

UPDATE: Report 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 Based on Stakeholder Feedback

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1. In March of 2020, the Authority sought and received feedback from stakeholders on the assumptions being used to carry out to analyze the financial consequences of prospective payment systems. The authors of this report (1) reviewed and synthesized all of the stakeholder comments and (2) took that feedback and used it to explore how conclusions reached in previous reports about those systems would be impacted under different assumptions. In some cases, this required significant updates to the modeling platform. This report describes what was learned from those explorations and where necessary describes the model updates. The report contains two major sections: (1) a review of the stakeholder feedback including any changes subsequently made to the model, and (2) analysis of the principal payment systems under consideration by the ISA. These include a two-stage ad valorem royalty, a variable ad valorem system where the rate is a function of the prices of the metals, and a blended system with an ad valorem royalty plus a profit-based royalty. Further, the work expanded on the metallurgical basis for the calculations by looking at a Mn-oxide end product similar to existing land based-Mn ores in addition to a Mn metal product.

Part I – Review of Stakeholder Feedback

2. Stakeholder feedback can broadly be classified into four categories – general feedback on the analytical approach, scope of the systems to be analyzed, changes to core model assumptions, and inquiries into the impact of assumption changes (sensitivity analysis). Specific feedback, classified in these four categories included the following
 - Objective, framing, or scope of analytical approach
 - Scope of systems to be considered
 - Basis of systems
 - Ultimate manganese product and basis of ad-valorem payments
 - Fundamental modeling changes
 - Rate and scale of collection
 - Production start up
 - Metallurgical processing efficiency
 - Sensitivity
 - Selection of target system return
 - Cost assumptions
 - Materials Prices
 - Taxes
 - Rate and level of collection of payments to environmental fund
3. In response to this feedback the working group requested four primary follow-up tasks which are described in this document. First, update the model to accommodate the feedback provided by stakeholder when appropriate. This included changes to input values as well as model restructuring to accommodate concepts deemed important in the comments. Second, adapt the model to address a system where the metallurgical processor produces cobalt, copper, and nickel metal as well as a manganese product that can be sold as an oxide on the existing Mn-ore market, and to reflect the impact of nodule abundance on collection rate. Third, explore the impact of price and sponsoring state taxation on payment system performance for a system producing all metal products. Fourth, explore the impact of cost uncertainty on payment system performance for a system producing three metals plus a Mn-oxide equivalent product.

Discussion of specific feedback

Analytical Approach: Objective, framing, or scope of analysis

4. Two stakeholders raised a similar issue that the current financial analysis, including what is presented here, represents the explicit monetary exchanges among the directly involved stakeholders (e.g., collector, metals processor, supply chain providers, ISA, sponsoring state). In doing so, this analysis does not attempt to estimate the externality costs (e.g., impact on ecosystem services, biodiversity, resource waste) associated with the mining activity. Notably, in not estimating this cost, the financial analysis carried out to date (including that presented in this update) do not internalize this cost. Analysis of these externality costs is beyond the study's scope and the resources available to the research team.
5. In a related point, two stakeholders have noted that in its current framing and presentation, the financial analysis implies a desire to incentivize mining activities to occur. Instead these stakeholders suggest that the focus of analysis should be that compensation is sufficient to society. While we have not been able to address externality costs, we have changed the focus towards a discussion of what the return to the CHM would be as measured by the revenues that can be achieved by the ISA
6. Most generally, two stakeholders indicated that the ISA and its member states should take a highly precautionary approach to establishing the payment system.
7. Most of the respondents (five), noted that the payment system should be evaluated to ensure that it does not unfairly subsidize (or disincentivize) seabed mining relative to pertinent land-based mining operations. One set of comments specifically mapped this issue to the selection of a minimum attractive rate of return for the collection contractor, noting that they felt that a seabed contractor does not require a higher rate of return to motivate mine operation, this differs from previous feedback received by the research team. Nevertheless, in this analysis, we have tried to reframe discussions around the return to the ISA.
8. All respondents indicated the payment system should fairly compensate the common heritage of mankind.

Scope of systems to be considered

Payment system basis

9. Most respondents did not specifically address the selection of payment system basis (ad-valorem, variable rate ad-valorem, blended ad-valorem and profit-based). One group specifically indicated that a profit-based system is not feasible and that only ad-valorem systems should be considered. One group specifically indicated a preference for the variable rate ad-valorem. One group felt that all options should continue to be considered.

Type of metallurgical processing

10. The analysis reported in previous reports has focused on the revenues associated with a system where nodules are eventually processed to produce cobalt, copper, nickel, and a basket of manganese metal and metal alloys. This framing was based on feedback from contractors in 2018. One set of comments specifically endorsed this as an important perspective to consider. However, two sets of comments indicated that it may be that nodules are not processed to produce manganese metal, but rather some oxide or other intermediate product. This intermediate product would be expected to sell as an equivalent to current manganese ore. These comments indicated that the model should be modified to consider this

possibility and to consider the value of manganese ore to be used in setting the basis of ad-valorem payments.

Fundamental modeling changes

Rate and scale of collection

11. Previously reported analyses assumed that contractors used one seafloor collector to extract approximately 3 million dry tons per year of nodules throughout most of the operating life of the mine. One stakeholder pointed the modeling team to a previous ISA report¹ on nodule abundance and noted that this rate of collection was not feasible given known abundance distribution and current collector technology. Instead, around 2.3 million dry tons per year was a more reasonable rate of collection for a single collector.

Production start-up

12. One stakeholder commented that it would take longer for facilities to be constructed and for ramp to full production to occur.

Expected future price uncertainty

13. One stakeholder commented that the uncertainty in future model prices should be larger than was previously assumed.

Efficiency of metal recovery

14. One stakeholder commented that during metals processing recovery efficiencies should be lower than previously assumed.

Sensitivity to modeling assumptions

Selection of target system return

15. The model can be used to explore a broad range of payment systems. As such, in past reports, the modeling team has tried to report on only systems that met some criteria for acceptability. Originally, the modeling team defined acceptability based on the median expected return to the contractor. Generally, systems were deemed acceptable if they provided a contractor internal rate of return of 17-18%. One set of comments asked to understand how the payment system would change if it provided a contractor return of 12%, 16%, and 20%.
16. In the briefing note from early 2020, the modeling team shifted away from the perspective of defining acceptability based on contractor return and instead favored defining acceptability based on the level of revenues received by the ISA. In this report we will focus on this perspective but will still explore the question about contractor return posed in one set of comments.

