In-Space Servicing, Assembly, and Manufacturing (ISAM) Roadmap

Strategic Landscaping Webinar: Perspectives Preparation

November 30, 2022




Agenda

1:00 pm Introductions and agenda
1:10 pm Background and scope
1:30 pm Roadmap process overview
1:45 pm Miro activity:
- Prepare landscape perspectives
- Discussion

2:45 pm Next steps
3:00 pm Close

ISAM Roadmapping

Funded by- Manufacturing USA Technology Roadmap (MfgTech) Grant Program, NIST, Department of Commerce

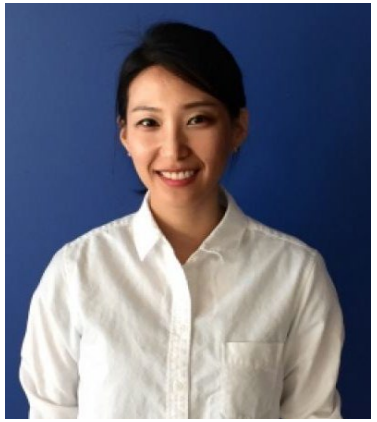
- “to develop technology roadmaps for promising advanced manufacturing clusters
- establish new or strengthen existing industry-driven consortia that address high-priority research challenges
- grow advanced manufacturing in the United States.
- Emphasize … technology roadmapping in areas of critical interest to the nation, including technology areas appropriate for potential future Manufacturing USA institutes.”

Image courtesy of NASA from BIG Idea Challenge

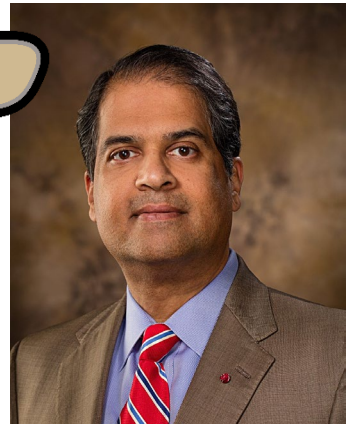
ISAM Roadmapping Team

Prof. Brad Kinsey, co-PI

Prof. John Roth, co-PI



Prof. Jinjin Ha



Prof. Ajay Malshe

Prof. Luz Sotelo

Prof. Michael Sealy

Dr. James Reilly

John Vickers

Dr. Salil Bapat

Steven Shade

Michelle Dennis

Albert Patrick

Vinay Vilas Kenny

Webinar for roadmapping (11/30/2022):

In-Space Infrastructure *for* In-Space Enterprise

ISAM: In-space Servicing, Assembly, and Manufacturing for Space 2.0- Commerce, Habitation, Security, and Exploration

Ajay P. Malshe, Purdue University

Acknowledgment: FACTORIES-IN-SPACE, Harsha and Ajay Malshe, 2018 NSF Manufacturing Blue Sky Competition

”The greatest gain from space travel consists in the extension of our knowledge. In a hundred years this newly won knowledge will pay huge and unexpected dividends.”

— Professor Wernher von Braun (1912-77)

Trend and Driver:

Space, “the final frontier,” is entering a new age beyond exploration (Space 1.0). Space commerce and inhabitation are now Space 2.0. The establishment of sustainable and safe infrastructure are critical for Space 2.0; manufacturing, assembly, and service play mission-critical roles for competitiveness.

Drivers for Urgency

Survival

Exploration

Democratization

Driver 1: Survival

- The world is expected to add another billion people within the next 15 years, bringing the total global population from 7.3 billion in mid-2015 to 8.5 billion in 2030, 9.7 billion in 2050, and 11.2 billion by 2100

  (Ref: https://esa.un.org/unpd/wpp/Publications/Files/Key_Findings_WPP_2015.pdf)

"There is enough on Earth for everybody's need, but not enough for everybody's greed" – Gandhi

"Mankind must colonize space or die out" – Stephen Hawking

World population growth, 1750-2100

Our World in Data

Annual growth rate of the world population

World population

2.1%

11.2 Billion

10.8 Billion

10.2 Billion

9.2 Billion

Theoretical carrying capacity

7.4 Billion

4.4 Billion

3 Billion

1.65 Billion

0.9 Billion

0.1%

2%
1.8%
1.6%
1.4%
1.2%
1%
0.8%
0.6%
0.4%
0.2%
0%

1760 1780 1800 1820 1840 1860 1880 1900 1920 1940 1960 1980 2000 2020 2040 2060 2080 2100

2015

Projection
(UN Medium Fertility Variant)

Data sources: Up to 2015 OurWorldInData series based on UN and HYDE. Projections for 2015 to 2100: UN Population Division (2015) – Medium Variant.
The data visualization is taken from OurWorldinData.org. There you find the raw data and more visualizations on this topic.

