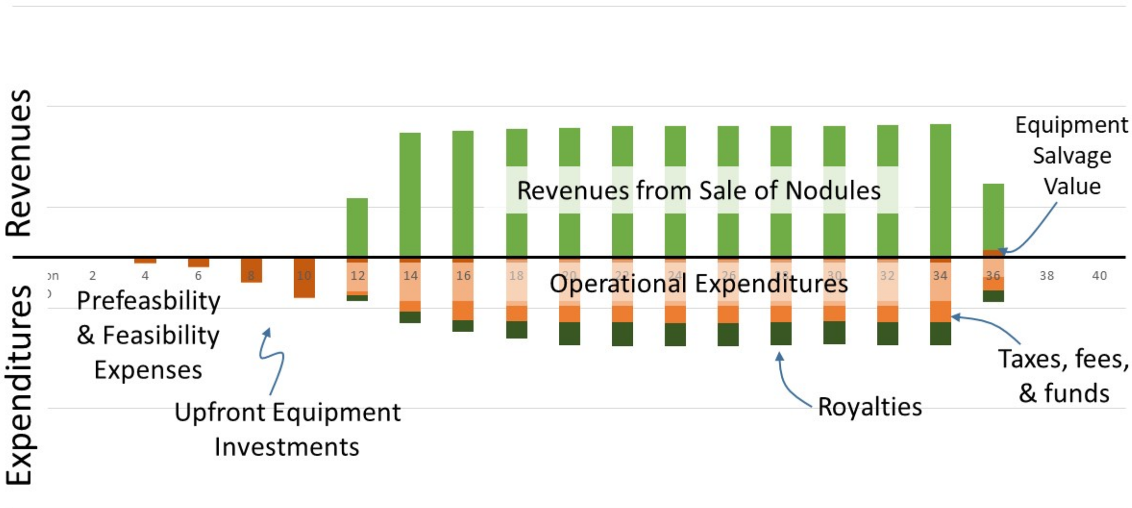


Figure 9. Royalties, taxes, and other types of fees must also be considered in evaluating the cash flows for seabed mining. This diagram specifically represents the cash flows associated with the nodule collector

Collector Revenues

157. Collector revenues are calculated from the nodule transfer prices and the quantity of nodules collected, both measured in tons. Nodule prices have already been discussed in detail in previous sections of this report and the calculated results will be shown in a subsequent section this report after the cash flow analyses are complete. The quantity of nodules collected per mine site per year is an input to the model and is currently set at 3 million dry tons per year for the baseline analysis.

Collector Costs

158. Nodule collectors have to perform a variety of tasks involving significant upfront investments and annual operating costs. Before collection can begin, pre-feasibility and feasibility studies including oceanographic exploration must be done to establish a mining plan. Next, investments in equipment must be made and equipment must be deployed to the mine site.

159. The collection process itself can be broken into multiple activities. Collectors move across the ocean floor gathering nodules. These are then sent up through a hose and riser system to a surface mining vessel where water and sediment are separated from the nodules and sent back down to the seabed for environmental reasons. Finally, nodules are transferred to cargo vessels to transport them to on-shore metals processors. All the while environmental monitoring must be done to monitor impacts on the marine environment and to ensure regulatory compliance.

160. A detailed process-based cost model was constructed for each of these activities except for pre-feasibility and feasibility which were estimated from industry norms. Results of these cost models were compared with a survey of costs submitted by various contractors to understand differences. Model modifications when justified were made to ensure a reasonable level of accuracy while still maintaining a generalized process rather than using a specific contractor's set of data.

161. As this is a parametric model, the input values can be changed to explore the collector costs assuming other conditions. Table 14 below shows the key general inputs used for the entire collection cost model under baseline assumptions.

Table 14. General Production Assumptions for Nodule Collection Cost Model

Production Target	3,000,000 dry tons/year
Dry as a % of Wet Nodules	30%
Average Nodule Coverage	10 kg/m2
Topology Factor	75% of recoverable area
Average Seabed Depth	5000 m

162. Capital investment requirements and annual operating expenses for the nodule collectors are estimated by determining the scale of operations needed to achieve the production target and then assigning a set of capital requirements and operating needs for each major process step, collection, lift, mining vessel and process water handling. Environmental monitoring activities are also modeled and will be explained in a later section of this report. Subsequent activities such as nodule transport have been assigned to the metals processor and were discussed in that section.

Nodule Collection

163. Collection activities are modeled assuming a fixed speed and size of the collectors. The production targets, downtimes, coverage and topology factor in the general inputs determine the seabed area that needs to be covered in a day. For a given collector width and speed, the area which can be covered by a single collector is calculated and compared with the required production to determine the number of collectors required. Each collector has a set of costs and operating requirements associated with it and thus the total cost of the system can be determined. The inputs assumptions for the cost calculations are provided in Table 15 below.

Table 15. Nodule Collection Cost Model Inputs

Collector Width	15 m
Collector Speed	0.7 m/sec
Power Required per Collector	1700 kW
Sweep Efficiency	90%
Dredge Efficiency	90%
Collector Maintenance Interval	24 days
Time Needed for Collector Maintenance	6 days
Other Collection Downtimes	20 days/year
Investment per Collector	$20 million
Collector Life	2 years
# of Collectors Held in Reserve	1 reserve/active collector

Nodule Lifting

164. Lifting the collected nodules to the surface is done through a hose and buffer system connected to a rigid vertical riser. There has been much discussion about using a single riser for multiple collectors. However, many contractors believe that at least in the short run, a single riser per collector is more likely as this allows independent control of the collector and greater simplifies the system and the movement of the mining vessel. The model can address the costs associated with multiple collectors per riser for future analysis. The baseline assumptions for nodule lifting are provided in Table 16 below.

Table 16. Nodule Lifting Cost Model Inputs

Average Pump Rate of 2-Phase Mixture	4.0 m/sec
Two Phase Mixture Density	1200 kg/m3
Width of Riser	35.56 cm
Riser Height per Pump	1500 m
# of Risers Held in Reserve	1 per active riser
Investment per Lift System	$60,000,000
Investment per Pump	$6,875,000
Investment per Buffer	$8,250,000
Investment per Flexible Hose	$6,000,000
Investment per Cabling	$5,500,000
Riser Life	5 years
Pump Power Requirement	1900 kW/pump

Mining Support Vessel and Process Water System

165. The mining support vessel provides the positioning and control of the collectors, houses the crew, stores supplies for the operations and provides temporary storage of the nodules. Further, it is equipped with a system for dealing with process water which must be returned down to seabed and a cargo transfer system designed to move the nodules to the larger cargo transport ships that will deliver the nodules to the land-based metals processor.

166. Much discussion has been given to the details of collector operations including the ways in which equipment will move along the seafloor and how many collectors can be associated with a single mining vessel. Nevertheless, the technology is still in a relatively early stage of development and testing and no single consensus exists around the details of how collection will occur. A conservative approach based on one collector and one riser per mining vessel is assumed. Inputs to the cost model related to the mining vessel and process water system are described in Table 17 below.

Table 17. Mining Vessel and Process Water System Cost Model Inputs

Investment per Mining Vessel	$450 million
Holding Capacity of the Mining Vessel	55,000 tons
Maximum Allowable Fill	95%
# of Crews Needed	2
# of Replacement Crews	1 per active crew

Mining Vessel Labor Requirements:	# of Workers	Monthly Wage
General Crew	16	$10,938
Mining System Crew	40	$16,250
Support Staff	56	$7,798

Mining Vessel Power Requirements:	
Propulsion, Positioning & Compensation Systems	2250 kW
Cranes & Handling Systems	3600 kW
Crew Quarters	1200 kW

Process Water System Requirements:	
Average Pumping Rate	1.9 m/sec
Investment per Pump System with Sensors	$15.5 million/system
Investment per Process Water System	$23 million/system
Process Water System Power Requirement	650 kW/system
# of Systems in Reserve	1 per active system

Nodule Collection Pre-feasibility & Feasibility Costs

167. Nodule collection requires an extensive amount of pre-feasibility and feasibility activities. These include exploration, nodule sampling, site selection, equipment testing, environmental baseline data collection, environmental impact assessment and mining plan development among many other details. It is anticipated that a significant investment will be needed due to the fact that many of the technologies needed are largely unproven and that only limited exploration has already occurred. For this reason, pre-feasibility costs are still estimated at 1% and the feasibility costs are estimated at 10% of capital expenditures. Costs associated with environmental monitoring during the exploration phase are counted as feasibility costs. The resulting pre-feasibility and feasibility costs will be presented after the discussion of environmental monitoring costs.

Costs Associated with Environmental Baseline Data Collection, Assessment and Monitoring

168. In 2018, the research team was specifically charged with estimating the cost of implementing an environmental management and monitoring plan. To accomplish this, the research team developed a set of interviews and surveys that were executed with both a number of contractors as well as experts in oceanography and in monitoring of existing offshore oil installations. This section describes what was learned by the team. As this is the first and only exposition of this research, the topic is covered in more detail than is true for the other sections.

169. The costs associated with environmental monitoring and management begin during the exploration phase. Specifically, during exploration contractors will need to collect environmental baseline data, conduct an environmental impact assessment, and monitor activities and impacts wherever a contractor conducts exploration. These same type of activities continue and intensify during exploitation most notably in the form of more comprehensive monitoring.

170. The development of the cost model for the collection of baseline data, environmental assessment, and monitoring activities associated with a polymetallic nodule mining begins with the definition of the environmental parameters of interest. The ISA has already elaborated a comprehensive and complete recommendation (ISBA/19/LTC/8, 2013) on the environmental parameters that should be considered of special interest for a polymetallic nodule mining operation. These are listed in Table 18 below.

Table 18. Environmental parameters that should be considered of special interest for a polymetallic nodule mining operation. This list is based on ISA recommendations (ISBA/19/LTC/8, 2013), which have recently been reviewed as part of recent Mining & Pelagic Workshop in August 2018.

Physical Oceanography	Geology	Chemistry and Geochemistry	Biological Communities	Sediment properties	Bioturbation	Sedimentation
• Currents • Temperature • Conductivity • Sediment in water column (Turbidity, TSS, PSD) • Satellite data analysis • Underwater noise level • Underwater lighting level (Measurements adapted to geomorphology and regional processes of ocean)	• Seabed geomorphology • Heavy metals and trace elements concentration in seabed.	• Background water column chemistry (phosphate, nitrate, nitrite, silicate, carbonate alkalinity, oxygen, zinc, cadmium, lead, copper, mercury and total organic carbon) • Information on heavy metals, trace elements, other chemicals released in the plume discharge	• Representative fauna samples for seabed (photos and samples) • Data on benthic megafauna, macrofaunal, meiofauna, microfauna, demersal scavengers and others associated with nodules. • Pelagic communities assessment. • Baseline metal levels in dominant species. • Marine mammals and birds sightings • Regional distribution of species and genetic connectivity.	• Seabed sediment physical properties (specific gravity, bulk density, shear strength, grain size, depth of change from oxic to suboxic or vice versa) • Organic, inorganic carbon, metals, nutrients, carbonate and redox in pore waters (as far down as 20cm).	• Profiles of excess Pb-210 from cores, at least five levels per core.	• Sedimentation rate • Sediment transport • Sediment loading

171. It is relevant to note that this cost model has been developed considering currently existing equipment and common practices in oceanography. The development of new technologies and the increasing use of autonomous vehicles may introduce significant changes that may impact the costs in the next decades.

Table 19. Key characteristics of the mining area and operation that influence the design of the environmental monitoring plan.

Average Depth	4500 m
Annual mined area	370 km^2
Active mining area (3 months)	90 km^2
Next active mining area	90 km^2
Preservation Reference Zone	250 km^2
Impact Reference Zone	100 km^2

172. Another required input to build the cost model is associated with the depth and extension of the areas to be monitored. These characteristics are defined in Table 19 above. A total of 5 different areas are considered in the model and each one is assigned a specific environmental monitoring plan with specific assets and associated activities. First, the “annual mined area”, which is defined by the annual production rate and the nodule abundance. The “active mining area” is defined as the area mined in a period of 3 months, which corresponds to the periodicity of the environmental monitoring cruises that will be conducted to relocate some of the environmental monitoring equipment. The “next mining area” corresponds to the area that will be mined in the next 3 months right after the active mining area has been covered by the nodule collectors. Finally, the two additional areas that will be monitored are the “preservation reference zone” and the “impact reference zone”. The input values for these two last areas have been defined by the research team as it is currently unknown the size that will be required by the regulations.

173. The monitoring system comprises 3 main elements (characteristics of these are listed in Table 20 below) that will be used to obtain sufficient data about the parameters listed in Table 18. The moorings will be equipped with sensors at different depths to collect oceanographic data of interest such as current velocity and heading at different depths, conductivity, temperature or turbidity among others. A research vessel will be required to obtain samples, additional oceanographic data, and maintain and relocate the moorings. The vessel will be equipped to measure oceanographic parameters, obtain water and seabed samples, and deploy remotely operated vehicles (ROV) and autonomous underwater vehicles (AUV). During the exploitation phase, it is expected that a significant part of the environmental monitoring will be conducted by AUVs and ROVs that will be deployed from the mining vessel.

