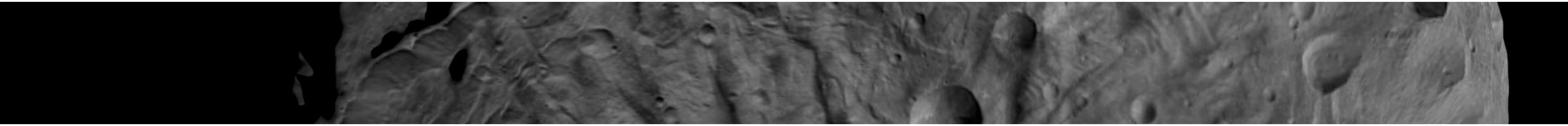
Framework for the Valuation of Asteroid Mining Options



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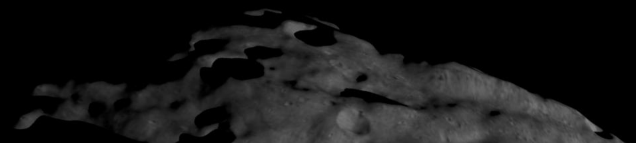
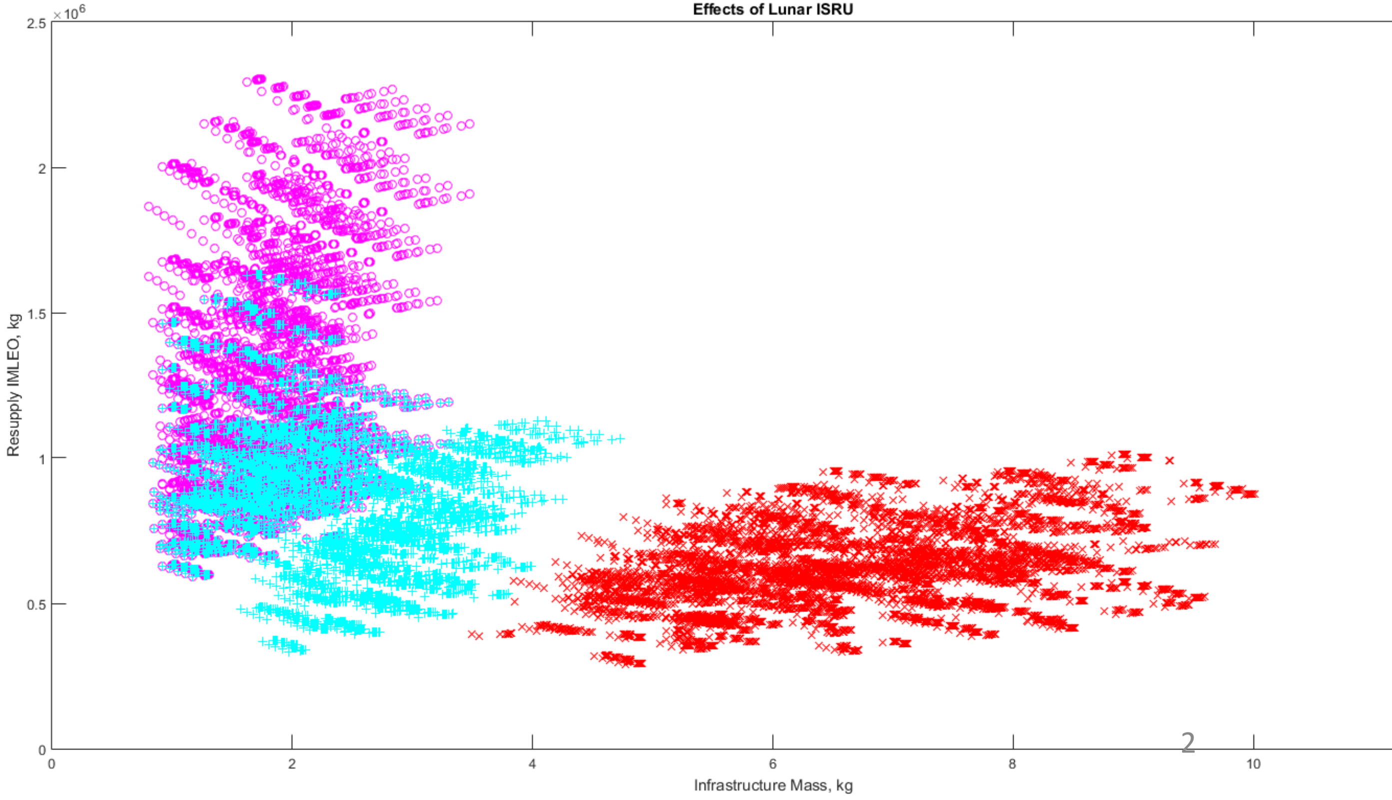
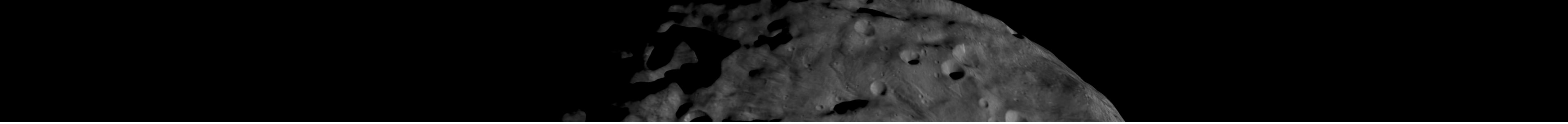
All banners Courtesy NASA