Cost Assumptions

17. One stakeholder requested to understand how results would be affected if costs were assumed to be 20% higher or lower than current model assumptions.

¹ International Seabed Authority. A Geological Model of Polymetallic Nodule Deposits in the Clarion-Clipperton Fracture Zone and Prospector's Guide for Polymetallic Nodule Deposits in the Clarion Clipperton Fracture Zone. Technical Study: No. 6. 2010.

Materials Prices

18. One stakeholder requested to understand how results would be affected if prices were assumed to be 20% higher or lower than current model assumptions.

Sponsoring State Tax Rate

19. Several stakeholders asked for exploration of the assumption that contractors would pay a 25% marginal rate for corporate income taxes to some sponsoring state, with one comment indicating that 0% and 15% sponsor state tax rate should also be investigated

Rate and level of collection of payments to environmental fund

20. Two stakeholders indicated that current assumptions of collecting the environmental fund may not reflect total externality costs of extraction and often lead to it taking a number of years before the fund is fully funded. They suggest an alignment of fund value with total externality costs and a more rapid filling of the fund, possibly even before any collection operations begin.

Modeling Response to Comments

Definition of Base Case Scenarios

21. Based on all of the comments received, the modeling team has made some adjustments to what is considered the baseline set of model assumptions and made modifications to accommodate

Rate and scale of collection

22. The modeling team implemented a module that estimates the average annual collection based on expected distribution of abundance within the area and the number of collectors deployed. Specifically, for this model we assume that nodule abundance is normally distributed throughout the area with a mean of 7.2 wet kg/m² and standard deviation of 6.1 wet kg/m² (as noted in ²). The area that can be traversed by a single rover over the entire production life is calculated based on the size and speed of the collector with consideration of down times and repositioning times. Additional areas for preservation reference zones (PRZs) and impact references zones (IRZs) are also included and an extra efficiency factor is added to account for the idea that the most abundant areas will not be aggregated conveniently. For two collectors operating over 25 years with consideration of production ramp-up and an abundance efficiency of 90%, the total area needed is approximately 12,500 km². This is compared to the accessible portion of the active contract area, of 75,000 km², and applying a topological factor of 75% to account for inaccessible locations and results in a potential area of 56,250 km². It is assumed that collection will be prioritized in the most abundant (and accessible) areas. Applying the mean and standard deviation of nodule abundance and adjusting for wet vs dry nodules results in an average abundance in the collected area of 10.9 dry kg/m².
23. Using current model assumptions, the model estimates that a collector operating one collection device would collect from a gross area of 6,600 m² over the life of the mine and would encounter an average abundance of 13.6 dry kg/m². Initial analysis indicated that such a collection operation would not produce very attractive returns. As such, the baseline assumption for the work reported in this document is that a collector operates two collectors, each with a dedicated surface vessel, which together would collect from

² International Seabed Authority. A Geological Model of Polymetallic Nodule Deposits in the Clarion-Clipperton Fracture Zone and Prospector's Guide for Polymetallic Nodule Deposits in the Clarion Clipperton Fracture Zone. Technical Study: No. 6. 2010.

a gross area of 12,500 m² over the life of the mine and would encounter an average abundance of 10.9 dry kg / m². This translates into collecting an average of 3.86 million dry tonnes per annum.

24. A real mine experiencing this distribution of abundance would be expected to collect more than this level in the early years (after ramp up to full production) and less than this in later years. The model was not built to reflect varying levels of production over the life of the mine. As such, all cases are modeled using an average production level per year throughout the full production period.

Production start up

25. Based on the feedback provided, we now assume that project timing proceeds as in Table 1. The main change was to change the design and build period from two years to three years duration. Although prefeasibility activities are associated with the exploration contract, it is considered in the economic analysis because investments that occur during that period are significant and effect the overall economics of the system. Note that following the timeline described in ISBA/24/C/CRP.1 we assume a one-year closure (shut down) period that occurs after the 30th year of the exploitation contract activities.

*Table 1. Basecase assumptions of project timing. *Prefeasibility represents activities that occur during the exploration phase. It is included in the economic modeling because significant investments are made during this period of time.*

	Start Year in Exploitation Contract	End Year
Prefeasibility	Before exploitation contract	
Feasibility	1	1
Construction (Design & Build)	2	5
Production (Ramp-Up)	6	7
Commercial production	8	30
Closure	See note in text	

26. Also, based on the feedback provided we now assume that in the first year of operation, the collector collects 70% and the second year collects 85% of the average full production collection value (3.86 million tonnes per annum in the base case). Year three to the end of full production collect at the average per annum value.

Expected future price uncertainty

27. Historical prices were re-evaluated with a particular emphasis on price uncertainty. Table 2 shows the key characteristics of modeled future prices. The normalized range is simply the ratio of the difference between the high and low range to the modeled long-term price.

Table 2. Key metal price assumptions

	Modeled Long Term Price (M US\$ per tonne contained metal)	Low Range (5th %ile - M US\$)	High Range (5th %ile - M US\$)	Normalized Range
Manganese (Metal Mix)	1,560	880	2,260	90%
Manganese Ore	400	220	580	90%
Nickel	18,336	10,300	26,600	90%
Cobalt	55,000	28,800	80,900	90%
Copper	7,000	3,700	10,300	90%

Efficiency of metal recovery

28. Modeled metals recovery efficiencies are now assumed to be 90% for manganese, nickel, and copper and 80% for cobalt.

Summary of Base Case and Key Changes

29. As with all previous reports by the authors, in this document the base case to be analyzed will be for a system where the nodules are ultimately processed to cobalt, copper, nickel, and a bundle of manganese metal and alloys and where the value of the nodule is assessed based on the value of those metals.
30. For this analysis, the assumed prices for these metals are described in Table 2. We assume the contractor operates two seafloor collectors each with a dedicated surface vessel and collects an average of 3.86 million dry tonnes per annum from the third year of start of extraction operations until the end of mine operation. In year one of extraction operation, 70% of this value is collected. In year two, 85% of this value is collected. Modeled metals recovery efficiencies are assumed to be 90% for manganese, nickel, and copper and 80% for cobalt.

All other assumptions remain unchanged from previous results.

