

Germinating the 2050 Cis-Lunar Econosphere

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Abstract—In early 2013, Marshall Space Flight Center’s upper management chartered a diverse team for a six-week “sprint” to speculate (in a disciplined manner) and paint (with broad brush strokes) a picture of how earth, space, and public/private entities might be operating and relating to each other... in the year 2100. Two 12-person groups of civil servants, one with members having 15 years or less of NASA experience and the other with more senior members, worked independently and then compared and integrated their conclusions. In 2014, the “Space 2100” team, with some new team members and different group boundaries, ran a longer sprint to a) develop more detailed estimates of the operations and economics of space activities in the vicinity of the Earth and Moon in the 2050 time frame, b) identify evolutionary paths, barriers, and opportunities, and c) suggest actions and philosophies to enable and invigorate progress towards the vision. This paper explores Space 2100’s first two sprints and their projections of NASA’s role in what will likely be a highly networked, international space industry and cis-lunar infrastructure.¹

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1. INTRODUCTION

The “Space 2100” effort evolved from a request by Center Director Patrick Scheuermann shortly after he began serving in September 2012. He wanted to engage employees at a grassroots level to shape and share unfettered, creative ideas about Marshall and NASA in the next century, far beyond any current strategic planning efforts.

Initial participants were invited based on suggestions of Center management, high-level staff, leaders, and/or by nomination from other organizations. The early Space 2100 teams suggested personnel for possible inclusion for later efforts and, as the conversation grows, MSFC is looking for ways to involve all who have a passion for the topic. To ensure balanced perspectives, Space 2100 emphasizes diverse teaming across organizations, specialties (administrative as well as technical), pay grades, and cultures.

In the more detailed sections below, we’ll see how the various teams arranged themselves so that gaining insights and reaching conclusions was as much about exploring

Space 2100’s conclusions and recommendations are not part of NASA’s or MSFC’s strategic planning per se, and do not represent official plans or policy.

2. SPACE 2100 - GENERIC APPROACH

Here are the fundamental principles that have guided annual Space 2100 “sprint” exercises. Some principles were defined up front by Center management, while others were evolved by the teams themselves:

- Sprints begin in January or February, lasting from 6 to 10 weeks, with teams meeting one to three times per

week for one to four hours.

- Work primarily with broad concepts, drilling down a layer or two here and there to verify that fundamental issues or principles have been identified and measured relative to each other.
- During brainstorming, there are no right or wrong answers. Embrace and explore all kinds of ideas - conventional, evolutionary, and radical.
- Tackle the heart of a given exercise by having two teams work independently, then come together to synthesize conclusions and recommendations.
 - Makes for workable group sizes (12-20 members each)
 - Provides more opportunities for everyone to contribute to the discussion
 - Guards against groupthink (desire for concurrence results in ignoring viable alternatives).
 - Point and counterpoint can flush out consensus solutions. It's OK to document
- For a given sprint, Center management establishes the main issue(s) and objective(s), and some aspects of team composition. Beyond that, teams self-direct.

Sprint completion is marked by a presentation to the Center Director and high level staff, followed by other activities to “grow the conversation” both within and beyond the confines of MSFC.

The following descriptions of our first two sprints are broken down into three parts:

- The Ask – Center Director’s request to The Team
- Team Structure, Working Assumptions, Process Flow
- Results – The team’s answer to The Ask

Verbiage describing the Asks is taken directly from kickoff documents defining the sprints.

3. 2013 SPRINT – EARTH AND SPACE IN 2100

The Ask

The objective for the 2013 Sprint exercise was to paint, in broad brush strokes, the future of space exploration/travel and NASA’s/MSFC’s roles through the year 2100, based on the following framework:

- What will the world look like in 2100?
 - What technologies will be online?
 - How will we be working?
 - What grand challenges will the world be facing?
- What will the world be doing in space in 2100?

What might NASA's role look like?

What pieces would seem "naturally" Marshall?

The Space 2100 team was asked to explore these questions in a dynamic environment that a) encourages brainstorming with a “no wrong answers” philosophy, b) provides cogent though not detailed insight and validation of major issues and concepts (the sprint was by definition short and the variability of what can happen in 85 years is prodigious), and c) values diversity of background, experience, ethnicity, and geographical origin so as to yield perspectives representative of MSFC’s population.