The Importance of Valuing Space Resources

- Technology and mission prioritization
- Quantifying the ROI for beyond-Earth orbit infrastructure and economic activities
  - The industry needs a quantitative way to discern which resources to invest in for prospecting and utilization
- Structuring a sustainable resource-based Space economy
  - Eventually, the industry needs to break its dependence on terrestrial "constrained resource" based economics





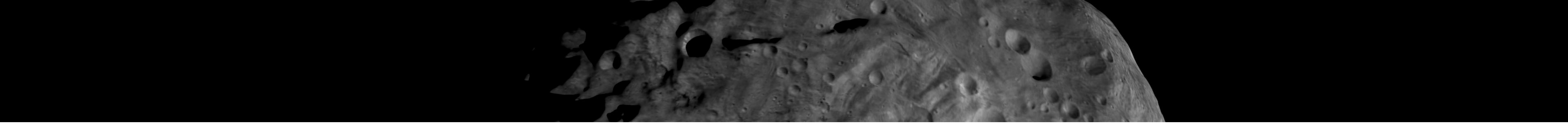
Our valuation approach

- Real Options Equation

$$V(t,T) = e^{-r(T-t)} * E\left[\max\left(0, W(T)\right)\right] \quad (1)$$

    - Value (V) of a real option that pays off W(T) at time T, where E is the expected risk-free value, $e^{-r(T-t)}$ is the discount factor, and t is the current time.
  - Some terrestrial use cases:
    - Real Property Development
    - Oil Drilling Rights
- How it can be applied to Space resources
  - Challenges of applying BS-ROV to Space
  - Our quantitative solutions
  - Life Support Unit as base currency

Shishko, Ebbeler, Fox (2003). NASA Technology Assessment Using Real Options Valuation. *Systems Engineering*, Vol. 6, No. 4.