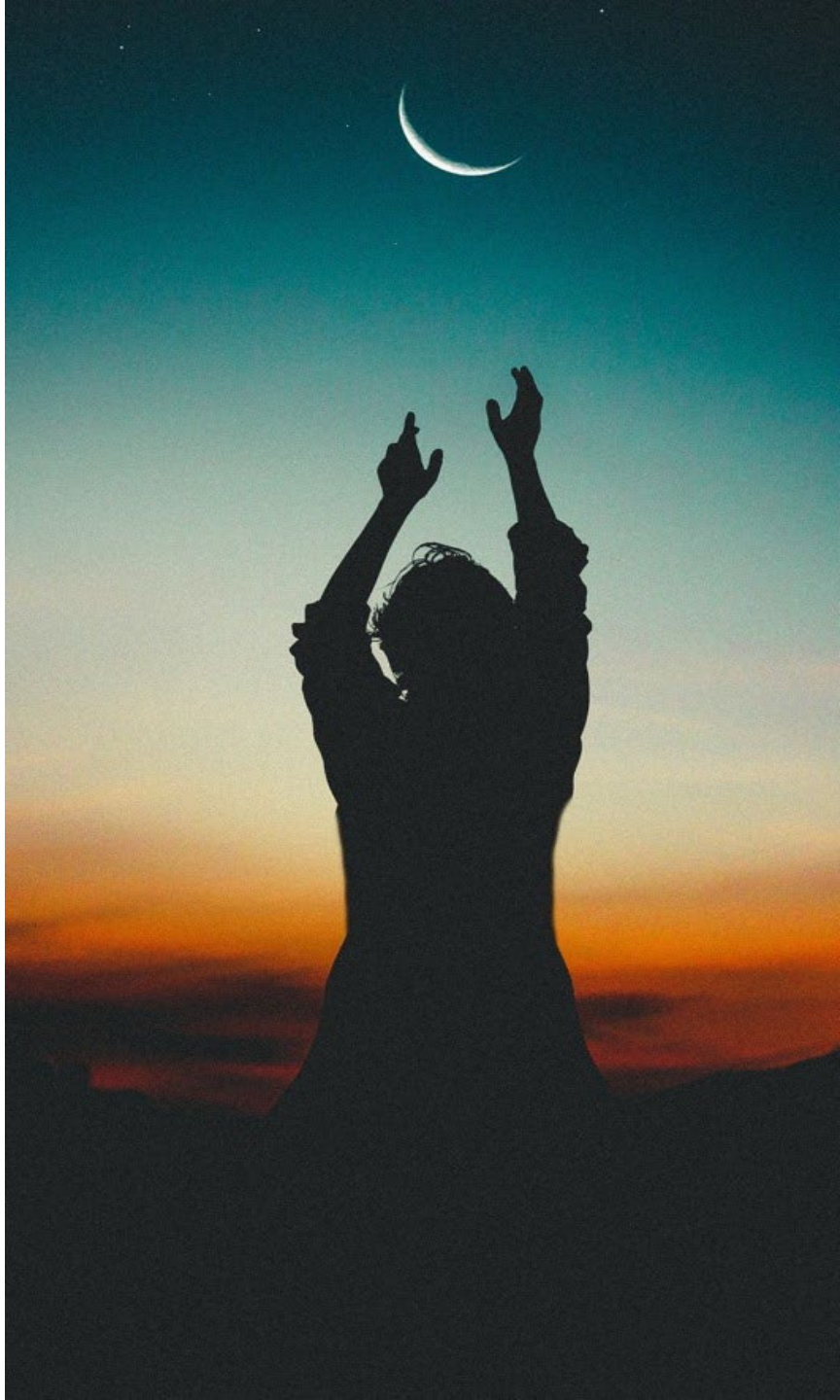
Driver 2: Exploration

- Transition from a consumer to an exploration driven economy for continued human progress
- Transition from risk-averse to risk-seeking society
- Making space habitable through exploration driven by curiosity and discovery
- Calling back to the **great explorers**

Driver 3: Democratization

1. Space exploration is funded by sovereign nations (powerful countries)
2. Space is commercialized by independent actors (ultra-wealthy)
3. In the future, Space must be accessible to large democracy and not in the hands of few

"Competition is not only the basis of protection to the consumer but is the incentive to progress."
Herbert Hoover



“Freedom lies in being bold.”

— Robert Frost

Vision

…for EXTREME: Extra Terrestrial Resource and Manufacturing Engineering

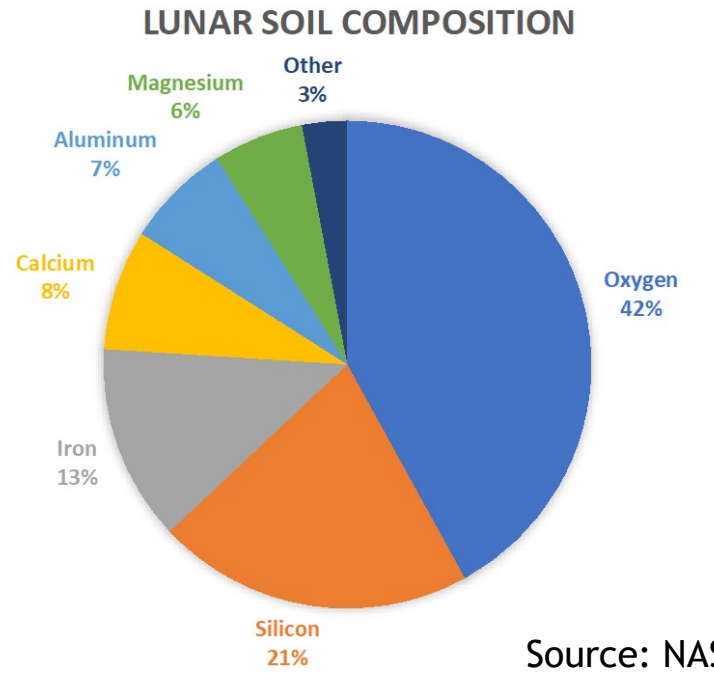
Manufacturing science and engineering **research, education,** and **translation** for ISAM and an *intramodal extraterrestrial supply chain* for sustainable commerce, security, habitation, and exploration.

Examples of Inquiries: ISAM 101

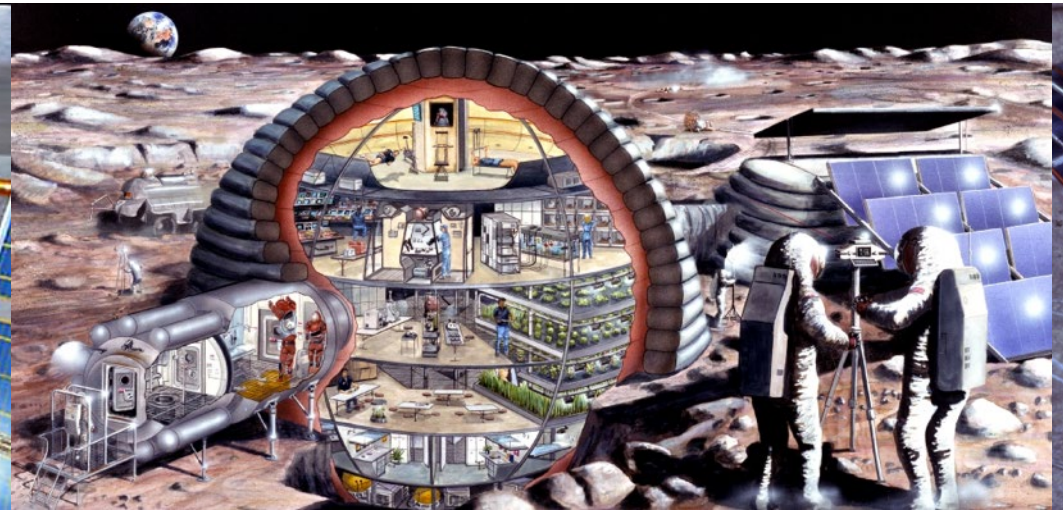
Space-based solar arrays could generate **40x** more energy than similar earth-based systems. (Business Insider)

