

## FROM CONCEPT TO COORDINATION: TOWARD CACE, AN ALLIANCE OF SPACE RESOURCES CENTERS<sup>s</sup>

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**Introduction:** Space resources research has evolved rapidly in the past decade from a largely conceptual discussion into a multidisciplinary field encompassing resource prospecting, regolith characterization, excavation and beneficiation, extraction and processing technologies, mission architectures, techno-economic analysis, and legal-policy frameworks [1–8]. Major national and international initiatives are now exploring how extraterrestrial resources may support sustainable exploration architectures and future space economies.

At the same time, research and development activities remain geographically and institutionally distributed. This diversity is one of the field's strengths, but it also creates fragmentation in terminology, research priorities, technical benchmarking, and mobility of early-career researchers. Reviews of lunar resource utilization and space resource governance consistently emphasize the importance of stronger coordination across scientific, engineering, economic, and policy domains [1–4,8].

In response to this need, discussions have recently begun among four multidisciplinary centers working actively in the field: the Center for Space Resources (CSR), the Andy Thomas Centre for Space Resources (ATCSR), the Center for Space Resources and Innovation (CSRI), and the European Space Resources Innovation Centre (ESRIC). In this paper we refer to the emerging framework connecting these institutions as CACE, using the initials of the participating centers.

**Founding centers and an open framework:** The present discussion focuses on coordination among these four founding centers, each of which hosts significant programs in research, education, industrial engagement, and policy dialogue related to space resources. Their activities include major international meetings such as the Space Resources Roundtable (SRR), Space Resources Week (SRW), Space Resources Fundamentals (SRF), and the Space Resources Initiative (SRI).

However, CACE is not conceived as an exclusive club. Rather, it is intended as a lightweight, non-binding, and expandable framework that may gradually connect a broader community of actors engaged in space resources research and development.

In this sense, the alliance is envisioned as open to future participation by additional centers, universities, research institutes, space agencies, and industry partners, particularly as new national programs and academic initiatives emerge in Asia, Europe, North America, and elsewhere. By starting with a small group of centers while maintaining openness to expansion, the framework aims to combine agility with inclusiveness.

**Why a center-based alliance?:** A key premise of CACE is that the most effective unit of long-term cooperation is the research center rather than the conference alone. Meetings such as SRR, SRW, SRF, and SRI provide essential venues for discussion and visibility, but they represent only part of the broader ecosystem of research laboratories, technology development programs, educational initiatives, and institutional partnerships.

A center-based framework therefore provides greater flexibility for sustained collaboration. It allows coordination not only during annual meetings but also through laboratory work, student supervision, visiting researcher programs, joint experiments, and shared educational activities.

This structure also reflects the technical nature of the field. Space resource utilization requires integration across planetary science, mining engineering, materials science, robotics, systems engineering, economics, and law [1–4,6–8]. Effective collaboration therefore benefits from institutional environments capable of bridging these disciplines.

**Areas for practical coordination:** At this stage, CACE is best understood as a platform for practical coordination rather than a formal governance body. Several areas appear particularly promising for early collaboration.

First, the alliance could strengthen resource characterization and viability assessment. Progress in ISRU depends critically on improved knowledge of the abundance, accessibility, variability, and engineering relevance of extraterrestrial resources [1–3]. Shared discussion across centers could help align prospecting priorities and analytical methods.

Second, CACE could support process integration and technical benchmarking. One challenge highlighted in recent literature is the difficulty of comparing ISRU processes when feedstock descriptions, flow-

sheets, and performance metrics are inconsistent [4,7]. Cross-center dialogue may help improve comparability and reproducibility.

Third, the alliance may facilitate mobility and workforce development, including graduate student exchanges, postdoctoral placements, and visiting researcher programs. Early examples of such exchanges already demonstrate the practical benefits of closer coordination.

Finally, CACE could provide a venue for connecting technology development with economic and policy considerations, helping to ensure that technical progress is evaluated within realistic operational and regulatory contexts [3,8].

**Discussion:** Importantly, the goal of CACE is not to establish a rigid institutional structure but to create a flexible environment for collaboration. By maintaining a lightweight framework and encouraging voluntary participation, the alliance can evolve organically as the space resources community grows.

The Space Resources Roundtable offers a natural setting to discuss how such coordination might develop in practice. The objective is not to finalize a detailed governance model but to identify practical steps that could strengthen connections among research centers and their broader communities.

**Conclusions:** The proposed CACE framework represents an initial effort to connect major space resources centers while maintaining openness to broader participation across academia, industry, and government institutions. By combining a small group of founding centers with an inclusive and expandable structure, the alliance aims to enhance international coordination while preserving institutional autonomy.

As space resources research continues to mature, such coordination may help strengthen the scientific foundations, technological capabilities, and workforce development needed to support future exploration architectures.

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