MAPPING THE LANDSCAPE OF SPACE EXPLORATION WITH A COMPREHENSIVE TECHNOLOGY TREE. R. Fonteyne and K. Konstantinidis, Foresight Institute, 101A Clay Street, Box 185 San Francisco, CA 94111, romain@foresight.org.

Premise: The space sector has experienced a recent influx of innovative and transformative technologies. This study presents a technology tree that maps the landscape of space exploration and the technologies required to support it. The tree includes nodes representing current advancements and their connections to various space technologies, which facilitate the development of novel capabilities and applications. It aims to improve coordination of efforts to identify and fund undervalued areas, while also providing experts with information about the state of space technologies to optimize research outcomes.

Introduction: The Space Technology Tree (https://foresight.org/ext/ForesightSpaceTree/) is a web-based tool developed and maintained by the Foresight Institute, a non-profit research organization that promotes the development of high-impact technologies. The technology tree is an open-source project that connects various technologies and applications, including future challenges and issues to be addressed, in order to give a more comprehensive understanding of the current building blocks and leading-edge technologies in space exploration. It will provide stakeholders, including researchers, funders, policy-makers and others, with more accurate insights on the evolution of the space domain from the present into the long term.

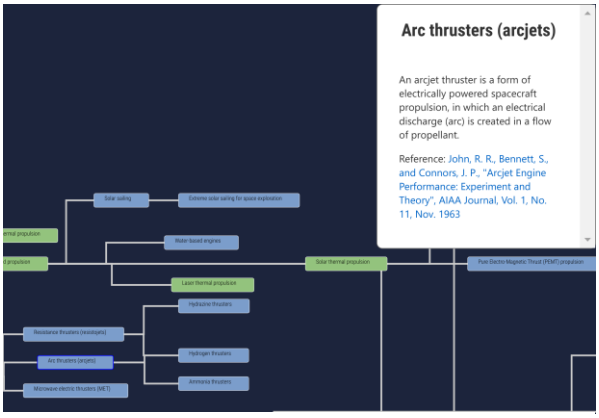

Figure 1: *Space Technology Tree page, displaying the node Arc thrusters (arcjets) as an example.*

The Space Technology Tree: The tree consists of specific types of nodes. *Technology nodes* describe the technologies necessary to enable the various space applications. To ensure completeness of the tree, systematic approach is followed, where these technologies are categorized into taxonomies based on existing technology taxonomies by NASA [1] and ESA [2]. *Mission nodes* describe the various space applications, each aiming to achieve specific goals.

These are organized into incremental roadmaps for each application field (e.g., Earth observation, Asteroid mining, etc.), based on the leading space agencies' mission roadmaps (e.g., the Global Exploration Roadmap [3]). The tree emerges by connecting technology nodes to the corresponding missions which they enable along the mission roadmaps. The tree is further comprised of two secondary components, that can be attached to a relevant technology or mission node: *Challenges* describe specific technical, economic, regulatory, etc. complications that a specific technology or mission might face; *Entities* describe stakeholder organizations (researchers, funders, policy makers, etc.) that are active on the topic of a given node and carry out related *projects*.

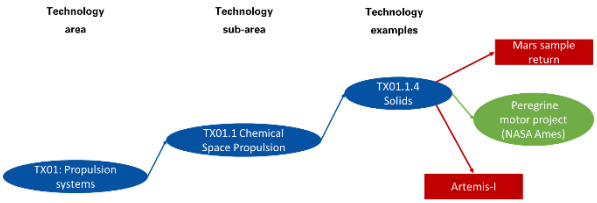

Figure 2: *Space Technology Tree's space propulsion representation with specific mission examples connected to the relevant taxonomy category. Blue ellipses represent taxonomy levels; green ellipses are relevant projects; red ellipses are missions that the technology enables.*

The technology tree tool allows users to visualize and analyze the nodes and connections within a tree structure, becoming a valuable resource for a variety of applications. It provides features such as the ability to see all the nodes and connections between them, search for specific nodes or connections, display the tree in a graphical format, and download the tree as a graph file. The diverse functionalities are useful for understanding complex systems, analyzing data sets, and identifying patterns and relationships within the tree structure, and can provide a powerful and intuitive way to explore and analyze a specific field of space exploration.

A Collaborative Process: The process for creating the Space Technology Tree involves a literature review to gather information from a wide array of references. This information is then used to create nodes within the tree, representing different technologies and applications within each field of space exploration. The tree is further refined through interviews with domain experts (researchers, investigators, funders, and executives) and feedback from stakeholders, ensuring

that it is accurate and up-to-date. Therefore, the process for building the tree is heavily based on expert inputs in each technology and application field to enhance content quality.

The diverse functionalities of the Space Technology Tree make it a powerful and intuitive tool for exploring and analyzing the field of space exploration, as well as for informing the aerospace community about global space exploration endeavors. The Space Technology Tree provides a comprehensive and reliable resource for understanding the current state of the field and its direction for the future.

Current Status and Future Work: The tree is currently comprised of more than 1,500 nodes describing technologies, missions, and challenges, collected from more than 300 references. The tree further lists over 12,000 entities working on specific space-related problems. Currently available technology and application fields include Space Propulsion, Space Power, Space Communications, Guidance, Navigation and Control (GNC), Earth Observation, In-Situ Resources Utilization, Space Robotics, Space Debris Mitigation, In-Space Manufacturing, and Space Structures—linked to the relevant listed planetary missions, asteroid mining missions, Earth observation missions, and lunar exploration missions.

New state-of-the-art technologies from ongoing research worldwide will continue to be added to the technology tree. In the longer term, the space technology tree's list of nodes will be updated to reflect changes as space exploration moves forward. Besides, the space mission roadmap gathering all the future space missions will be improved, refined, and expanded as the project progresses. The tree tool interface will continue to be updated to improve the technology and mission search functions, and the overall user experience. Feedback from the space community is valued and always encouraged; comments from users can help identify useful future improvements and feature additions for the tool, as well as additional inputs for the technology tree and mission roadmap.

Contact Information: The Space Technology Tree welcomes questions and comments for additional technology and mission nodes, challenges, and tool functionalities from the community. The authors can be reached at kostas@foresight.org or romain@foresight.org.

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References: [1] Miranda, D. (2020) *2020 NASA Technology Taxonomy* (No. HQ-E-DAA-TN76545). [2] European Space Agency (2020) *ESA Technology Tree, version 4.0* (ESA STM-277 3rd ed., April 2020). [3] International Space Exploration Coordination Group (2018) *The Global Exploration Roadmap*.