Understanding the Economics of Seabed Mining for Polymetallic Nodules

International Seabed Authority
Council Meeting – Kingston, Jamaica
March 6, 2018

Richard Roth
Research Team: Randolph Kirchain, Frank Field and Thomas Peacock

Massachusetts Institute of Technology
Materials Research Laboratory

MSL
Materials Systems Laboratory

Goals of the Presentation

- Understand the various activities required to successfully retrieve nodules from the seabed and process them into saleable materials
- Explain the costs associated with each of the required process steps
- Explore the sources of revenues and the implications of different approaches to revenue sharing (between Contractors & Common Heritage of Mankind)
- Discuss sources of uncertainty and their impacts on revenues and financial/investment decisions

How would a seabed mining project develop?

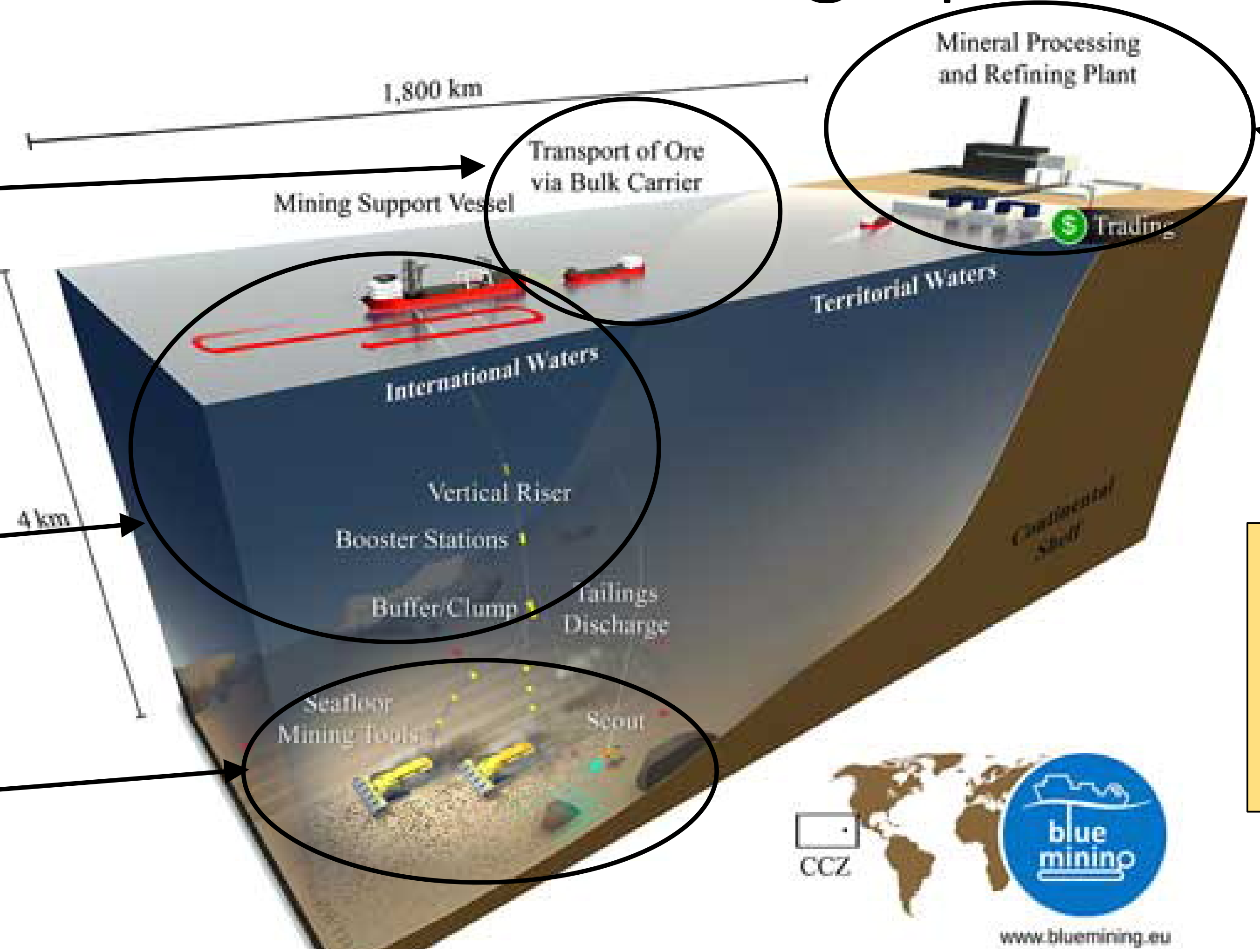
	Timing		
Exploration	6 years	**Pre-feasibility**	Seabed Surveying Studying Site Details
	4 years	**Feasibility**	Develop Mining & Processing Plan Determine Equipment Needs
Construction	3 years	**Investment**	Purchase & Deploy Equipment
Operations	23 years	**Mining**	Mining & Process Operations (see next slide for details)
	2 years	**Shut Down**	Ramp Down Operations

What's required for the mining operations?

