When The ~~Price~~ Cost is Right:

Stochastic Modeling of an Asteroid Mining Business Case

Matthew Rehberg, Joseph Kenrick

Jeffrey Greene, Ken Liange, DeLaine Meyer, and Colby Moxham

The work being presented is a subset of the work done as part of the Colorado School of Mines 591 and 592 Space Resources Projects Class. For more details on the other aspects of an asteroid mining business case, please see the contacts and summaries below.

Asteroid Mining Business Case

Spacecraft Cost and Mass

Matthew Rehberg
mrehberg@mines.edu

SCAMM focuses on creating a spacecraft cost and design given uncertain input parameters.

Matthew works as an autonomy systems engineer on Blue Origin's New Glenn Rocket

Cash Flow

Joseph Kenrick
joseph@lunaroutpost.com
SCFM analyzes the cash flow side of an asteroid mining business.

Joseph works as the Project Manager for Lunar Outpost Oceania's Trailblazer program.

Competition

Jeffrey Greene
Jeffrey.b.greene@lmco.com
Jeff performed reviews of both resources and asteroid mining companies, created risk reduction techniques and designed the processing system

Jeff is an AI/ML engineer at Lockheed Martin Space

Prospecting

Ken Liang
kennethliang@mines.edu

Focused on low-cost/low-mass power and prospecting system architectures.

Ken is the co-founder & CTO of Orbital Mining Corporation.

Political Risk

DeLaine Mayer
Delainemayer@gmail.com

DeLaine researched the geo- and astropolitics of space tech commercialization.

DeLaine is Head of Partner Success at Genecis Bioindustries.

Engine Analysis

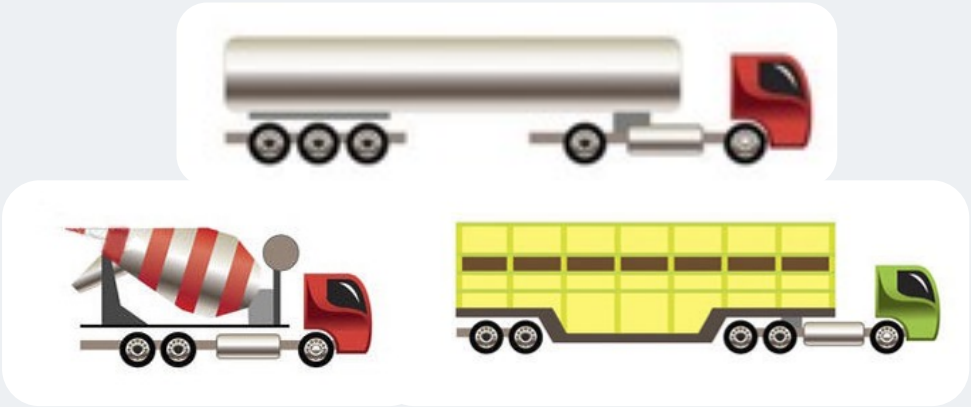
Colby Moxham
Cmoxham@mines.edu

Colby's expertise is in thermal analysis while employed at Lunar Outpost.

He now works as a senior thermal analysis at Ultra Safe Nuclear Corporation.

Story Board

- Where are we going to sell asteroid material?
- What type of resource are we going to sell?
- What type of spacecraft design is most economically efficient?
- What does the overall business case look like?



Cost – $1.16 b
Return – 0.060 kg
Sale Price – $19.3 b/kg

The cost in question.

Earth

11.44

GTO

0.68

EML-1

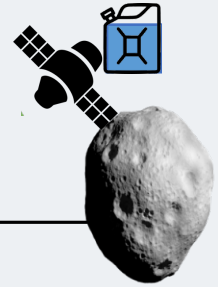
0.58

Moon
Transfer

0.09

Earth
Escape/Capture

0.5 - 5



Near Earth Asteroid

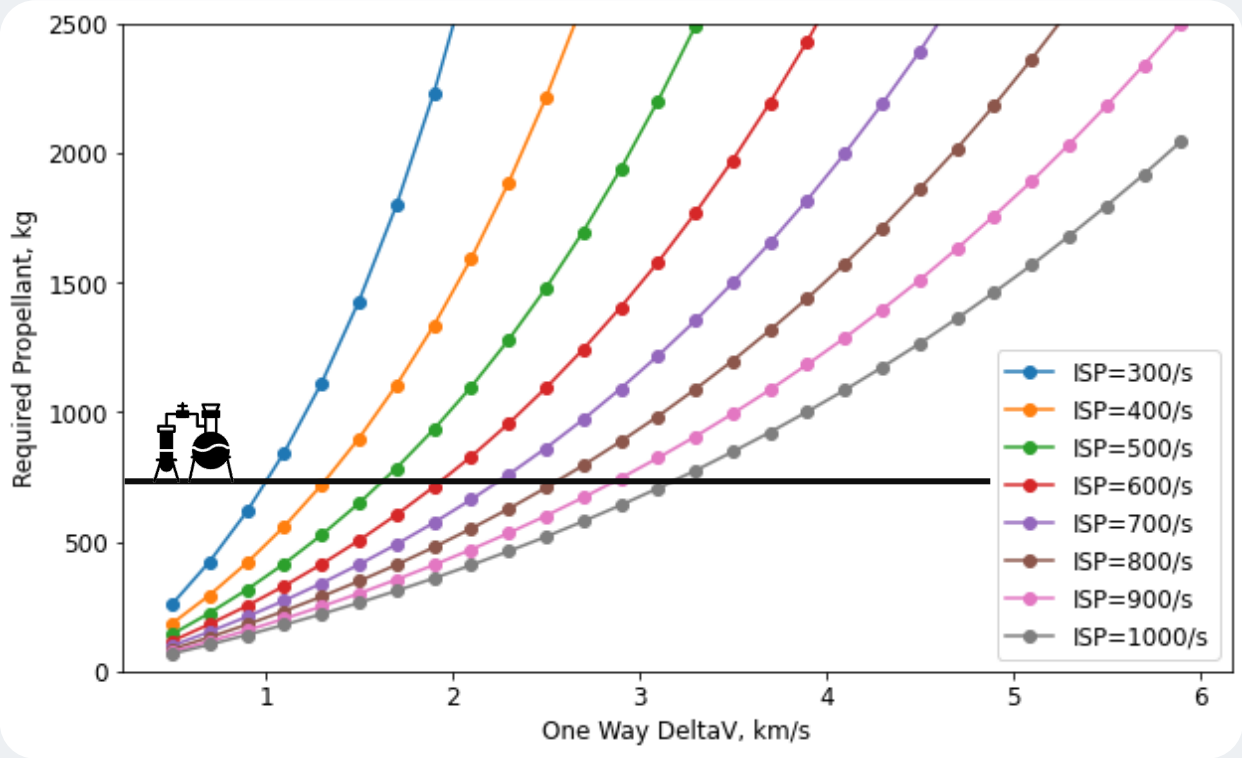
We chose to analyze selling material at EML-1. For modelling implications, the location dictates only the deltaV to and from a Near Earth Asteroid.