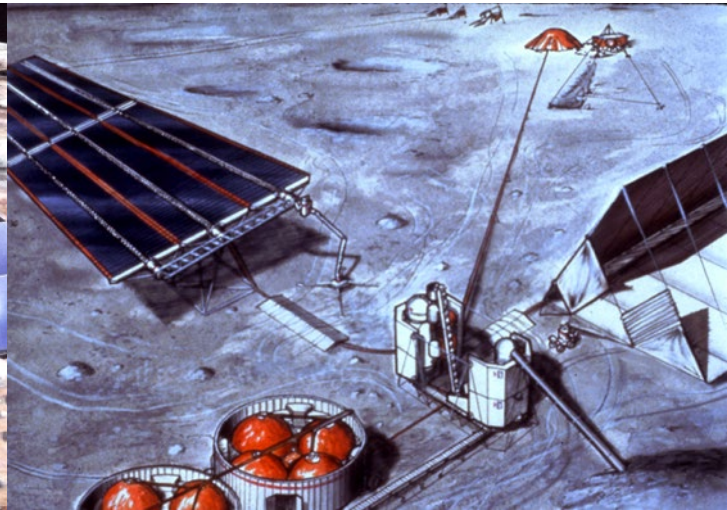
A long-term vision of success for building "Factories-in-Space" mandates that we start asking fundamental questions today:

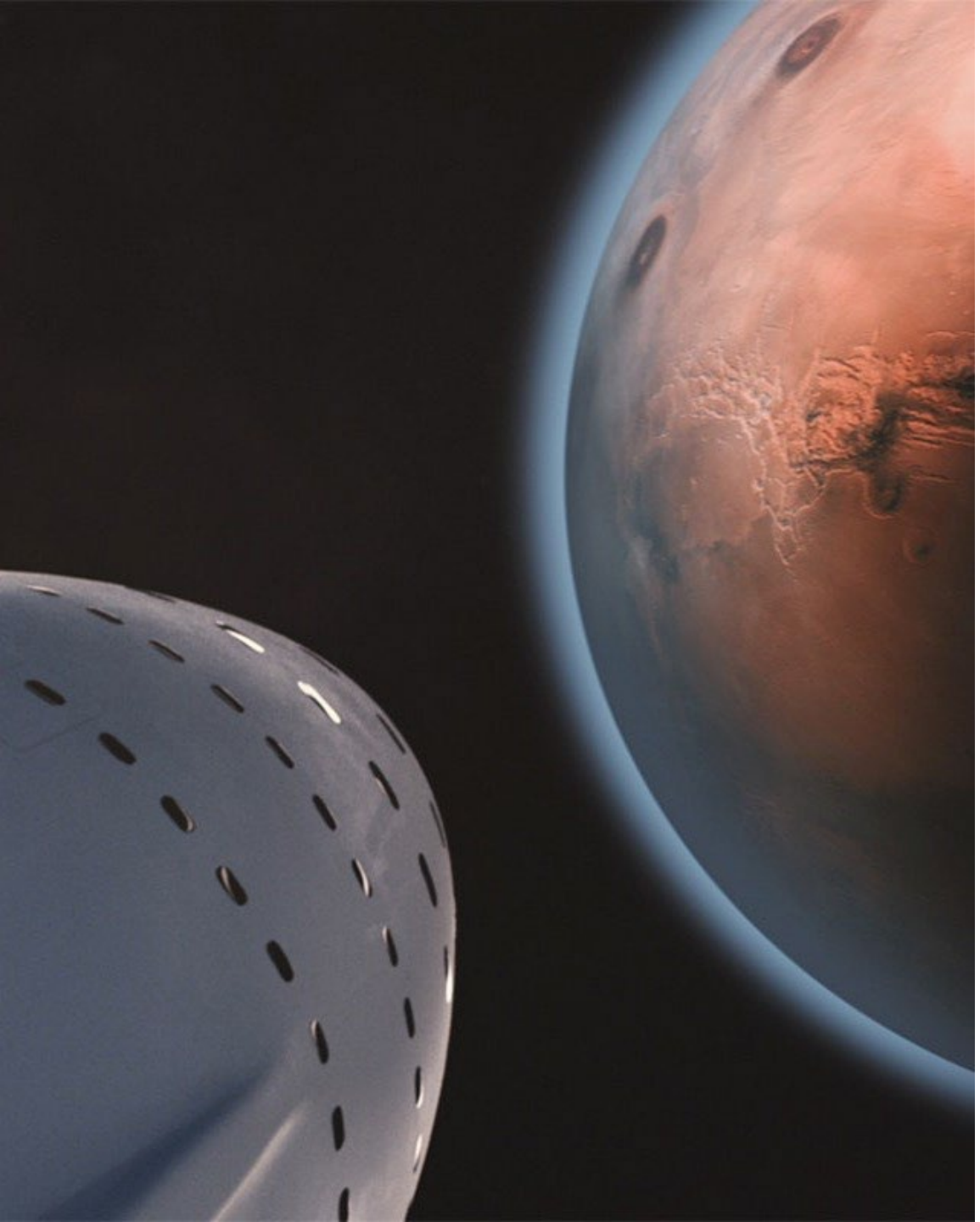
- ✓ *What type of products and services should be manufactured?*
- ✓ *What type of factories will be required to produce such products?*
- ▪ *What kind of energy and material extraction systems need to be developed?*
- ✓ *What type of processes will be required to produce these products?*
- ✓ *What fundamental advancements in our understanding of manufacturing science and engineering are required to scale these processes economically?*
- ▪ *What autonomous systems need to be developed, like robonauts and AGVs, that can maneuver to assemble components in these extraterrestrial factories?*