Transport

Lift/Platform/ Process Water

Nodule Collection

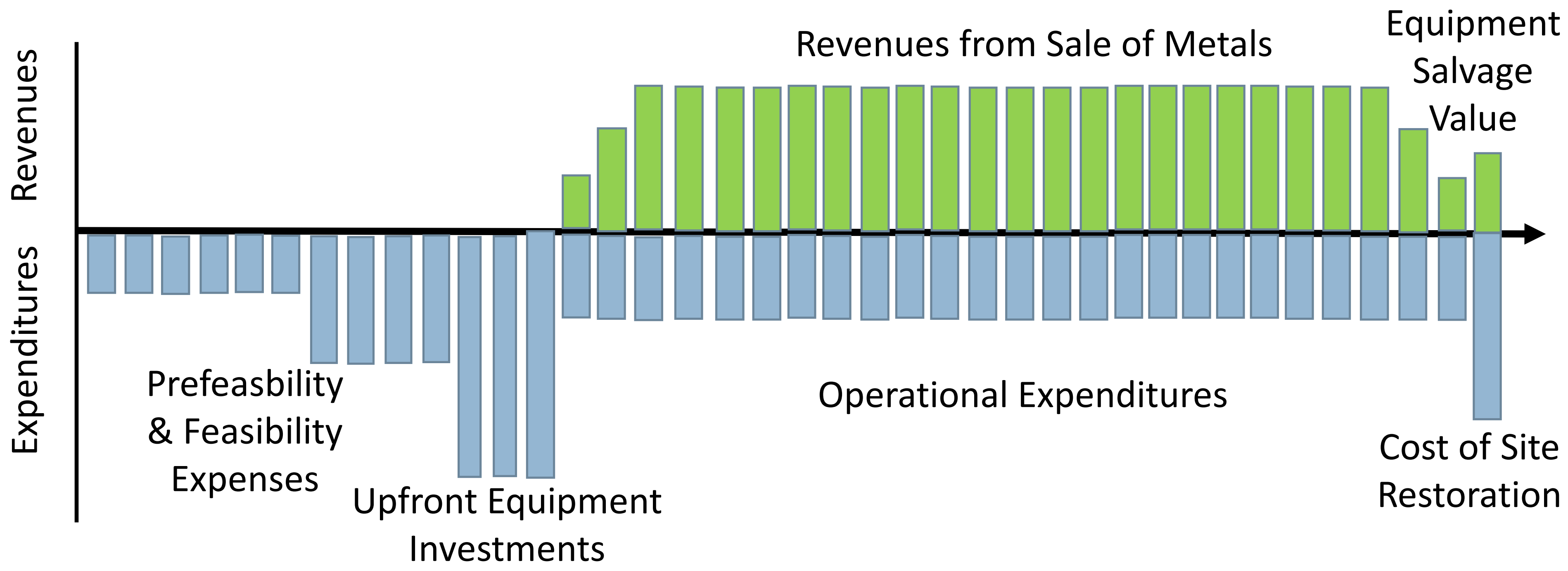


Metallurgy
Separate the four metals

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

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

Let's keep track of cash flows through project life



Investors will only take on project if discounted future revenues are large enough to provide a return on their investment that is competitive with other investment opportunities

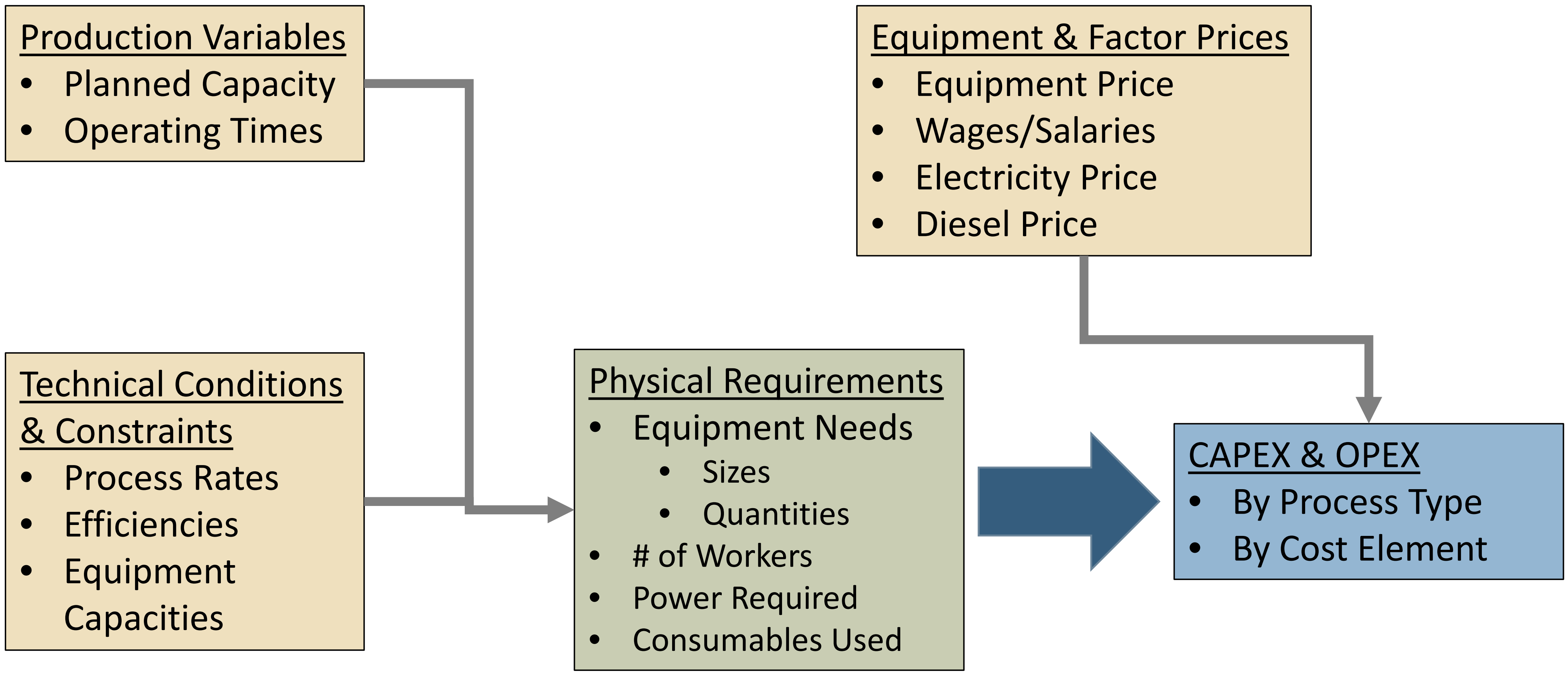
System is only economically viable if **Revenues exceed Expenditures**
All cash flows need to be **discounted** to account for time value of money
(One dollar today is worth more to me than one dollar in the future)

What Drives Costs & Revenues?

- Upfront Costs
  - Feasibility Studies
  - Collection System & Platform
  - Transport Ships
  - On-shore Metallurgical Plant
- Revenues
  - Sales of 4 metals: Manganese, Cobalt, Copper & Nickel
  - Revenue = Quantity Sold * Unit Price of Metal

- Operating Costs
  - Energy
    - Electricity for collectors, risers & pumps and for the platform
    - Fuel for transport ships
    - Electricity & fuel for metallurgy plant
  - Labor
    - Personnel on platform
    - Crew on transport ships
    - Workers at metallurgy plant
  - Maintenance (for all equipment)
  - Process materials (mostly for metallurgy plant)

How can costs of nodule mining be modeled?