250 kg Dry Mass

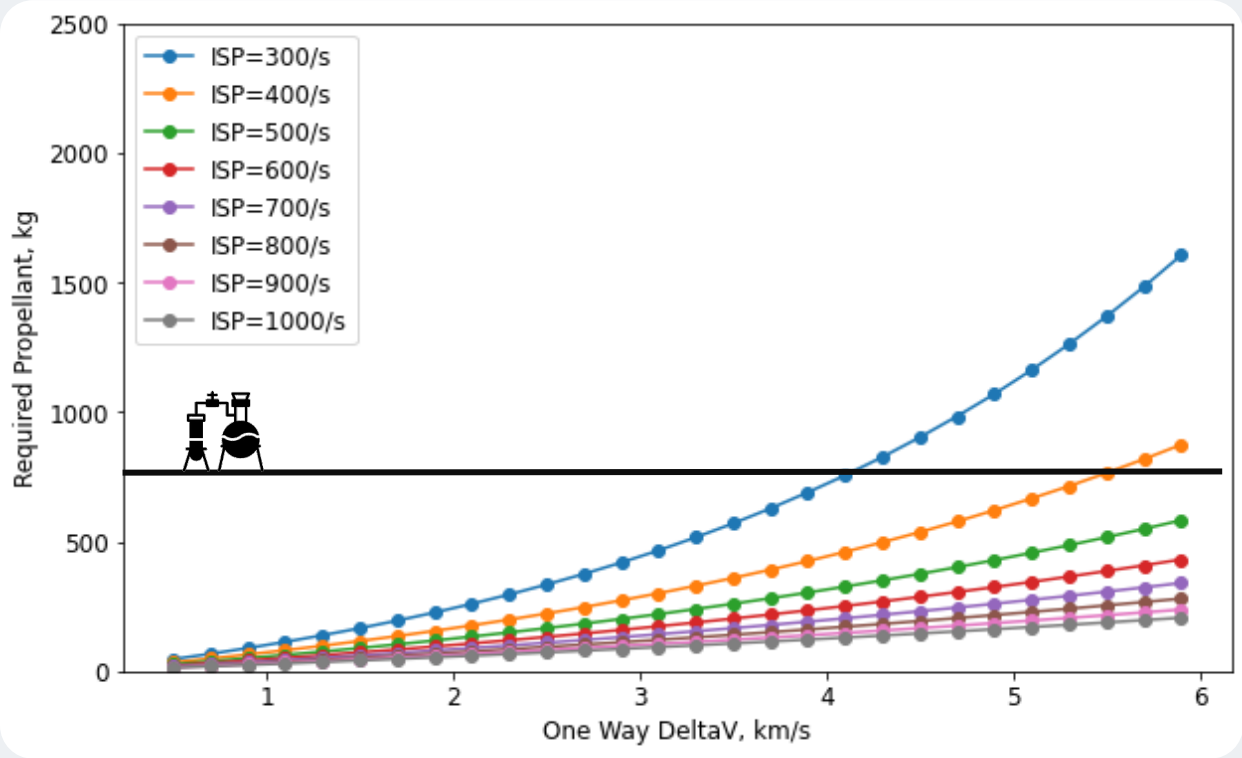
Propellant Mass Used to Deliver Payload > Payload Mass

We chose an architecture where we harvest water from the asteroid and we utilize that water as propellant to delivery the payload to EML-1.

All Propellant is Launched with Spacecraft



In-Situ Propellant used from Asteroid to EML-1

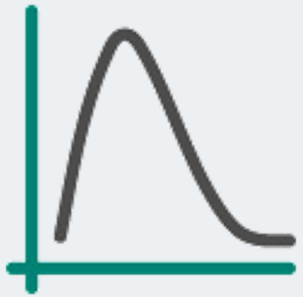


A Stochastic Cost And Mass Model (SCAMM) was created that varied input parameters along a distribution defined by a minimum, p10, p50, p90, and a maximum value.