Identifying “Reasonable” Payment Systems

31. The goal of this analysis has always been to identify a payment system that generates the largest return for the common heritage of mankind (CHM). Identifying such a system proves to be more complicated than it appears. First of all, such an analysis cannot answer the question as to whether any given return represents sufficient compensation for the resources extracted. That information must come from outside this analysis. Secondly, while a payment system with very high royalty rates could conceivably provide very large revenues, if those rates are too high (and the extracted payments too large), then a seabed mining operation would not be financially attractive for any contractor.

32. The challenge is, therefore, to find the system that provides the high return to the CHM while providing sufficient financial motivation to potential contractors (It is important to note again that this analysis does not answer the question as to whether any given level of compensation to the CHM is sufficient. This must be assessed separately). Previously, the research team has tried to identify “sufficient financial motivation” solely in terms of the rate of return expected for the contractor – referred to as a minimum attractive rate of return (MARR).
33. Recently a number of stakeholders have pointed out that previous agreements surrounding the royalty rates have stipulated: “the rates of payments under the system shall be within the range of those prevailing in respect of land-based mining of the same or similar minerals in order to avoid giving deep seabed miners an artificial competitive advantage or imposing on them a competitive disadvantage”.³ In light of this, the ISA has commissioned a report, authored by RMG consulting, to benchmark the royalty rates typically charged for the mining of cobalt, copper, nickel, and manganese.⁴ This report recommends that ISA consider royalties in the range of 2-10% of value.⁵ Although it does not specify whether this applies to metal value or the value of the contained ore.
34. The same report by RMG also notes that “It is however important to acknowledge that for a thorough comparison between jurisdictions the effective tax rate needs to be discussed and compared.” A 2006 World Bank report by Otto et al.⁶ reports effective tax rates for mining operations in 24 countries around the world. Omitting the lowest 10% of rates, the report by Otto et al. suggests a range of effective tax rates from 40% to 65%. It is important to note that this range is not explicitly limited to countries or mines producing cobalt, copper, nickel, and/or manganese.
35. Summarizing these findings, we have looked for systems that meet the following criteria
- Ad-valorem rates: 2% - 10% of value
 - Effective tax rate: 40% - 65%
36. Because the systems we are evaluating in this report utilize ad-valorem rates that differ over the life of the mining operation, to compare with other reported rates, we computed an equivalent fixed (i.e., constant of the mining operation) ad-valorem rate. We define this equivalent rate as the fixed rate that would yield the same cumulative, undiscounted revenues to the ISA as the system being explored. Effective tax rate is defined as the share of net revenues (total revenues minus costs) that is transferred to either the ISA (royalties), an environmental fund, or a sponsoring state.

³ 1994 Agreement, Annex, Section (8)(1)(b).

⁴ ANALYSIS OF TAX REGIMES: COMPARATIVE ANALYSIS OF TAX REGIMES OF LAND-BASED MINING IN 15 COUNTRIES, RMG Consulting, October 12, 2020.

⁵ ANALYSIS OF TAX REGIMES: COMPARATIVE ANALYSIS OF TAX REGIMES OF LAND-BASED MINING IN 15 COUNTRIES, RMG Consulting, October 12, 2020, p. 26.

⁶ Mining Royalties: A Global Study of Their Impact on Investors, Government, and Civil Society” by Jame Otto et al. (2006, The International Bank for Reconstruction and Development / The World Bank)

Part II – Analysis & Results

Options for the Payment System

37. In previous discussions, the research team has pointed out that there are two key considerations in identifying the preferred payment system for the ISA. The first characteristic is how much revenue would that system be expected to return to the ISA over the life of a mining operation – the level of return. The second characteristic is how is the system configured to provide that return. Here there are two major decisions: 1) the basis of payments – what determines the magnitude of payments in a given year and 2) how the rate might change with time or other prevailing conditions.
38. Based on stakeholder comments and previous analyses, the research team has limited analysis in this report to 1) a two-stage ad-valorem system (2AV), 2) a metal price-based, variable-rate ad-valorem (VaV), and 3) a blended system that combines a fixed ad-valorem through mining operations and a profit-based payment that begins in year 5 of operations. The research team has previously indicated that they believe a profit-based system is not cost-effective for the ISA, but to honor stakeholder requests we include it in key analyses here. For this analysis we focus on the base case scenario but explore how future prices and sponsoring state taxation would impact payment system performance.

Level of return from the payment system

39. The financial model was exercised across a broad range of ad-valorem and blended (ad-valorem and profit-based system) system configurations. Figure 1 shows some important features of those results. Specifically, we plot ISA cumulative revenues (y-axis) vs (a) effective tax rate, (b) effective fixed ad-valorem rate, and (c) return to the contractor. On the plots for effective tax rate and effective single stage royalty rate, we overlay a blue region that corresponds to the ranges defined by the information in reports by RMG or Otto et al. (see previous section for details).
40. One set of stakeholders asked how the system would perform if it was crafted to provide a return of 12%, 16%, or 20% to the collecting contractor. The specific level of performance for a system depends on a number of system characteristics. Nevertheless, we can get a good sense of how performance would change under these different scenarios. Specifically, looking across this range of systems, we see that a system providing a 12% return ($\pm \frac{1}{4}\%$) would generate \$21.9 billion to \$23.4 billion of revenue to the ISA for the CHM. A system providing a 16% contractor return would generate \$8.1 to \$12.6 billion of ISA revenue. A system providing a 18% contractor return would generate \$2.4 to \$4.7 billion of ISA revenue. The lower values in these ranges are systems where first stage and second stage rates are equal. The higher values in the ranges are for systems where there is large disparity between first stage and second stage rates.