Source: NASA

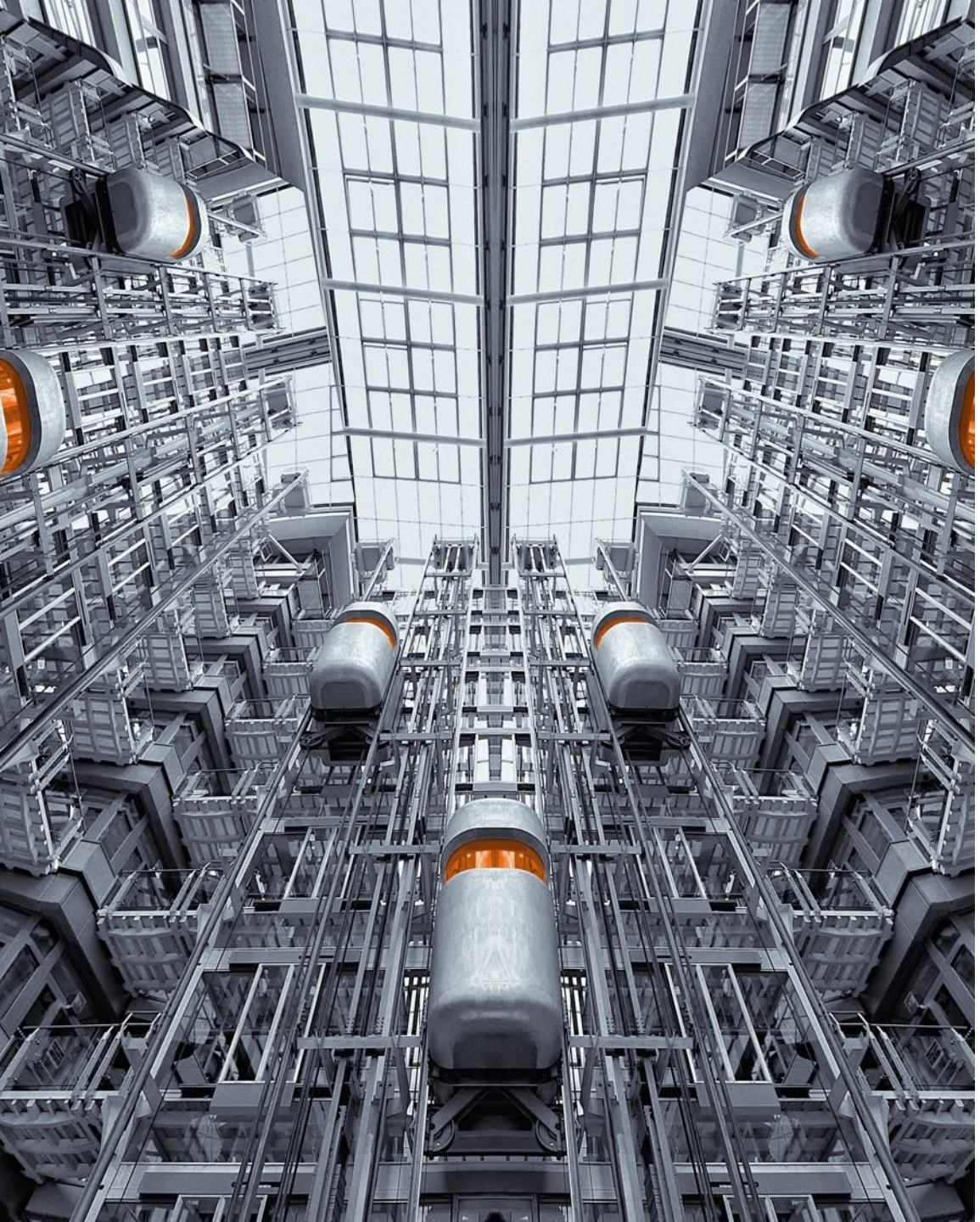






Locations

- Earth orbit
- Surface of the moon
- Asteroids and comets
- Surface of planetary bodies
- Interplanetary space



Industry Coverage

- Energy
- Communications
- Mining
- Transportation
- Medicine
- Housing
- Infrastructure
- Food and air
- And more…

Operations

- Servicing
- Storage & Distribution
- Assembly
- Fabrication
- Repair & Maintenance
- Means maximize ISRU

Common Concerns

- Safety & Well-being of human operators
- Protection from extreme environments
- Security of physical, data and earth-links
- On-site, on-demand, and custom maintenance and back-up systems
- Human-machine robotic interfaces
- High-density and high-speed computing
- Sustainable energy utilization

Launch:

On October 7, National Manufacturing Day, Purdue University (the Cradle of Astronauts) joins with leaders in industry and government to launch the world's first national and international webinar series for this new age of *equitable space*. The objective is to engage, interact and act to enable a national network.

“The fact that we live at the bottom of a deep gravity well, on the surface of a gas covered planet going around a nuclear fireball 90 million miles away and think this to be normal is obviously some indication of how skewed our perspective tends to be.”

— Douglas Adams

Perspectives - preparation for the Strategic Landscaping Workshop (Purdue University, January 17-18, 2023)

The Roadmap Canvas is the entry point to the road mapping process which will be presented and explained in more detail on Day 1 of the workshop.

In order that we engage your thinking ahead of the workshop, we wish you to complete a short assignment:

- We have included a link to the digital version of the Roadmap Canvas to be used on Day 1 with instructions on what we wish you to accomplish. These instructions are summarized on Slides 11-13.
- Complete these steps by close of business on Thursday, December 8th. We do not expect you to take more than 1 hour to complete this assignment.

There will be opportunity on Day 1 to summarize and share your Perspectives in plenary and add to these initial thoughts.

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ISAM Roadmap Objectives & Deliverables

Our ***goal*** is to enable in-space servicing, assembly, and manufacturing (ISAM) and catalyze development for equitable and sustainable space commerce.

The *objectives* of the Advanced Space Manufacturing roadmap project are to:

1) Identify the technical barriers and knowledge gaps towards the realization and deployment of ISAM
2) Identify the fundamental (TRL 1-3) and applied (TRL 4-7) research and commercialization opportunities for industries, academics, national labs, and government agencies
3) Prioritize the development and deployment opportunities for ISAM technologies over a 10-year time horizon
4) Embrace the opportunities available through incorporating diversity, equity, and inclusion in ISAM development activities

The *scope* will include:

- Design, Materials, and Processes (digital twin, composite materials, robotics/automation, additive manufacturing, etc.)
- Products, Services (replacement components, infrastructure, environment-health-safety considerations, etc.)
- Security (cybersecurity)
- Sustainability (*in situ* resource utilization, minimization/elimination of space junk, etc.)
- Workforce development and knowledge-skills-abilities (K-12, college level (associates degree through postdoc), professional training, etc.)
- Supply chains to facilitate, establish, and operate ISAM
- Earth to low-earth orbit (LEO), LEO to moon (cislunar), and lunar surface. (In-space and on-surface will be considered separately.)

This roadmapping effort only includes in-space servicing, assembly, and manufacturing for space and for earth

The *deliverables* will include:

- A strategic ISAM landscape roadmap that includes a prioritized set of key trends and drivers, value streams, and key process indicators
- A series of topical roadmaps providing high-level workflows, capabilities, and resources needed to achieve ISAM objectives
- A summary of taxonomy (and corresponding definitions), standards, protocols, and additional insights generated through the roadmapping process

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What is Roadmapping?

