A Decadal Shift: From Space Exploration Science to Space Utilization Science

A Whitepaper Submitted to The Planetary Science Decadal Survey Committee

The National Academies, Space Studies Board
500 Fifth Street, NW, Washington, DC 20001
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We urge the Decadal Survey Committee, which is charged with developing "a comprehensive science and mission strategy for planetary science,"[1] to temporarily shift research priorities in the United States **from space *exploration* science to space *utilization* science.**

Following five decades of space exploration science, what can we accomplish in the next half century? If our goal is to maximize returns during *this* time frame, we can reap far greater scientific—and societal—benefits if we choose to focus on the celestial objects that are (energetically) closest to Earth, that offer the earliest opportunities for establishing self-sustaining economic returns, and that present a real, if rather small, threat[2] to everyone alive on Earth today.

By putting **near-Earth objects** at the top of the planetary science agenda, and focusing on resource development for the next decade, your committee can help launch the next generation of profitable space industries, which would allow the nation to develop, over subsequent decades, a far better understanding of the solar system and the universe than would otherwise be possible.

Reframing the Space Studies Agenda

The key question facing the committee is: **"Spend or invest?"**

One approach, the current default, is to assume that a certain level of federal funding will be available to explore "the most important scientific questions expected to face the [planetary science research] community during the interval 2013-2022."[3] Within robust budgetary constraints, your committee would then prioritize the various research agendas, and decide what kind of support each area deserves during this funding cycle.

We believe that this approach is not in the national interest. Instead, a decadal investment in space resource development would benefit the nation's economy and its research community.

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A novel approach, one that could revolutionize the space studies arena, is to invest in *applied* planetary science for the upcoming decade. The huge population of near-Earth objects—some 20,000 larger than 140 meters, as Michael Nolan, et al., point out,[4] and perhaps 500,000 larger than 45 meters[5]—offers tremendous opportunities, not only for scientific discovery but also for industrial and **economic development**.

Such an approach needs to be framed in politically acceptable language. For example, the Space Studies Board could promote "A decade of near-Earth resource discovery," to complement Earth-observation programs. Or, "A space robotics decade." The robotics meme is particularly cogent; any substantive advance in space-based research and development will require significantly more capable robotic systems.

If the committee takes this new route, prioritizing the suite of applied sciences that will be required to develop near-Earth asteroids, planetary scientists will be able to employ more powerful tools in the coming decades. A growing ecology of resource extraction industries, given sufficient process efficiencies, will become economically self-sustaining. Profit driven firms will promote the development of a number of space-based tools, including sensors, actuators, propulsion systems, and material processing systems.

Historians of science and technology recognize that new science is often enabled by new technology. For example, Steven Chu, the new Secretary of Energy, described the strategy he used that led to his Nobel prize: "Use some new technology and have a first peek."[6] By supporting the applied sciences required to bring asteroid mineral resources into the human economy—and there is much work that needs to be done—planetary researchers will be rewarded with an array of new technologies with which to "have a first peek."

We can chose to spend, decade by decade, the small subsidy offered by national largesse. Or, we can reframe the agenda. Your committee can articulate this new course, showing how we can accelerate the evolution of robotics, build next-generation technologies, and simultaneously address contemporary, real-world problems.

Addressing "The Nation's Most Pressing Problems"

The National Research Council's Committee on the Rationale and Goals of the U.S. Civil Space Program determined earlier this year that two of the most important goals for the nation's civil space program are to:

- Expand the frontiers of human activities in space.
- Provide technological, economic, and societal benefits that contribute solutions to the nation's most pressing problems.[7]

What "pressing problems" could space resources be used to address? What space science programs could help "expand the frontiers of human activities in space"?

There are but three fundamentally valuable space resources: location, energy, and matter. By exploiting the first, terrestrial satellite systems support multibillion dollar industries. Space-based solar power (SBSP) systems aim to harness the second. Large scale SBSP,[8] indeed *any* large-scale off-planet industry, will require substantial quantities of refined metals and minerals derived from the third fundamental resource: matter.

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Asteroids offer **the only source** of matter not stuck at the bottom of a gravity well.

Asteroid mineral wealth is on the critical path for any multi-decade scenario designed to increase, or simply maintain, human wellbeing on Earth. While it now appears that the alarms raised in the 1970s were somewhat premature, real shortages of key industrial minerals are evident today and seem likely to increase through the current century.