Economic Model of the System of Payments and Stakeholder Feedback

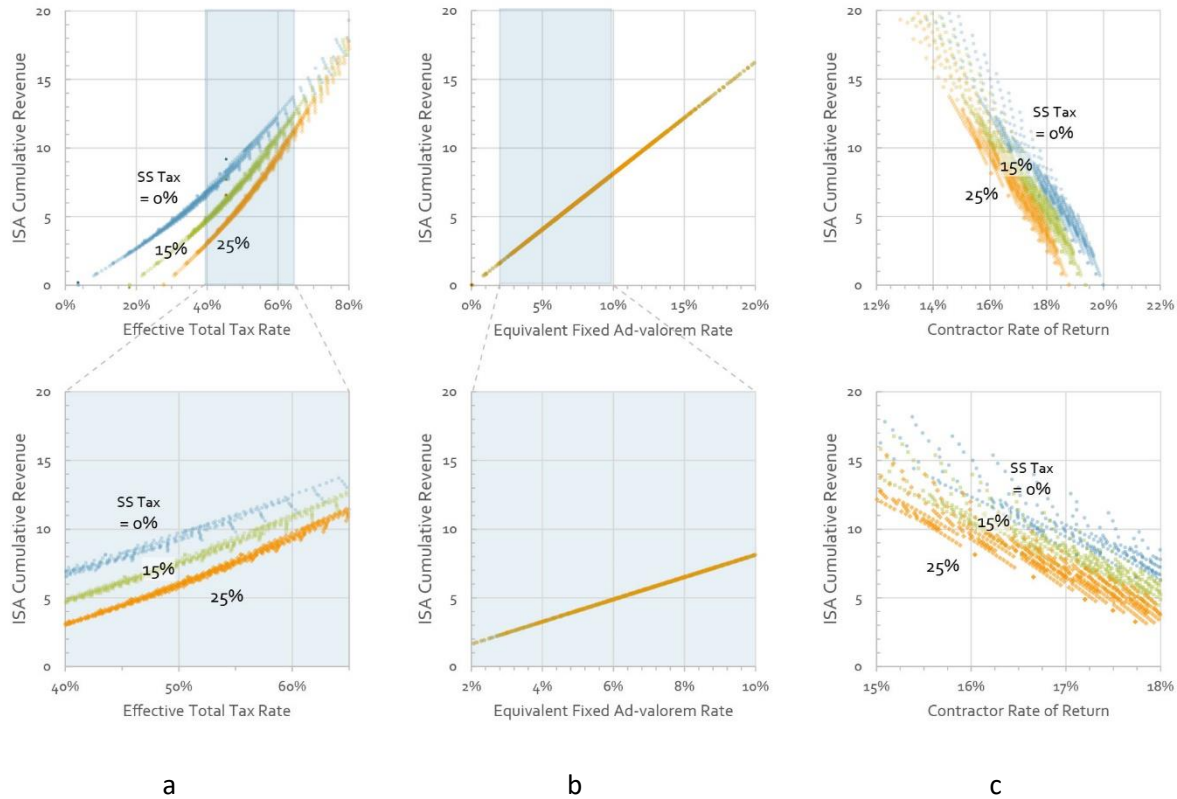


Figure 1. ISA cumulative revenue (in billions of US\$) for a broad range of payment system configurations and for three assumptions about prevailing sponsoring tax corporate income tax rate (SS tax). ISA cumulative revenue is plotted against a) effective total rate of taxation for the contractor, b) equivalent single stage ad-valorem rate, and c) contractor rate of return.

41. Combining these ranges with the model results we identify the bounds described in Table 3. Using the most constraining of these values would suggest that a system that produced somewhere between \$3.2 billion and \$8.1 billion in ISA revenues could be considered similar to payment systems applied to land-based mining operations.

Table 3. Characteristic ranges of payment systems in land-based mining of equivalent commodities and the resultant expected ISA revenues from model simulations.

	Range	Low – ISA Revenue	High – ISA Revenue
Effective Tax Rate	40% - 65%	\$3.0 billion	\$11.5 billion
Fixed Ad Valorem Equivalent	2% - 10%	\$1.6 billion	\$8.1 billion

42. Unfortunately, this is a tremendously broad range for the level of return. In the research team's opinion, this does not provide sufficient guidance on the selection of a payment system. In the hope's of continuing the dialog towards selecting a system, here we choose three sets for more in depth exploration.
43. Table 4 details several key financial characteristics of three sets of possible payment systems. Each set contains one two stage ad-valorem system (royalties basis is value of metals collected, first rate applies to beginning of collection operations, second rate applies from year five until the end of operations), a blended system (combines ad-valorem and profit basis system; first rate is ad-valorem that applies

throughout collection operations, second rate is profit-based rate which applies from year five until end of operations), and a variable rate ad-valorem system (first rate applies at beginning of operations, second pair of rates are the rate bounds that apply from year 5 until the end of collection operations, rate varies depending on prevailing metal prices). The three payment systems were evaluated at each of three different levels of lifetime cumulative revenue to the ISA. The first set would provide \$3 billion USD, the second set \$4.5 billion USD, and the third set \$6.0 billion USD. All three of these fall within the range of system characteristics identified in the benchmarking discussion earlier in this document (within 40 – 65% effective tax rate and collecting an effective fixed ad-valorem rate between 2 – 10%)

44. The most important point that this table makes is that each of the three systems types being considered can be designed to provide a given level of return to the CHM.

Table 4. Key financial characteristics of selected payment systems. All values are the median of 2,000 simulation runs.

System	Median ISA Revenue (\$M)	Effective Tax Rate	Equivalent Fixed Ad-valorem Rate	Collector Rate of Return
\$3.0 billion Options				
Two Stage Ad Valorem: 2% → 4%	3,030	40%	3.7%	18%
Ad Valorem & Profit: 1% AV & 14% on Profits	3,030	40%	3.7%	18.2%
Variable Ad Valorem: 2% → between 3% & 7%	3,050	41%	3.7%	18%
\$4.5 billion Options				
Two Stage Ad Valorem: 2% → 6%	4,440	45%	5.4%	17.7%
Ad Valorem & Profit: 2% AV & 18.5% on Profits	4,430	45%	5.4%	17.8%
Variable Ad Valorem: 2% → between 5% & 9%	4,460	46%	5.5%	17.7%
\$6 billion Options				
Two Stage Ad Valorem: 2% → 8.25%	6,000	50%	7.4%	17.3%
Ad Valorem & Profit: 2% AV & 28% on Profits	5,990	50%	7.4%	17.5%
Variable Ad Valorem: 2% → between 7% & 14%	6,000	52%	7.4%	17.3%

Selecting the basis of payments – response to future conditions

45. All three types of systems of payments can be designed to provide an equal expected level of revenues to the ISA for the CHM. (See Table 4.) However, these three systems respond differently if future conditions are not as expected. The most notable way in which these systems differ is how the level of revenue would change if future metal prices differ from the modeled expected future prices.