Table 20. Key charactereistics of the three main components within the environmental monitioring system: Moorings, Research Vessel, and the Mining Vessel.

Main Element	**Moorings (submerged and full depth)**	**Research Vessel**	**Mining Vessel (Underwater Autonomous Vehicles)**
Frequency of operation	Active 24/7 (except during maintenance ops)	Active 24/7 throughout visits during exploration or exploitation.	Depend on exploration or exploitation
Area of operation	Throughout of active area. Previously mined areas IRZs and PRZs	Throughout active area. Previously mined areas IRZs and PRZs	-Throughout active area. Previously mined areas IRZs and PRZs
Exploration Phase	1 full-depth mooring 3 short moorings	- 1 R/V for 1 x 5 weeks per year + 1 AUV + 1 ROV	
Exploitation Phase	8 full-depth mooring 16 short moorings	- 1 R/V for 4 x 4 weeks per year	5 AUVs (24/5) 1 Glider 1 ROV
Tasks	CTD (Hydrography) ADCP (currents) Turbidity sensors Sediment traps Noise measurement Light measurement	CTD (Hydrography) ADCP (currents) Turbidity Water samples (biology, chemistry and sediment content) Seabed samples (biology, chemistry and sediment)	CTD ADCP Turbidity Video (biology observations)

In the cost model it is important to differentiate between the assets and activities conducted during the exploration phase from those during the exploitation. A typical environmental monitoring operation during the exploration phase comprises the deployment of 4 moorings and a 5-week research cruise conducted by a research vessel.

174. During the exploitation phase, the 5 areas defined in Table 19 above will be actively monitored. A total of 24 moorings are considered to be deployed during the exploitation phase: 10 in the active mining area, 5 in the impact reference zone, 5 in the preservation reference zone and 4 in the next mining area. Apart from that, a research vessel will relocate the moorings of the mining areas every 3 months and obtain more data and samples. Additionally, 5 AUVs, 1 glider and 1 ROV will be operated and deployed from the mining vessel or from an auxiliary vessel. These vehicles will obtain environmental data from the active mining area and its surroundings. The glider will conduct additional surveys in other areas of interest such as the impact reference zone.

Table 21. Assumed costs for all the main elements that comprise the monitoring system. Estimates are based on current available technologies in the market.

Main Element	Moorings	Research Vessel	Underwater Unmanned/manned Vehicles
Capital Cost	Average cost per mooring: 250,000 USD Operating life: 5 years	Chartered (No CAPEX)	Subcontracted (No CAPEX)
Operating Cost	10% Maintenance	- Charter: 50,000 USD/day	20,000 USD/day per vehicle (exploration) 5,000 USD/day per vehicle (exploitation)
Others	Labor cost associated to data processing and analysis: 25,000 USD per mooring per year	Data and lab analysis 500,000 USD per trip.	Data analysis costs: 25,000 USD per vehicle per year

175. The assumed costs for all the main elements that comprise the monitoring system have been estimated considering current available technologies in the market. A number of expert oceanographers have been consulted to determine and validate all the costs presented as presented in Table 21 above. The only CAPEX considered corresponds to the moorings that will be owned by the collector. The rest of the equipment is considered to be rented or operated by third parties and, therefore, only OPEX are accounted. A significant reduction in the cost of the AUVs has been introduced for the exploitation phase because of the expected length of the contracts. Apart from the capital and operating costs of the equipment, the cost of laboratory analysis and the development and update of environmental models, environmental impact assessments (EIA), environmental impact statements (EIS) and environmental management and monitoring plans (EMMP) have been also considered in the cost model.

Modeling the Costs of Implementing Environmental Management and Monitoring

176. Costs associated with executing the environmental management and monitoring plan were estimated in detail and incorporated into the cost model. Three main costs are considered. These are: the cost of moorings, the cost of unmanned underwater vehicles, and the costs of research vessels and data modeling. Table 22 below shows the cost model inputs for the moorings including analysis related to the size of the preservation reference zones (PRZs) and impact reference zones (IRZs).

Table 22. Environmental Monitoring Mooring Cost Model Inputs

	Exploration	Exploitation
Cost per Mooring	$250,000	$250,000
Mooring Maintenance Cost	10%	10%
Mooring Data Analysis Cost	$25,000/mooring/yr	$25,000/mooring/yr
Mooring Life	---	5 years
Mooring Redeployment Interval	---	3 months
Perimeter Mooring Spacing	---	5 km
Active Area Mooring Coverage	---	50 km2/mooring
Next Area Mooring Coverage	---	25 km2/mooring
# of PRZs	1	1
PRZ Size	60 km2	250 km2
# of IRZs	1	1
IRZ Size	100 km2	100 km2
IRZ Inner Mooring Coverage	50 km2	50 km2
IRZ Perimeter Mooring Spacing	3	3

177. Table 23 below shows the cost model inputs for the unmanned underwater vehicles (UUVs), gliders and remotely operated vehicles (ROVs).

Table 23. Environmental Monitoring UUV, Glider and ROV Cost Model Inputs

	Exploration	Exploitation
Operating Days	---	260 days/year
Equipment Life	---	10 years
UUV Operating Cost	$5,000/day	$10,000/day
Active Mining Area UUV Coverage	---	25 km2/UUV
Glider Operating Cost	---	$5,000/day
Active Mining Area Glider Coverage	---	100 km2/glider
ROV Operating Cost	$5,000/day	$10,000/day
# of ROVs per Mining Vessel	---	1
Data Analysis Cost per UUV/Glider/ROV	$25,000/vehicle/year	$25,000/vehicle/year

178. Table 24 below shows the cost model inputs for the research vessels and general environmental modeling .

Table 24. Environmental Monitoring Research Vessel and Data Modeling Cost Model Inputs

	Exploration	Exploitation
Research Vessel Operating Cost	$50,000/day	$50,000/day
Data and Sample Analysis Cost per Cruise	$500,000/cruise	$500,000/cruise
Cruise Duration	4 weeks	5 weeks
# of Cruises	4/year	1/year
Environmental Modeling Costs	$200,000/year	$50,000/year
EIA, EIS, EMMP Costs	$150,000/year for each	

179. Overall, during the exploration phase, the total CAPEX for environmental monitoring (as was noted earlier, during the exploration phase this comprises collection of baseline data, development of an environmental impact assessment, and monitoring impacts wherever a contractor conducts exploration), is modeled to be approximately 1,000,000 USD (for the life of project). That corresponds to the acquisition of the moorings. The total average annual OPEX is 3,250,000 USD per year. For the exploitation phase, the total CAPEX associated with environmental management and monitoring is modeled to be 6,000,000 USD

(every 5 years and corresponding only to the acquisition of the moorings) and the expected annual OPEX is 20,050,000 USD per year during the exploitation period.

Costs for Supply and Crew Transport

180. The mining vessel will require support from a supply vessel that will transport fuel, provisions, and equipment. Additionally, the mining vessel crew and technicians will have to be transported to and from the vessel to the shore. In order to minimize the time that the workers spend traveling, a fast crew transport vessel is the most appropriate solution considering the fact that the operations will take place out of the reach of a helicopter. Both vessels will be chartered by the collector and, therefore, are accounted as OPEX in the model. Using these estimates for a one-mining vessel operation with an annual production of 3 million metric tons of dry nodules we estimate a total OPEX for the supply vessel of 4,200,000 USD per year and 1,260,000 USD per year for the crew support vessel OPEX. Key assumptions underlying these estimates are shown in Table 25.

Table 25. Assumptions for supply and crew transport vessel costs

Main Element	1 Supply Vessel	1 Crew Transport Vessel
Operation	2 weeks per month	1 week per month
Capital Cost	Chartered (no CAPEX)	Chartered (no CAPEX)
Operating Cost	Charter: 25,000 USD/day	- Charter: 15,000 USD/day

Transport Costs

181. The model considers the transport vessels to be owned by the nodule collectors and thus contribute to their CAPEX and OPEX. An alternative approach might have been to consider a third-party shipment provider. However, because it is expected that multiple ships will be needed on a full-time basis to ship all of the nodules from a single site, it would be reasonable to have dedicated shipping.

182. Three cargo ship sizes are considered in the model, very large cargo containers (VLCC), Capesize transport vessels and Supramax transport vessels. The main difference between these are their capacities and the associated investment requirements and operating costs. The model analyzes the cost of using each of the three ship sizes and automatically selects the least expensive option. The input assumptions for each of the ships are provided in Table 26.

Table 26. Cost Model Assumptions for Nodule Transport Options

Distance to Port	1000 nautical miles
Fuel Consumption at Port	3 ton/day
Fuel Cost	$400/ton
Crew Replacements	2
Monthly Crew Salary	$10,938/worker/month

	VLCC	Capesize	Supramax
Base Ship Cost (ship without additional systems)	$90 million	$53 million	$30 million
Additional Systems Cost	$10 million	$5 million	$5 million
Ship Speed	12 knots	12 knots	12 knots
Capacity	250,000 tons	100,000 tons	50,000 tons
Unload Time	2 days	2 days	2 days
% of Time at Berth	50%	50%	50%
Load Time	3 days	2.5 days	2 days
Crew Required	25 workers	20 workers	15 workers
Fuel Consumption	45 tons/day	25 tons/day	15 tons/day

183. Pre-feasibility and feasibility costs for the transport activity are relatively limited as ore transport is a generally well-established process. However, some development is needed on the ore transfer system that will allow large volumes of nodules to be transferred to a cargo ship at sea sometimes under difficult weather conditions. In this work, pre-feasibility was estimated as 1% of transport CAPEX and feasibility was limited to only 2.5% of transport CAPEX.

184. For a three million tons of dry nodules operation scale and 1000 nautical mile distance to port, the optimal shipping approach is to use Supramax vessels. At this scale and considering the capacity and vessel speed and other times, 60 annual trips would be required and 3 dedicated vessels would be required. The cost results for transport are presented in Table 27.

Table 27. Cost Results for Transport System

Transport OPEX	$57.9 million/year
Transport CAPEX	$105.0 million
Transport Pre-feasibility Cost	$1.050 million
Transport Feasibility Costs	$2.625 million

Nodule Collection Cost Model Results

185. The nodule collection cost model is used to evaluate the upfront investments, periodic maintenance investments and annual operating costs for all processes conducted by the collector and subject to ISA regulation. Table 28 below shows the distribution of CAPEX and OPEX by activity.

Table 28. CAPEX and OPEX Results by Activity for Nodule Collection

	CAPEX	Annual OPEX	OPEX/ton
Collection	$80 million	$15.6 million	$5.21
Lift	$429 million	$78.8 million	$26.27
Mining Vessel	$900 million	$193.7 million	$64.22
Process Water	$123 million	$17.5 million	$5.84
Environmental Monitoring	$6 million	$20.0 million	$6.68
Transport	$105 million	$57.9 million	$19.31
TOTAL	**$1,643 million**	**$382.5 million**	**$127.53**

186. In addition, there are periodic investments required for the maintenance of equipment. These are presented in Table 29 below.

Table 29. Recurring Maintenance Investments for Nodule Collection

	Investments	Period	Annual Equivalent
Collectors	$40,000,000	2	$30,000,000
Risers, Pumps, Hoses	$42,250,000	5	$12,675,000
Moorings	$6,000,000	5	$1,450,000

187. The environmental monitoring costs incurred during exploration need to be allocated to the feasibility study costs. The resulting pre-feasibility and feasibility costs for the nodule collector including the full costs of those activities plus the environmental monitoring during exploration are presented in Table 30.

Table 30. Pre-feasibility and Feasibility Costs for Nodule Collectors

Collector Pre-feasibility Costs	$16 million
Collector Feasibility Costs	$182 million

Payments to the ISA and Sponsoring State

188. Nodule collectors will also have costs associated with payments to the ISA and their sponsoring state.

Administrative Fees to the ISA

189. In terms of the ISA, we assume that collectors will make the administrative pavements shown in Table 31. It should be noted that these fees were recently updated, but the values shown here were used in the analyses presented in this document. As is noted in the final line of Table 31, the analyses presented here also assumed that an annual fixed fee of 1 million USD will be credited any royalty or profit-based payments in a given year. The specifics of this rule are still not settled. Nevertheless, it was modeled in the way described here.

Table 31. Administrative fees paid by the collector to the ISA

Fee	Amount	
EXPLORATION		
Exploration contract application fee	0.5	million USD
Annual administrative fee during exploration contract	0.047	million USD/annum
EXPLOITATION		
Exploitation contract application fee	1	million USD
Annual reporting fee during exploitation contract	0.1	million USD/annum
Annual fixed fee during exploitation contract (credited against any royalty or profit-based payments that exceed this amount)	1	million USD/annum

Extraction-related Payments to the ISA

190. We assumed that collectors would make payments to the ISA related to the extraction of nodules. These payments were modeled in three forms: value-based royalty (ad-valorem), profit-based, or blended. For each form, we modeled cases where the rates that set extraction-related payments could vary between two stages of operation. Rates were not allowed to go down from stage 1 to stage 2. Stage 2 was modeled to begin after five years of operation. Five years was selected because it sat at the midpoint of the typical time for a collector to generate an annual profit. Across the majority of simulation runs, the collector begins to generate an annual net profit after three to seven years.