The USGS reports that **the U.S. imports 100% of 18 essential industry minerals.**[9] The National Academies' Committee on Earth Resources recently identified the platinum group metals (PGMs)—used in catalytic converters and fuel cells—as "most critical" for industrial development.[10] More than 75% of the world's platinum—and more than 85% of the rhodium—comes from a single geological feature in South Africa."[11] Some models project terrestrial platinum depletion within a few decades.[12] The supply of rare Earths (e.g., terbium and neodymium), used in new electric car motors, are raising geopolitical tensions as "China tightens [its] grip on rare minerals."[13] Other vital high-tech metals—gallium, indium, and hafnium—are being reported as "potentially running short ... within the next decade."[14] In addition, mineral extraction from increasingly poor terrestrial ore bodies strains already distressed ecosystems on Earth.

Near-Earth objects (NEOs) are a motley crew, drawn from across the solar system, and perhaps beyond. Some are spent comets, offering water that can be used as propellant. Some are rich in carbonaceous volatiles. Others are rich in industrially critical minerals.[15] Near-Earth asteroids (NEAs) that are related to the most common type of observed-fall meteorite (H type ordinary chondrites) contain platinum group metal deposits at levels comparable to profitable terrestrial mines (~4.5 ppm, of combined ruthenium, rhodium, palladium, iridium, and platinum).[16] While it seems that H type ordinary chondrites are drawn from a single parent body in the main asteroid belt,[17] and preliminary data show that the population of NEAs does not map precisely to the population of observed-fall meteorites (the near-Earth asteroid population is shifted towards the less metallic LL type),[18] **a good percentage** of the 500,000 estimated NEOs larger than 45 meters[19] are **expected to be metal rich** (H type ordinary chondrites, or other more metallic types).

For a fuller analysis of asteroid mining economics, please see our recent letter to the Review of U.S. Human Space Flight Plans Committee.[20] NASA HQ Associate Director, Michael Hawes, welcomed our suggestions, citing our "points regarding space resources, asteroid mining, and space solar power [as] clearly thought out and well articulated."[21]

Political Strategy

Support for a decade of near-Earth resource discovery and acquisition can be found by *funding what people want*. In addition to the need for industrially critical metals, we can draw upon a range of current trends, interests, and motivations:

▪ **President Obama** initiated a "sweeping review" of national space policy in May.[22] By shifting the space science agenda as herein suggested, the president will be able to rebut critics who claim that he does not support space exploration.[23] He can describe a forward looking shift in national policy, from space *exploration* to space *utilization*.

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▪ Earlier this month, **NASA Administrator Charles Bolden** wrote, “We must find innovative ways to inspire and educate the next generation of scientists and engineers, or watch other nations assume our leadership role.”[24]

▪ **Younger generations** are quite clearly *not interested* in manned missions to Mars.[25] Recent successful Mars missions are “cool,” not because of the destination, but because they use fairly sophisticated robots. Humans like to anthropomorphize talented robots. We find them inspirational—in space, or at the movies: Everybody loves Wall-E.[26]

▪ For **those with practical interests,** the canard of “life on Mars” is not compelling. While potentially traumatic for those of certain religious faiths, discovery of microbial life, or even fish-like life, would have little economic or environmental impact, compared to the loss of access to industrially critical minerals.

▪ For those concerned with **international relations,** joint efforts to advance knowledge of asteroid resources and mining techniques offer the nation opportunities to “increase space collaboration [which] can provide broad benefits to the United States by making space a routine place for all nations to operate (thereby enhancing the security of space assets).[27] By crafting new agreements, the U.S. could engage in “fence mending” with international partners who were frustrated by recent management of the ISS.[28]

▪ Asteroids offer **NASA human space flight** (HSF) practical destinations. Low-Earth orbit evaluation of experimental robotic mining systems, perhaps utilizing the ISS, and human-robot rendezvous at NEAs, present the prospect of meaningful economic returns. The “Flexible Path,” promoted by the Augustine Committee, identifies NEAs as possible human destinations.[29] Asteroid mining provides *a reason to fund* HSF beyond LEO.

▪ Recent reports produced by the Space Studies Board and the Aeronautics and Space Engineering Board highlight key weaknesses in **NASA’s technology development,** which a comprehensive asteroid resource recovery program would bring into focus. Enabling technologies—including spacecraft autonomy, instrument miniaturization, optical communication, and mineral sampling, gathering, and analysis—were given the worst grade among all major theme areas examined (“D,” with falling expectations) in the 2008 report, “Grading NASA’s Solar System Exploration Program.”[30] A 2008 review of NASA’s exploration technology development program identified the effectiveness of “in situ resource utilization” technologies as a “red flag” area, that “threatens the success of the project/program.”[31] These areas of technological weakness would become funding priorities under a near-Earth resource discovery and acquisition program.