Where are we getting the cost data?

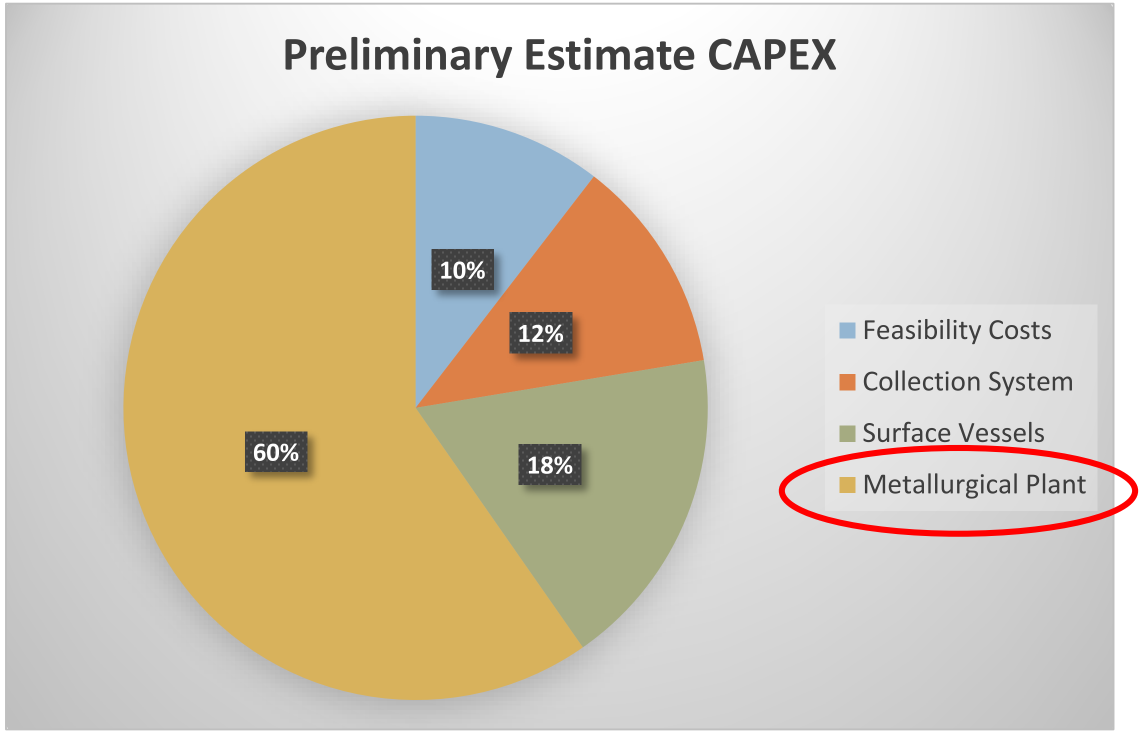
<u>Production Variables</u>
- Scenarios (eg. Capacity)
- Industry Averages (eg. Uptime)
- Earlier Seabed Mining Studies

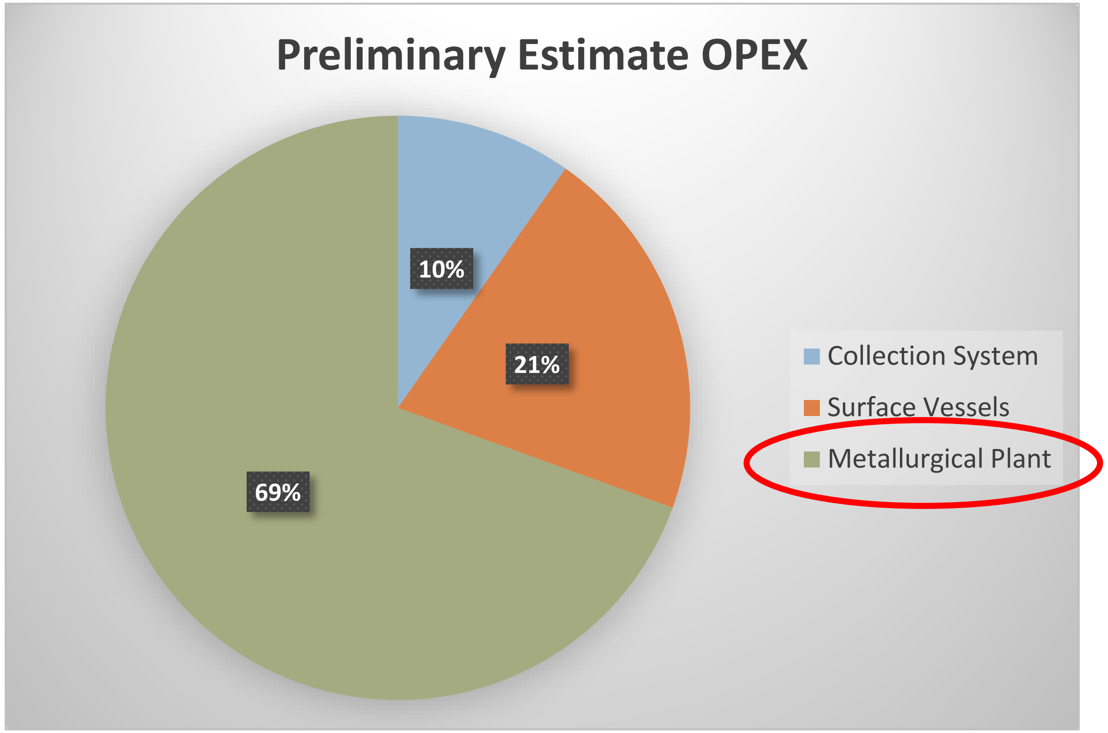
<u>Technical Variables</u>
- Physical Relationship (eg. Process Rates)
- Geophysical Data (eg. Coverage, Topology)
- Engineering Rules of Thumb (eg. Extraction Efficiencies)

<u>Equipment Prices & Factor Costs</u>
- Published Price Data
- Estimates from Similar Industries (eg. Land-based Mining)
- Regional Economic Data

- Leveraged previous seabed mining studies and related literature whenever possible
- Reverse engineered inputs from high level results and performed reality checks to validate the approach
- Uncertainty: there is significant variation among the many sources

Why are costs so high?