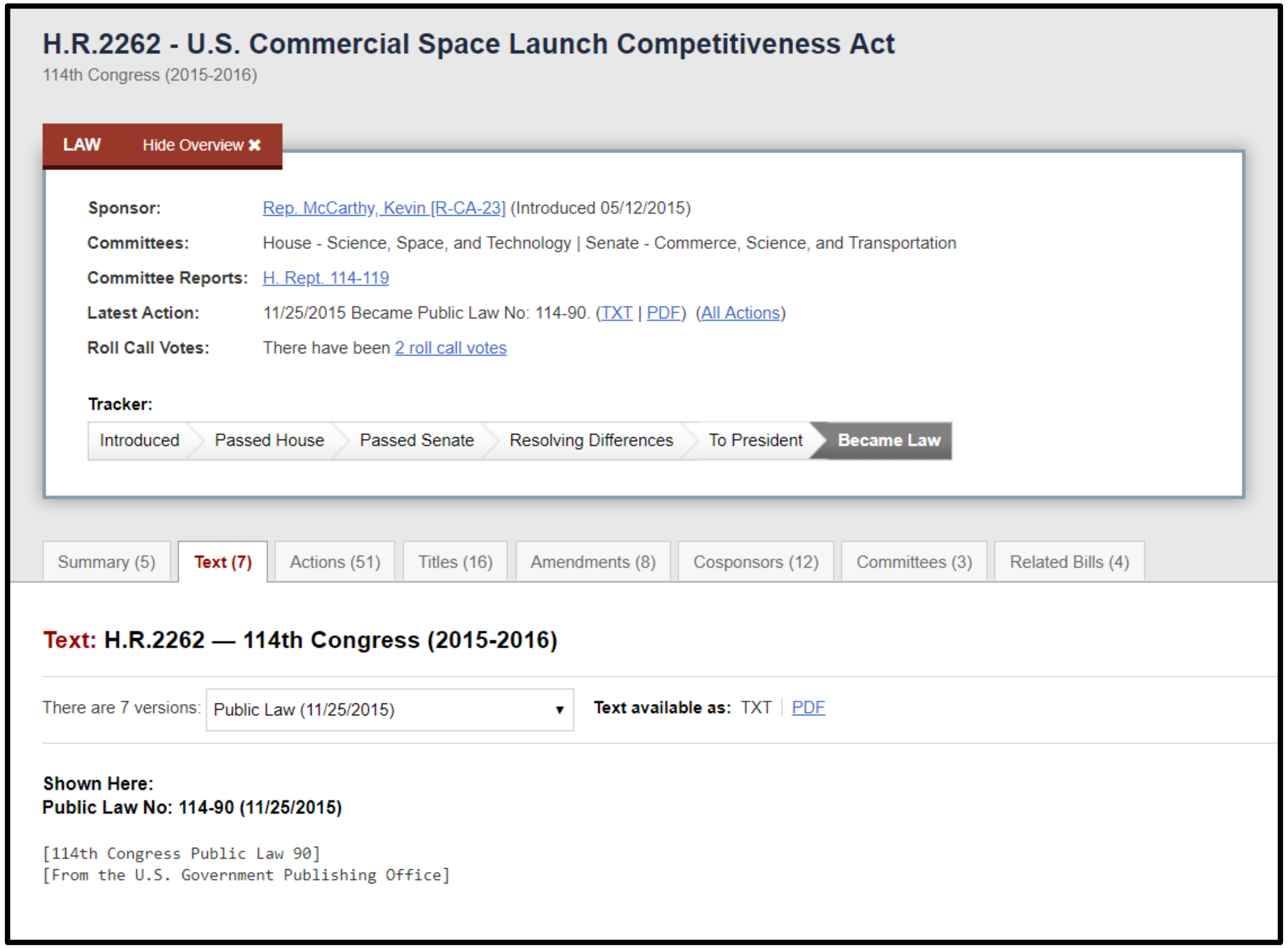
Asteroid Mining Option Equation

$$V(t) = V_{ROV}(t) * P_{win} * R_{market}(t) * R_{SKG} - I_{isru}(t) \qquad (2)$$

- V is the present value of an exercisable option to mine a Space resource at a future point in time t,
- $V_{ROV}(t)$ is the equivalent price of a European put option with an exercise date of t, according to Real Options Valuation,
- P_{win} is the probability that the option holder will be the absolute benefactor of the resource,
- $R_{market}(t)$ is the composite risk factor of market materialization and price sensitivity of the Space resource as a function of time,
- R_{SKG} is the risk factor accounting for any residual scientific knowledge risks associated with the resource, and,
- $I_{isru}(t)$ is the time-dependent CapEx required to mine the resource.

P_{win} : Competition and Legal Rights

- Inability to secure tenure allows competition until extraction
- Probability that Guarantor of specific option wins out on specific resource



H.R.2262 - U.S. Commercial Space Launch Competitiveness Act

114th Congress (2015-2016)

LAW Hide Overview ✖

Sponsor: Rep. McCarthy, Kevin [R-CA-23] (Introduced 05/12/2015)

Committees: House - Science, Space, and Technology | Senate - Commerce, Science, and Transportation

Committee Reports: H. Rept. 114-119

Latest Action: 11/25/2015 Became Public Law No: 114-90. (TXT | PDF) (All Actions)

Roll Call Votes: There have been 2 roll call votes

Tracker:

Introduced | Passed House | Passed Senate | Resolving Differences | To President | **Became Law**

Summary (5) | Text (7) | Actions (51) | Titles (16) | Amendments (8) | Cosponsors (12) | Committees (3) | Related Bills (4)

Text: H.R.2262 — 114th Congress (2015-2016)

There are 7 versions: Public Law (11/25/2015) ▾ **Text available as:** TXT | PDF

Shown Here:
Public Law No: 114-90 (11/25/2015)