191. We assumed extraction-related payments could take on the form of royalties. Specifically, we calculated the magnitude of royalty payments on an ad valorem basis using gross metal value of the four principal metals contained in the nodules removed from the seabed. Ad valorem rates were always computed on the gross value of the metals contained in the collected nodules (we refer to this as gross metal value (GMV) as it represents a quantity of metal greater than that which will be ultimately recovered on processing (net metal)due to losses in the metallurgical process).

192. To express this more formally, let w_i represent the mass fraction of the *ith* metal of interest within the nodules. ($i \in \{copper, cobalt, manganese, nickel\}$) . Based on that, we can define GMV as

$$GVM_t = M_t \left(\sum_i w_i p_{it} \right) \tag{21}$$

where M_t is the mass of nodules collected in period *t* and p_{it} is the market price for metal i in period *t*. The amount of funds collected from an ad-valorem system in year t, N_t, using an ad-valorem rate of magnitude ν_t is expressed as:

$$\mathrm{N}_t = \nu_t GMV_t \tag{22}$$

193. We also assumed that extraction-related payments could be based on the level of collector profit in a given year. These will be referred to as profit-based payments , whose magnitude will be represented as Π_t , and are assessed at a profit-based rate, π_t . Profit-based payments were always computed based on the net operating revenue including any fees paid to the ISA ($NORif_c$). $NORif_{ct}$ represents the collector's revenue minus operating costs (including capital carryforward charges) and fees paid to the ISA in year *t*. Mathematically, this is defined as:

$$NORif_{c,t} = NOR_{c,t} - fees_{ISA,t} - Rev_{Oth,t} \tag{23}$$

194. where *t* is the year of interest, NOR_c is the net operating revenue of the collector (see equation (6)), $fees_{ISA}$ equals the fees collected by the ISA for administrative purposes, and RevOth are the payments made to the ISA or some other designee for the purposes of an environmental or sustainability fund. Note that $NORif_c$ does not include any debit for sponsoring state taxes (Rev_{SS}).

195. Based on these definition, we compute the profit-based payments as:

$$\Pi_t = \pi_t NORif_{c,t} \tag{24}$$

196. It is common feature of national income tax regimes to allow for the carryforward of losses from one year to offset profits made in a future year.[22] Countries may put limits on the rate at which these losses can be carried forward, but typically carryforward is either unlimited or capped at five years.[23] For the modeling here, we assume that all capital expenditures prior to the start of production can be deducted against future profits. This was the simplest assumption to implement and is consistent with many government policies. In practical terms, these capital carryforwards are typically exhausted by year five in most simulation runs as such the unlimited assumption would be practically equivalent to policies even for countries with a five year cap.

197. Finally, we modeled an extraction-related payment system that combined both an ad-valorem rate and a profit-based rate. These systems will be referred to as blended systems. Note that for the blended systems the ad-valorem rate begins in the stage 1 and remains in place, unchanged, in stage 2. The profit-based rate begins at stage two. Computation of both is the same as was described in the sections on ad-valorem only and profit-based only systems, respectively.

Payments into an Environmental or Sustainability Fund

198. There has been considerable discussion about the structure and amount for any environmental or sustainability funds to be used either for general environmental remediation or to have as a guarantee in case of unexpected environmental damage. The baseline analysis includes a 1% payment of the gross metal value of the nodules removed from the seabed up to a maximum of $500 million per mine site. An alternate scenario with no environmental fund was also analyzed.

199. Because the magnitude and fate of any such funds is unclear, we do not assume that these represent revenues to the ISA. In subsequent analyses, funds collected for these purposes are assigned to the actor "Other".

Payment of Corporate Income Taxes to a Sponsoring State.

200. We assumed that collectors would have to pay corporate income taxes to a sponsoring state. That is, the collector operation will be housed in an entity that would be subject to the fiscal rules in the sponsoring State. Such rules, including corporate income taxes rates vary by country. Here we assume capital and loss carryforward just as with calculation of ISA royalties. A typical value of 25% was used for the corporate income tax rate in this analysis.

Cash Flow Timings

201. The planning and execution of a deep sea mining activity progresses over several stages and over many years. To accurately account for the financial implication of cash flows spread out over such a period of time, the separates cash flows across four major phases. These are: Pre-feasibility, Feasibility, Design and Build, and Operations. The Operations phase was modeled as comprising three sub-phases: Ramp up, Full Operation, and Shutdown. We assume that the Exploitation Period includes both Design and Build and Operations. The baseline assumptions for the start and duration of each of these phases in show in Table 32 below.

1.

[22] James Otto, Craig Andrews, Fred Cawood, Michael Doggett, Pietro Guj, Frank Stermole, John Stermole, and John Tilton, "Mining Royalties: A Global Study of Their Impact on Investors, Government, and Civil Society", World Bank, 2006.

[23] James Otto, "The taxation of extractive industries", UNU- WIDER Working Paper 2017/75, March 2017.

202. Investments are assumed to occur during all four phases. Our baseline assumption for the first three stages – Pre-feasibility, Feasibility, and Design and Build – is that whatever investment is associated with that phase is uniformly spread across the duration of that phase. So, if $60 million USD were invested in Pre-feasibility and that phase lasted six years, $10 million dollars would be allocated to each year of that duration.

Table 32.Baseline assumptions for start and duration of key phases of the mining activity.

	Phase Start year	**Phase Duration** years
Pre Feasibility	1	6
Feasibility	4	4
Design and Build	8	3
Operation Phase		
Ramp Up	11	2
Full Operation	13	24
Shutdown	37	1
Total Exploitation Period		30

203. We assume that production levels during the Ramp up phase are reduced from levels during full production. Specifically, that production levels in year t ($Prod_t$) are:

$$Prod_t = \begin{cases} 0 & t < r_{start} \\ Prod^* \times \left(\dfrac{t - r_{start}}{\left(r_{duration} + 1\right)} \right) & r_{start} \leq t < \left(r_{start} + r_{duration}\right) \\ Prod^* & \left(r_{start} + r_{duration}\right) \leq t \end{cases} \tag{25}$$

where $Prod^*$ is the nominal full production level, r_{start} is the year in which ramp starts, and $r_{duration}$ is the duration of the ramp.

204. We assume that no production occurs during the shutdown year. Rather we assume that equipment is sold for salvage during the shutdown year. Our baseline assumption is that salvage values are 15% of original Design and Build investments, but 0% for investments during Pre-feasibility and Feasiblility.

Results

205. This section describes the analyses carried out to study potential payment systems for the ISA. This process was carried out in two stages. A multi-stage approach was needed to be able to both examine many different payment system configurations and to characterize the most promising systems in detail. To satisfy the first goal, we analyzed hundreds of system configurations using baseline assumptions only. Analysis based on one set of assumptions can be done quickly, so it is possible to analyze many payment system configurations. This kind of approach is referred to as a screening analysis as it is used to filter (i.e.

screen) out the less promising systems and identify the more promising alternatives. These promising payment systems were identified and were analyzed across a broad range of assumptions. (This analysis across a broad range of assumptions was done probabilistically and is referred to as a Monte Carlo analysis. Details on the Monte Carlo method are provided in the Analytical Approach section of the document.) The results from this broad range of analyses was used to make a more conclusive assessment of the expected performance of those payment systems.

Screening Analyses

206. To identify financial payment schemes that met specific economic goals, a screening analysis was conducted across a large sweep of rates for systems where mining activity-based rates were computed based on:

4) Ad-valorem only
5) Profit-based only
6) Combination (blend) of ad-valorem and profit-based rates.

207. In all cases, we analyzed systems that involved two stages. The first stage commenced with the beginning of mining and continues for five years. The second stage extends from the end of the fifth year until the end of mining operations. Rates could go only go up in the second stage.

208. To limit complexity for the blended systems (3), we analyzed a configuration where there was a single ad-valorem rate that applies to both stage 1 and stage 2 (i.e., for blended systems only – ad valorem rate in stage 1 = ad-valorem rate in stage 2) and a profit-based rate that begins in stage 2 (i.e., for blended systems only – the profit-based rate in stage 1 was always zero (0)).

209. These screening analyses were conducted using baseline model values (i.e., without consideration of uncertainty) including the baseline projected metal prices and baseline cost model results. These screening analyses were then used to identify a limited set of systems to explore in greater detail. These systems were selected because they provided an IRR to the collector of 18%, 17.5% or 17%. Nevertheless, there were an infinite number of systems available that would have provided each of these three levels of IRR. To limit this to a tractable set of candidates, we tried to limit the options to two or three per IRR, we tried to select from the full breadth of the possible systems, and we gave strong preferences to systems comprising integer percent rates. (A few systems with rates of X.5% were selected for further evaluation because they generated results sufficiently closer to the target IRR values.)

210. Each of the selected systems, we analyzed via Monte Carlo simulation. From these results, the distributions of eleven metrics were computed. Clearly, several of these metrics are interrelated. As is shown in Figure 10 below revenue shares to the ISA (S_{ISA}) largely tracks with the ISA NPV (NPV_{ISA}). Because of this similar behavior and in the interest of brevity and clarity, we will use only one of these (NPV_{ISA})) to identify promising systems, but we will report on all metrics for those systems evaluated in detail.

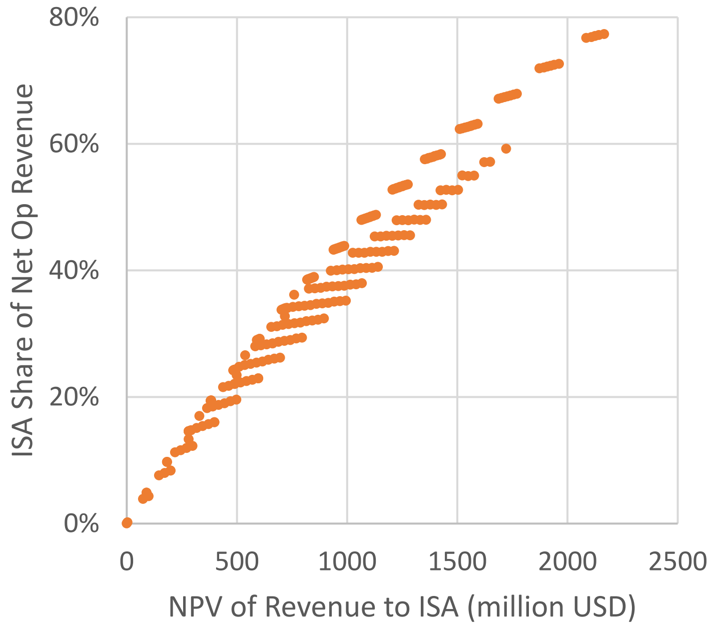


Figure 10. The two metrics of return to ISA (i.e. NPV of Revenue to ISA and ISA share of Net Operating Revenue over the life of the mine) track closely. In this figure, each point represents baseline results of one of the nearly 500 system configurations that were tested, including ad-valorem only, profit-based only, and blended systems

Ad Valorem Only Systems

Results from the Screening Analysis

211. ISA NPVs and Collector IRRs were calculated under baseline assumptions for ad valorem rates ranging:

- Stage 1: 0% to 10% of GMV
- Stage 2: plus an additional 0% to 10% of GMV
  (Stage 2 rate = Stage 1 rate + Stage 2 add'l rate)

212. Ad valorem rates were always computed based on value of the metal contained in the collected nodules (We refer to this as gross metal value (GMV) as it represents a quantity of metal larger than that which will be ultimately recovered (net metal). Gross metal recovered is larger than net metal recovered due to losses in transport and metallurgical process losses.) The analysis was done considering both a 1% environmental liability fund and with no fund.

213. The graphs below show the results of the screening analysis and include first stage ad valorem rates varying on the x-axis and the additional second stage (after 5 years) rates on the y-axis. Please note that the y-axis represents the additional rate which is added to the first stage ad valorem rate. (So, the point 2%, 3% on this plot represents a system charging 2% in stage 1 and 5% (i.e., 2% + 3%) in stage 2.

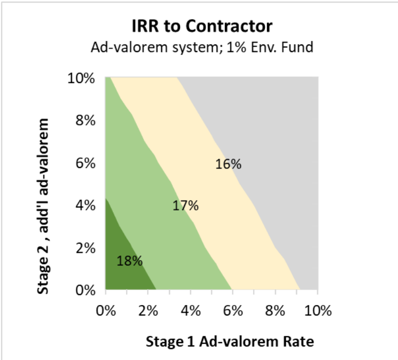


Figure 11. Screening analysis of return (IRR) to the collector for a range of stage 1 and stage 2 ad-valorem only rates. 1% of gross metal value is collected for an environmental or sustainability fund.