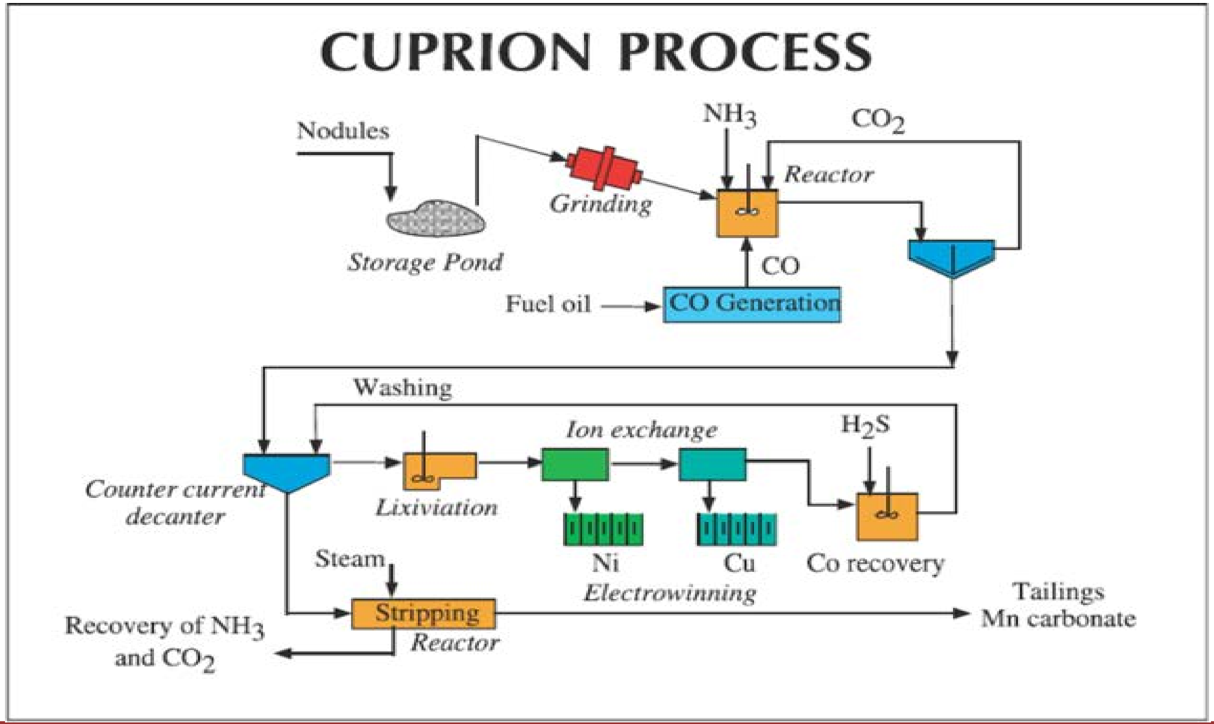
Total CAPEX between $3.0 and $4.0 billion

Total OPEX between $600 million and $1.1 billion/year

What goes on in the metallurgy plant & why is it so expensive? *(example process)*

Four metals, Ni/Cu/Co/Mn, must be separated from nodules, one by one

1. Nodules must be prepped (ground & washed)
2. Nickel & Copper are separated by electrowinning
3. Cobalt is recovered through reaction with Hydrogen Sulfide
4. Process materials are removed leaving Manganese carbonate



Upfront Capital Expenses
- Expensive equipment in the form of reactor vessels, electrowinning furnaces, etc.
- Large buildings/site required for operations

Ongoing Operational Expenses
- Electricity for electrowinning processes
- Fuel for preparation steps
- Consumables for prep & Cobalt recovery
- Labor throughout the process

Image from http://www.omlus.com/ocean-minerals-llc-technology/

Let’s move on to revenues

Revenue = Quantity for Sale * Price of the Metal

Summed up for the four metals

Quantity for Sale ≠ Weight of Nodules

4 metals only make up about 30% of nodule mass
There are losses throughout process
100% recovery not practical in metallurgy plant

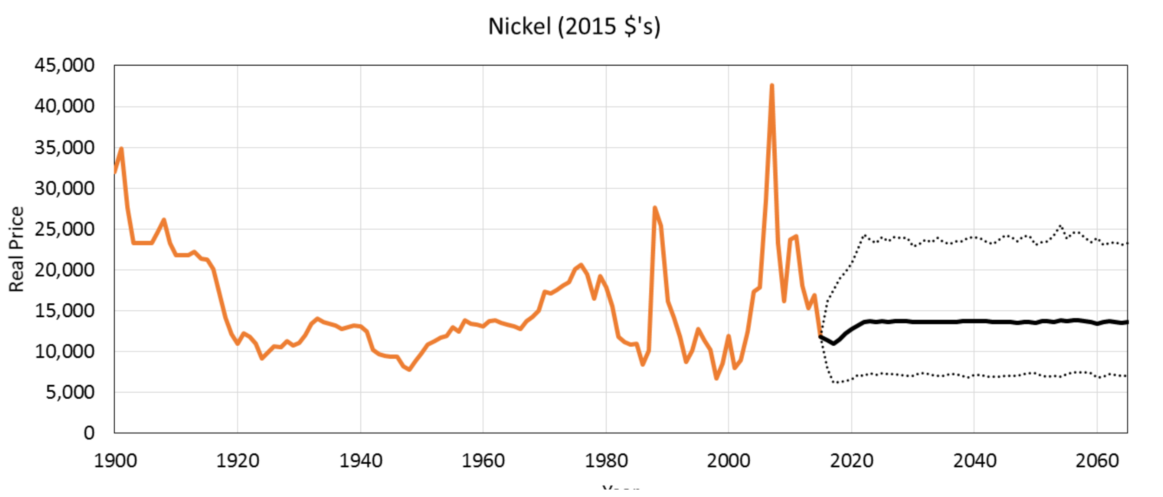
	Composition	Recovery	Current Price *($/ton)*
Mn	27.00%	95%	$1,600
Ni	1.30%	95%	$16,000
Co	0.25%	85%	$50,000
Cu	1.20%	90%	$7,000
Other	70.00%		