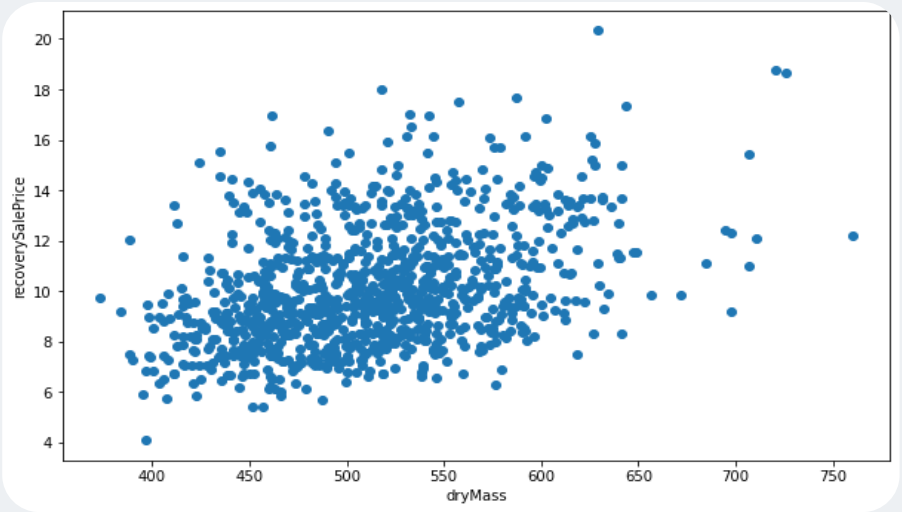
Inputs

- Power Source
- Engine Type
- Cost Estimation Relationships
- Payload Capacity
- Asteroid Max Radius
- …
- 90 Other Parameters

Weibull Distribution



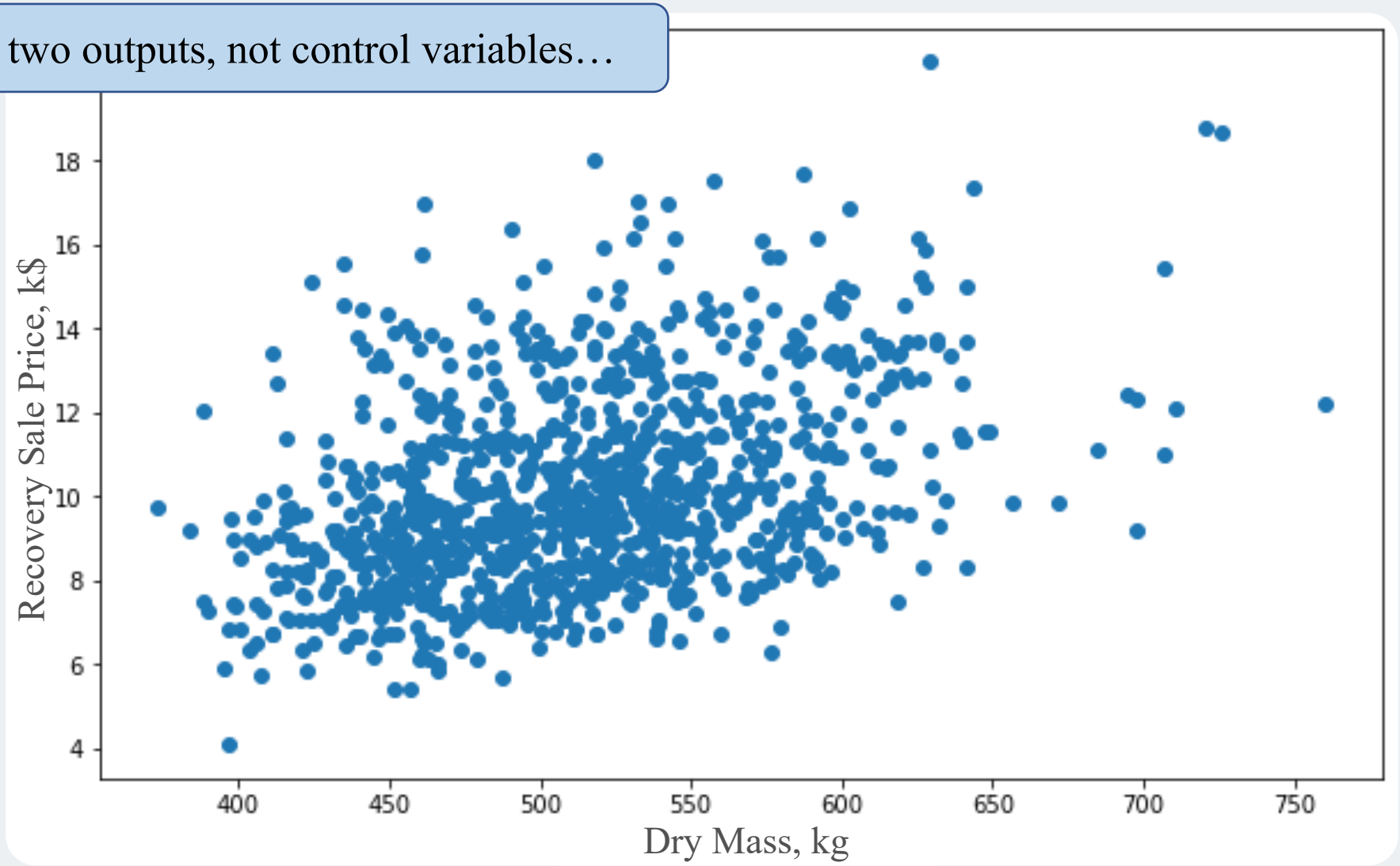
SCAMM



Outputs

- R&D Cost
- TFU Cost
- Recovery Sales Price
- Dry Mass
- …

But these are two outputs, not control variables…



$$(RSP)\ RecoverySalePrice = \frac{R\&D + TFU + Launch}{payloadMass\ * roundTrips}$$

There is an economic advantage when using solar thermal as the heating source for processing, but this technology has a low TRL.