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[114th Congress Public Law 90]
[From the U.S. Government Publishing Office]
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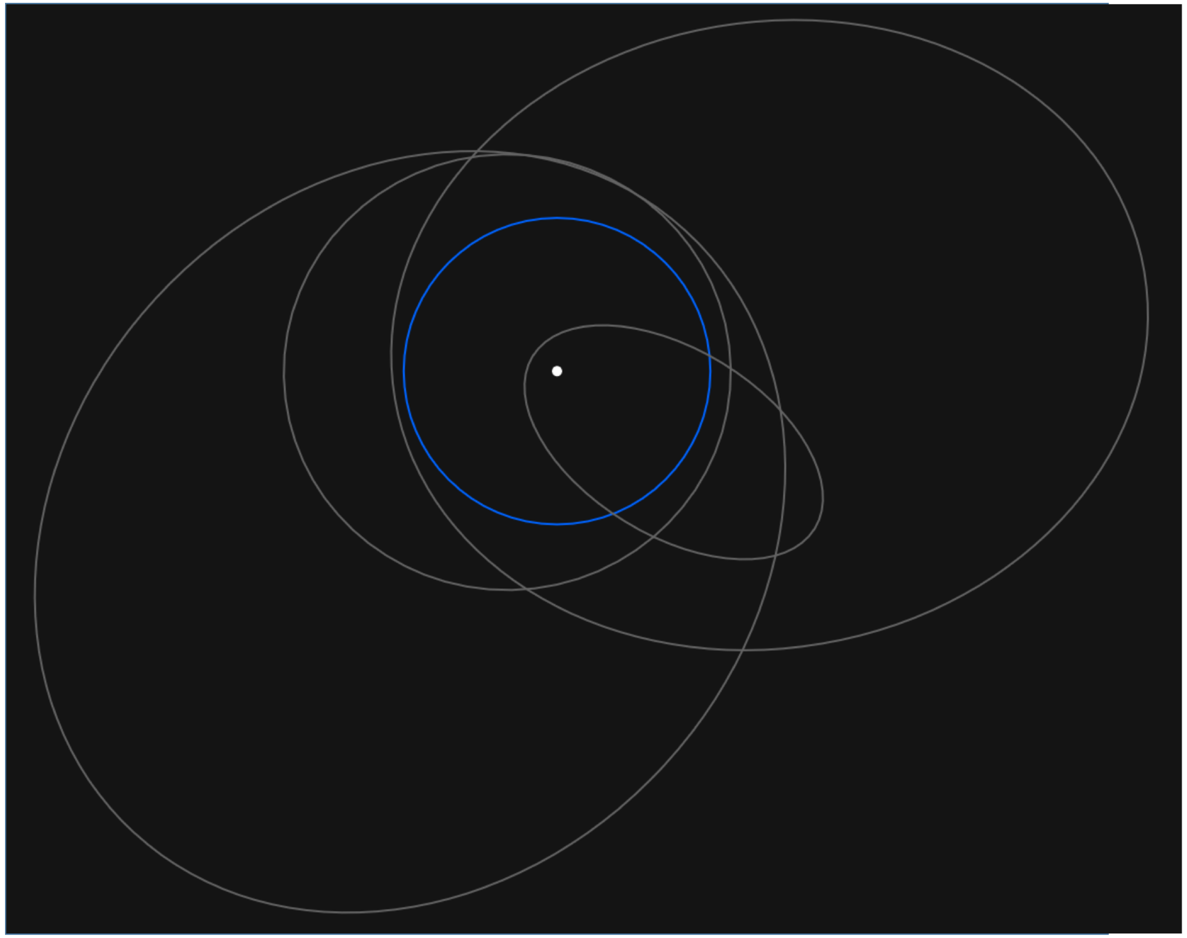
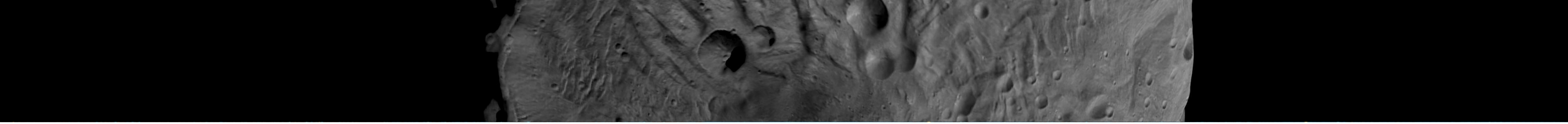
R_{market} : Market Materialization and Timing