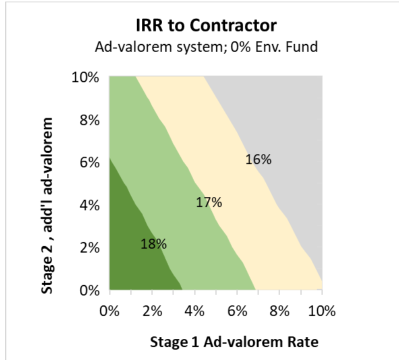


Figure 12. Screening analysis of return (IRR) to the collector for a range of stage 1 and stage 2 ad-valorem only rates. 0% of gross metal value is collected for an environmental or sustainability fund.

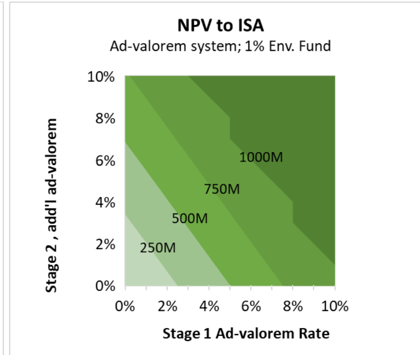


Figure 13. Screening analysis of net present value of revenues to the ISA for a range of stage 1 and stage 2 ad-valorem only rates. NPV to ISA is unaffected by funds collected for an environmental or sustainability fund.

214. A limited set of combinations of first and second stage ad valorem rates were chosen for a more in-depth analysis. For this analysis, three Collector IRRs were chosen, 17%, 17.5% and 18% and the combinations of first and second stage ad valorem rates that yield these IRRs were chosen for further investigation. These are listed and defined in the first three columns of Table 33.

Table 33. Ad-valorem systems chosen for further evaluation including key results derived from Monte Carlo simulations.

System	Ad-Val Rate (St1&2)	Stage 2 Profit Rate	Collector IRR (IRRc)	ISA NPV (NPV_{ISA})	ISA Share (S_{ISA})	Sponsoring State Share (S_{SS})	Other Share (S_{Oth})	Collector Share (S_c)	ISA Share (S_{ISA})	Sponsoring State Share (S_{SS})	Other Share (S_{Oth})	Collector Share (S_c)
AV6% / AV6%	6%	6%	17%	598	4,309	3,603	500	10,414	23%	19%	3%	55%
AV1% / AV9.5%	1%	9.5%	17%	716	6,095	3,029	500	9,009	32%	16%	3%	48%
AV3% / AV8%	3%	8%	17%	663	5,331	3,286	500	9,656	28%	17%	3%	51%
AV2% / AV6%	2%	6%	17.4%	490	3,976	3,441	500	10,180	21%	18%	3%	54%
AV1% / AV6.5%	1%	6.5%	17.4%	499	4,207	3,348	500	9,966	22%	18%	3%	53%
AV4% / AV4%	4%	4%	17.4%	398	2,875	3,735	500	10,932	15%	20%	3%	58%
AV1% / AV3.5%	1%	3.5%	18%	280	2,299	3,627	500	10,804	12%	19%	3%	57%
AV2% / AV2%	2%	2%	18%	199	1,441	3,867	500	11,460	8%	21%	3%	61%

Detailed Analysis of Selected Systems

215. Full Monte Carlo analysis was conducted on each of the sets of ad valorem rates to get a better understanding of the distribution of results. The resulting simulation results for a 2% ad valorem rate rising to 6% after 5 years are shown in the figures below.

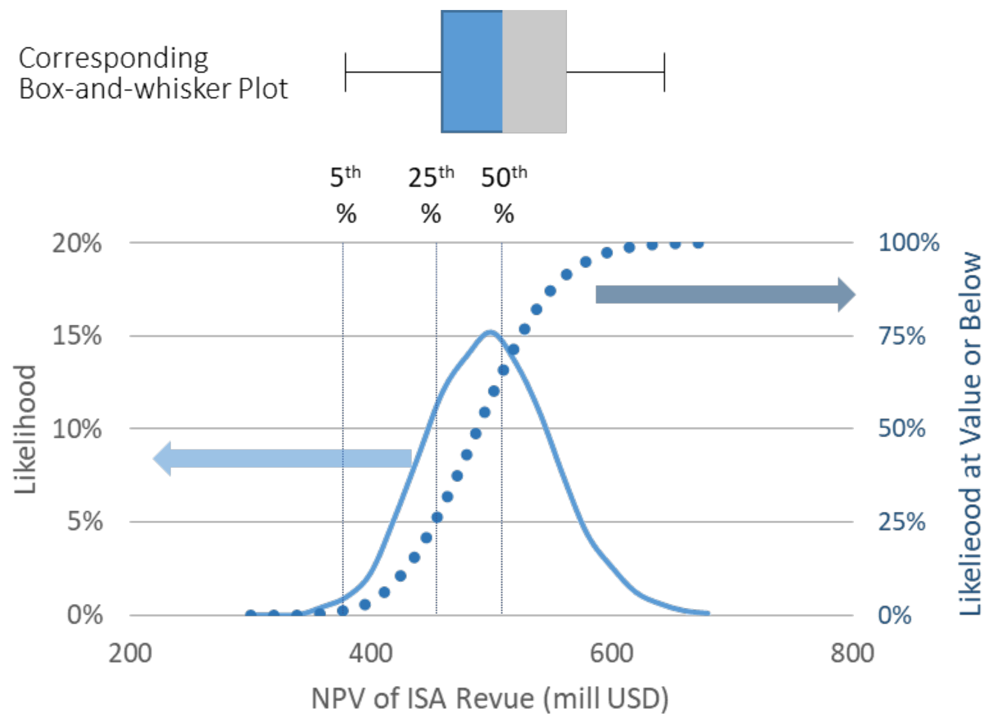


Figure 14. Monte Carlo results for analysis of net present value (NPV) of the revenues received by the ISA (excludes environmental or sustainability fund) for an ad-valorem only system starting at 2% and rising to 6% after five years. Probability density function (PDF: solid line referring to left axis) and the cumulative distribution function (CDF: dotted line referring to right axis). Three lines are provided to label the 5th percentile, 25th percentile, and 50th percentile for this distribution. Above the plot is a box and whisker representation of the same information. This more condensed format will be used in several subsequent plots.

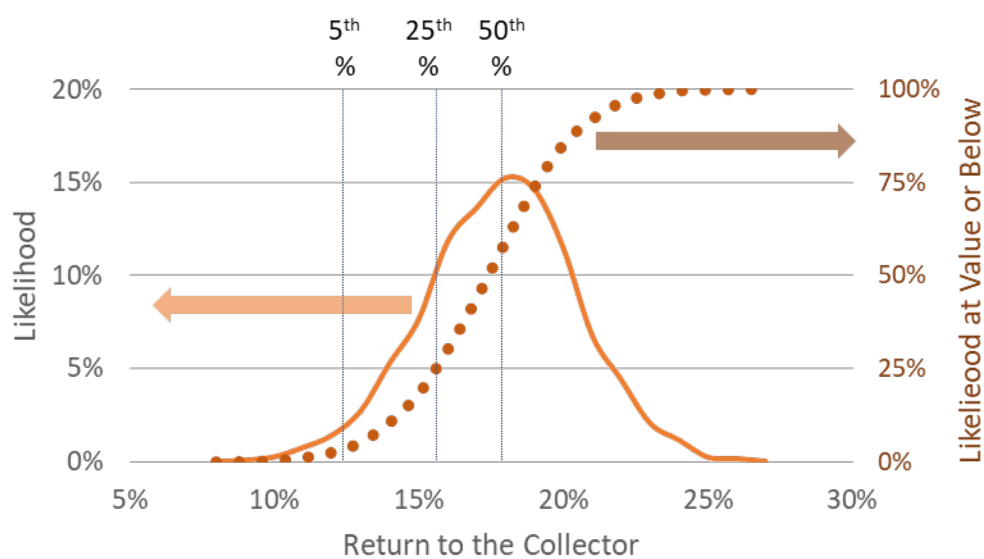


Figure 15. Monte Carlo results for analysis of return to the collector (IRR) for an ad-valorem only system starting at 2% and rising to 6% after five years. Probability density function (PDF: solid line referring to left axis) and the cumulative distribution function (CDF: dotted line referring to right axis). Three lines are provided to label the 5th percentile, 25th percentile, and 50th percentile for this distribution. 75th and 95Th percentiles would mirror these to the right of the 50th.

216. From this analysis, one can observe not only the mean values for the NPV_{ISA} and IRR_c, but also the spread on the results. We see that NPV_{ISA} averages just under 500 million USD LoM but can range from around 300 to nearly 700 million USD LoM (See Figure 14.), while the average collector IRR is around 17.5%, but can range from 7% to 27% (See Figure 15 above.).

217. A common and concise way to report on the spread in uncertain results is to provide not only the median value (50th percentile of the distribution – the value at which half of the observations are above and half are below) but to also report the quartiles (25th and 75th percentile: The 25th percentile represents the value at which 25% of observations were lower.) and the 5th and 95th percentiles. The lower three of these values 5Th, 25Th, and 50Th percentiles, are called out in Figure 14 *and* Figure 15*. We adopt this approach in the so-called box-and-whiskers plots which follow.*

218. Results are presented for all selected combinations of first and second stage ad valorem rates in the figures below. Figure 16 below shows the results for ISA NPV. The graph shows 5 points for each set of rates. The lowest point on the whisker (horizontal bar) is the 5th percentile. The bottom of the blue block represents the 25th percentile. The mid-line represents the 50th percentile (or median). The top of the grey block represents the 75th percentile level and the top of the upper whisker (horizontal bar) represents the 95Th percentile of the distribution.

219. The results in Figure 16 below are grouped by return to the contractor. An interesting result is that even with a given return grouping, there are systems that can provide a higher NPV to the ISA. For example, although the AV1%/AV10% system provides a similar return to contractors compared to the constant AV6% system (both provide a return of about 17% to the contractor), the former system generates more than 100 million USD more NPV on average for the ISA than the latter.

220. Figure 17 below plots the distribution of collector IRR values found in the Monte Carlo analyses. From these we can see that systems within each grouping do indeed generate similar results for the collector. In fact, within each grouping results are similar both in terms of the expected value and the spread of values.

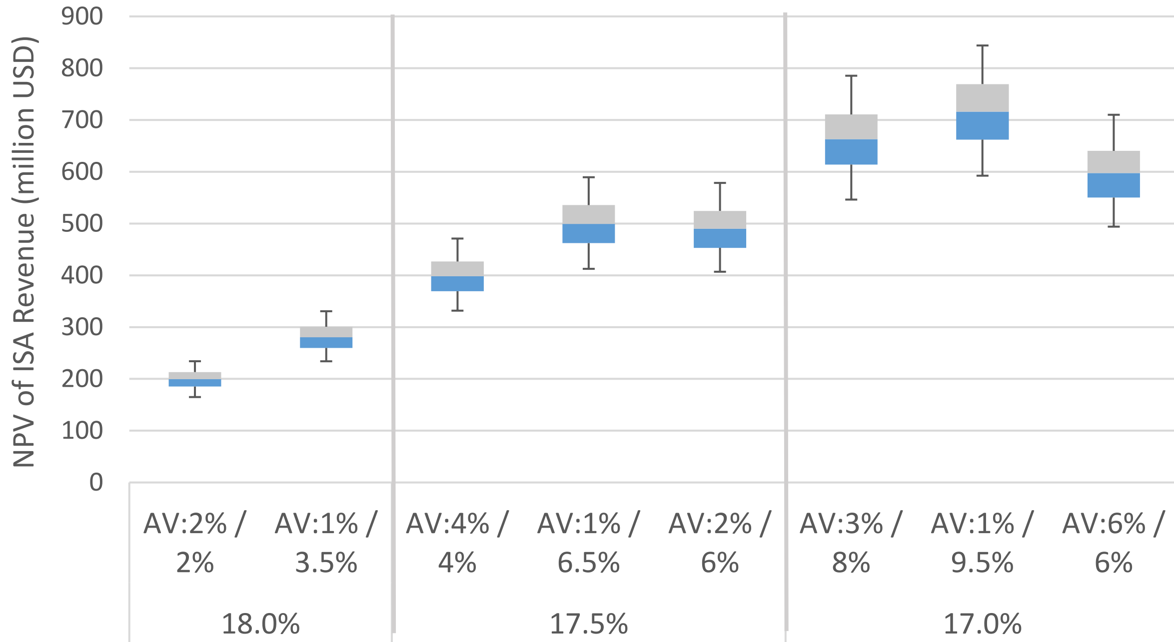


Figure 16. Distribution of NPV of Revenue to the ISA for a range of ad-valorem only systems.

