A General Model of ISRU Technology Valuation and Technology Portfolio Construction for Crewed Mars Missions

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SPACE RESOURCES ROUNDTABLE
GOLDEN, CO, JUNE 6, 2023

SPACE RESOURCES WORKSHOP

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We have been valuing ISRU technologies based on their economic impact on scarce launch mass.

Historically, ISRU has been valued for its potential to reduce launch mass

However, launch mass is expected to be less scarce in the future of crewed space missions to Mars

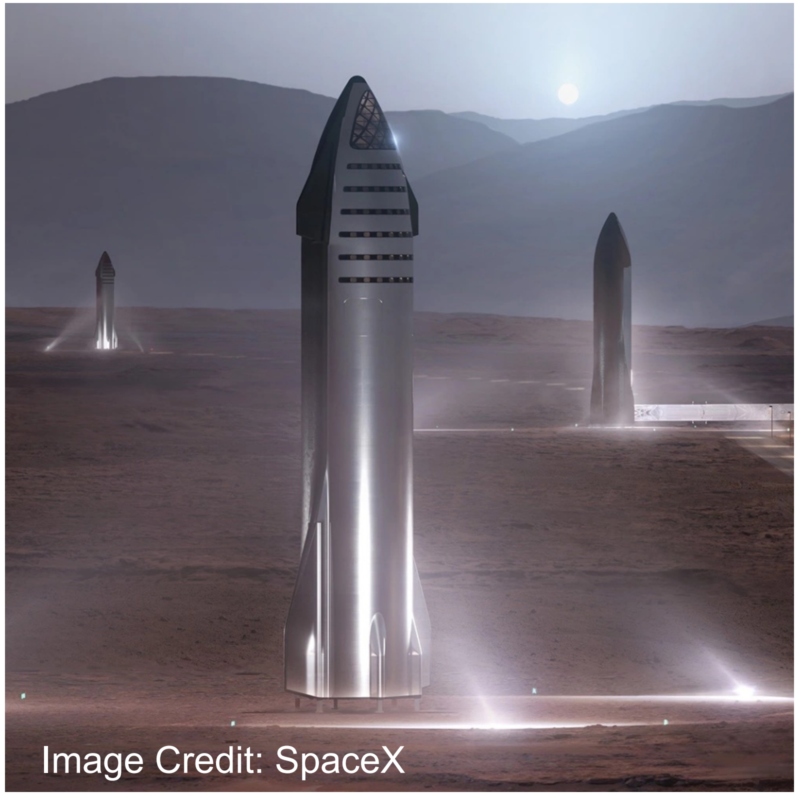

Image Credit: SpaceX

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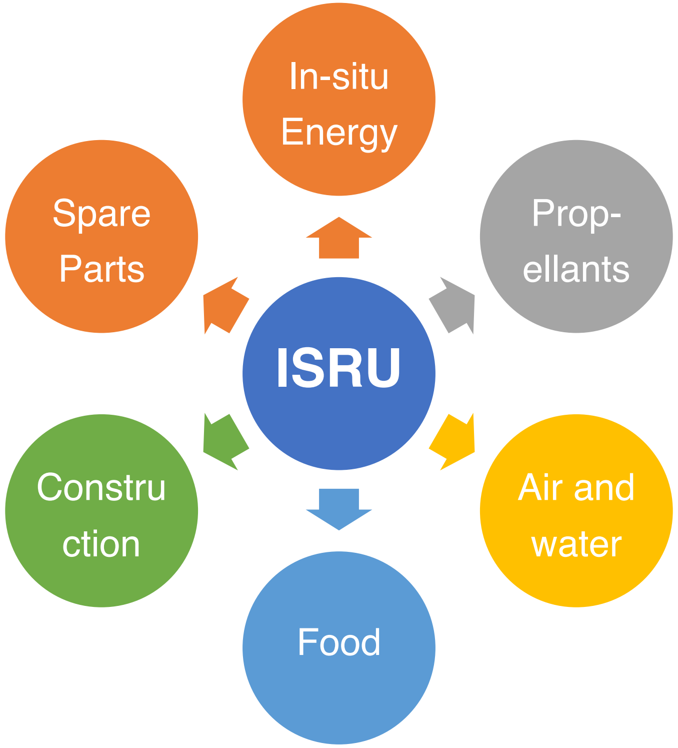
Question: how to calculate the *total* expected value of the ISRU technology portfolio for crewed missions?

Problem statement: seek a ***method*** and a ***unit of measure*** to calculate the ***total*** expected value of investing in ISRU.

Fabricating / repairing systems: Life Support, Mobility, Food, Cryo Fluids Management

Habitats, Roads, Landing Pads, Berms, Towers, Utilities



Liquid oxygen, methane, hydrogen, nitrogen

Life support consumables, including food

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ASTRA Methodology and Approach