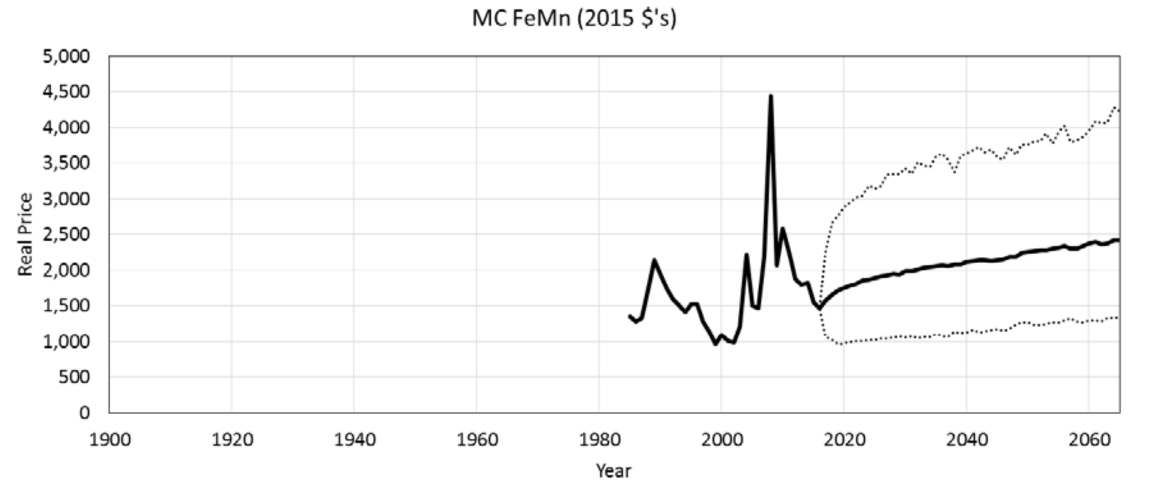
Assuming 3 million dry tons nodules collected per year at today’s prices

	Amount Material Recovered *(tons)*	Revenue *($millions)*
Mn	769,500	$1,231
Ni	37,050	$593
Co	6,375	$319
Cu	32,400	$227
TOTAL	**845,325**	**$2,370**

What about future prices?

- Large historic variation for all relevant metals
  - Large uncertainty in future prices
- Could just use today's price
- Do a trendline analysis, but over how many years?
- Construct a more sophisticated statistical analysis using additional macro-economic data
- Investigate interactions between supply and demand



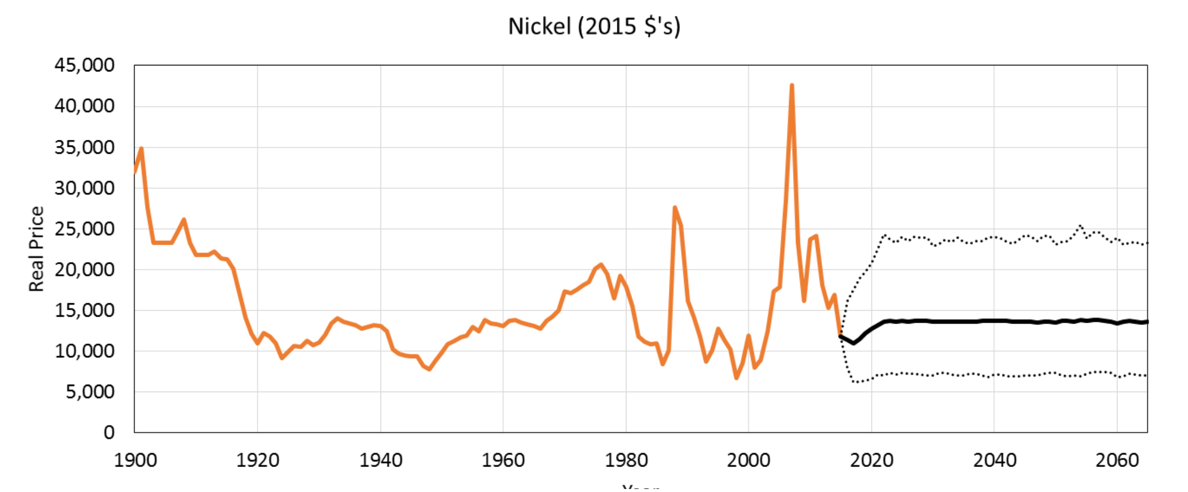


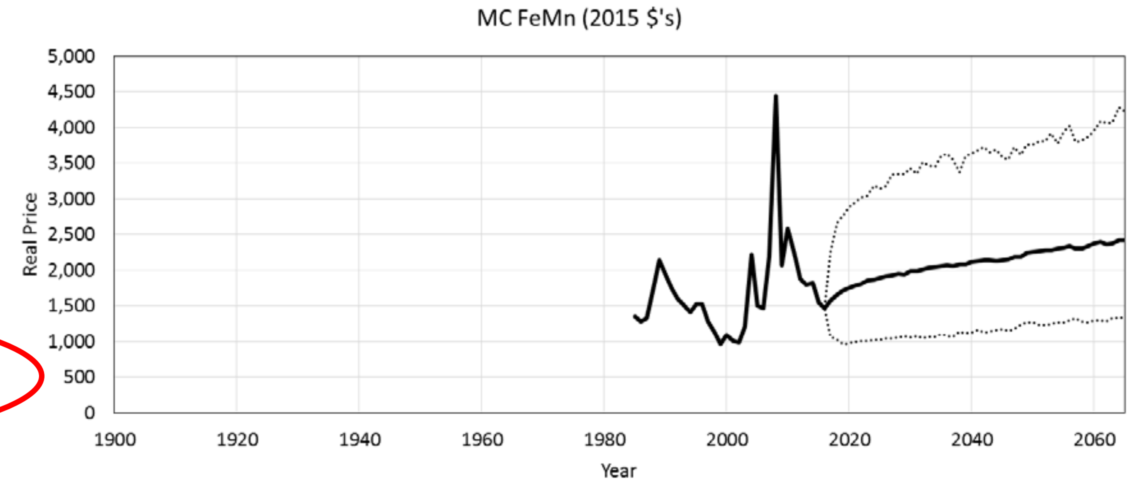
What about future prices?