- Roadmaps are structured visual representations that support strategic alignment within and between organizations

- Roadmapping processes enable strategic dialogue, communication, decision making and coordination

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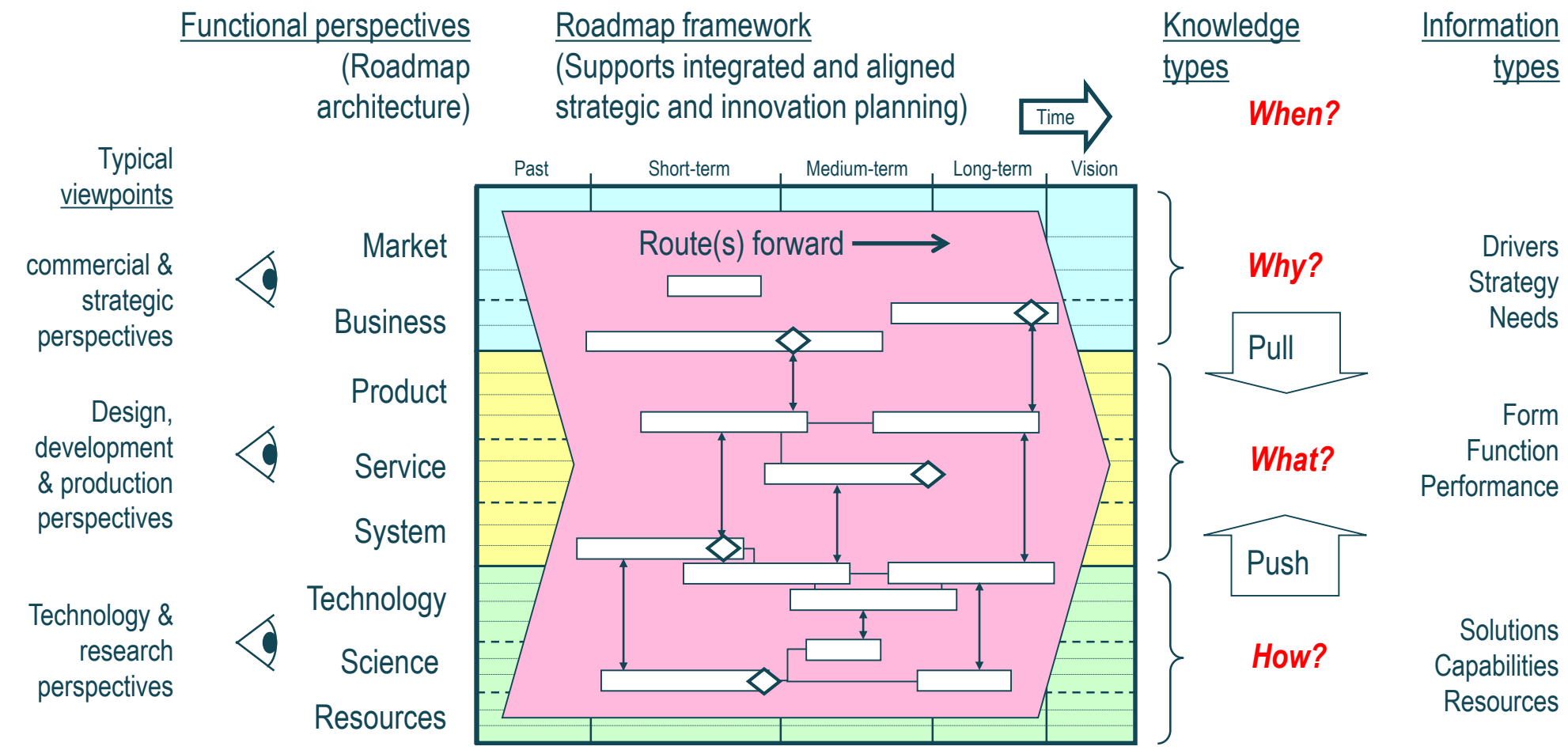
Roadmap framework



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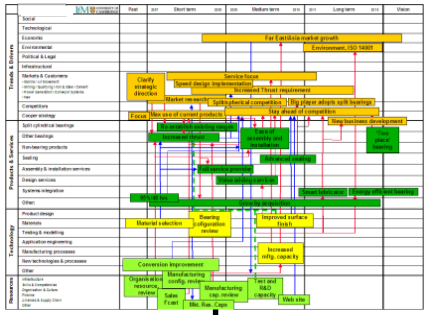
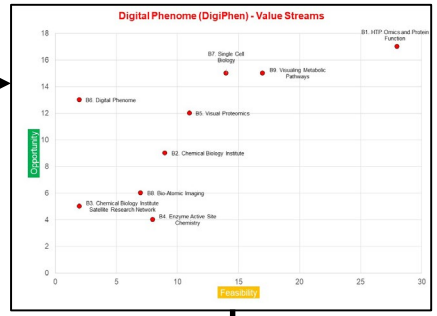
In-Space Manufacturing Roadmap: Process Overview

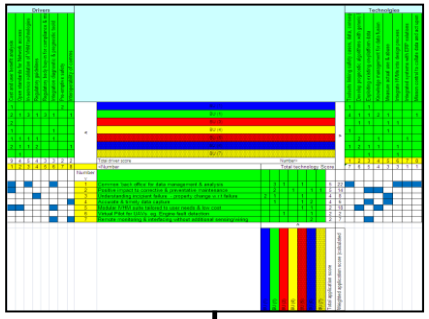
Landscaping (Workshop #1)

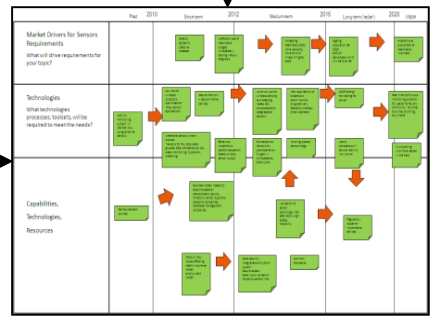


Portfolio selection



Linkage grids





Topic Roadmapping (Workshop #2)

Roadmap process description

Roadmap preparation involves a series of design and workshop activities.