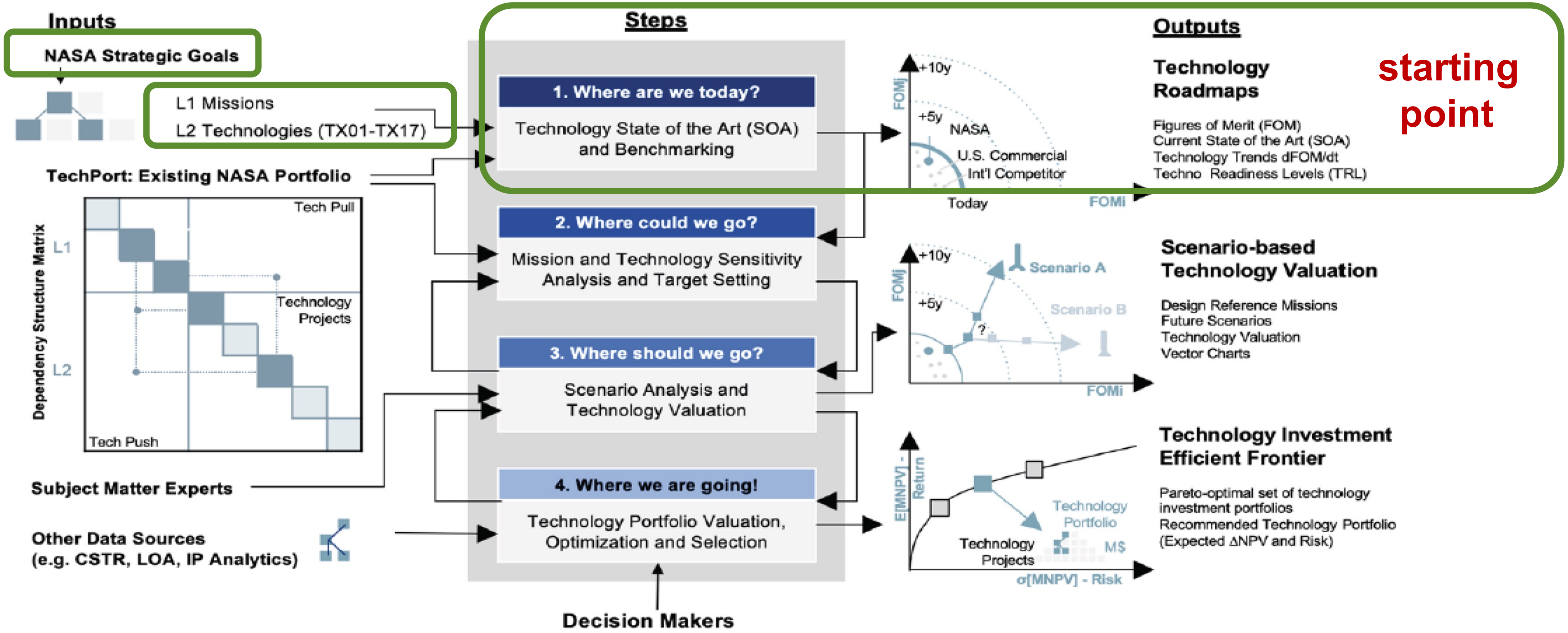

Figure 6: Advanced Space Technology Roadmapping Architecture (ASTRA) methodology with inputs on the left, the key steps with guiding questions in the center and the outputs on the right side. The technology investment efficient frontier made up of a set of Pareto-optimal portfolios (see lower right) is the main output. Final decisions are made by human decision-makers.

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Operationalizing ASTRA to calculate “value of ISRU”

1. Define a goal-driven, stakeholder-value-related Figure of Merit for ISRU-enabled human exploration architectures
2. To quantify the impact of ISRU technologies on this Figure of Merit, build a detailed tradespace exploration model that can generate and score alternative architectures from varying ISRU technology inputs
3. Calculate the top-level Figure of Merit and Lifecycle Cost for alternative architectures with varied ISRU technology selections and a range of assumptions for their performance under uncertainty
4. Use outputs to construct efficient portfolios of technologies that trade off risk vs. return, where return is typically defined as benefit at cost and risk is typically defined as the variance of the return.

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1. Select an Appropriate Goal-driven Figure of Merit

Define a goal-driven, stakeholder-value-related Figure of Merit for ISRU-enabled human exploration architectures

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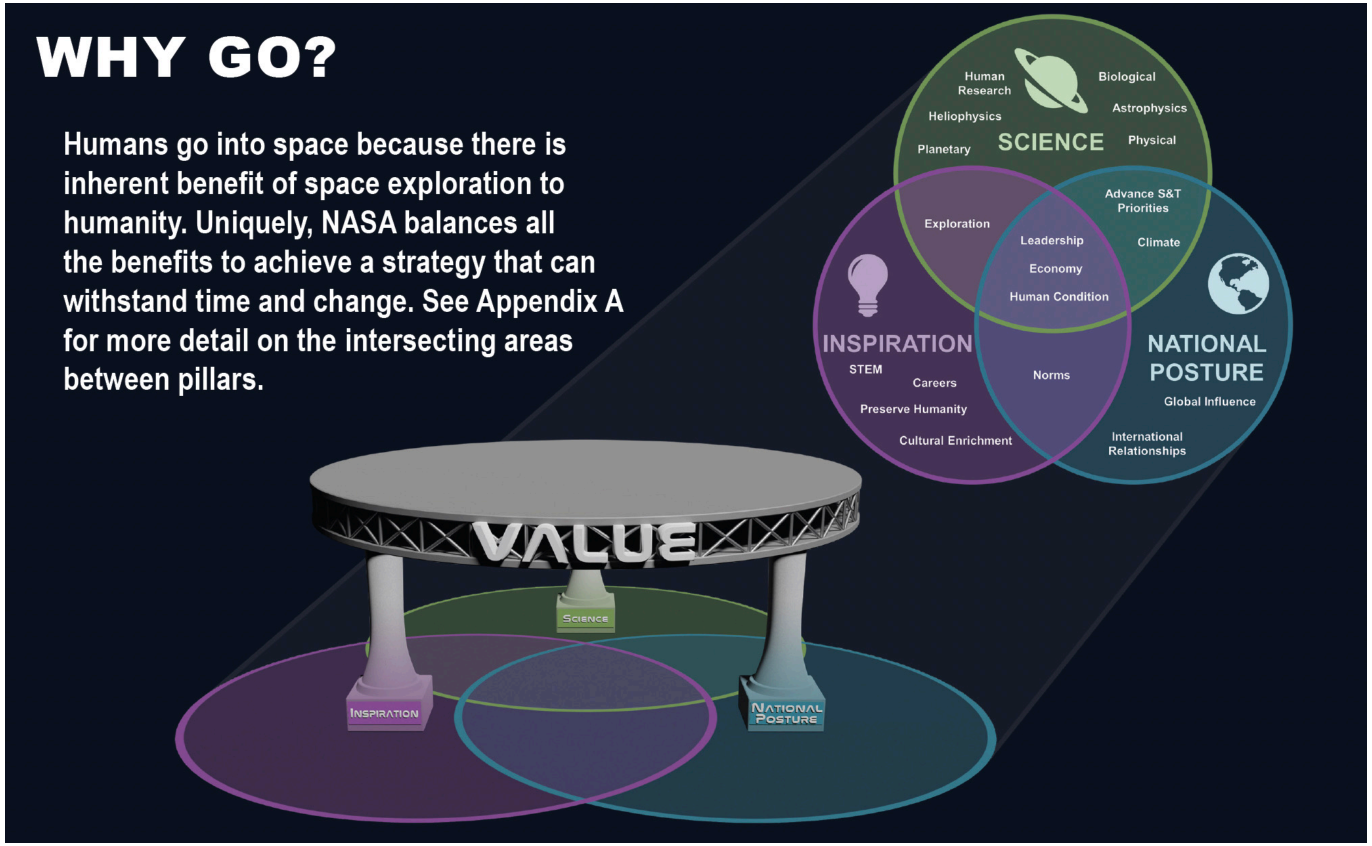
Goals define value. However, to capture value efficiently, we must make good use of scarce resources.