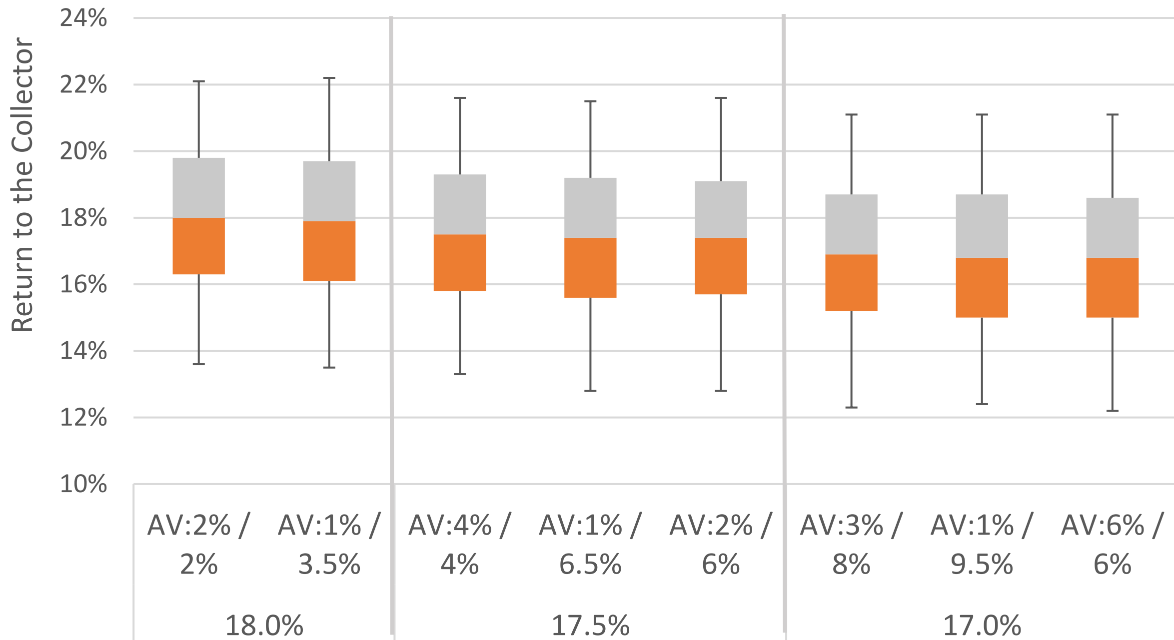


Figure 17. Distribution of modeled Rates of Return for the collector for a range of ad-valorem only systems.

221. Table 34 below shows the 50th percentile (median) and 25th percentile result of both collector IRR and ISA NPV for all of the ad-valorem only systems investigated in detail.

Table 34. Results for collector IRR and ISA NPV for the selected ad-valorem only systems.

		18.0%			17.5%			17.0%	
	System→ Percentile↓	AV:2% / 2%	AV:1% / 3.5%	AV:4% / 4%	AV:1% / 6.5%	AV:2% / 6%	AV:3% / 8%	AV:1% / 9.5%	AV:6% / 6%
IRR	5	13.6%	13.4%	13.2%	12.8%	12.8%	12.3%	12.4%	12.3%
	25	16.3%	16.1%	15.8%	15.6%	15.7%	15.2%	15.0%	15.0%
	50	18.1%	17.8%	17.4%	17.4%	17.4%	16.9%	16.9%	16.8%
	75	19.9%	19.6%	19.2%	19.2%	19.1%	18.7%	18.7%	18.7%
	95	22.2%	22.1%	21.5%	21.5%	21.6%	21.2%	21.1%	21.2%
ISA NPV	5	165	234	332	413	407	546	592	494
	25	185	260	369	462	453	614	662	550
	50	199	280	398	499	490	663	716	598
	75	213	301	427	536	524	711	769	640
	95	234	331	471	589	578	785	844	710

Profit-based Systems

Results of Screening Analysis

222. ISA NPVs and Collector IRRs were calculated under baseline assumptions for profit-based rates ranging

- Stage 1: 0% to 50% of Net Operating Revenue including Fees for the collector ($NORif_c$)
- Stage 2: plus, an additional 0% to 50% of $NORif_c$
  (Stage 2 rate = Stage 1 rate + Stage 2 add'l rate)

223. Profit-based rates were always computed based on the net operating revenue including any fees paid to the ISA ($NORif_c$). $NORif_c$ represents the collector's revenue minus operating costs (including capital carryforward charges) and fees paid to the ISA. Using the symbols defined previously

$$NORif_{c,t} = NOR_{c,t} - fees_{ISA,t} - Rev_{Oth,t} \tag{26}$$

224. Where $fees_{ISA}$ equals the fees collected by the ISA for administrative purposes and for contracts. Note that $NORif_c$ does not include any debit for sponsoring state taxes (Rev_{SS}). The analysis was done considering both a 1% environmental liability fund and with no fund.

225. The graphs below show the results of the screening analysis and include first stage profit-based rates varying on the x-axis and the additional second stage (after 5 years) rates on the y-axis. Please note that the y-axis represents the <u>additional</u> rate which is added to the first stage rate. (So, the point {5%, 10%} on this plot represents a system charging 5% in stage 1 and 15% (i.e., 5% + 10%) in stage 2.

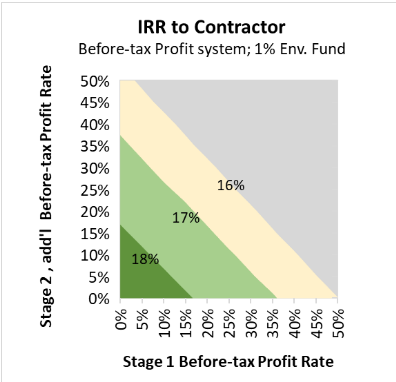


Figure 18. Screening analysis of return (IRR) to the collector for a range of stage 1 and stage 2 profit-based only rates. 1% of gross metal value is collected for an environmental or sustainability fund.

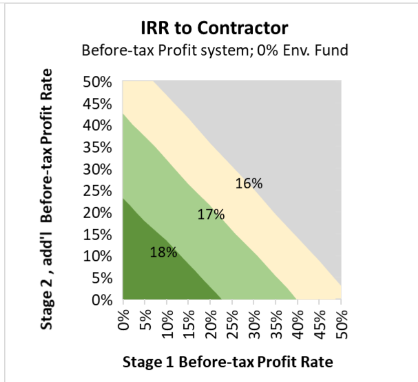


Figure 19. Screening analysis of return (IRR) to the collector for a range of stage 1 and stage 2 profit-based only rates. 0% of gross metal value is collected for an environmental or sustainability fund.

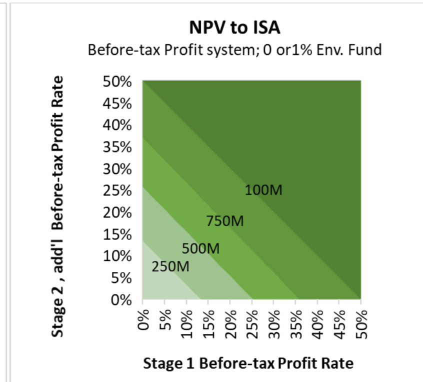


Figure 20. Screening analysis of net present value of revenues to the ISA for a range of stage 1 and stage 2 profit-based only rates. NPV to ISA is unaffected by funds collected for an environmental or sustainability fund.

226. A limited set of profit-based systems were selected for more in-depth analysis. For this analysis, systems associated with three levels of Collector IRRs were chosen: 17%, 17.5% and 18%.

227. It is important to note that the initial revenues received by the ISA from a profit-based system are small. This occurs because during the first few years of operation, firms will depreciate the assets they have put into place over the preceding decade. As such, accounting profit for most firms will remain zero for 3 to 6 years from the beginning of operation and no profit-based revenues would come in to ISA during that time. Figure 21 below plots the simulated revenues that could be received by the ISA during the first five years of exploitation only for both an ad-valorem only system with a stage 1 rate of 6% and staying at 6% for stage 2 and for a profit-based only system starting at 30% in stage 2 and staying at 30% in stage 2. Both of these systems are expected to provide an ISA NPV of about 600 million USD.

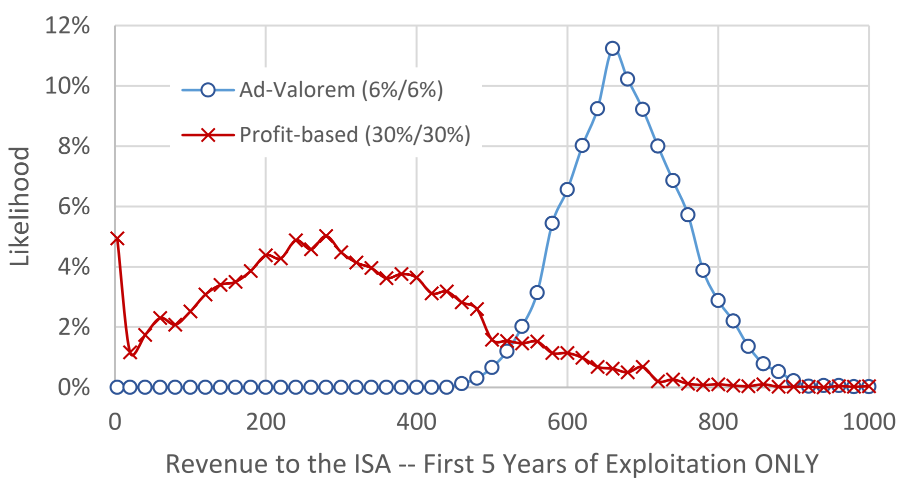


Figure 21. Early stage (first five years of exploitation only) revenues received by the ISA in simulations of a ad-valorem only system (AV6%/AV6% -- blue line) and a profit-based only system(PB30%/PB30% -- red line). Note that both systems produce a similar NPV of total ISA revenues. Generally, profit-based systems provide little revenue to the ISA in the early years of exploitation.

228. Because of this general trend to provide little early stage revenue, we elected to evaluate in depth only systems where the Stage 1 profit-based rate was 0%. The specific systems selected are evaluated are defined in the first three columns of Table 35 below.

Table 35. Profit-based systems selected for in depth analayses.Systems are defined by the first three columns. The other columsn show key results for those systems derived from Monte Carlo analysis.

System	Ad-Val Rate (St1&2)	Stage 2 Profit Rate	Collector IRR (IRR_C)	ISA NPV (NPV_{ISA})	ISA Share (S_{ISA})	Sponsoring State Share (S_{SS})	Other Share (S_{Oth})	Collector Share (S_C)	ISA Share (S_{ISA})	Sponsoring State Share (S_{SS})	Other Share (S_{Oth})	Collector Share (S_C)
PB0% / PB17.5%	0%	17.5%	18%	337	3,028	3,620	500	10,861	17%	20%	3%	60%
PB0% / PB25%	0%	25%	17.7%	483	4,338	3,308	500	9,923	24%	18%	3%	55%
PB0% / PB27.5%	0%	27.5%	17.6%	535	4,802	3,223	500	9,668	27%	18%	3%	54%
PB0% / PB37.5%	0%	37.5%	17%	726	6,517	2,773	500	8,319	36%	15%	3%	46%

Detailed Analysis of Selected Systems

229. Full Monte Carlo analysis was conducted on each of the selected profit-based systems to get a better understanding of the distribution of results. The resulting simulation results for a 0% profit-based rising to 27.5% after 5 years are shown in Figure 22 and Figure 23 below.

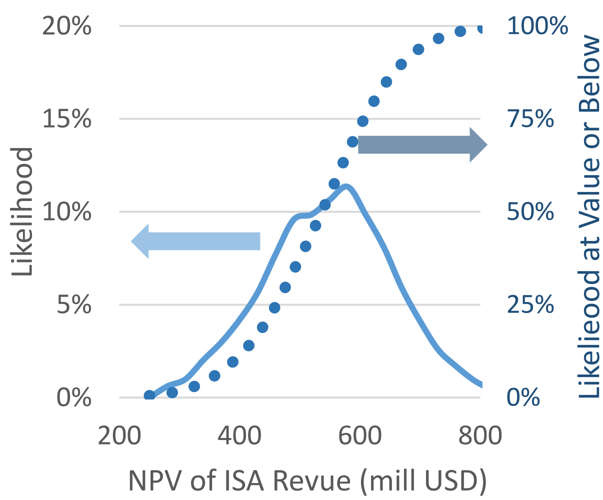


Figure 22. Monte Carlo results for analysis of net present value (NPV) of the revenues received by the ISA (excludes environmental or sustainability fund) for a profit-based only system starting at 0% and rising to 27.5% after five years. Probability density function (PDF: solid line referring to left axis) and the cumulative distribution function (CDF: dotted line referring to right axis).

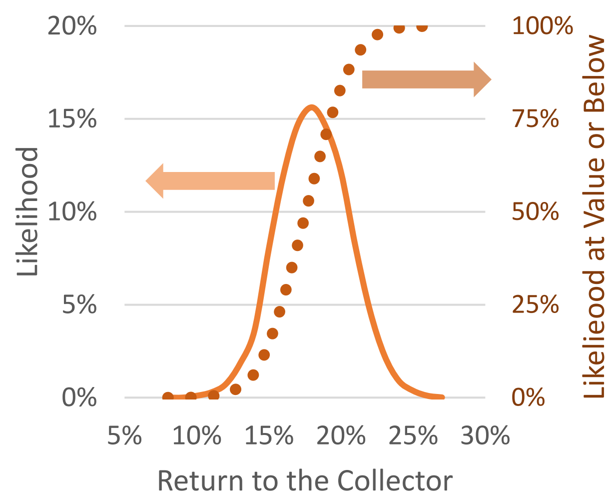


Figure 23. Monte Carlo results for analysis of return to the collector (IRR) for a profit-based only system starting at 0% and rising to 27.5% after five years. Probability density function (PDF: solid line referring to left axis) and the cumulative distribution function (CDF: dotted line referring to right axis).