This engagement will include a series of ‘S-Plan’ workshops as part of the overall process design

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Roadmap canvas for In-Space Manufacturing

In-space Servicing, Assembly and Manufacturing (ISAM)			Current	2023 Short Term 2024	2025 Medium Term 2027	2028 Long Term 2032+
Why: Trends and Drivers	External	Geopolitical, Regulatory, and Legal				
		Environmental				
		Societal				
		Technological				
		Economic				
	Internal	Space Policy				
		Mission Needs				
		Research Needs				
	Other	Other Trends and Drivers				

We will focus on the Trends & Drivers layer

Roadmap canvas:

Trends & Drivers Layer

In-space Servicing, Assembly and Manufacturing (ISAM)			Current	2023 Short Term 2024	2025 Medium Term 2027	2028 Long Term 2032+
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		Environmental				
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		Technological				
		Economic				
	Internal	Space Policy				
		Mission Needs				
		Research Needs				
	Other	Other Trends and Drivers				

Trends & Drivers Layer:

Definitions

In-space Servicing, Assembly and Manufacturing (ISAM)			**Taxonomy Definitions/Explanations** *Notes: All line-item topics selected based on an assumption that the boundary conditions are limited to U.S. based efforts. Definitions are intended to stimulate contributions; participants are welcome to provide all relevant input.*
Why: Trends and Drivers	External	Geopolitical, Regulatory, and Legal	National security and readiness; U.S. industry global competitiveness; legal considerations and framework; national and international regulations and standards impacting ISAM value stream throughout the entire lifecycle; threats to U.S. ISAM progress from global adversaries; policies for catalyzing fair competition for equal and competitive opportunities for all.
		Environmental	Impact of in-space and on-earth environmental considerations on ISAM activities (e.g., in-situ resource utilization (ISRU) – material extraction, utilization, and management; implementing circular economy principles – waste minimization through reuse/redistribution, refurbish/remanufacture, and repurpose/recycle, i.e., the 6 R's).
		Societal	Social factors including cultural perceptions, demographic characteristics, career attitudes and availability of skilled workforce, equity (acceptability, availability, accessibility, and affordability to ISAM), health, and safety as they pertain to ISAM activities (e.g., models for sustained interaction between and among space communities, human operating in extreme conditions for biology, the human desire to explore the next frontier).
		Technological	Factors including development and innovations that pose opportunities and threats to ISAM (e.g., on-earth developments that minimize resource availability, energy generation, and storage, transitioning earth-based processes to ISAM, automation, autonomy, robotics, materials manufacturing in low gravity).
		Economic	Economic factors such as economic and currency growth/decline/stability, availability of government and private funds, inflation and wage rates, and unemployment. Potential for economic savings; commercial market opportunities
	Internal	Space Policy	Roles of government, private investments, and corporations for addressing pre-competitive issues; fair and equitable democratization of space
		Mission Needs	Long-term strategic goals and sub-goals of space agency and private entities that are achieved through the development of ISM developments (e.g., enabling space science and commercial viability by eliminating the constraints of launch requirements).
		Research Needs	Innovations supporting new commerce models and markets, processes, and products; threats and opportunities for small businesses.
	Other	Other Trends and Drivers	Opportunities and threats related to establishing a new industry sector in the space environment, for commerce on earth and for in space.

What is a Trend / Driver?

Trend & Driver: A fact or event that causes us to take an action

We can think of a driver in the following ways:

- An External opportunity that we should exploit
- An External threat that we must defend against

Format for a driver:

- An **<Observation>**, therefore a **<Consequence>**
- We **see X**, therefore we need to **respond Y**

Example #1: A well structured and precise driver

Observation:

Development of ISAM technologies is expensive.

Consequence:

Collaborations and consortia would reduce the costs for individual companies and government agencies.

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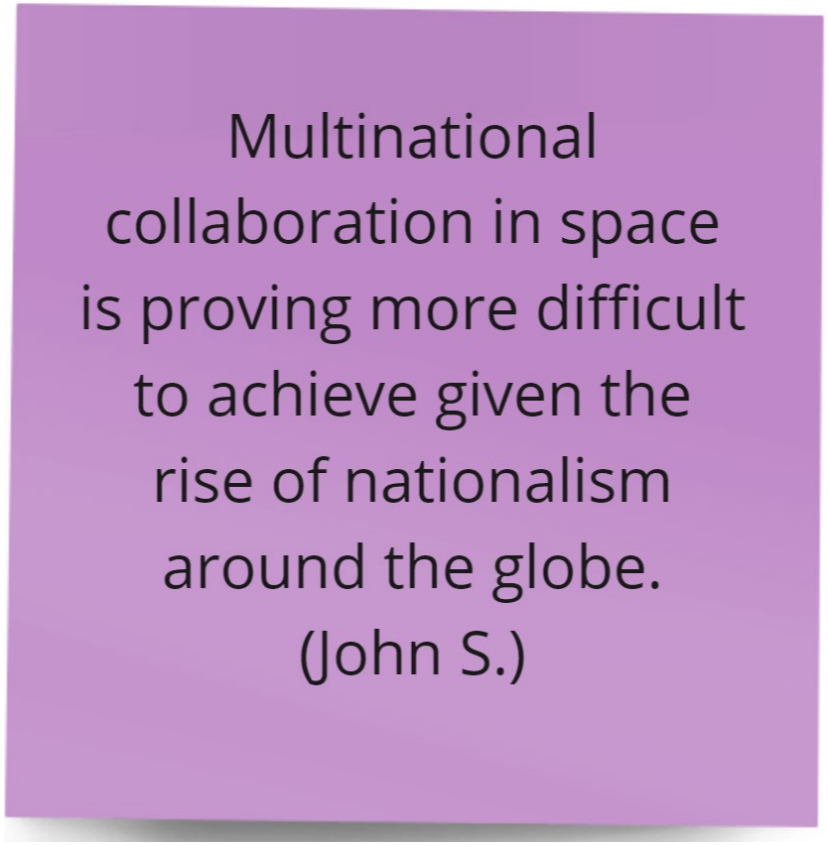
Example #2



Observation:

[There is a] rise of nationalism around the globe.

Consequence:

Multinational collaboration in space is proving more difficult to achieve.

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1:00 pm Introductions and agenda

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1:30 pm Roadmap process overview

1:45 pm Miro activity:

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- Discussion

2:45 pm Next steps

3:00 pm Close

Perspectives - preparation for Workshop #1 (Strategic Landscaping)