46. Figure 2 plots how each of the \$4.5 billion systems would respond if prices were either below expected levels or above expected levels. (For clarity of presentation, we show results only for the \$4.5 billion systems. The response of the systems designed at other levels of revenue to the ISA respond in an analogous manner.) We see from this plot that despite the fact that all three provide the same level of expected return (median of \$4,400 million USD to ISA for CHM), they respond differently if conditions deviate from the expected. Specifically, we see that the two-stage ad-valorem system (2% going to 6%) varies the least with realized future prices ranging from 3,300 million if prices are 20% below expected to 5,600 if prices are 20% above expected. The variable rate ad-valorem system and blended system drop a similar amount if prices are below expectations (2,800 and 2,700 million if prices are 20% below expectations). The variable rate ad-valorem, however, performs the best if realized prices exceed expectations, providing an additional \$2,000 million return over the two-stage ad-valorem if prices are higher than expected.

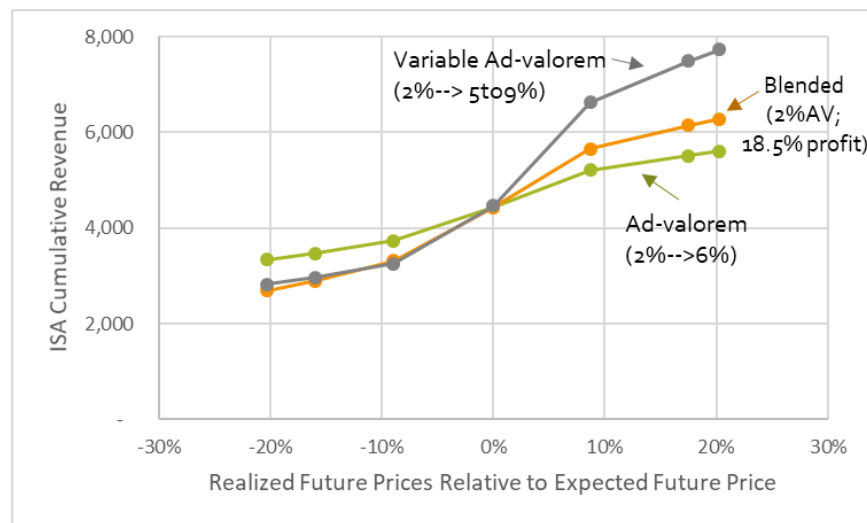


Figure 2. Impact of realized prices on the performance of three payment systems. ISA cumulative revenues over the lifetime of mine operations in million USD. All three systems have a median ISA cumulative revenue of 4,400 million USD. Realized prices are plotted relative to expected future prices. 0% here means no deviation from expected future prices.

Sensitivity to Sponsoring State Tax Rate

47. Looking back to Figure 1, we can see that the assumption about sponsoring state tax rate can have an influence on the choice of level of return to the ISA (for the CHM). Table 5 explores this influence by comparing payment systems that would impose the same levels (45% and 50%) of effective tax rate on the collector. If sponsoring state taxes are lower, the ISA can collect more royalty revenue while maintaining a system with the same level of effective taxation. More precisely, over the range of effective tax rates being considered in this analysis, a change of sponsoring state tax rate by 10% would allow the ISA to collection 1-1.5 billion USD more revenue for the CHM while still maintaining the same level of effective taxation on the collector.

Table 5. Influence of sponsoring state tax rate on key financial characteristics of systems.

Assumed Sponsoring State Tax Rate	System	Median ISA Revenue (\$M)	Effective Tax Rate	Equivalent Fixed Ad-valorem Rate	Collector Rate of Return
Systems Imposing a 45% effective tax rate					
25%	Two Stage Ad Valorem: 2% → 6%	4,440	45%	5.4%	17.7%
15%	Two Stage Ad Valorem: 2% → 8¼%	6,000	45%	7.4%	17.9%
0%	Two Stage Ad Valorem: 3% → 10¼%	7,860	45%	9.7%	18%
Systems Imposing a 50% effective tax rate					
25%	Two Stage Ad Valorem: 2% → 8¼%	6,000	50%	7.4%	17.3%
15%	Two Stage Ad Valorem: 4% → 10%	7,450	50%	9.2%	17.3%
0%	Two Stage Ad Valorem: 5% → 12¼%	9,140	50%	11.2%	17.4%

Implication of a system producing a Mn-ore type product

48. As mentioned earlier, some stakeholder feedback highlighted that the metallurgical processor may not extract a mix of manganese metal and alloys as have previously been assumed. Instead, it may be the case that metallurgical processors will extract cobalt, copper, and nickel and a manganese containing product (e.g. manganese rich slag) that is sold for a value similar to manganese ore. (Because its value is assumed to be similar, we will refer to this product as manganese rich slag (MRS).) In this section we carry out a preliminary investigation as to the implications of a system producing MRS.

Two key reasons for the importance of the manganese product

49. All feedback to the research team has indicated that extracting value from the manganese fraction of nodules is important to make the mining of polymetallic nodules financially viable. There are at least two important implications of the form of manganese production.

Establishing system cash flows

50. As has been discussed in previous reports and presentations, while the metallurgical processor sits outside of the jurisdiction of the ISA, it plays an important role in setting the overall revenues that flow into the system. If metallurgical processor revenues are lower, then they will pay less for nodules. In turn, this makes revenues to the collector go down.
51. Assuming that an MRS product can be sold for its metal value but at prevailing prices for manganese ore leads to a significant reduction in assumed system revenues. Manganese ore currently sells in the range of \$400 per tonne of contained manganese. This is nearly 75% lower than the assumption made in the base case where we model a metallurgical processor selling a bundle of manganese metal products into the electrolytic manganese metal and ferro-manganese markets at an average price of \$1,560 per tonne of contained manganese. Clearly, this reduces revenues to the system.
52. On the other hand, this effect is moderated by the fact that the processing to an MRS product should significantly reduce capital and operating expenditures compared to processing to manganese metal. We have attempted to consider both of these effects in the updated model.

Setting the basis of ad-valorem payments

53. A second, important but independent point is that the magnitude of a royalty payment in an ad-valorem system is set by both the rate of payment (e.g., 2% vs. 5%) AND the basis that is used to determine the value of the resource being extracted. To date, model results have been based on the revenues associated with a system producing manganese metal AND the basis of resource value has been set using that same metal value. There is no formal reason why the value used to estimate future system revenues (for the purpose of designing a system) and the value used to establish magnitude of payments (during the operating of that system) need to be the same. For instance, a system could be modeled to generate revenue from the sale of MRS while the basis of payments could be contained metal assessed using metal prices. While this may seem surprising, there are many examples of this (see description of tin royalties in Otto et al. page 45 or cobalt on page 47.) A rate can be selected to generate the same level of revenue to the ISA for any basis. Notably, however, the rate would need to be different to generate the same level of revenue for different bases. (See the example in Table 6.)
54. In the section that follows we present results for the MRS system primarily assuming an MRS basis for determining nodule value. However, we briefly explore the implications of the basis to reinforce the importance of this decision. The ISA will need to establish the basis for determining the value of nodules in an ad-valorem system.