Processing Power Source

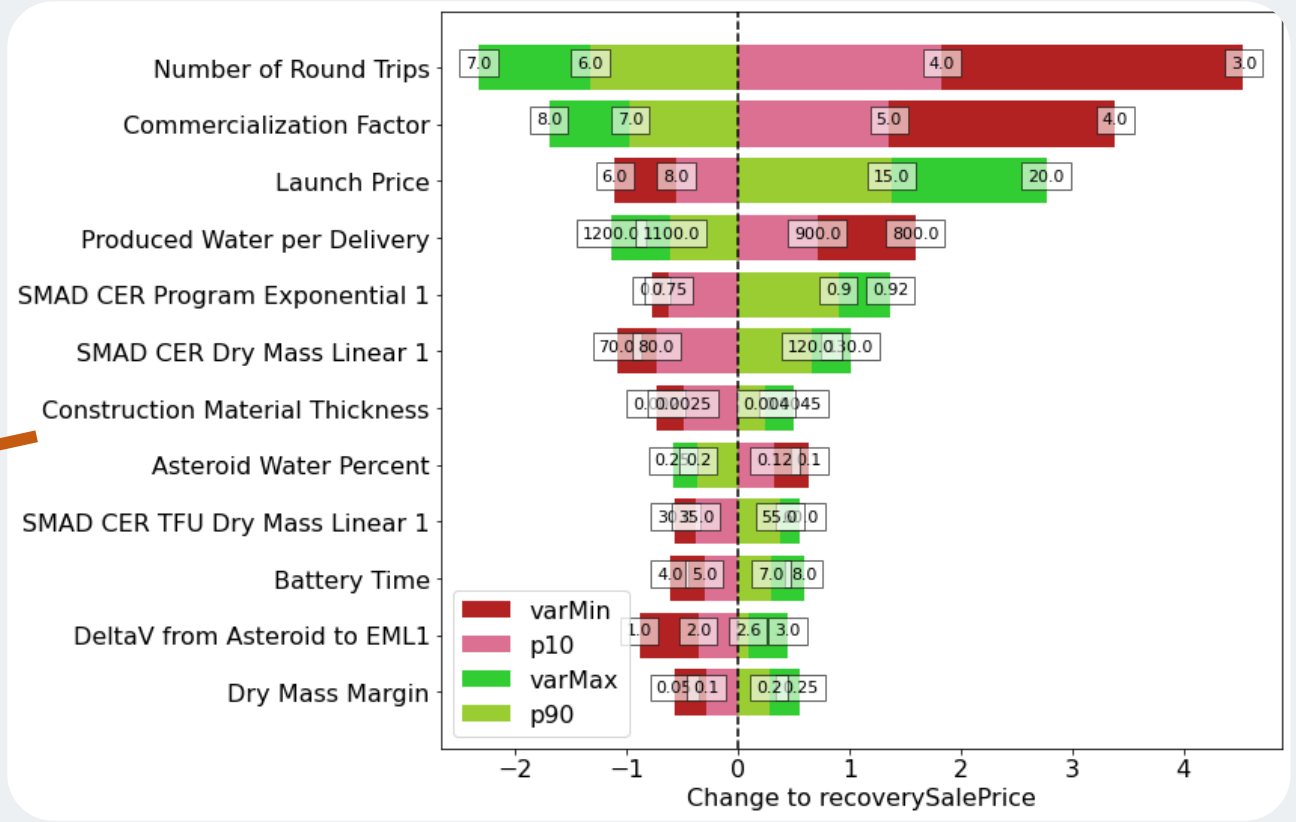
TRL

Engine Type

Complexity

TRL

RSP ($k/kg)	Solar Panels	Solar Thermal
Dirty Steam	20.2 ± 4.9	11.8 ± 2.5
GO2-GH2	21.5 ± 6.6	12.3 ± 3.0
LH2-LO2	20.4 ± 6.4	13.6 ± 3.3