▪ While clearly accelerating its development, the current recommendation draws on the **Space Studies Board** 2008 recommendation for an NEA Sample Return mission.[32] The Decadal Survey whitepaper by Michael Nolan, et al., “Near-Earth Objects,” is good; we support the work that they suggest. We would extend their goals to include bringing high-value asteroid resource to Earth. While this is clearly an ambitious undertaking, such a program makes NEOs far more relevant to the public, and makes the research expense an attractive investment.

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Recommendations

For the upcoming decade, planetary science should organize itself around two large (> $1 billion) missions, deployed more or less in sequence:

- **Near-Earth Resource Survey** (NERS) mission
- **Near-Earth Resource Acquisition** (NERA) mission

At least half of all planetary science funding should be used to support these missions. Other missions should employ tools that are similar to those used for these top priorities.

We recommend the following specific actions:

1. Create Robust Data Management Systems

With 500+ primitive-bodies data sets today, and 600+ anticipated, leveraging “modern database technologies” is key, as Reta Beebe, et al., argue in their Decadal whitepaper.[33] An XML-based data format, similar to the “CCSDS Recommendation for Space Data Systems,”[34] should allow all data for all NEOs to be analyzed with a Web browser. Data acquisition is also critical. Funding to enhance NASA’s Deep Space Network (DSN) is vital. As Barry Geldzahler and Les Deutsch note in their Decadal whitepaper, the DSN “is a critical part of every NASA solar system mission.”[35]

2. Drive the Evolution of Asteroid Observation and Characterization

Funding for survey telescopes, such as Pan-STARRS and LSST, is critical. As is support for NEO spectral analysis,[36] including education, instrumentation, and training. Space-based telescopes may provide useful information, such as the “IR Observatory in a Venus like Orbit,” proposed by Harold Reitsema and Robert Arentz in their whitepaper.[37] We also need better understanding of space weathering phenomenon, which impact NEO characterization as well as spacecraft operations. The work described by John Cooper, et al., in their whitepaper, is clearly valuable,[38] particularly at Earth orbit (1 AU).

3. Survey a Large Population of NEOs (~250 objects) — NERS

A large number of modular survey crafts can be manufactured and deployed relatively inexpensively. CubeSat-based spacecrafts—such as the *Houyi,* which was designed to “tag and track” the potentially hazardous *Apophis*—offer lifecycle costs on the order of $20 million.[39] Launching one $30 million craft every month, for five years, and directing each craft to survey four NEOs, results in 240 detailed surveys, at a cost of $1.8 billion.

4. Deploy Experimental Asteroid Mining Systems — NERA

During the second major mission, a variety of mineral processing systems, selected through open competitions driven by prize money awards, should be deployed to LEO, perhaps near the ISS, and then on to promising NEOs. J. Edmund Riedel, et al., identify several useful technologies for these missions in their whitepaper.[40]

5. *Learn* How to Mine Asteroids

All systems deployed under this program will be experimental. Each iterative engagement with NEOs will teach us how to do it better next time. Every cycle will require dedicated scientist to model, observe, and analyze, and then adapt the next round of deployed systems to extract maximum benefit from this promising and challenging domain.

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Conclusions

In response to a similar set of recommendations presented to the Review of U.S. Human Space Flight Plans Committee,[41] Bryant Cramer, USGS Associate Director for Geography, emphasized their commitment to work, "in cooperation with NASA and the U.S. State Department, to promote the development of space resources." Dr. Cramer wrote that for "the nation **to truly exploit deep space resources,** we need our civil space agency to develop the 21st Century equivalent of the Transcontinental Railroad."[42] It is, however, unlikely that the requisite technology will *look* like a railroad (unless the space elevator surprises everyone, and suddenly becomes feasible). Instead, the 21st Century vehicle that we seek could be *a flotilla of ever more capable* ***robotic spacecrafts.***

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[1] The National Academies. "Planetary Science Decadal Survey: 2013-2022: Statement Of Task (Revised)." <http://sites.nationalacademies.org/SSB/CurrentProjects/ssb_052412>

[2] We recognize that "mission concepts for space-based [NEO] hazard mitigation are out of scope" for this survey. The recommendations presented herein do not focus on hazard mitigation, but rather the potential for developing near-Earth resources.

[3] The National Academies. "Planetary Science Decadal Survey: 2013-2022: Statement Of Task (Revised)." <http://sites.nationalacademies.org/SSB/CurrentProjects/ssb_052412>

[4] Nolan, Michael, et al. "Near-Earth Objects: Community White Paper to the Planetary Science Decadal Survey, 2013-2022." Space Studies Board Decadal Survey. 2009. <http://www8.nationalacademies.org/ssbsurvey/DetailFileDisplay.aspx?id=49>

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[6] University of California TV. "Conversations with History: Steven Chu." May 2004. <http://www.youtube.com/watch?v=y-7gWs0XtUw>

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