230. From this analysis, one can observe not only the mean values for the ISA NPV and Collector IRR, but also the spread on the results. We see that the NPV of ISA revenues averages just over 500 million USD but can range from around 300 to nearly 700 million USD (See Figure 22.) while the average collector IRR is around 17.5%, but can range from 7% to 27% (See Figure 23.).

231. ISA NPV and Collector IRR results are presented for all selected profit-based system rates in Figure 24 and Figure 25 below. The results in Figure 24 are grouped by return to the contractor. As with the ad-valorem only systems, we see that even with a given return grouping (in this case the only grouping is the two systems that provide around 17.5% IRR to the collector), the systems do not provide the same NPV to the ISA. The 0%/27.5% system provides about 50 million dollars more NPV on average to the ISA compared to the 0%/25% system.

232. Figure 25 below plots the distribution of collector IRR values found in the Monte Carlo analyses.

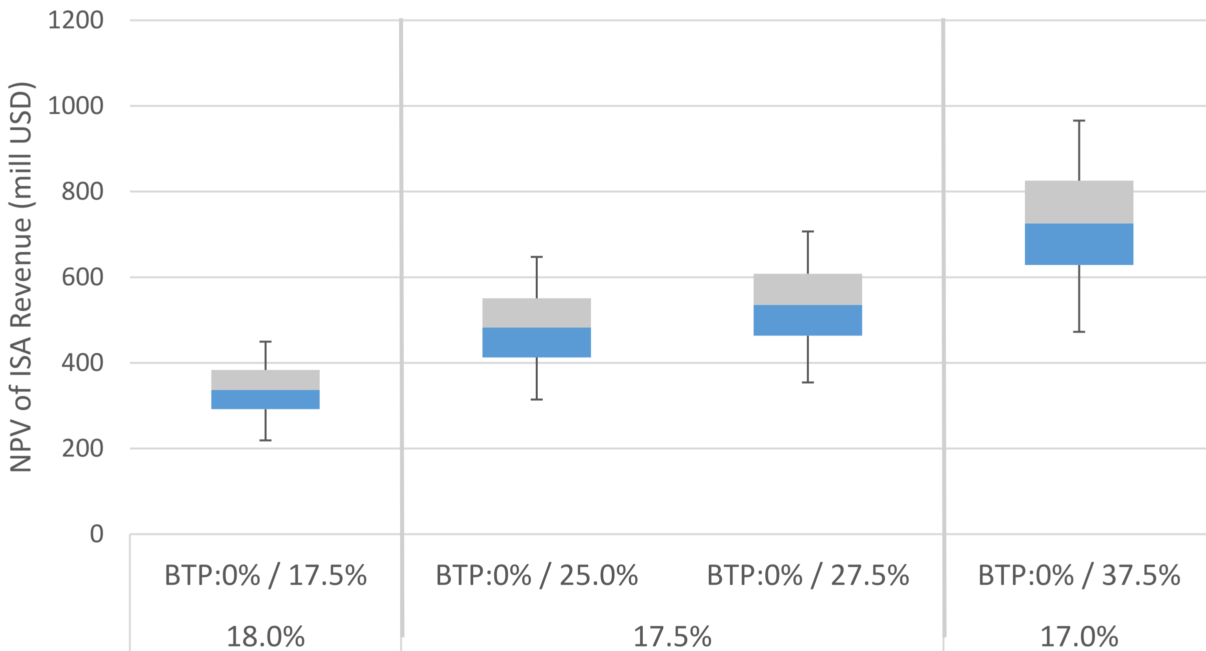


Figure 24. Distribution of NPV of Revenue to the ISA for a range of profit-based only systems.

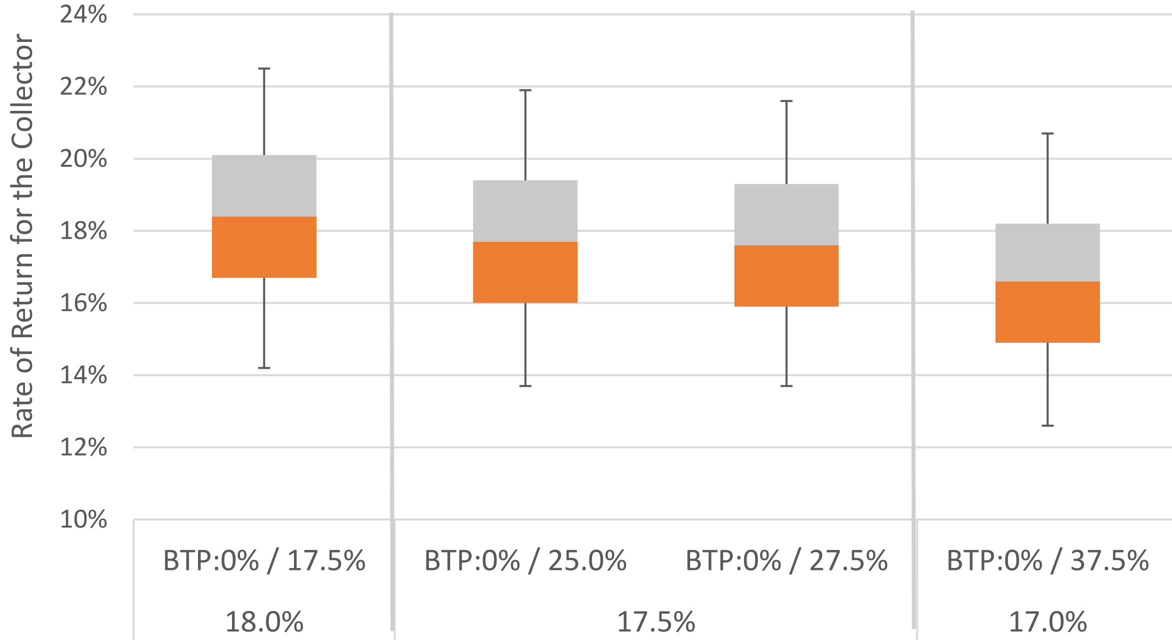


Figure 25. Distribution of modeled Rates of Return for the collector for a range of profit-based only systems.

233. Table 36 shows the 50th percentile (median) and 25th percentile result of both collector IRR and ISA NPV for all of the profit-based only systems investigated in detail.

Table 36. Results for collector IRR and ISA NPV for the selected ad-valorem only systems.

		18%	17.50%		17%
	System→ Percentile↓	BTP:0% / 17.5%	BTP:0% / 25.0%	BTP:0% / 27.5%	BTP:0% / 37.5%
IRR	5%	14.3%	13.7%	13.7%	12.6%
	25%	16.7%	16.0%	15.9%	14.9%
	50%	18.4%	17.7%	17.6%	16.6%
	75%	20.1%	19.5%	19.3%	18.2%
	95%	22.5%	21.9%	21.7%	20.6%
NPV	5%	219	314	354	472
	25%	292	413	463	628
	50%	337	483	535	726
	75%	383	551	608	825
	95%	450	648	707	966

Combination (Blended) Systems

Results of Screening Analysis

234. ISA NPVs and Collector IRRs were calculated under baseline assumptions for blended systems with the following characteristics

- Stage 1&2: 0% to 10% gross metal value collected

- Stage 2 only: plus an additional 0% to 50% of NORif$_c$

235. Note that for the blended systems the ad-valorem rate begins in the stage 1 and remains in place, unchanged, in stage 2. The profit-based rate begins at stage two. Computation of both is the same as was described in the sections on ad-valorem only and profit-based only systems, respectively.

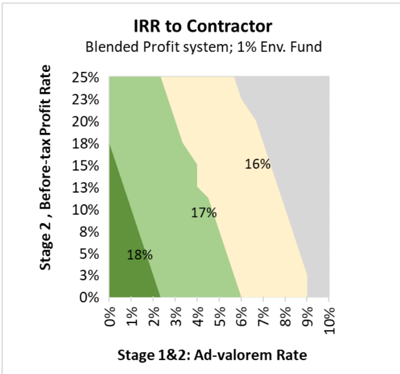


Figure 26. Screening analysis of return (IRR) to the collector for a range of blended systems. 1% of gross metal value is collected for an environmental or sustainability fund.

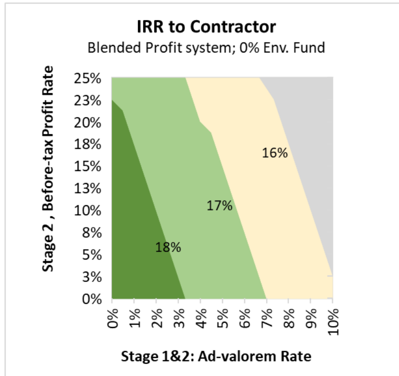


Figure 27. Screening analysis of return (IRR) to the collector for blended systems. 0% of gross metal value is collected for an environmental or sustainability fund.

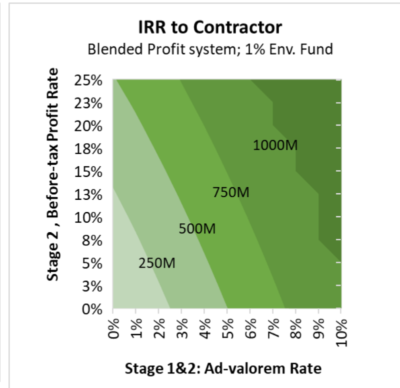


Figure 28. Screening analysis of net present value of revenues to the ISA for a range of blended systems. NPV to ISA is unaffected by funds collected for an environmental or sustainability fund.

236. A limited set of combinations of ad-valorem and profit-based rates were chosen for a more in-depth analysis of the blended systems. For this analysis, systems associated with three levels of Collector IRRs were chosen: 17%, 17.5% and 18%. The specific systems selected are evaluated are defined in the first three columns of Table 37 below.

Table 37. Blended systems selected for in depth analayses. Systems are defined by the first three columns. The other columns show key results for those systems derived from Monte Carlo analysis.

System	Ad-Val Rate (St1&2)	Stage 2 Profit Rate	Collector IRR (IRRc)	ISA NPV (NPV$_{ISA}$)	ISA Share (S_{ISA})	Sponsoring State Share (S_{SS})	Other Share (S_{Oth})	Collector Share (S_c)	ISA Share (S_{ISA})	Sponsoring State Share (S_{SS})	Other Share (S_{Oth})	Collector Share (S_c)
AV1% + PB10%	1%	10%	18.5%	286	2,393	3,815	500	11,379	13%	21%	3%	63%
AV2% + PB15%	2%	15%	17.5%	467	3,847	3,464	500	10,258	21%	19%	3%	57%
AV3% + PB7.5%	3%	7.5%	17.5%	427	3,312	3,620	500	10,659	18%	20%	3%	59%
AV3% + PB20%	3%	20%	16.5%	644	5,259	3,146	500	9,237	29%	17%	3%	51%
AV5% + PB7.5%	5%	7.5%	16.3%	615	4,652	3,321	500	9,621	26%	18%	3%	53%

Detailed Analysis of Selected Systems

237. Full Monte Carlo analysis was conducted on each of the selected blended systems to get a better understanding of the distribution of results that could be expected from such systems. The simulation

results for a blended system that includes a 2% ad-valorem rate for both stages 1 and 2 plus a profit-based rate of 15% that begins in stage 2 (AV2%+PB15%) are shown in Figure 29 and Figure 30 below.

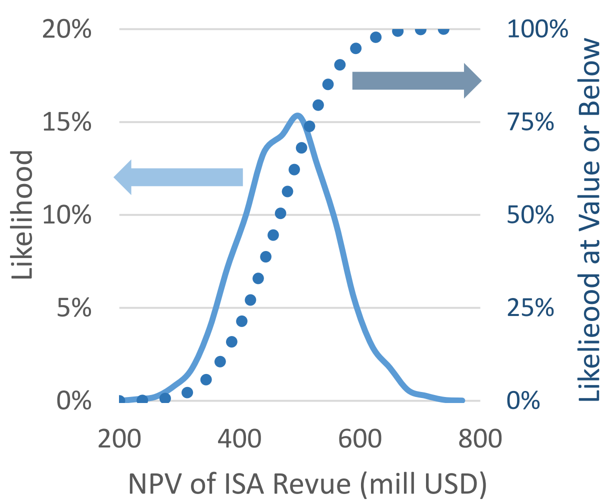


Figure 29. Monte Carlo results for analysis of net present value (NPV) of the revenues received by the ISA (excludes environmental or sustainability fund) for a blended system that includes a 2% ad-valorem rate for both stages 1 and 2 plus a profit-based rate of 15% that begins in stage 2 (AV2%+PB15%). Probability density function (PDF: solid line referring to left axis) and the cumulative distribution function (CDF: dotted line referring to right axis).