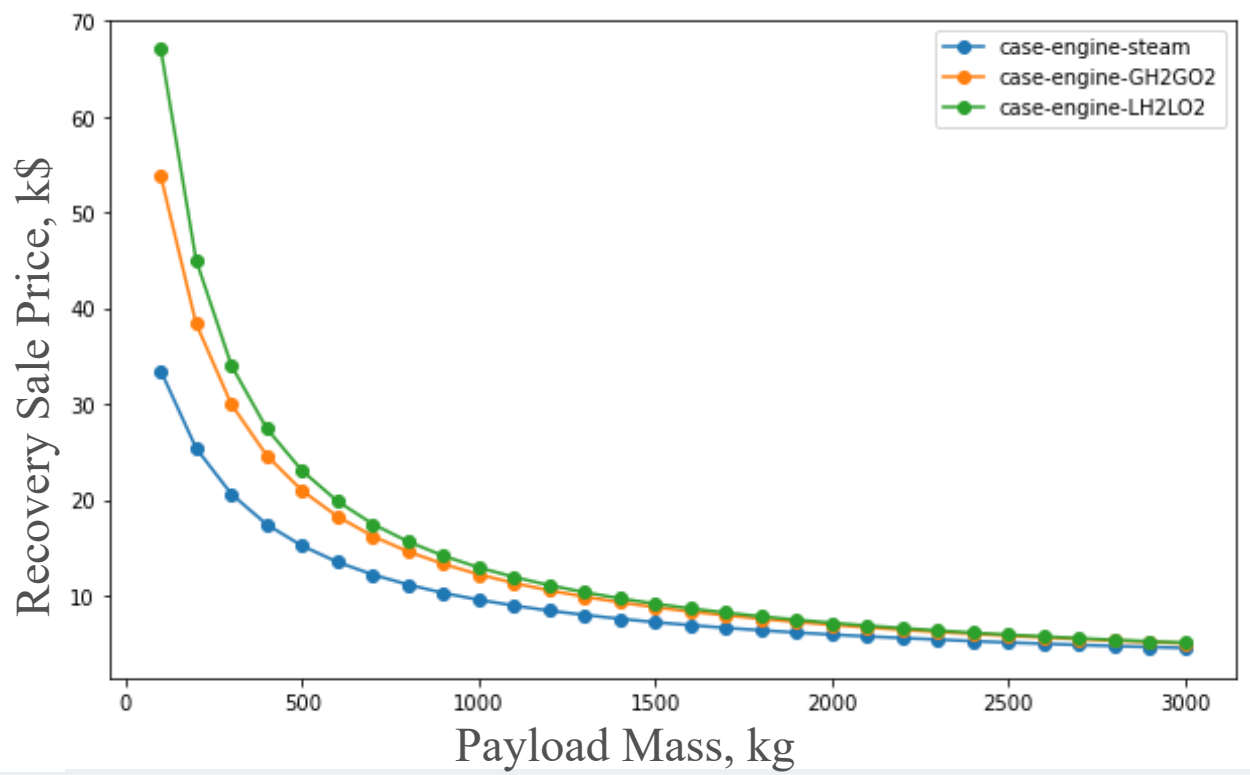


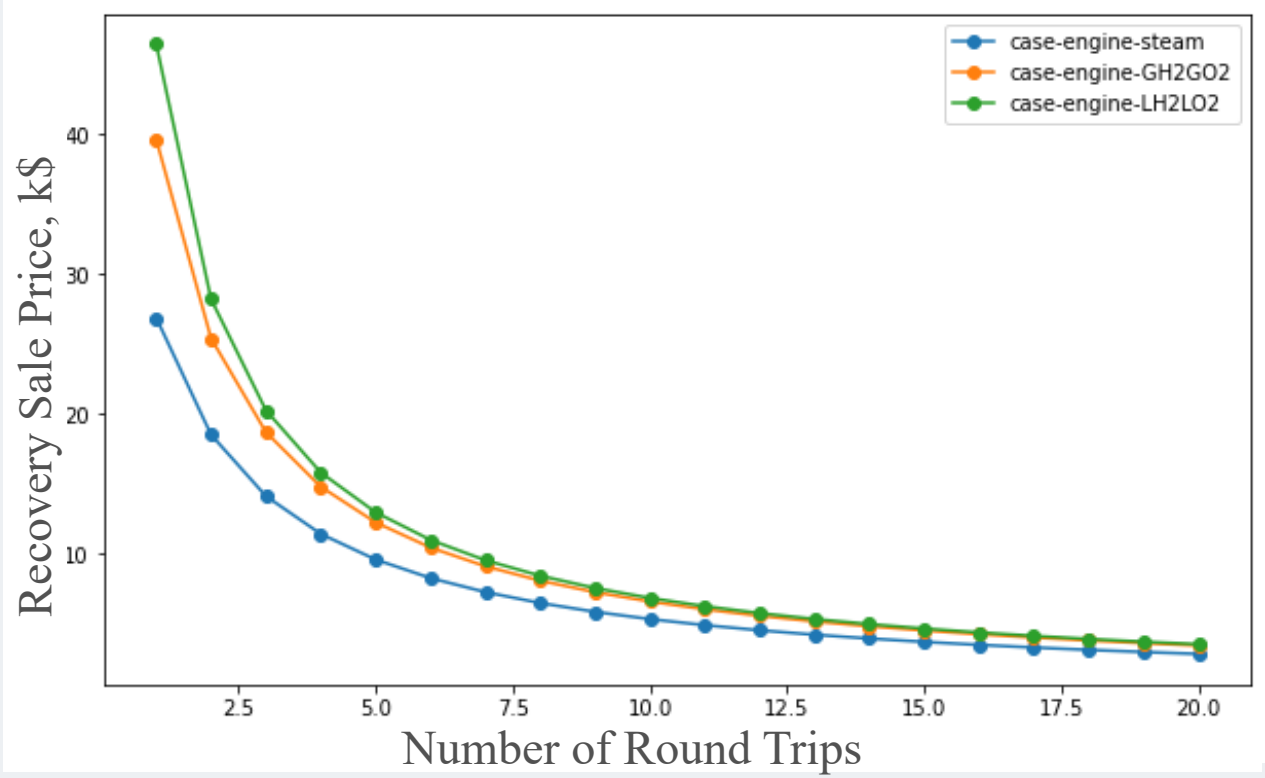
This tornado plot shows the 12 most influential variables for the RSP…

for a given engine type and a given processing power source.

SCAMM analyzes a single spacecraft. It does not analyze a business which has operating expenses, cares about the time value of money, and must scale.

For that we introduce the Stochastic Cash Flow Model (SCFM).





SCFM also stands for standard cubic feet per minute. It's a fun nod to both listed authors having worked in terrestrial resources (oil and gas) before transitioning to space resources.