National Aeronautics and Space Administration (2023). "NASA's Moon to Mars Strategy and Objectives Development: A blueprint for sustained human presence and exploration throughout the Solar System"

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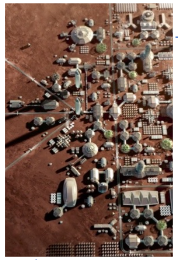
Approach: anchor the Figure of Merit to human space exploration value-related goals and to resource(s) that we expect to be scarce.

VALUE-RELATED GOALS

Successful mission to Mars and **safe return of the crew:** “A triumph of the human spirit”

New **scientific and technological knowledge:** “Life, and learning to live, on other worlds”



Inspiration and **National Posture**: “One giant, sustainable leap for all humankind”

BUT WHAT ARE THE SCARCE RESOURCE(S)? (*not* mass)

?

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Scarcity lies at the heart of economics

"Economics deals with scarcity, which arises because **the resources available are limited to satisfy our unlimited needs and wants**."

- **Ahmad Nasrudin**, writing on penpoin.com, Jan 6, 2023

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A leading candidate for a scarce resource in a post-mass world: Crew Time Services.

- **Free crew time remaining after personal time and after supporting mission systems = time available to be utilized for mission value-related goals**

Image Credit: NASA

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We define 'Mission Value time' as the time available after crew time liens required for health & survival.

- **Benefit Proxy Metric:** 'Mission Value Full-Time Equivalent' (MVFTE) Persons on Mars
- **Cost Metric:** Lifecycle cost {per MVFTE, per year}

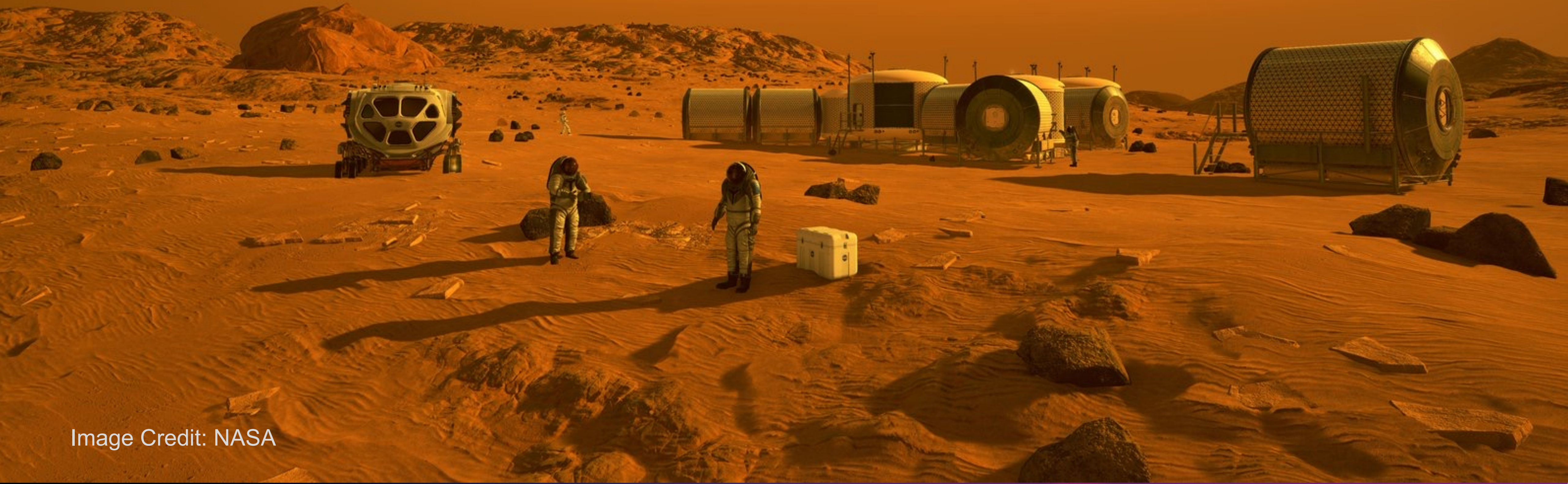

Image Credit: NASA

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2. Build a Tradespace Exploration Model

To quantify the impact of ISRU technologies on this Figure of Merit and on the Cost Metric, build a detailed tradespace exploration model that can generate and score alternative architectures from varying ISRU technology inputs

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Case Study: NASA's 2023 RASC-AL "Homesteading Mars" Challenge

Main Theme Requirements – "Earth-independence-establishing mission"

- Minimum of 4 crew, operating from at least one site on Mars
- Minimum surface stay of 7 years for each crew member, followed by safe return
- No mass limit for infrastructure pre-deployment
- However, limit of 2-years-worth of pre-deployed food and spares
- And, a stringent resupply limit of just 5 tons every 2 years

Design challenges for a 7-year mission with minimal resupply

- Mitigating risks to crew health, especially from radiation
- Dealing with failures of critical systems
- Delivering Mission Value to NASA and the US taxpayer