Cost estimation for MRS Processing

The CAPEX and OPEX associated with the processing of nodules into the three metals plus a MRS are difficult to estimate as there is no single practiced or established metallurgical approach. However, extrapolations from existing nickel processing facilities provide a useful first order estimate. SNL Lavalin, a major mining and minerals processing engineering consultancy, has provided a benchmarking study⁷ to one of the nodule collectors that outlines the capital requirements for recently constructed nickel processing facilities and then provides additional cost estimates to upgrade these facilities to capture copper, cobalt and the remaining manganese rich slag. That study looked at multiple different types of nickel facilities. For the purposes of this work, we chose to use values based on a nickel RKEF (rotary kiln electric furnace) process designed for 2.4 million tons per annum with modifications for extraction of the other materials and a scaling factor to adjust for the higher project volumes of 3.68 million dry tons of nodules per year. SNL Lavalin estimated the CAPEX at \$993.90/tonne or a total of \$2.385 billion. However, this included an estimated 45% charge for cost overruns. In order to maintain consistency with our model assumptions for the Mn metals processes, we eliminated the overruns resulting in a capital expense of \$1.645 billion. We then scaled this up considering a limited amount of economies of scale (applying an exponent of 0.9 as a scaling factor) to obtain a total capital expense of \$2.53 billion for a plant able to process 3.68 million dry tons of nodules per year.

To estimate the operating expenses, we took a similar approach, looking at the average of the current nickel cost curve, reverse engineering the cost per ton of ore processed and then added factors for the extra costs associated with copper and cobalt extraction and resulting in a manganese rich slag (MRS) or manganese oxide ore equivalent. In 2019, S&P Global Market Intelligence estimated that the average nickel cash cost (minus royalty) was \$8.80/kg Ni with an ore grade of 1.80% and a 90% metallurgical recovery rate, resulting in an operating cost of \$142.56/kg of ore for both mining and refining of the

⁷ "Polymetallic Nodules Process Plant Benchmark Study", SNL Lavalin, October, 2018.

nickel. We divided that into the mining cost (70%) and refining cost (30%) based on information from the S&P Global Market Intelligence database⁸ to give a refining cost of \$42.38/ton ore. Finally, we added a 7% premium for the extraction of cobalt and a 12% premium for the extraction of copper. These values were based on the additional capital expenses for these activities provided in the SNL Lavalin report. The resulting OPEX is estimated at \$50.44/ dry ton of nodules processed.

These values are rough estimates based on similar, but not identical nickel processing facilities. Significant variation is seen in both the capital expenses for nickel plants and the values on the nickel cost curve. More work is needed to get a better view on the processing route and costs if an MRS approach is be used.

Results of MRS Systems

Level of return from the payment system

55. Based on the assumptions described in the preceding section, we analyzed several payment system configurations for a system producing MRS. As noted previously, it is possible for a system to produce MRS while the basis for ad-valorem payments can also be MRS value or may be metal value. Table 6 shows the relevance of these two considerations.
56. In the first row of Table 6 we see the performance of a payment system that is equivalent to the two-stage ad-valorem system described in Table 4. Because the basis of ad-valorem payment remains the metal value of manganese, the expected revenue to the ISA remains the same at just over \$4.4 billion USD. Notice, however, that many other aspects of the system financial characteristics have changed because total revenue coming into the system have declined. For a system where MRS is produced, this 2%/6% ad-valorem system translates into an effective tax rate of 52% (vs. 45% when the system produces a Mn metal mix) and yields an expected collector rate of return of 13.4% (vs. 17.7%). It is likely tempting to redefine the basis of ad-valorem payments according the value of Mn in MRS. The second row of Table 6 shows the performance of a 2%→6% ad-valorem system where value is based on MRS. In this case, revenues to the ISA for the CHM drop to \$2.7 billion USD. The third row of this table shows that to keep revenues to the ISA similar to the metal-based 2%→6% system, a MRS-based system would need to charge at the 2%→10% level.

Table 6. Financial characteristics of three possible payment systems for a system producing MRS.

Basis of Payments (Mn fraction)	System	Median ISA Revenue (\$M)	Effective Tax Rate	Equivalent Fixed Ad-valorem Rate	Collector Rate of Return	Average Gross Nodule Value (\$/t)	Average Nodule Transfer Price (\$/t)
Metal Value	Two Stage Ad Valorem: 2% → 6%	4,430	52%	5.4%	13.4%	\$859	\$265
MRS Value	Two Stage Ad Valorem: 2% → 6%	2,720	44%	5.4%	14%	\$527	\$257
MRS Value	Two Stage Ad Valorem: 2% → 10%	4,430	52%	8.9%	13.5%	\$527	\$264

⁸ "S&P Market Intelligence 2019: Nickel", S&P Global, <https://platform.marketintelligence.spglobal.com/>, Retrieved July 1, 2020.

57. Figure 3 plots similar system characteristics for a broad range of payment system configurations for cases where revenue and value are set based on a Mn metal mix product (blue points) and cases where revenue and value are based on an MRS product (green points). We can see that across the board, systems that impose an equivalent level of effective tax, represent an equal equivalent fixed ad-valorem rate, or provide an equivalent rate of return to the contractor always generate less revenue for the ISA. Furthermore, we see that systems that provide the same level of revenue to the ISA, generate a far lower rate of return to the contractor (e.g., a system providing \$4,400 million USD revenues to the ISA is modeled to generate a contractor return between 17% and 18%, while an MRS-based system providing that level of revenue is modeled to generate a return around 13.5%). In fact, all of the systems considered in this analysis for the MRS-based system (green points in Figure 3c), which includes a system with no royalty at all, provide contractor returns far below the threshold levels that contractors have previously indicated were necessary to secure financing for seabed mining (17-18%).