SCFM Inputs

- Operating Expenses
- OpEx Economies of Scale
- Launch Frequency
- Round Trip Time
- Fixed Price Contracting
- …

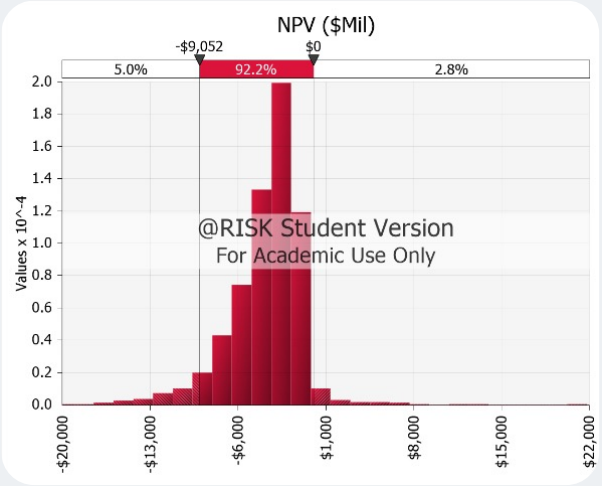
Outputs from SCAMM

- TFU
- R&D
- Water Return Capacity
- Launch Mass

Weibull Distribution

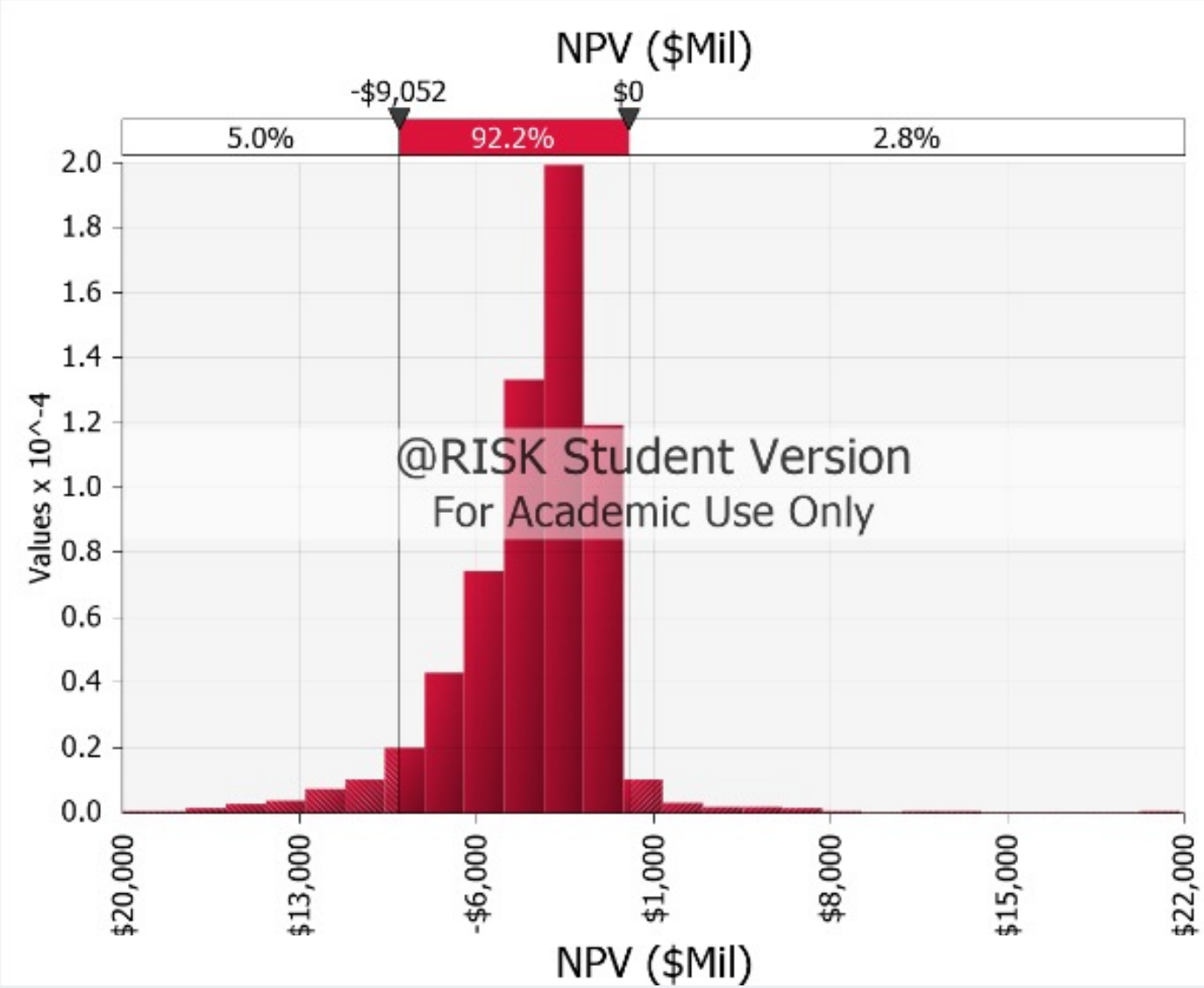
Variable Correlations

SCFM



Outputs

- NPV
- IRR
- …



Analysis was performed to set the most influential and controllable variables to their upper quartile values gave over 40% of simulations having a positive NPV.

But this is the Space Resources Roundtable…

What can be done to make asteroid mining have a higher probability of being positive NPV?