Source and full competition details: https://rascal.nianet.org

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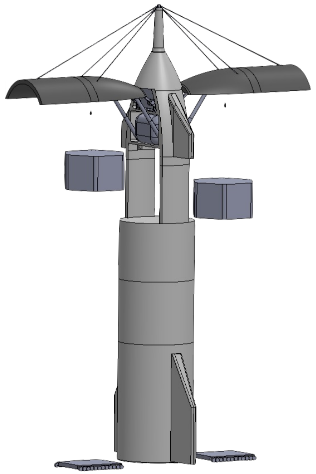
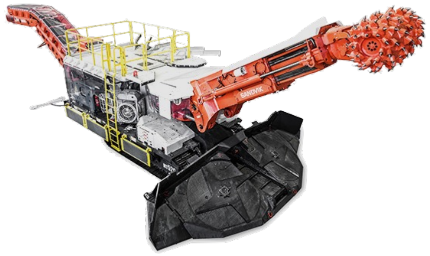
‘Pale Red Dot’ Case Study

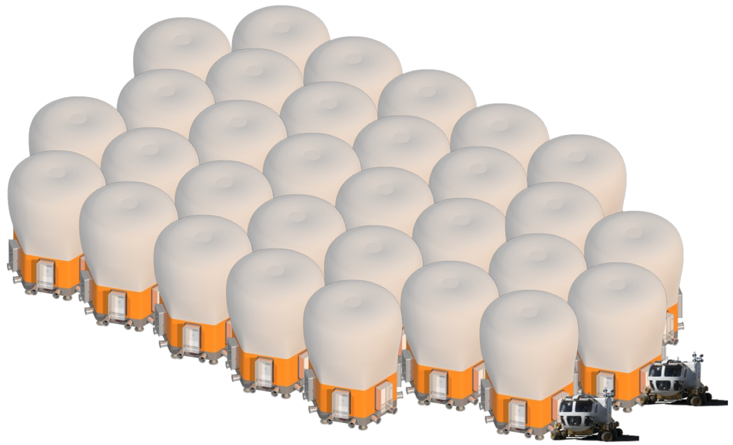
StarCrane



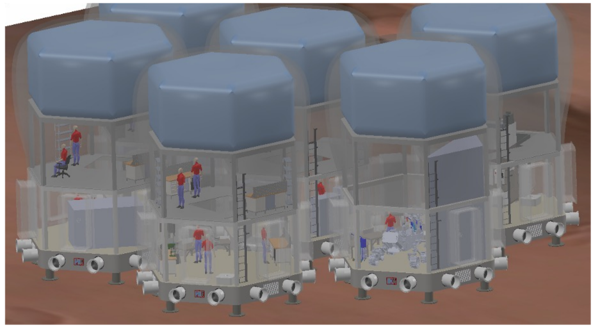
Tunneling Capabilities

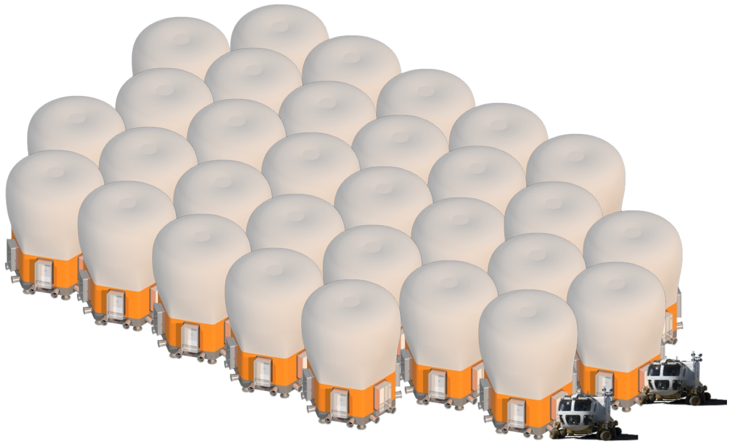


Consumables ISRU



Mars Makerspace for High Manufacturability of in-situ parts





Two villages near each other, 18 crew per village with 100% food production and space to thrive, not just survive.

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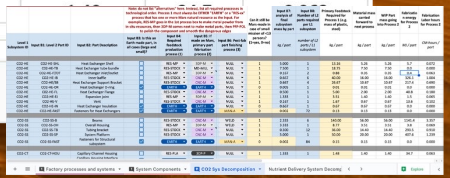
Two critical sub-models: Crew Time sub-model (515 lines) and Manufacturability sub-model