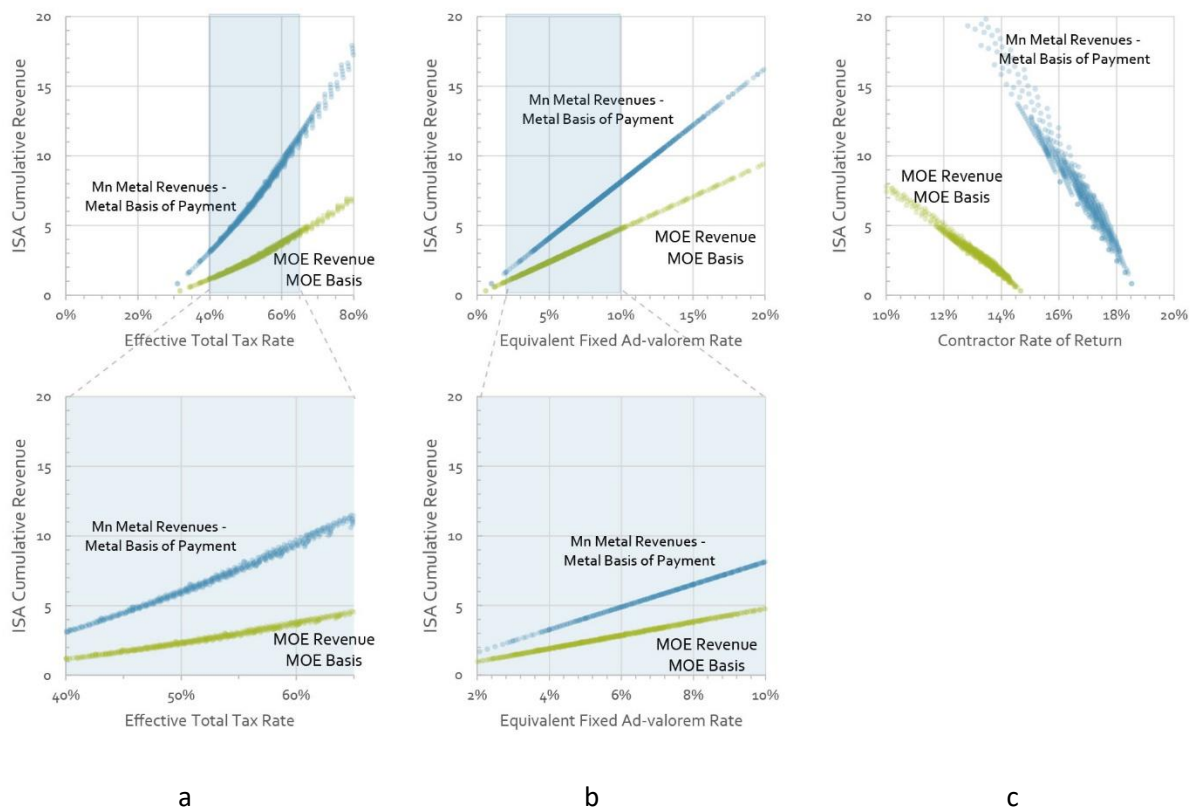


Figure 3. ISA cumulative revenue (in billions of US\$) for a broad range of payment system configurations applied to collection and production systems where the metallurgical processor produces a mix of manganese metal and alloys and where ad-valorem is based on such value (blue points) and where the metallurgical processor produces a manganese-ore equivalent product (MRS) and where ad-valorem is based on such value (green points). ISA cumulative revenue is plotted against a) effective total rate of taxation for the contractor, b) equivalent single stage ad-valorem rate, and c) contractor rate of return.

58. In fact, in Table 7, we see that if we impose the same ranges of reasonable system characteristics (i.e., effective tax rate between 40% and 65% and equivalent fixed ad-valorem rate between 2% and 10%) that an MRS-based production system would yield between \$1.9 and \$5 billion USD.

Economic Model of the System of Payments and Stakeholder Feedback

Table 7. Characteristic ranges of payment systems in land-based mining of equivalent commodities and the resultant expected ISA revenues from model simulations for a case where both revenues and nodule value are set based on a metallurgical process produces manganese ore-equivalent.

	Range	Low – ISA Revenue	High – ISA Revenue
Effective Tax Rate	40% - 65%	\$1.9 billion	\$7.3 billion
Fixed Ad Valorem Equivalent	2% - 10%	\$1.0 billion	\$5.0 billion

59. Because the research team has not investigated the MRS-based system as extensively as the metal-based system, we explore an important source of uncertainty for these conclusions – the costs of constructing a facility that processes nodules to extract three metals and MRS. Figure 4 plots how ISA cumulative revenue would be affected for an equivalent level of effective total tax rate or contractor rate of return if capital expenditures were 25% lower than for the baseline assumptions for the MRS case. (Equivalent fixed ad-valorem rate is not affected by lower capital expenditures and therefore this plot would not differ than the one presented in Figure 3b.) We can see from this plot that lower capital expenditures have little impact on the effective total tax rate and therefore any systems defined using that criterion. However, lower capital expenditures could have a significant impact on realized contractor rate of return. Although lower capital expenditures improve contractor rate of return, only extremely low revenue systems (e.g., at or below \$1 billion total cumulative ISA revenue) would allow that metric to climb above 16%.

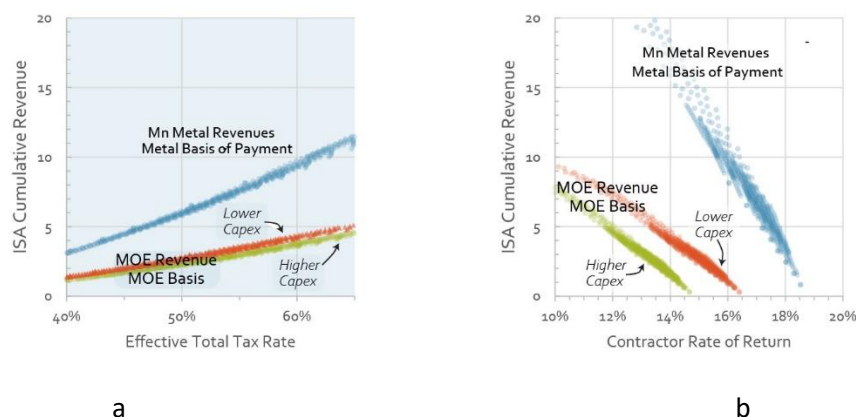


Figure 4. ISA cumulative revenue (in billions of US\$) for a broad range of payment system configurations applied to collection and production systems where the metallurgical processor produces a mix of manganese metal and alloys and where ad-valorem is based on such value (blue points) and two cases where the metallurgical processor produces a manganese-ore equivalent product (i.e., MRS) and where ad-valorem is based on such value (green points = default capital expenditure assumptions; red points = 25% lower capital expenditure assumptions). ISA cumulative revenue is plotted against a) effective total rate of taxation for the contractor and b) contractor rate of return.