Even the most sophisticated statistical analysis can only capture past behavior. Structural changes in:

- Supply (due to new sources like seabed), or
- Demand (due to new technologies such as Electric Vehicles)

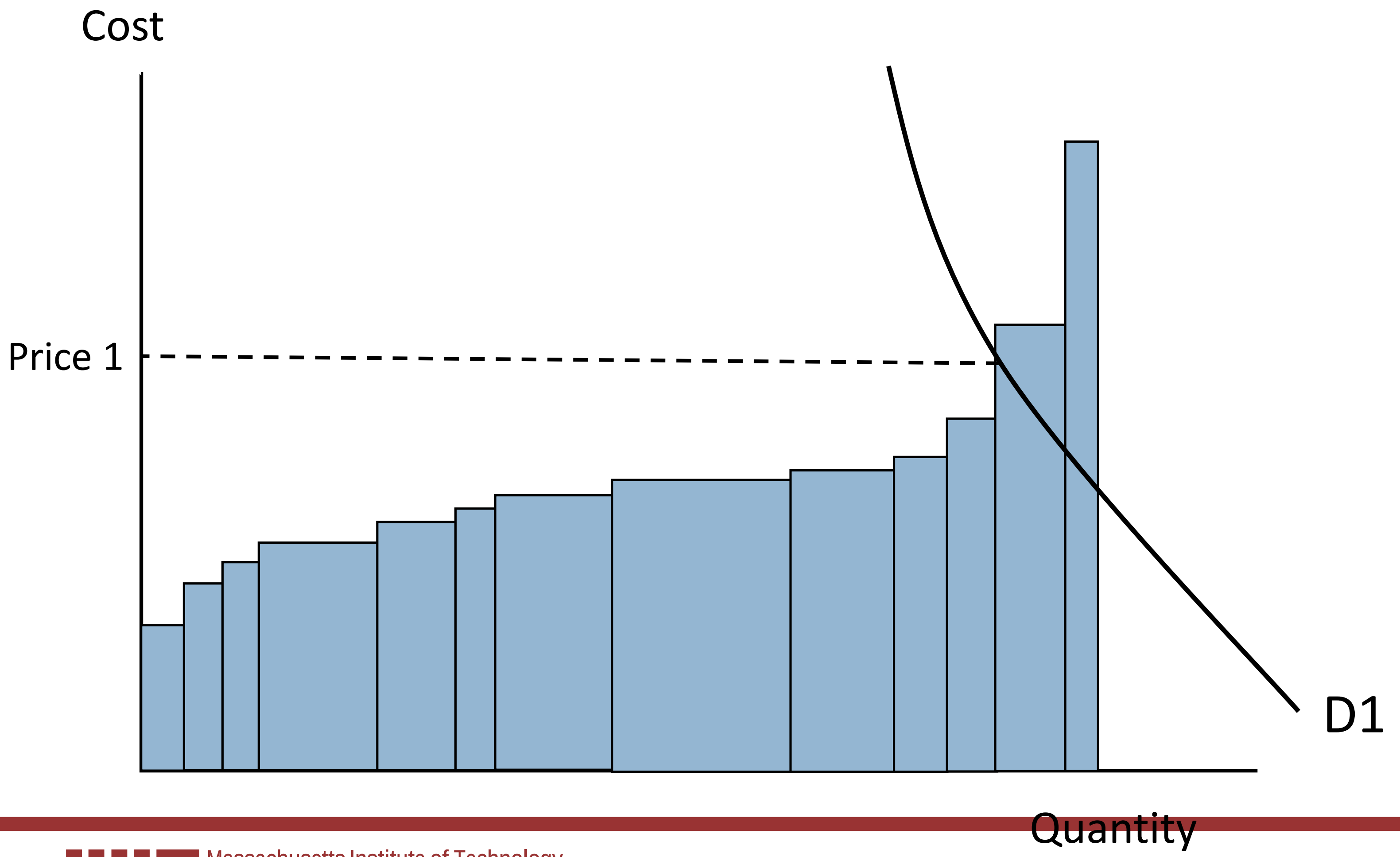
cannot be captured by historical/statistical models