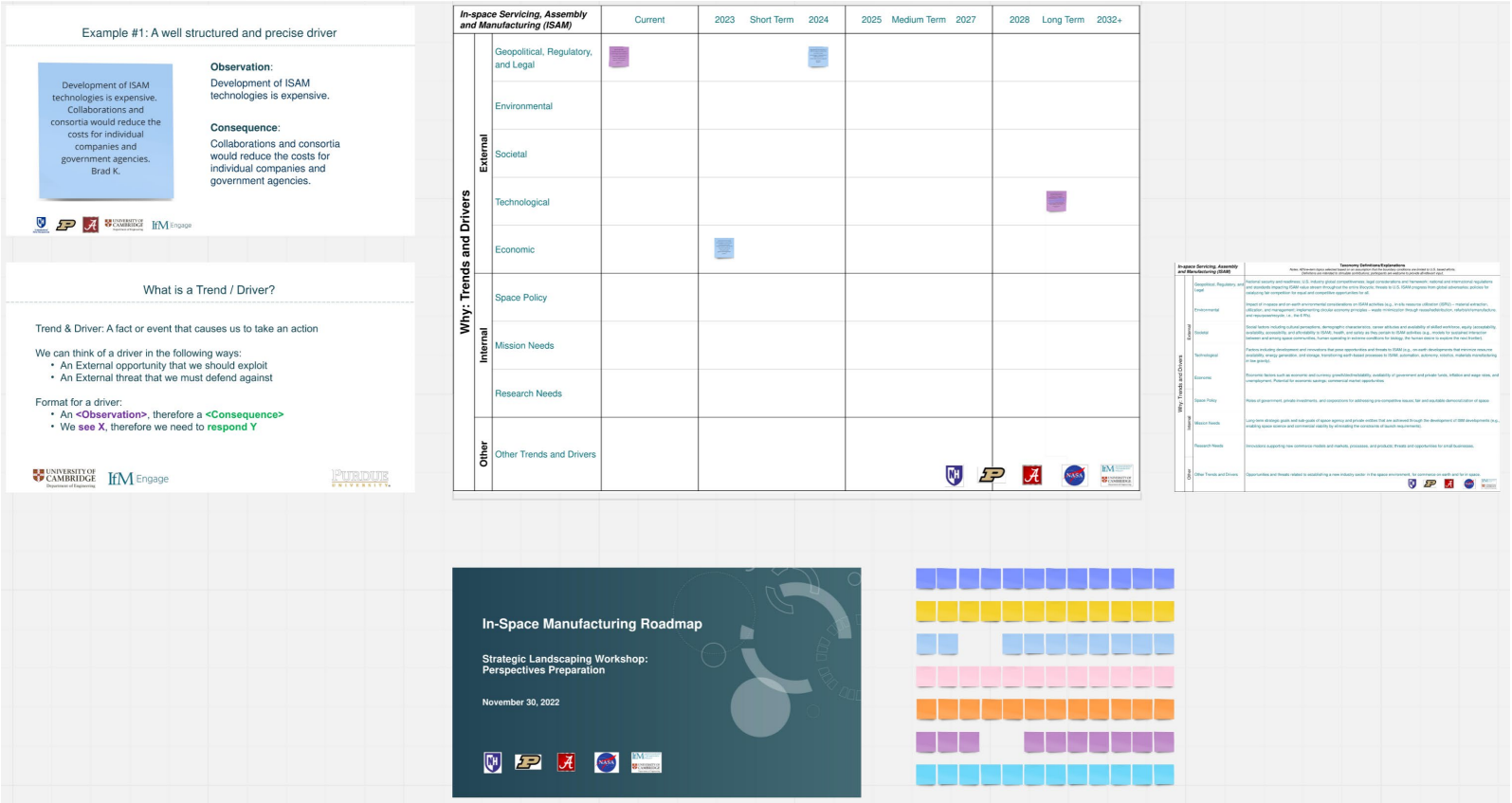
The Roadmap Canvas is the entry point to the road mapping process which will be presented and explained in more detail during the Strategic Landscaping Workshop at Purdue University in early 2023.

In order that we engage your thinking ahead of the workshop, we wish you to complete a short assignment.

There will be opportunity for a few minutes during the workshop to summarize and share your Perspectives in plenary and there will be plenty of opportunity during the rest of the workshop to add to these thoughts.

Protocol for generating digital “sticky notes”

Step 1:
Click on this link to access the roadmap canvas on Miro:
https://miro.com/app/board/uXjVPaFbXfA=/



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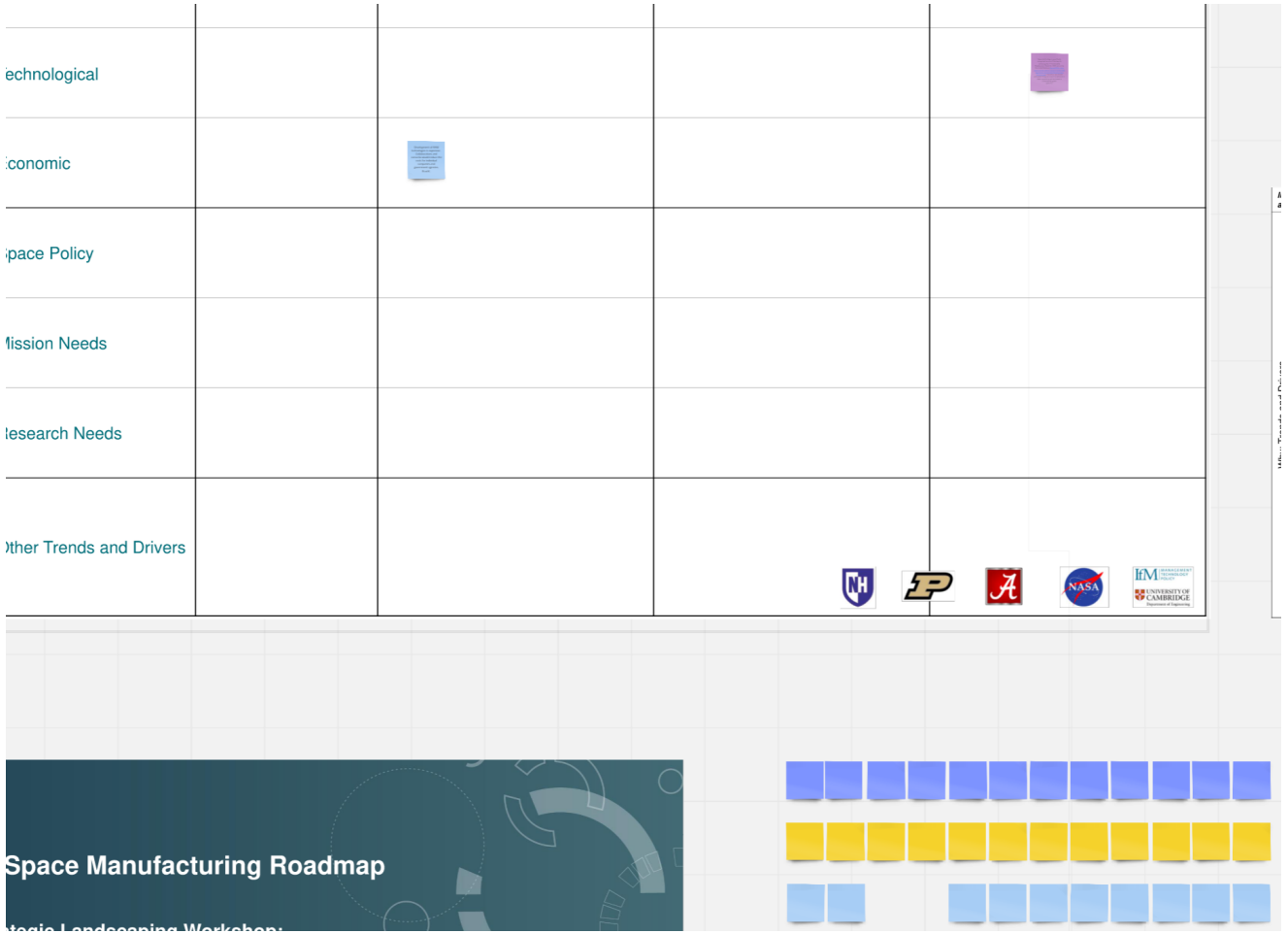
Protocol for generating digital “sticky notes”