60. For the research team, these results indicate that there are important gaps in our understanding of an MRS-based system. Either costs are far lower than currently estimated (for example operating multiple collectors from a single surface support vessel), revenues are higher, or lower threshold sources of funding have emerged. In any case, it is difficult to make a recommendation on an appropriate level of return for this system at this time.

Selecting the basis of payments – response to future conditions

61. While it is difficult to comment on the appropriate level of revenue or return for an MRS-based system, it is still possible to offer guidance about the configuration of a payment system in this context. All three types of systems of payments that are being considered here, can be designed to provide an equal expected level of revenues to the ISA for the CHM. (See Table 4 for an example of this.) However, these three systems respond differently if future conditions are not as expected. The most notable way in which these systems differ is how the level of revenue would change if future metal prices differ from the modeled expected future prices.
62. Figure 5 plots how each of three \$4.5 billion systems, implemented in a MRS-basis, would respond if prices were either below or above expected levels. Just as when these systems are applied in a metal-based context, we see from this plot that despite the fact that all three provide the same level of expected return (median of \$4,400 million USD to ISA for CHM), they respond differently if conditions deviate. Specifically, we see that the two-stage ad-valorem system (2% going to 10%, MRS-basis) varies the least with realized future prices ranging from \$3,300 million if prices are 20% below expected to \$5,700 million if prices are 20% above expected. The variable rate ad-valorem system and blended system drop a similar amount if prices are below expectations (\$2,700 and \$2,900 million, respectively, if prices are 20% below expectations). The variable rate ad-valorem, however, performs the best if realized prices exceed expectations, providing an additional \$1,800 million return over the two-stage ad-valorem if prices are higher than expected.
63. Based on these modeled results, the research team continues to recommend the ISA to select a variable-rate ad-valorem system.

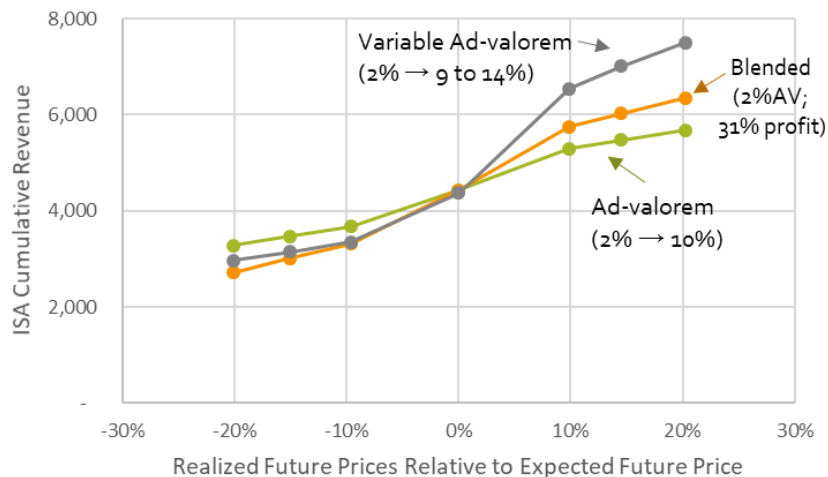


Figure 5. Impact of realized prices on the performance of three payment systems for a processing system producing cobalt, copper, and nickel metal and an MRS (manganese-ore equivalent) product. ISA cumulative revenues over the lifetime of mine operations in million USD. All three systems have a median ISA cumulative revenue of 4,400 million USD. Realized prices are plotted relative to expected future prices. 0% here means no deviation from expected future prices.

Concluding Remarks

64. Based on the results presented here, the research team feels that it is appropriate to stay with the recommendation presented in earlier reports. Namely, a payment system based around a variable ad-valorem charging 2% of nodule value for beginning of collection operation and a variable rate ranging from 5% to 9% of nodule value beginning in year five of collection operations. Until further information is collected about the MRS based system, we assume that nodule value is based on four metals including a mixture of Mn metal and alloys.
65. Based on model refinements, this system yields a median \$4.43 billion in lifetime revenue to the ISA under base case assumptions. This system is within the bounds of reasonableness for effective tax rate and ad valorem rates as shown by RMG, Otto and others. This system captures more revenue (\$7.7 billion) if prices are higher than anticipated and keeps the tax rate nearly constant at high prices, thus enabling ISA to achieve the maximum benefits. Of course, this also means that if prices are lower than expected, ISA will receive less (\$2.8 billion), but a still reasonable amount.
66. An alternate approach would be to go with a two-stage ad-valorem system starting at 2% of nodule value, rising to 6% in the fifth year of collection operations. This would still achieve median return to the ISA of \$4.43 billion in lifetime revenue, but would not fully capture upside benefits if prices rise.
67. While an MRS-based system has some benefits, refinements are needed to better understand this system before we could make a full recommendation. However, an ore system will necessarily have a lower price basis for the ad valorem, and therefore the rates must be adjusted if ISA intends to receive the \$4.43 billion that would be associated with the system described above.
68. Next steps are to set the details of the implementation of the royalty systems. There are many ways in which an ad-valorem system could be implemented. The basis of value could be the ore, the metal contained in the ore, the net-smelter revenue, and others. The research team strongly believes that for an initial implementation of a payment system the value basis should be a transparent, internationally available price index and should not require collecting information from stakeholders outside of ISA jurisdiction. The ISA needs to establish exactly which price indices will be used, how will the quantity of nodules removed be reported, what will be the schedules, reporting and specific techniques used for the assaying of nodules removed from the seabed, and the frequency of the royalty payment calculation. The modeling work presented in this report is based on 2 collectors from 2 mining vessels operating simultaneously.
69. Further refinements to cost, particularly around the idea of multiple collectors operating from a single mining vessel, could be insightful. If it could be done, the use of multiple collectors from a single mining vessel would save the collectors considerable upfront expenses, but this introduces many additional technical challenges compared to a one-ship-one-collector operation. At first glance, this should not matter to the ISA as their revenue would be unchanged. However, the contractor IRR would rise considerably indicating that the ISA may have been justified in charging higher ad valorem rates to share in this increased profitability of the system.