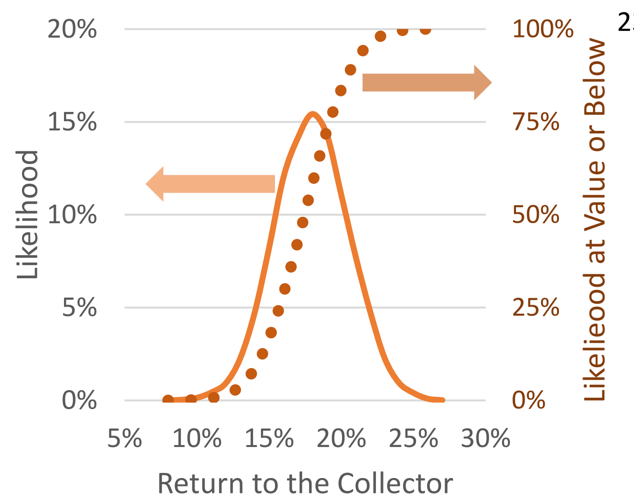


Figure 30. Monte Carlo results for analysis of return to the collector (IRR) for a blended system that includes a 2% ad-valorem rate for both stages 1 and 2 plus a profit-based rate of 15% that begins in stage 2 (AV2%+PB15%). Probability density function (PDF: solid line referring to left axis) and the cumulative distribution function (CDF: dotted line referring to right axis).

239. From this analysis, one can observe not only the mean values for the ISA NPV and Collector IRR, but also the spread on the results. We see that the NPV of ISA revenues averages just over 450 million USD but can range from around 250 to nearly 700 million USD (See Figure 29.) while the average collector IRR is around 17.5%, but can range from 7% to 27% (see Figure 30 above.).

240. ISA NPV and Collector IRR results are presented for all selected blended system rates in Figure 31 and Figure 32 below. The results in Figure 31 are grouped by return to the contractor. As with the ad-valorem only systems, we see that even with a given return grouping (the two groups here are 17.5% and 17% return), the systems do not provide the same NPV to the ISA. It is notable, however, the differences are smaller for the blended systems than was observed for the ad-valorem only or profit-based only systems. For example, the AV2% + PB15% system provides about 350 million dollars more NPV on average to the ISA compared to the Av3% + PB7.5% system.

241. Figure 32 plots the distribution of collector IRR values found in the Monte Carlo analyses.

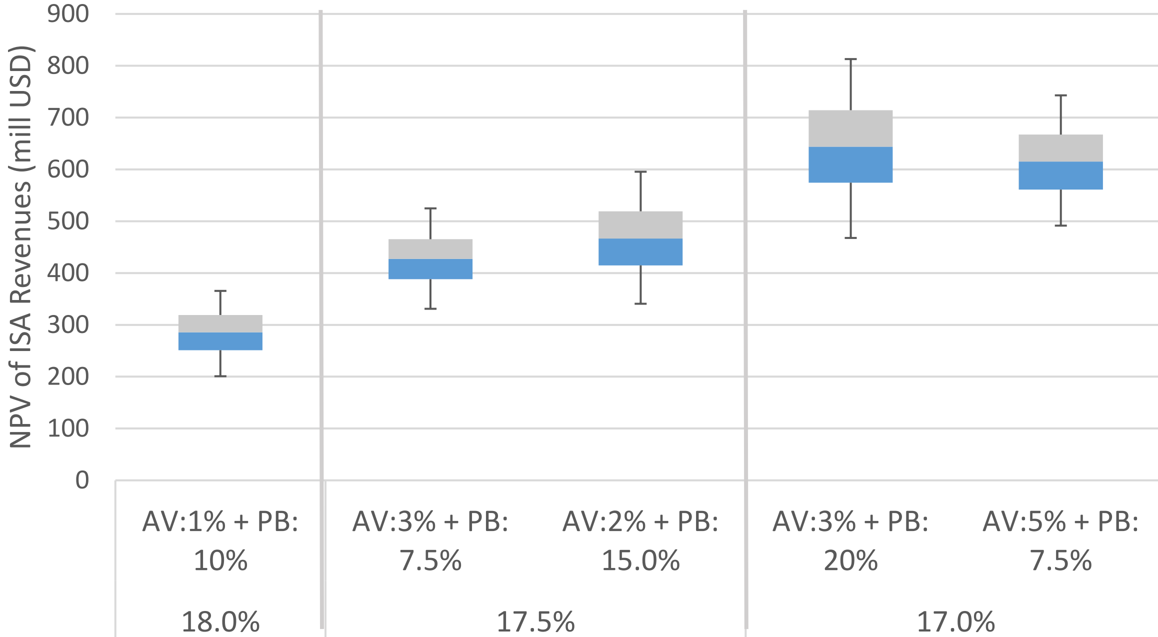


Figure 31. Distribution of NPV of Revenue to the ISA for a range of blended systems.

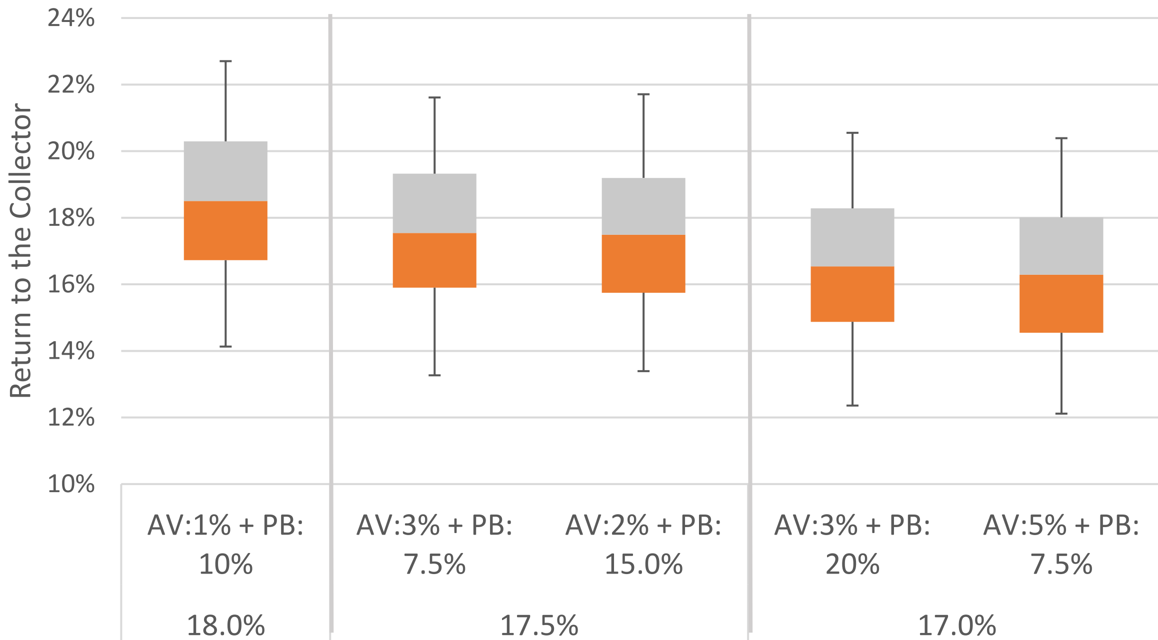


Figure 32. Distribution of modeled Rates of Return for the collector for a range of blended systems.

242. Table 38 shows the 50th percentile (median) and 25th percentile result of both collector IRR and ISA NPV for all of the blended systems investigated in detail.

Table 38. Results for collector IRR and ISA NPV for the selected blended systems analyzed in detail.

		18%	17.50%		17%	
	System→ Percentile↓	AV1% + PB10%	AV2% + PB15%	AV3% + PB7.5%	AV3% + PB20%	AV5% + PB7.5%
IRR	5	14.1%	13.4%	13.3%	12.4%	12.1%
	25	16.7%	15.7%	15.9%	14.9%	14.5%
	50	18.5%	17.5%	17.5%	16.5%	16.3%
	75	20.3%	19.2%	19.3%	18.3%	18.0%
	95	22.7%	21.7%	21.6%	20.6%	20.4%
NPV	5	201	341	331	468	491
	25	251	415	388	574	561
	50	286	467	427	644	615
	75	319	519	465	714	667
	95	366	595	525	813	743

Summary of Results and Discussion.

243. Figure 33 shows the trade-off space between ISA NPV and Contractor IRR. Each of the financial payment systems that were investigated in detail is plotted. Those using a purely ad valorem system are labeled AV (blue circle). Those using a purely profit-based system are labeled PB (red X). Those using a blended system involving both an ad valorem rate and a profit-based rate are labeled as B (blended – green diamond). We see from this plot that within each cluster the return to the contractor is reasonably similar. Nevertheless, within each cluster there can be significant variation in the NPV of revenues to the ISA. This implies that some of these systems should be more favorable to the ISA than others.

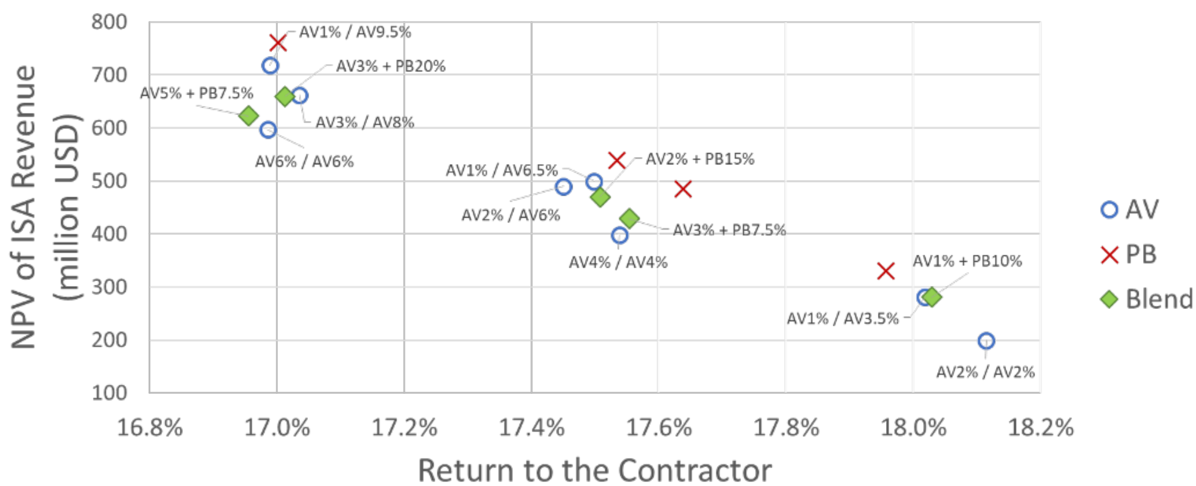


Figure 33. NPV of ISA Revenue vs return to the collector for each of thes systems studied in detail. Note that within each cluster the return to the contractor is reasonably similar. Nevertheless, within each cluster there can be significant variation in the NPV of revenues to the ISA.

244. One important consideration for the ISA is the cost of administering a revenue collection system. (These costs would include the costs to collect and assess assay samples for an ad-valorem system and the costs to collect tax-related filings for a profit-based system.) It is important to note that this analysis

did not investigate such costs. Nevertheless, it is generally accepted that among the options considered here administrative costs are lower for a system involving only an ad-valorem rate compared to one involving a profit-based rate.

245. The ISA should carefully consider the administrative costs of a profit-based system.

246. An additional consideration is the timing for ISA to receive funds. While the NPV calculation discounts all revenues according to timing and thus provides a consistent basis for comparison, it does not reveal that a purely profit tax based systems would delay all income to the ISA until after the upfront investments are sufficiently depreciated, on the order of 5 years. As a result, the purely profit tax based approach may not satisfy the needs of the ISA or the desires of the member states.

247. Regarding this issue, it is worth noting that in the UNCLOS agreement, the language implies that a payment system comprising either "a royalty system or a combination of a royalty and profit-sharing system" is preferred. That is to say that in these original agreements a system relying only on a profit-sharing mechanism was not preferred.

248. The authors do not believe that a purely profit-based system is well suited for the ISA at least for the initial round of contractors because it will likely provide very little revenue to the ISA for the first five years of a mining operation.

249. An additional consideration involves technology learning. It is reasonable to expect that the costs associated with DSM will decrease as the Collectors acquire more knowledge as time goes on. A profit-based system will automatically share these benefits while a purely ad valorem system would not allow the ISA to capture any share of that improvement.

250. A similar note is that the financial payment systems involve different ways to share the risk associated with uncertainty. An ad valorem system only shares risk associated with price uncertainty, while a profit-based system shares risks from both price and cost uncertainty. As a result, there is some appeal to having an ad valorem system in place right from the start to make sure ISA is able to capture any upside potential associated with metals price increases while limiting early exposure to cost overruns. Later, after the upfront investment are fully recouped, a combined system that incorporates a profit-based rate would allow ISA to capture both the upside potential of higher prices and the benefits of lower costs brought about by technological learning.

251. A blended (combination) system that incorporates both ad-valorem and profit-based rates, has many attractive features. It would have higher costs. The ISA should weigh these benefits and costs.