Level 1 Subsystem ID	Input B1: Level 2 Part ID	Input B2: Part Description	Input B3: Is this an Earth made part, in all cases (large and small)?	Input B4: Required feedstock production process (1)	Input B5: If made on Mars, primary part fabrication process (2)	Input B6: Post-fab part finishing process (3)	Can it still be Mars-made in case of small mission of <13 persons? (1=yes, 0=no)	Input B7: analysis of final subsystem mass by part (kg / part)	Input B8: Number of L2 parts required per L1 subsystem (number of L2 parts / L1 subsystem)	Primary Feedstock Required for Process 1 (e.g. mass of plastic, steel) (kg / part)	Material mass carried forward to next process (kg / part)	WIP Part mass going into Process 2 (kg / part)	Fabrication energy for Process 2 (MJ / part)	Fabrication Labor hours for Process 2 (CM-hours / part)
						Note: do not list "alternatives" here. Instead, list all required processes in technological order. Process 1 must always be EITHER "EARTH" or a "RES-xx" process that has one or more Mars natural resource as the input. For example, RES-MP goes in the 1st process box to make metal powder from in-situ resources, then 3DP-M comes next to make metal parts, then PFP-POL to polish the component and smooth the dangerous edges								
CO2-HE	CO2-HE-SHL	Heat Exchanger Shell	☐	RES-MP	3DP-M	NULL	1	5.000	1	13.16	5.26	5.26	5.7	0.072
CO2-HE	CO2-HE-TB	Heat Exchanger tube bundle	☐	RES-STOCK	MD-MILL	NULL	1	7.500	1	18.75	7.50	7.50	0.0	0.000
CO2-HE	CO2-HE-IT/OT	Heat Exchanger inlet/outlet	☐	RES-MP	3DP-M	NULL	1	0.167	2	0.88	0.35	0.35	0.4	0.063
CO2-HE	CO2-HE-IB	Inner baffle	☐	RES-STOCK	CNC-M	NULL	1	0.667	6	40.00	16.00	16.00	326.1	1.004
CO2-HE	CO2-HE/SB	Heat Exchanger Support Bracket	☐	RES-STOCK	CNC-M	NULL	1	0.667	4	26.67	10.67	10.67	217.4	0.690
CO2-HE	CO2-HE-OR	Heat Exchanger O-ring	☑	EARTH	EARTH	NULL	0	0.005	1	0.01	0.01	0.01	0.0	0.000
CO2-HE	CO2-HE-FL	Heat Exchanger Flange	☐	RES-STOCK	CNC-M	NULL	1	0.500	1	5.00	2.00	2.00	40.8	0.180
CO2-HE	CO2-HE-EJ	Expansion joint	☐	RES-MP	3DP-M	NULL	1	1.333	1	3.51	1.40	1.40	1.5	0.065
CO2-HE	CO2-HE-V	Vent	☐	RES-STOCK	CNC-M	NULL	1	0.167	1	1.67	0.67	0.67	13.6	0.102
CO2-HE	CO2-HE-IN	Heat Exchanger Insulation	☑	EARTH	EARTH	NULL	0	0.667	1	0.67	0.67	0.67	0.0	0.000
CO2-HE	CO2-HE-FAST	Fasteners for Heat Exchangers	☑	EARTH	EARTH	MAN-A	0	0.002	72	0.13	0.13	0.13	0.0	0.000
CO2-SS	CO2-SS-B	Beams	☐	RES-STOCK	CNC-M	WELD	1	2.333	6	140.00	56.00	56.00	1141.4	3.357
CO2-SS	CO2-SS-OH	Overall Housing	☐	RES-MP	3DP-M	WELD	1	3.333	1	8.77	3.51	3.51	3.8	0.069
CO2-SS	CO2-SS-TB	Tubing bracket	☐	RES-STOCK	CNC-M	NULL	1	0.300	12	36.00	14.40	14.40	293.5	0.910
CO2-SS	CO2-SS-SP	System Platform	☐	RES-STOCK	CNC-M	NULL	1	5.000	1	50.00	20.00	20.00	407.6	1.239
CO2-SS	CO2-SS-FAST	Fasteners for Structural subsystem	☑	EARTH	EARTH	MAN-A	0	0.002	84	0.15	0.15	0.15	0.0	0.000
		Capillary Channel Housing	☐	RES-PLA	3DP-P	NULL	1	1.333	1	1.48	1.40			
		Capillary Housing Interface												

...y processes and systems | 1 System Components | 11 CO2 Sys Decomposition | Nutrient Delivery System Decomp

Number of times the activity is repeated	Per.... [period of repetition of activity]	And per... [physical unit]	Average Nominal Duration of activity [minutes]	Modifier for scale-dependent gains from specialization or losses from excessive task switching: Large (L), Small (S) or Neutral (N)	How many crew engage in this activity per repetition and per physical unit?	In which team or category is this activity book-kept?	Total duration in person-minutes per mission	
							6.75%	Perform growing house/plant growth-related functions in surface module during Mars Surface Operations.
2	Month	Farm Module	60	S	2	Agriculture	537600	Adjust growing medium mixture, manually to augment automated system, manually via keyboard, when necessary to optimize plant growth.
12	Year	Farm Module	120	S	2	Agriculture	537600	Adjust/move plant containers/plumbing/lighting, manually while wearing protective gloves, when necessary to optimize plant growth.
1	Day	Farm Module	60	L	1	Agriculture	3844667	Remove plant material, manually using hand tools while wearing protective gloves, to harvest plants/vegetables for crew consumption.
4	Week	Farm Module	20	S	1	Agriculture	778027	Monitor plant growth, remotely via video feed to surface habitat, to verify/measure proper functioning of greenhouse.
2	Week	Farm Module	20	S	2	Agriculture	778027	Monitor plant growth, visually in person, to verify/measure proper functioning of greenhouse.
12	Year	Farm Module	240	L	2	Agriculture	1011200	Sanitize growth trays with UV and hot water bath after every growth cycle
12	Year	Farm Module	90	S	2	Agriculture	403200	Prepare seeds for next cycle depending on nutrients needed for crew diet/requests



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Generalized Model of ISRU Technology Valuation for Mars

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3. Calculate Figure of Merit and Cost

Calculate the top-level Figure of Merit and Lifecycle Cost for alternative architectures with varied ISRU technology selections.

In this study, we varied the level of versatility / capability of the Makerspace and computed the effects to the intermediate variables of Manufacturability and Crew Time.