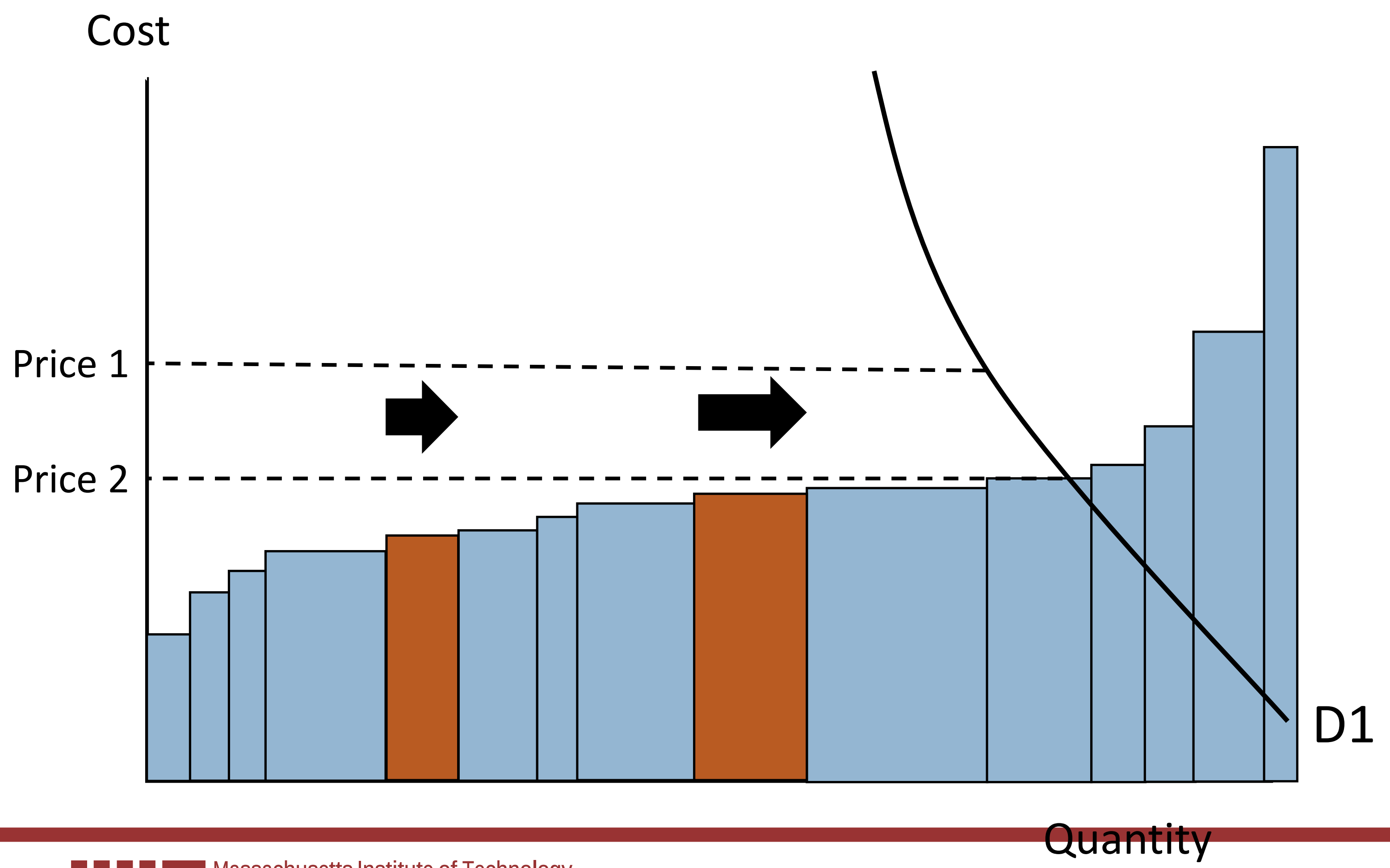
- Construct a more sophisticated statistical analysis using additional macro-economic data
- Investigate interactions between supply and demand

How might new mining technology potentially affect prices through supply-demand modeling



- Individual mines represented by cost and capacity
- Mines are ordered with increasing costs
- Price is determined by the intersection of demand with supply

How might new mining technology potentially affect prices through supply-demand modeling



New mines are added according to their initial capacity and cost

- Inserted into the supply curve at their cost point

Results in stretching of the supply curve

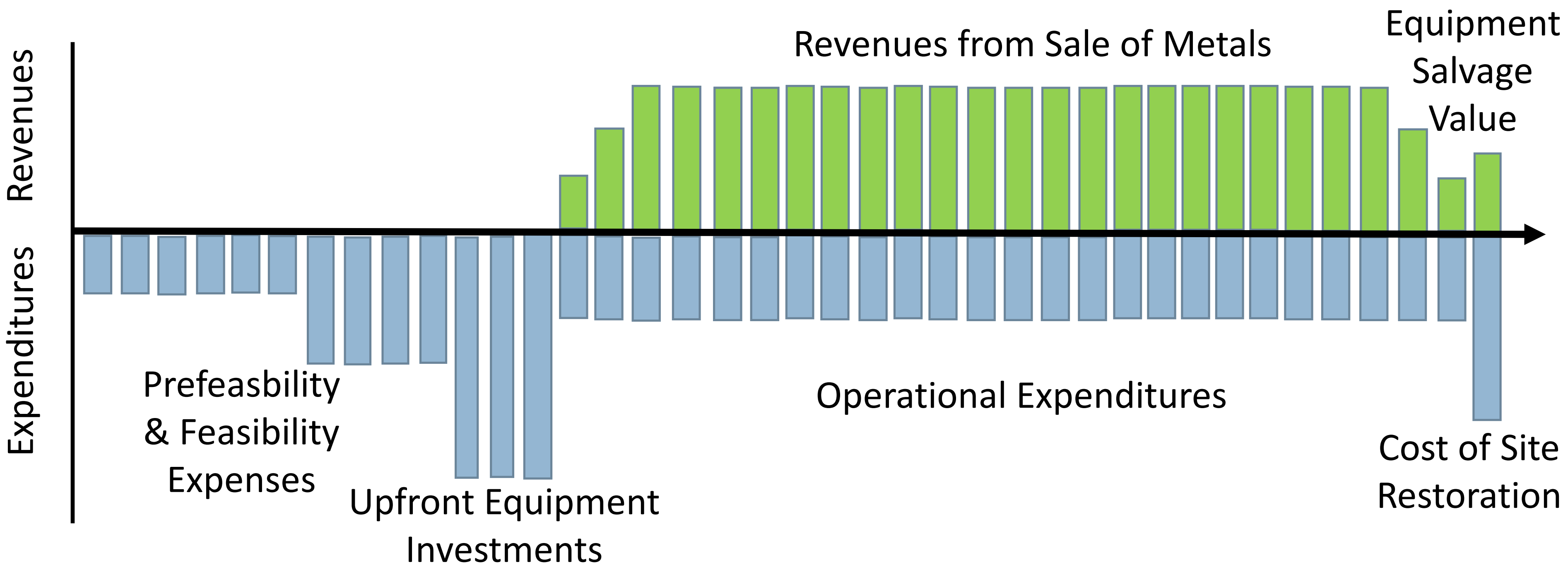
Demand now intersects supply at a lower price

Effect is most pronounced when demand intersects supply on a steep part of the curve

Why is future price uncertain? And why does that matter so much?