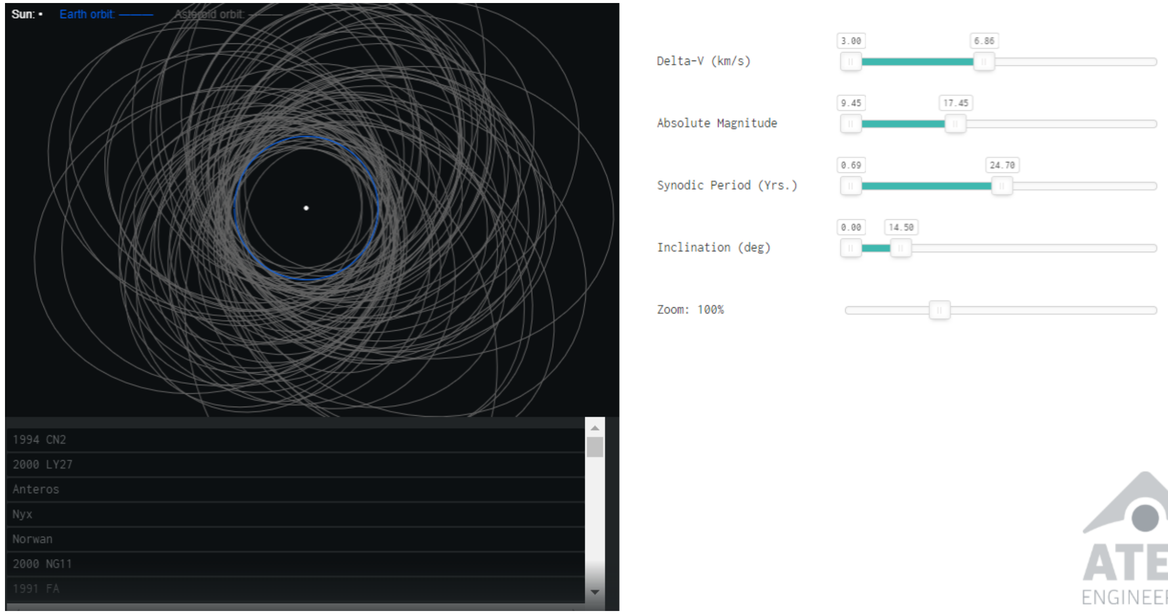
- Materialization of ISR market is a large factor at this stage.
- As launch costs go down, value of ISR *may* also decrease.
  - Must 'bet' on magnitude of movement of future value as well as volatility based on current value.
- Time dependent market supply and demand for resources.
  - 10 year missions not unrealistic.





R_{SKG} : Strategic Knowledge Gaps & Prospecting Data

- Scientific ambiguity in abundance of resource
- Importance of prospecting
  - Residual volatility
- ISRU technologies strongly tied to the science of underlying resources (type of material; molecular structure of material; resource consistency; gravitational environment etc.)



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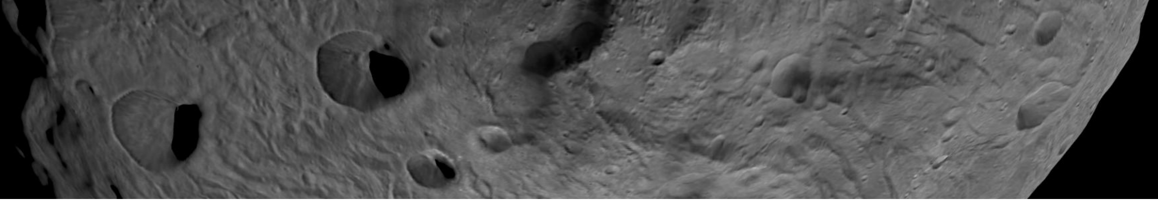
$I_{ISRU}(t)$: ISRU Infrastructure & Technology