Step 2A:
Select a blank sticky note and type a trend / driver using in brief

Step 2B:
Include your name in parenthesis
(so we can check for clarification or expansion)

Tips for using Miro:
[Sticky notes – Miro Support]



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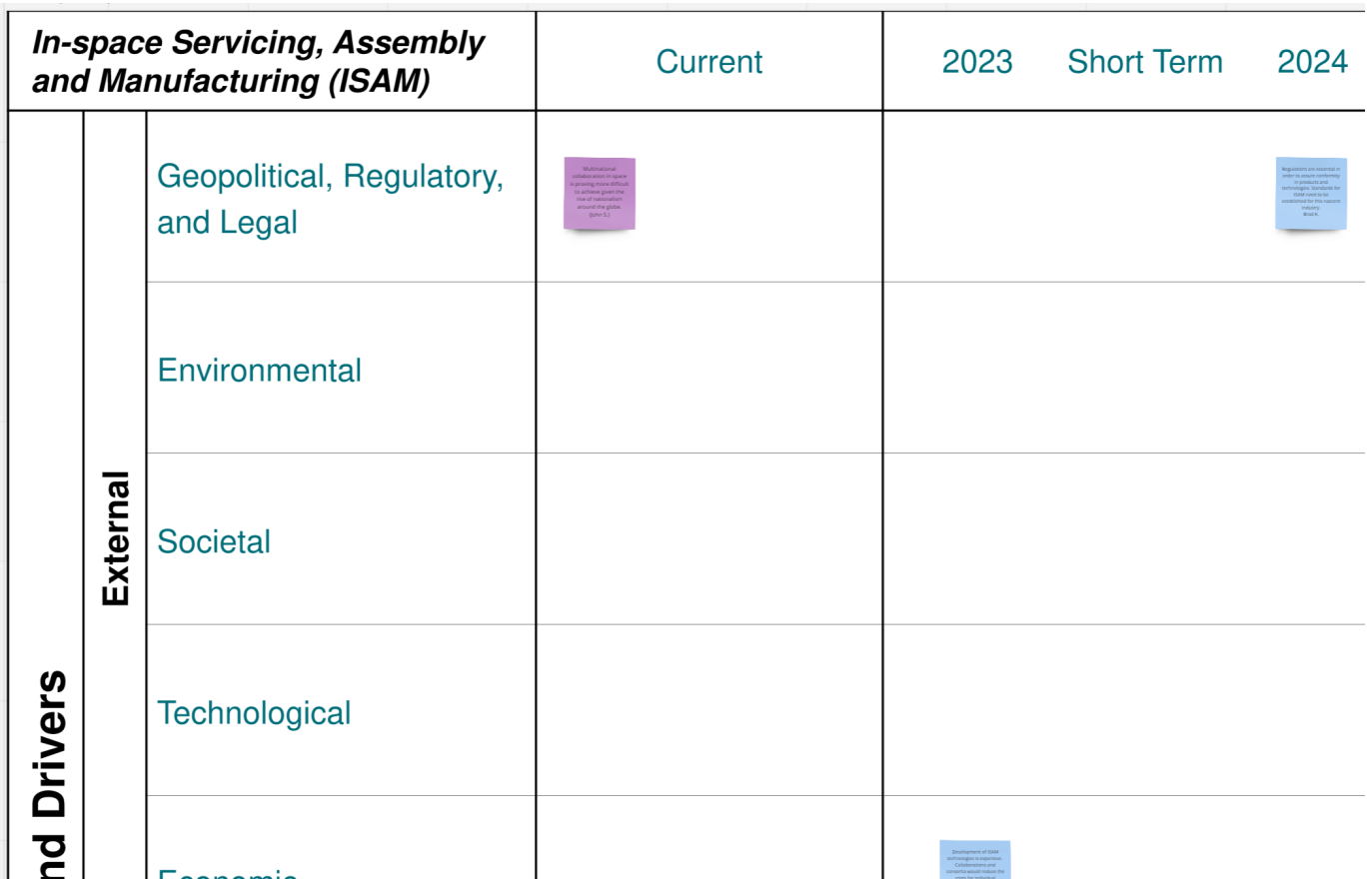
Protocol for generating digital “sticky notes”

Step 3:
Move your digital sticky note to the landscape canvas. Align with a (horizontal) driver category and (vertical) time zone as appropriate

Note: Try to add a few sticky notes in each time zone



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Trends & Drivers Layer:

Taxonomy Definitions

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		Economic				
	Internal	Space Policy				
		Mission Needs				
		Research Needs				
	Other	Other Trends and Drivers				
What: Potential Commercial Outcomes	Facility and Process Related	Primary Manufacturing Processes				
		Secondary Manufacturing Processes				
		Intermediate Inputs				
		Process Control and Quality				
		Data Transmission and Cybersecurity				
		Material Handling and Storage				
		Facility Design				
		Servicing and Maintenance				
	Product Related	Design and Modelling / Digital Twin				
		Assembly and Construction				
		Sustainability				
		Servicing				
	Market Related	Commercial Market Opportunities				
		Financing				
	Other	Other Commercial Outcomes				

Strategic Landscaping Workshop (WS1):
January 17-18, 2023
Purdue University

We will complete the top two layers and select priority areas for additional development at the Topic Roadmapping Workshop (WS2) in 2023

Perspectives - preparation for the Strategic Landscaping Workshop

In preparation for the (2-day) Strategic Landscaping Workshop, all perspectives added to the Miro board will be organized into groups for discussion on Day 1.

You will have time on Day 1 of the workshop to summarize and share your perspectives in plenary and there will be plenty of opportunity during the rest of the workshop to add to these thoughts.

Here is the registration link to attend:
https://www.eventbrite.com/e/in-space-servicing-assembly-and-manufacturing-isam-roadmapping-workshop-tickets-467542561387?utm-campaign=social%2Cemail&utm-content=attendeeshare&utm-medium=discovery&utm-source=strongmail&utm-term=checkoutwidget

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