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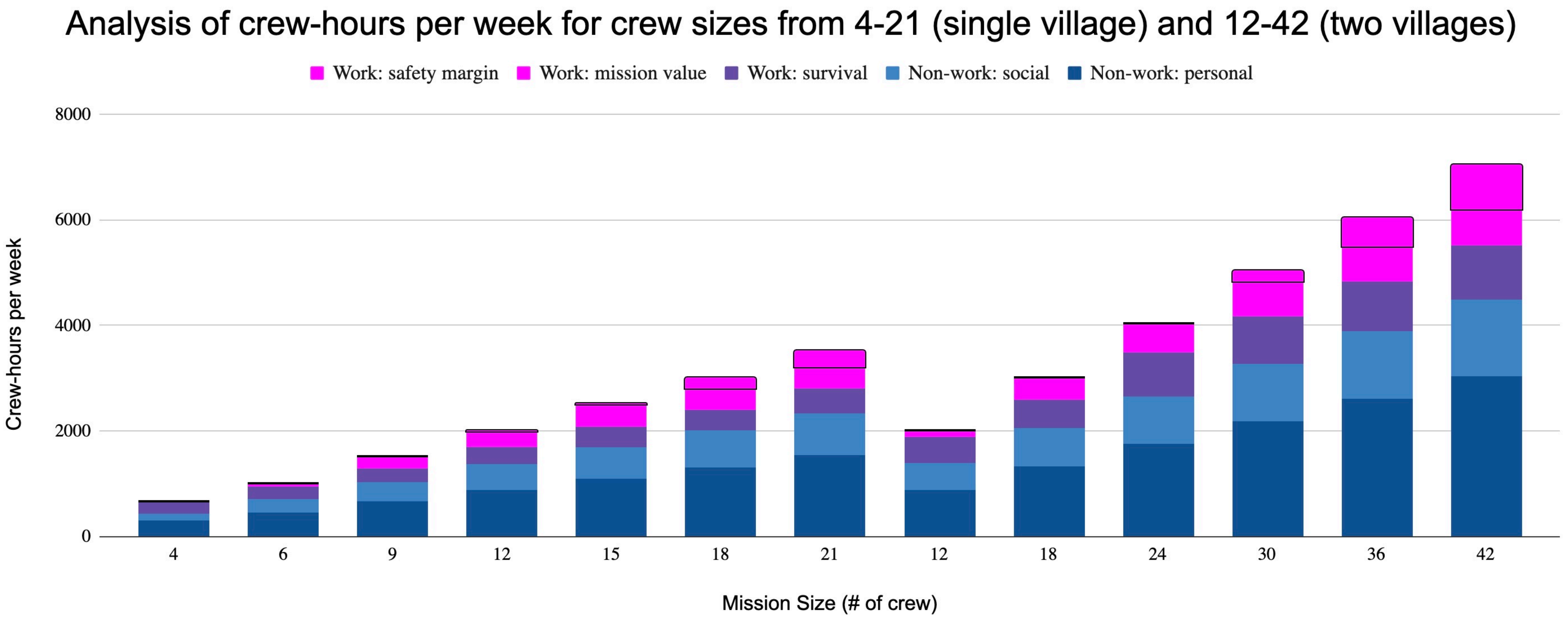
Results from Pale Red Dot crew time model



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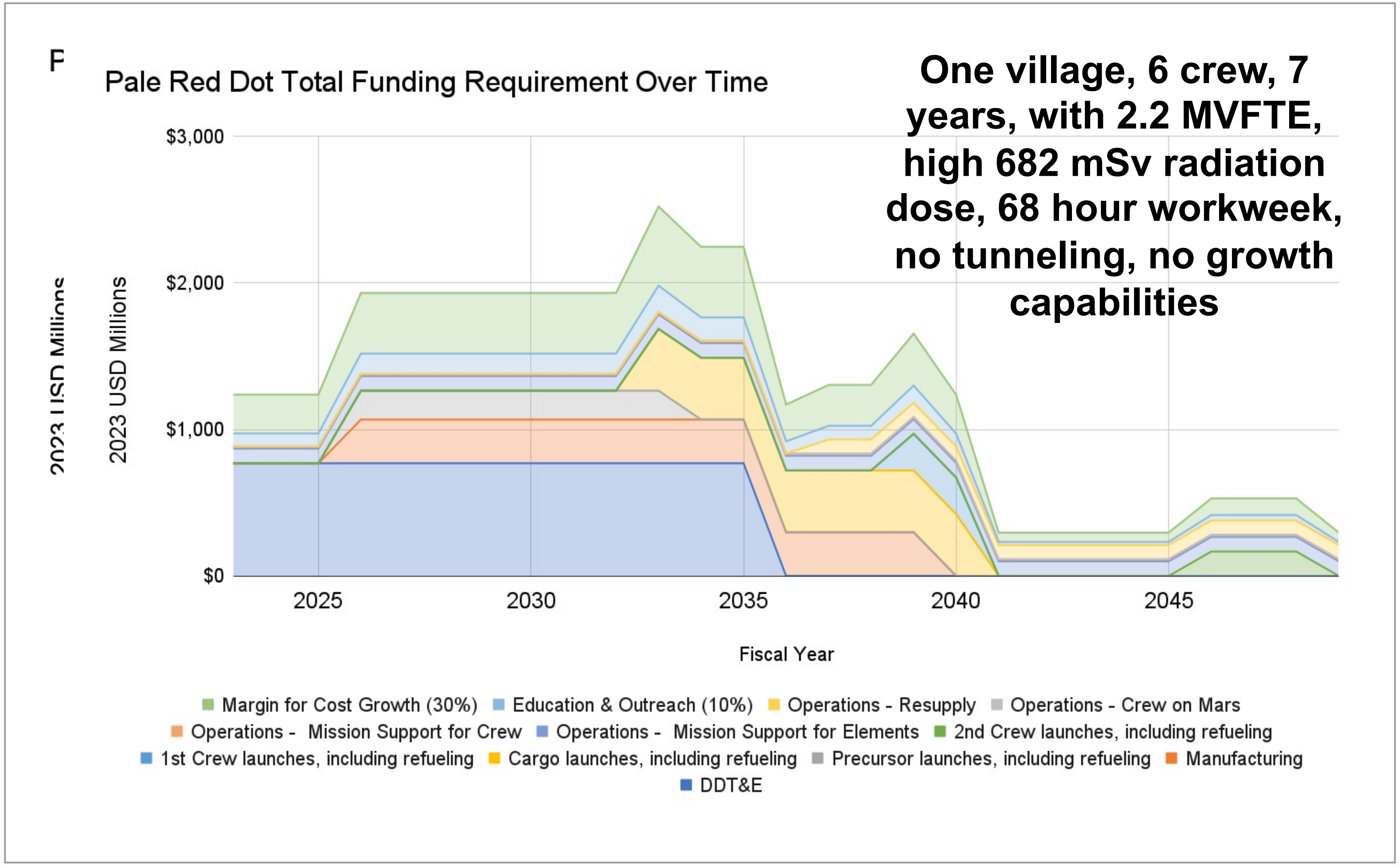
Modeled lifecycle cost for alternative architectures



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4. Construct efficient portfolios of technologies

Use outputs to construct efficient portfolios of technologies that trade off risk vs. return, where return is typically defined as benefit at cost and risk is typically defined as the variance of the return.