- Target a total round trip time less than 10 months
- Increase launch rate above 1.0 launch/year
- Greatly reduce or automate away operating expenses per craft

- Design a single craft for multiple trips
- Scale to >=1000 kg payload capacity
- Use solar thermal processing techniques

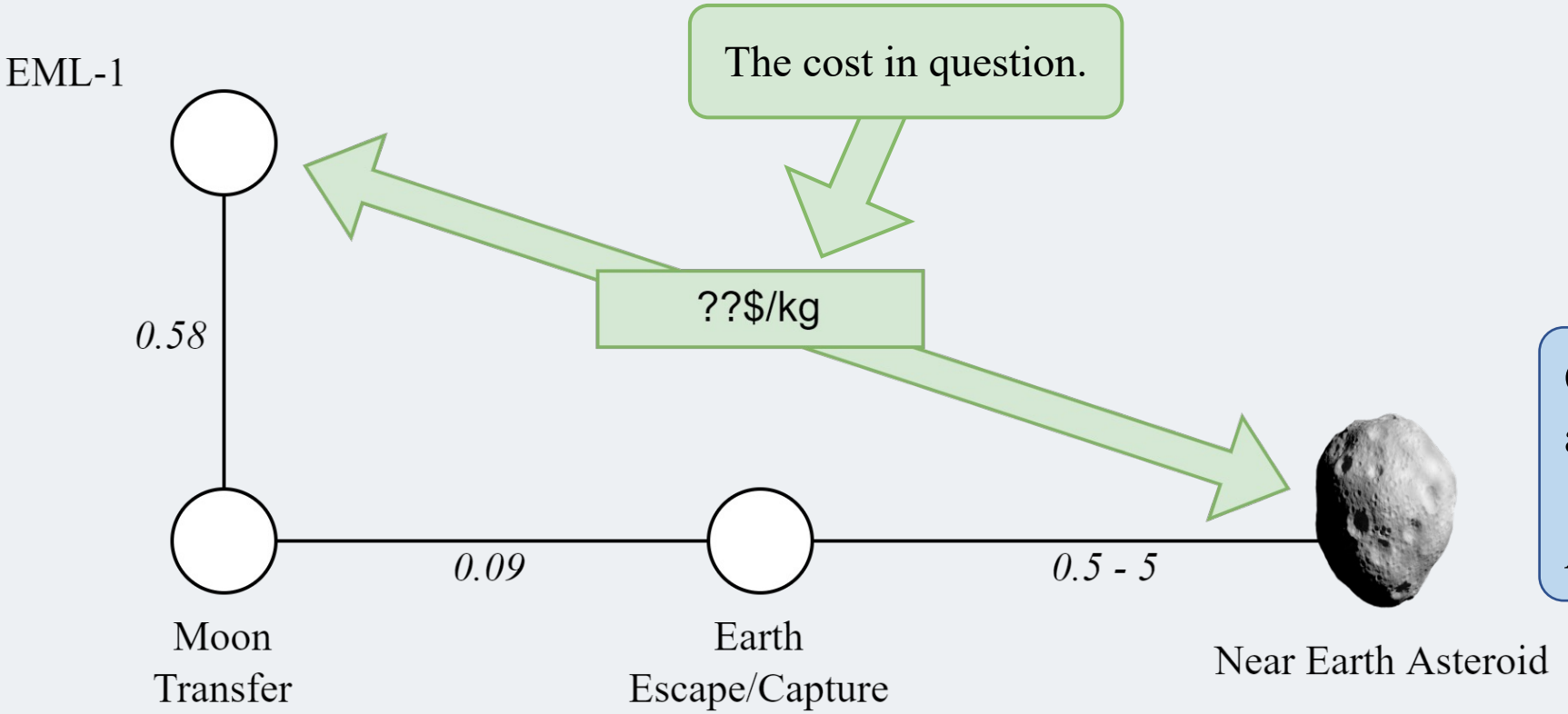
What is the utility of these models?

Q: Are these models available for use?
A: Inquire within…

Questions and Answers

If I had to give a cost for delivering 1 mT…

Year 1: $60,000 – $100,000 / kg
Year 15: $3,000 – $8,000 / kg



Q: Are these models available for adaptation to my business?