252. Of course, one needs to note that downside potential, particularly on metals prices is always possible and that any system that allows the ISA to capture upside benefits exposes it to downside risks as well.

Consideration of the Impact of National Fiscal Regimes

253. As was reported earlier, a substantial amount of collector net operating revenue (NOR_c) modelled would be payable to the collector's sponsoring State in the form of corporate income taxes and other payments. In fact, for the payment systems that were studied in detail, several transfer 20% of NOR_c to the sponsoring state (PS_{SS}≈20%). Several ISA stakeholders asked the research team to explore the implications of that share being less.

254. The modeling assumption that effects that share is the sponsoring State corporate income tax rate, which was 25% in all of the other analyses presented in this manuscript. In this section we explore the impact of changing that assumption. Effectively, we are asking the question: If the sponsoring state **effective** tax rate were lower, how could the ISA extraction related payments increase while still meeting the contractors return threshold? Please note the emphasis on the word effective in the preceding sentence. We highlight effective tax rate because there are many mechanisms (tax deductions, incentives etc.) under national fiscal regimes that could lead to a rate lower than the nominal or headline corporate income tax rate, particularly in the case of extractive industries. How payments made to the ISA will be treated for tax purposes in the sponsoring State will vary depending on national fiscal rules. Such rules may treat payments to the ISA as a deductible tax expense or as a tax credit against tax payments due to the sponsoring State. For the purposes of modelling assumptions, it has been assumed that payments made to the ISA are deductible from income, but not credited against sponsoring State taxes.

255. Because the model applied here cannot capture all of the intricacies of any specific national tax regime, we model a lower effective tax rate by simply lowering the nominal tax rate assumed in the model. Specifically, to explore the implications of a lower effective tax rate, we focus on two systems that we have analyzed in detail: AV2%→AV6% and AV2%+PB15% . Looking back to Table 33 and Table 37, we see that for baseline conditions (i.e. 25% sponsoring state tax rate) either of these two systems, over the analysis period, would yield approximately (undiscounted):

- \$4 billion to ISA (S_{ISA}) (PS_{ISA}=22%),
- \$3.5 billion to sponsoring state(S_{SS}) (PS_{SS} = 19%),
- \$10 billion to contractor (S_c) (PS_c = 57%),
- Also, 0.5 billion into an environment/sustainability fund (S_{oth}).

256. If the sponsoring state **effective** tax rate were halved to 12.5%, ISA extraction-related payment rates could, theoretically, increase and not impact contractor returns. Indeed, it turns out that, under those conditions there are two systems – AV2%→AV9% and AV3%+PB22.5% -- that provide about the same returns to the contractor (about \$10 billion) but the share going to the ISA grows by nearly \$2 billion to \$5.6 – 5.9 billion. Figure 34 makes it clear that this increase in ISA revenue derives directly from the decrease in sponsoring State revenue. The authors note that at the first meeting of an open-ended working group of the Council in respect of the development and negotiation of the financial terms in February 2019, participants did not consider that a detailed discussion of the interaction with State fiscal regimes was needed, albeit national taxes should be reflected in the model as a cost to contractors.[24] Nevertheless, the ISA should consider further how such payments to the ISA will be treated for national tax purposes, because, as demonstrated here, those rules represent a key variable in this analysis. Equally, the ISA should determine initially a fair return to mankind as resource owner.

1.

[24] See ISBA/25/C/15 at paras. 12 and 13

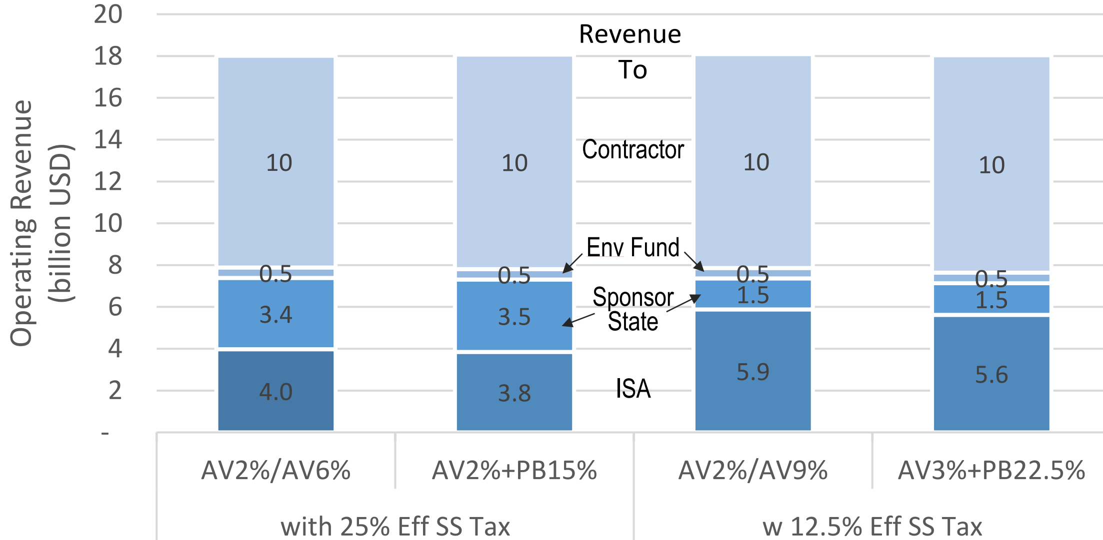


Figure 34. Distribution of undiscounted cumulative cash flows under two different sponsoring state effective tax rates. Note that the effective rate could be achieved both through differences in the nominal rate or through other rules within a national tax regime that allows for deductions or credits.

Recommendations and Additional Discussion

257. At a high level the payment system is defined by three to four characteristics. These can be expressed as answers to the following questions:

- ❖ Rate basis: Will extraction-related payments be based on metal value (ad-valorem) only or metal value and a share of contractor profit?
- ❖ Rate stability: Will the rate of payment be fixed or will (can) it change at pre-defined stages during the lifetime of the mining operation?
- ❖ Basis of rate change (if the rate will (can) change): What will trigger the change: time or some other metric of firm fiscal performance (e.g. recoupment of investment)?
- ❖ Rate level: What will the rate of payment (per value or per unit of profit) be for the first stage of mine operations? If the rate level is staged, what will the level be for future stages?

Structuring the Decision-making process

258. ISA decision makers can use the information provided in this report to begin to answer these questions and, therefore, design a payment regime that meets ISA and other relevant stakeholder goals. To do this, the authors of this report would suggest that the ISA decision makers first address one key question (we will call it questions zero):

1) *How much return should a contractor expect to generate from operating under whatever payment regime is selected?*

(See the section entitled "A Note of the Role of Contractor Return in the Analysis" on page 14 for an explanation as to why this is the first question to answer.) As described earlier in the document, many contractors communicated to the research team the need to generate an 18% expected return in order to raise sufficient capital to undertake a polymetallic mining operation. To provide flexibility, this work describes analysis of systems that model results suggest would provide expected returns of 17%, 17.5% and 18% to the contractor.

259. Once a target return has been identified, ISA decision makers should decide on the basis of payment within the payment system.

2) *Will extraction-related payments be based on metal value (ad-valorem) only or metal value and contractor profit?*

Generally, an ad-valorem system limits the ISA's risk of receiving low to no payments – even if a firm does not turn a profit in a given year, they would still be expected to make ad valorem-based royalty payments. Conversely, a profit-based system does create the risk of low to no payment years, but it also increases the potential to receive high payments in years where firms have high profits. (Generally, high profits would be expected when prices are high or when operating costs are low, or both.)

260. The next question that should be addressed by ISA decision-makers are the other aspects of fiscal context under their control. This includes annual and administrative fees as well as (and more importantly) the level and form of payments collected to build up a fund for environmental liability or other sustainability-related goals.

3) *Should there be an environmental/sustainability fund and if so, how should it be implemented and what rates should apply?*

261. One final framing question needs to be considered before the rates within the payment system are selected.

4) *Will the rate of payment be fixed or will (can) it change during the lifetime of the mining operation?*

In the eyes of the authors, this question is critical. If payments remain fixed, more revenue will come into the ISA during the first few years of operation, but this will necessarily translate to less revenue coming to ISA over the life of the mine. Either ISA can collect more now or more in total, but not both while still holding to some targeted expected return to the contractor. To put some quantification to this point, consider the ISA Share (S_{ISA}) values shown in Table 33. Specifically, compare S_{ISA} for the ad-valorem system that uses a fixed 6% rate for the life of the mining operation (first row in the table) with the SISA for the system that starts with a 3% ad-valorem rate and switches to an 8% rate after five years of operation (third row in the table). The fixed 6% system will bring in double the revenue for the first five years, but in total the AV3% → AV8% system will bring in over 1 billion USD more to the ISA over the life of the mine (4,309 billion USD for AV6% vs 5,331 billion USD for the AV3% → AV8% system).

262. If the ISA elects to implement a system with a staged rate, then they will also need to define what causes the rate to change.

5) *What will trigger the rate change: time or some other metric of firm fiscal performance?*

The analyses presented here all assume a time-based trigger of five years. Future work should consider fiscal performance-based triggers such as profitability or annual returns on investment.

263. Finally, once these questions have been answered ISA decision-makers can use the information and relevant trade-offs presented here to select the system that will provide them with the maximum revenue to be derived from the development of the common heritage of mankind while still providing sufficient return to motivate a mining contractor to invest in a mining operation.

6) *What will the rate of payment (per value or per unit of profit) be for the first stage of mine operations? If the rate level is staged, what will the level be for future stages?*

Authors Recommendations

264. Based on consideration of the various characteristics of different payment systems, the authors have selected what appear to be the best options for implementation by the ISA. The table below provides the recommended financial payment options using either: a) a two-stage ad-valorem only system or b) a combined ad-valorem and profit-based system for each target Collector IRR. The results presented here all assume an environmental liability fund collection rate of 1% of gross metal value collected up to a maximum of $500 million per mine site and an assumed sponsoring State tax rate of 25% of profit. The recommendations are based on all of the points discussed in the results section and seek to maximize the NPV to the ISA while still ensuring that the ISA will receive a reasonable amount of the revenues in the early years. Notably, in the authors' opinion, the wise choices for ad-valorem only systems involve a two-stage rate. As such, no fixed rate ad-valorem only systems are included in our recommendations.

Table 39. Characteristics of recommended systems for three levels of expected returns to the collector. All of these results assume an environmental fund rate of 1% of GMV to a max of $500 million USD per mine site and a sponsoring state corporate income tax rate of 25%.

Return to Contractor	**System**	**ISA NPV** (million USD)	**Cumulative ISA Revenue** (million USD)	**Share of NOR_c to Collector**
17%	AV3%→ AV8%	$660	$5,300	51%
	AV3% + PB20%	$640	$5,300	51%
17.5%	AV2%→ AV6%	$490	$4,000	56%
	AV2% + PB15%	$470	$3,850	57%
18%	AV1%→ AV3.5%	$280	$2,300	63%
	AV1% + PB10%	$285	$2,400	63%

Future Work

265. The results presented in this document are the best estimates of the authors as of the time of its writing. Nevertheless, as has been indicated earlier in the document, the nature of this inquiry is such that there are many sources of uncertainty. Additionally, there are many questions relevant to the economics of seabed mining and to the setting of the payment regime in particular that were outside the scope of this work. Here we detail important future work that would reduce some of the uncertainty and answer some additional questions.

266. On the revenue side of the mine economics question, three of the materials markets present significant sources of uncertainty that warrant further consideration. The first is the dynamics of the manganese market. The supply from one polymetallic nodules operation is sufficiently large that it alone might impact the manganese market and its price. This is especially true for the high value electrolytic manganese market that has been discussed by some contractors. The ISA should undertake a study of the dynamics of the manganese market including understanding how prices will likely be effected by new seabed supply. Secondly, the ISA needs to understand whether the nickel market will likely bifurcate into a high-purity market (into which seabed derived nickel would compete) and a low-purity nickel market. If this occurs, then seabed derived nickel may command a higher price. Similarly, it will be important to investigate a similar question for cobalt. Specifically, will the market support a high price for cobalt derived from non-conflict sources and will sources generally expand to support electric mobility. All of these issues become particularly relevant as multiple contractors come on-line.

267. It will be important for the ISA to understand the economic impact of seabed mining on land-based production of the same minerals in developing countries. This consideration does not impact the financial model per se presented in this study, but is important because UNCLOS requires a portion of the revenues derived by ISA to be placed into an economic assistance fund to compensate land-based producers who can demonstrate that their economies have been adversely affected by seabed mining. It will be important to be able to quantify any potential impact so that decisions can be made around the amount of ISA income that will need to be diverted into such a fund and therefore not be available for distribution to member States.

268. Also, on the revenue side, the economic assessment could be refined with better estimates of tract abundance and its variation. The variation is interesting because a contractor is likely to mine the most abundant areas first to generate high revenues early. This could significantly improve the financial metrics of the contractor.

269. Finally, it is important to understand the economic value of the ecosystem services that will be impacted by seabed mining. This must be weighed against the revenues that would derive from the system.