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ASTRA Methodology and Approach

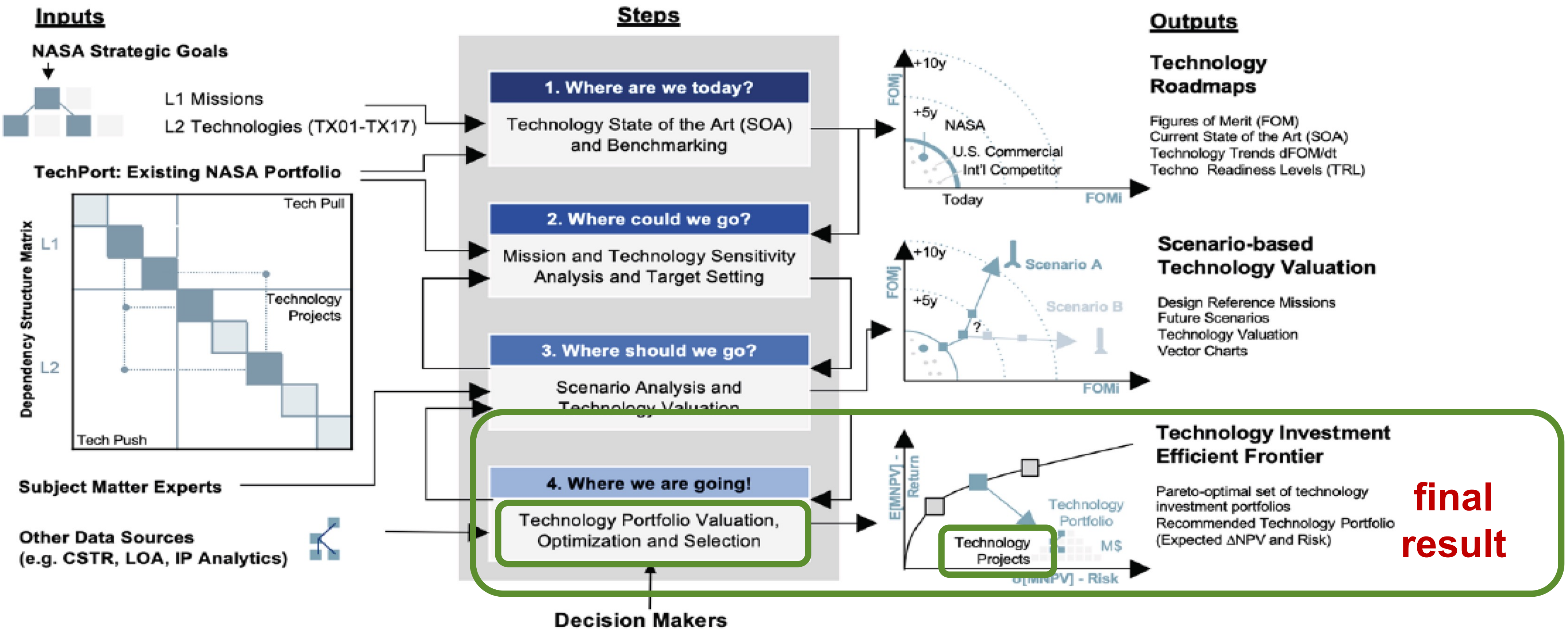

Figure 6: Advanced Space Technology Roadmapping Architecture (ASTRA) methodology with inputs on the left, the key steps with guiding questions in the center and the outputs on the right side. The technology investment efficient frontier made up of a set of Pareto-optimal portfolios (see lower right) is the main output. Final decisions are made by human decision-makers.