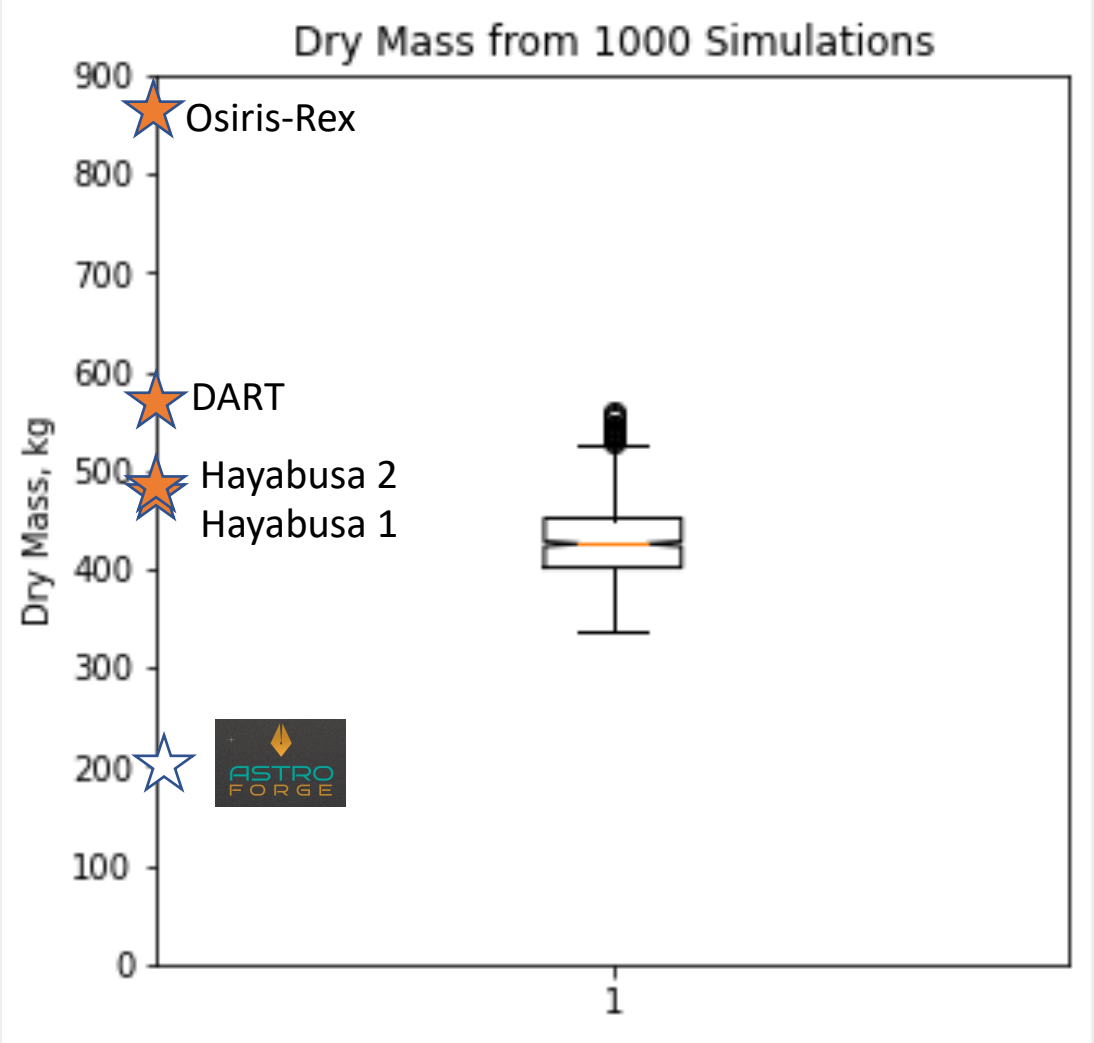
A: Inquire today…

Backup Slides

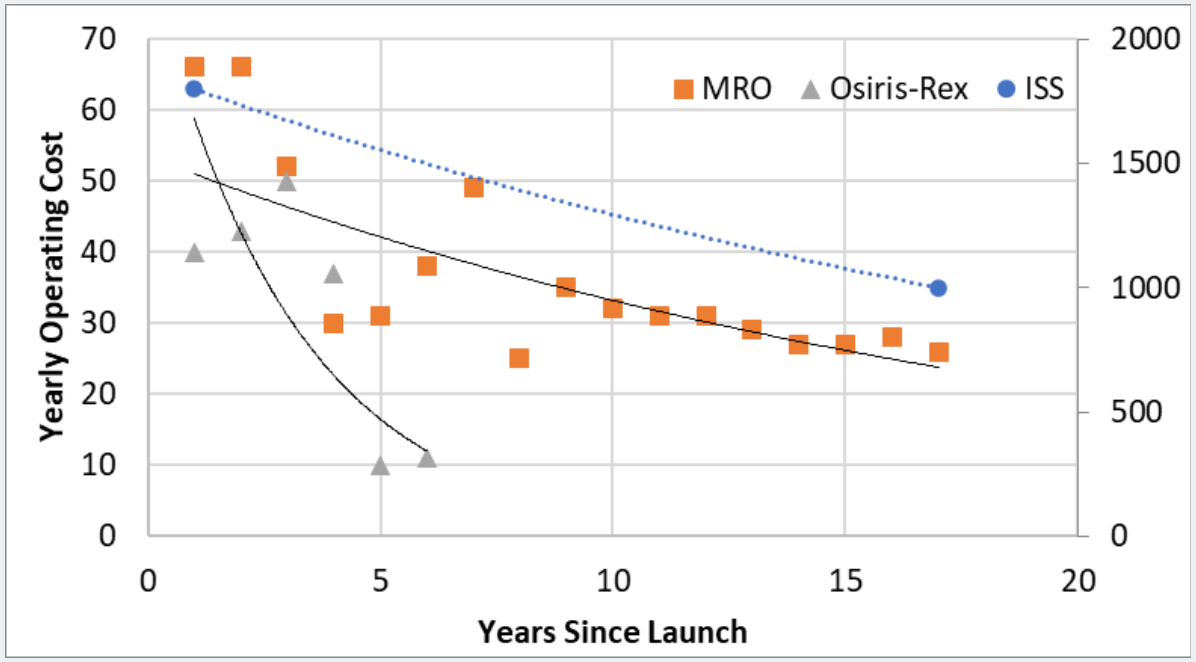
For model validation, the results of SCAMM was set to return 1 kg. The results were compared to a limited dataset of publicly available costs and masses of previous asteroid missions.

	R&D	TFU	Total	Dry Mass	Total/kg
Units:	**M$**	**M$**	**M$**	**kg**	**k$/kg**
Osiris-Rex[1]	140.9	644.4	785.3	880	892
DART[1]	40.6	267.4	308	580	531
SCAMM[2]	144 ± 27	67 ± 10	201 ± 37	420.5 ± 39	508 ± 58
SCAMM[3]	23 ± 5	12 ± 6	35 ± 11	420.5 ± 39	83 ± 15

A commercialization factor is used to account for reductions in cost commonly seen in commercial industry compared to government.



[1]The Planetary Society, 2023
[2]Commercialization factor set to 1
[3]Commercialization factor with a p50 of 6



Operating expenses were modeled after existing data on previous missions.