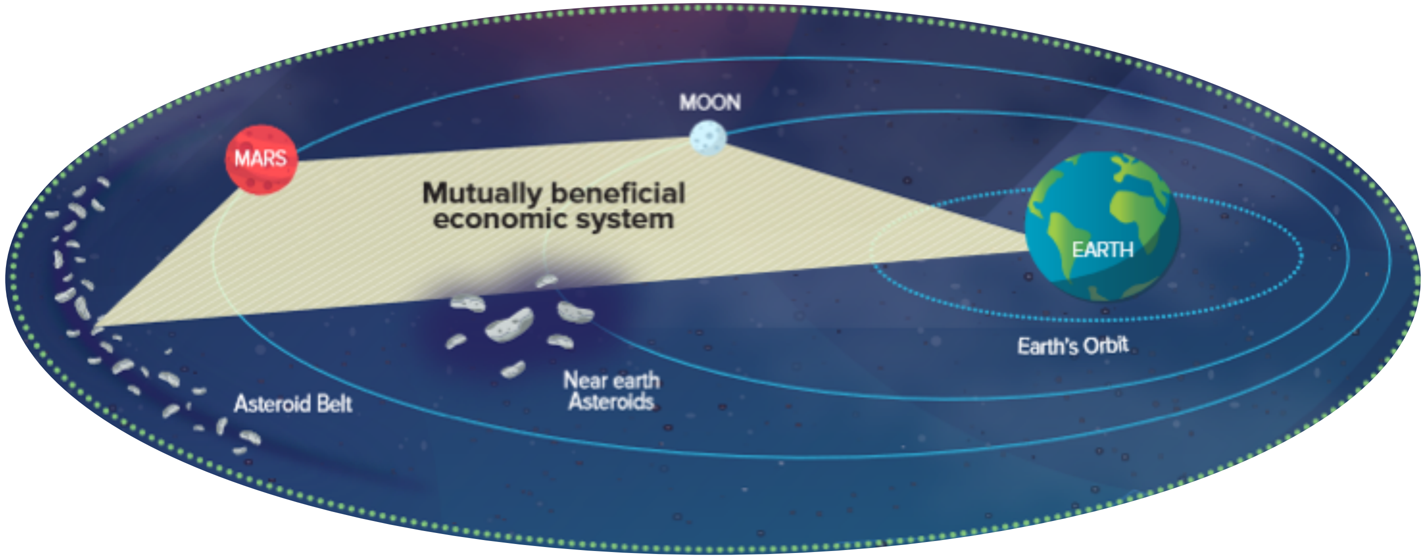
- An option to mine a resource needs to account for the follow-on investment required to mine it.
  - Unlike, eg. developing a parking lot, the cost of the follow-on investment for Asteroid Mining not currently well defined nor stable.
  - The mining costs vary with time on a short scale as well, eg. Launch windows affording opportunities for cheaper, or more expensive intersection trajectories.
  - Infrastructure for space resource utilization (orbital depots, mining capabilities &c.) can also drastically alter the cost of independent mining missions and activities.

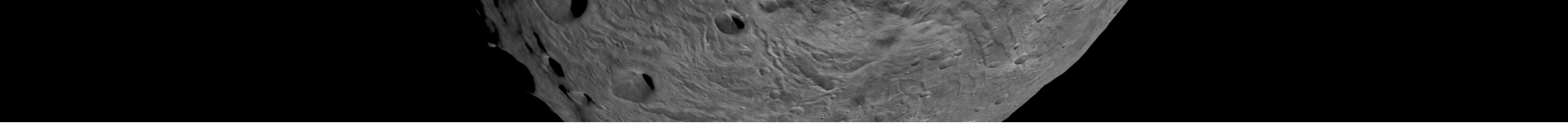


Introduction to the Life Support Unit (LSU)