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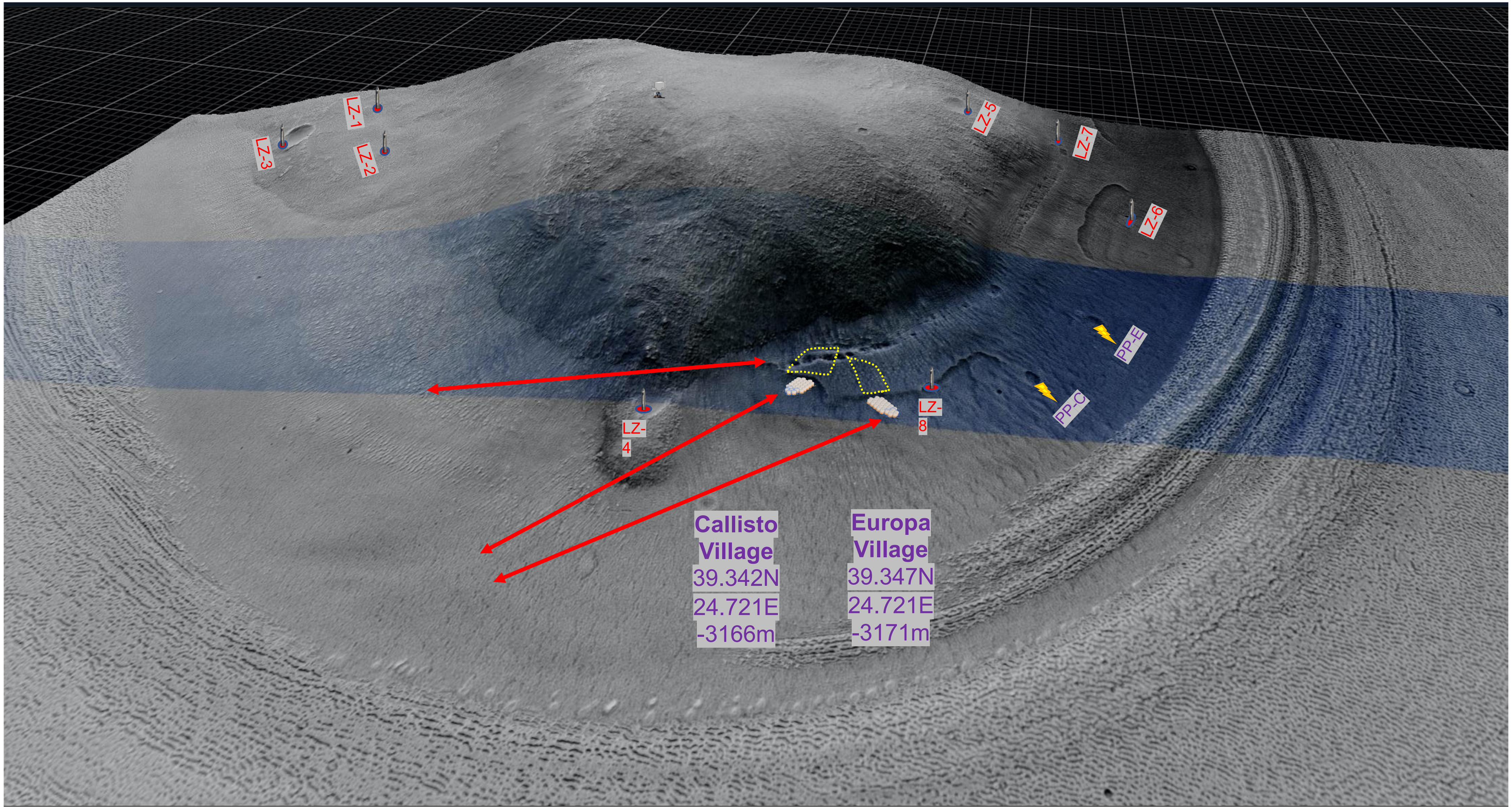
Next week – presenting Pale Red Dot at 2023 RASC-AL



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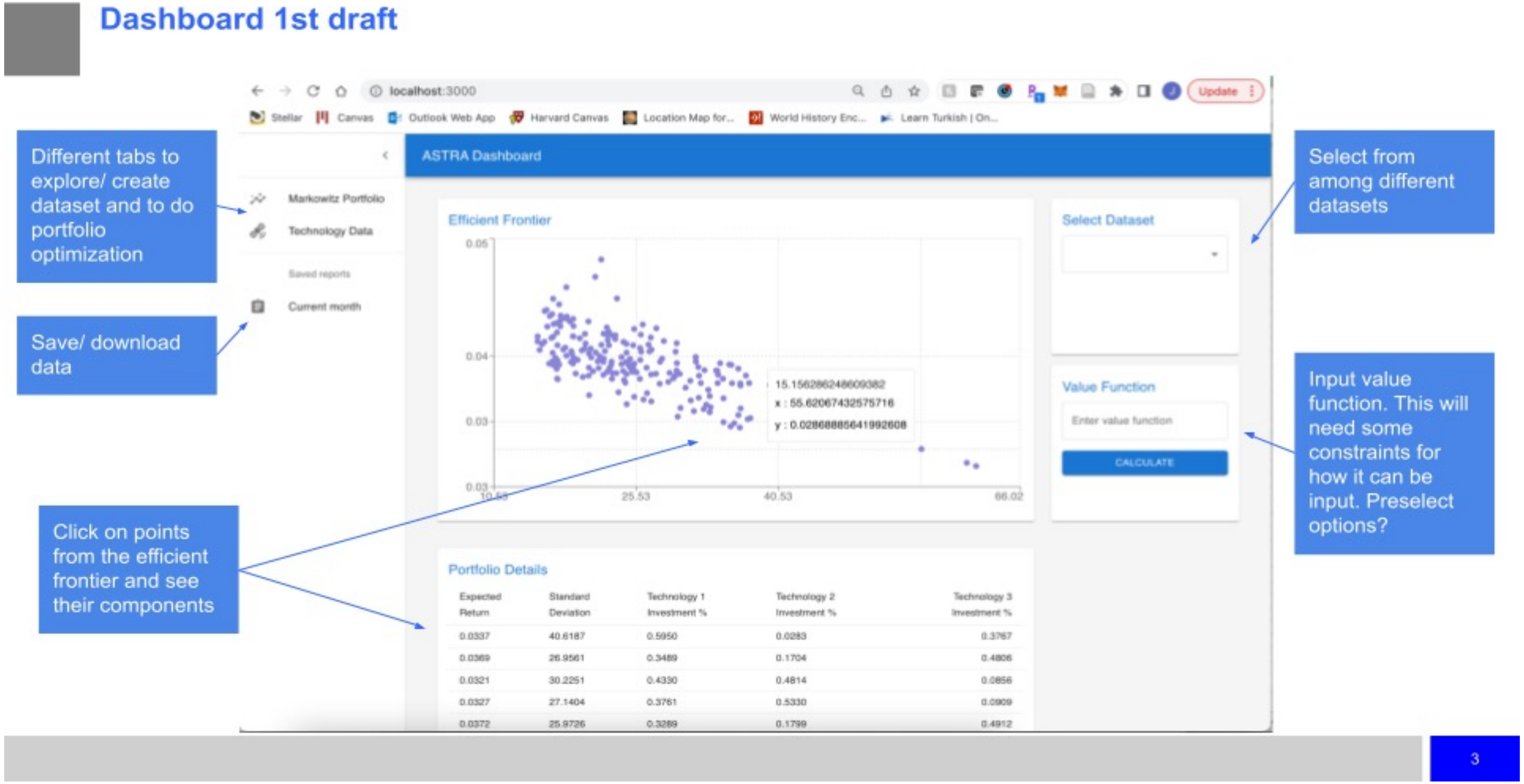
Future work – ASTRA Cloud Tool to support portfolio construction



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Thank you!

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