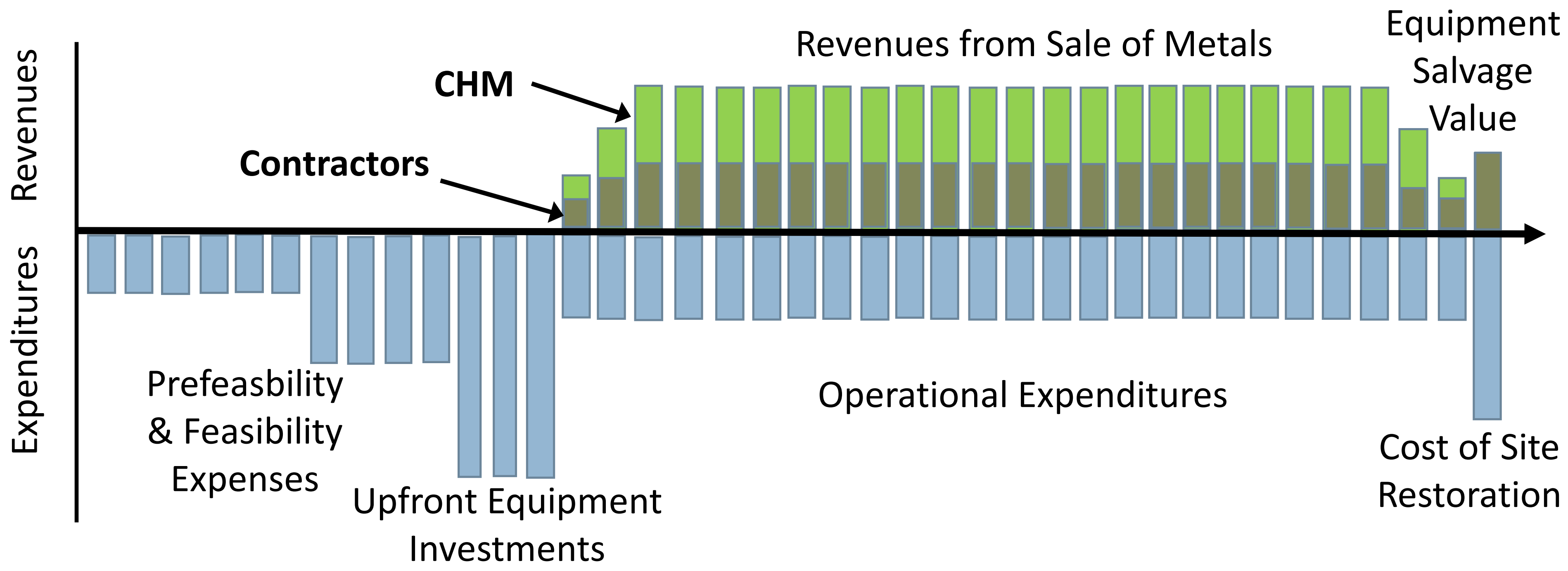
- Both supply/demand and statistical models require some forecasting of the future
  - The future can never be known with certainty
  - Models can only hope to provide some insights, not definitive results
  - Changes in the economy, technology, nature, etc. can all have big impacts
- Since revenues are proportional to prices, uncertainty can have major impact on profits
  - High Prices → Large Revenues → Lots of Profit
  - Low Prices → Smal Revenues → Low Profit or Maybe Even Losses
- Investors may be reluctant to spend a lot of money upfront if their future profits/revenues are very uncertain

How can we think about dividing revenues between contractors and Common Heritage of Mankind (CHM)?



Investors will only take on project if discounted future revenues are large enough to provide a return on their investment that is competitive with other investment opportunities

How can we think about dividing revenues between contractors and Common Heritage of Mankind (CHM)?



Investors will only take on project if discounted future revenues are large enough to provide a return on their investment that is competitive with other investment opportunities

Need to offer the contractors enough revenues to make it worthwhile and to attract investors
Financial institutions/other investors require higher rates of return for projects with higher levels of risk

How large should the contractors share be? What rate of return will be needed to attract investment?

Higher Risk

Greater Rate of Return Required

Nearly Guaranteed Investment (for example: Gov't bonds)	→	Very low returns required (0% - 3%)
Land based mining	→	Moderately high returns required due to price & geological risk (typically above 15%)
Seabed mining	→	Higher returns than land based mining Same risks, plus technological risk Never been done at scale before Banks may be unwilling to provide loans
Highly Speculative Venture Capital (Angel investments in new tech)	→	Very high returns required (sometimes well in excess of 100%)

What mechanisms can be used to divide revenues?

Increasing Risk to CHM

Increasing Upside Potential

Mass Based	$/dry ton of nodules removed from seabed	Guaranteed revenue, but if prices rise, CHM does not get any additional benefit.
Revenue Based or Ad Valorem	$/$ revenue (% of revenue) or $/$ value of nodules removed	CHM only subject to risk of price variation, not contractors cost overruns. If prices rise, CHM gets extra benefit. Simple to calculate & monitor
Profit Based	$/$ profit (% of profits)	CHM revenues subject to both price & cost uncertainties. Very complicated to monitor. What rules for calculating profit will apply?

**combination strategies are also possible*

Knowing the rate of return required by investors, revenue sharing mechanism rates can be calculated.
Other factors such as environmental bonds or other fees need to be included.
Resulting share of revenue to CHM can also be determined.

Why are profits difficult to determine & monitor?

- Profits are usually reported on the firm level, not individually for each project
  - Can firms re-invest revenues and count that against profit?
  - Do R&D expenditures count against profit?

- How are upfront costs spread over the operating period?
  - Are there any profits prior to the full upfront investments being repaid?
  - If so, how much of upfront investments can be charged against profit each year (depreciation schedule and rates)

- Every jurisdiction has its own rules for calculating profit

- How will profits be monitored? By who? How will monitoring be funded?

So what now?

- MIT has constructed three interconnected models to evaluate system
  - Cost Model
    - Collection/Risers/Platform
    - Transport
    - Metallurgy
  - Price Forecast Model
    - Current approach is a statistical model
    - Propose more detailed supply/demand model to investigate how seabed mining might impact metals prices
  - Cash Flow Model
    - Considers different revenue sharing mechanisms
    - Used to investigate what rates are appropriate
- Next step is to run models under different scenarios to provide guidance about the revenue sharing mechanisms and rates