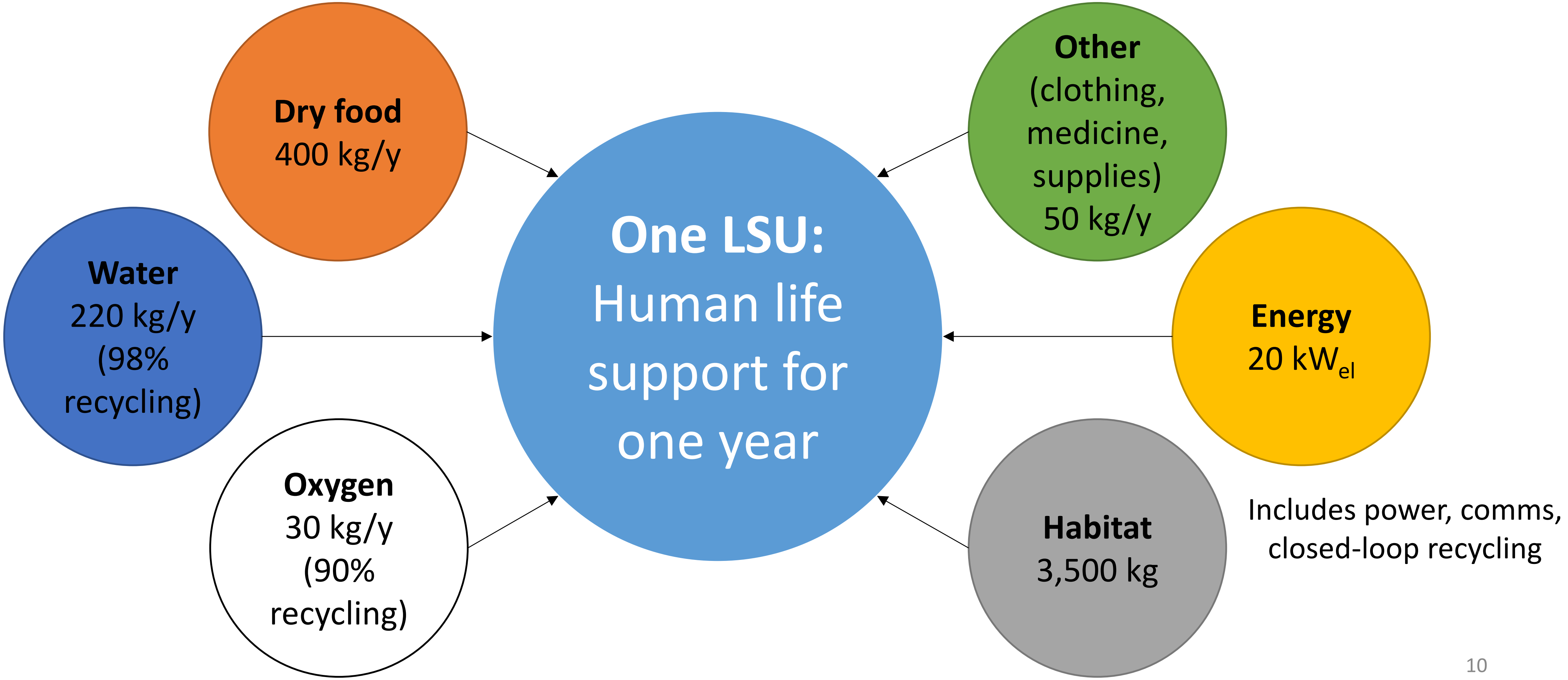
$$V(t) = V_{ROV}(t) * P_{win} * R_{market}(t) * R_{SKG} - I_{isru}(t)$$

- Tied to terrestrial currency not given
  - Disadvantages of fiat currency
- Using the LSU to optimizing valuation results



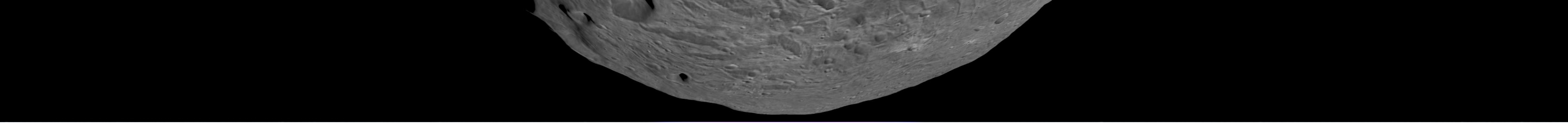


LSU components:



ISRU Valuation, LSU and the Future

SELF-SUSTAINABLE POPULATION	50,000 people		25,000,000 people
EXPORTS (TO ORBITAL STATIONS OR OTHER SOLAR SYSTEM SETTLEMENTS)	173M people's worth of inorganic material needs per year		77M people's worth of inorganic material needs + 250M people's worth of air, water and food per year
AVAILABLE SOLAR POWER	1.3 TW (~11% current power on Earth)		4.0 TW (~32% current power on Earth)
GROSS "INTERPLANETARY" PRODUCT (BASED ON INDUSTRIAL AND SOLAR ENERGY CAPACITY)	$8T		$24T
PRIMARY MATERIAL EXPORTS (MILLIONS OF TONS PER YEAR)	4	Steel	59
	84	Aluminum	9
	9	Magnesium	4
	28	Glass	9
	174	Regolith for shielding	77
	7	Solar PV	8
		Plastics	58
		Breathing Air	15
		Water	15
		Food	4
		Propellant (CH4/02)	259



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