Team Structure, Working Assumptions, Process Flow

24 civil servants were invited to participate in the activity, organized as two equal-sized teams. Team X consisted of engineers, project managers, and financial managers having 15 years or less of civil service experience, while Team Y was made up of engineers, project managers, and Information Technology (IT) professionals of longer tenure.

The teams convened in joint meetings to establish mutual working assumptions, and participants shared articles and links across teams via email and Explornet, MSFC’s internal social network. The assumptions were:

- No major calamities, e.g., apocalyptic conditions due to asteroid impacts, large-scale nuclear war, etc.
- No “technological singularities” or quantum breakthroughs like warp drive or transporters (puns intended)
- The U.S.’s economic/political structures remain essentially intact, including NASA

Once the ground rules were defined, Teams X and Y held independent brainstorming sessions spread over a few weeks, with freshly found, thought-provoking articles and links kept internal to each team. These sessions, while guided by facilitators, were wide-open to ideas, no matter how far-fetched they seemed initially. In subsequent discussions, the “best” (still neither right nor wrong) concepts percolated to the top and each team reached consensus on what would be brought forward to the full group.

Figure 1 illustrates The Ask and Process Flow, and identifies some qualities of the independent team efforts without going into the actual content of their projections.

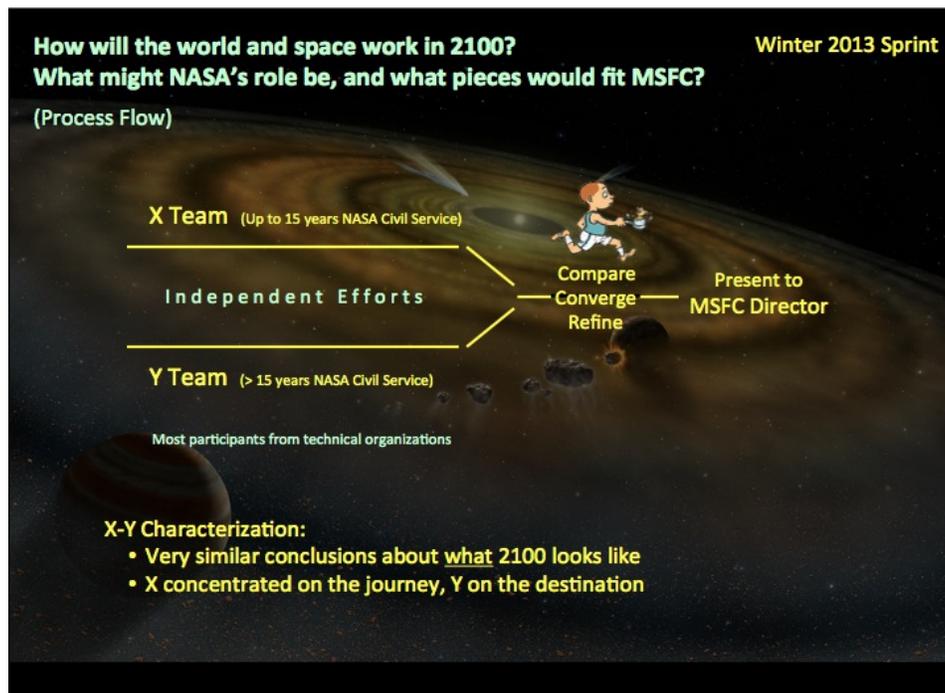


Figure 1 – Executing the 2013 Sprint

When the teams came together to distill results, these were the major inputs:

Team X had modeled a possible path from 2013 to 2100 based on three “big picture” influences:

- The U.S. Constitution - Providing for the common defense, promoting the general welfare, and securing the blessings of liberty (NASA’s work can be mapped to these)
- Frederick Jackson Turner’s frontier theory - U.S. society/culture shaped by a shifting frontier line between settlement and wilderness, which led to an innovative, aggressive, and independent mindset in the nation [1].
- Technological Breakthroughs

Team Y had pondered technology progression and

breakthroughs from 1900 to 2013, contemplated orders of magnitude between those two endpoints, and then extrapolated and/or projected expectations for 2100.

Both teams identified a number of technologies and/or breakthroughs that could drastically re-shape what 2100 looks like. The consensus was that a) most of them will not have matured by then, though it’ll be delightful if they do, and b) gauging the impact of such “big ticket” items is extremely difficult even if time and data are plentiful. Because this exercise was extremely short in duration and broad in scope, we assumed conservative progress in these technological areas.

Figure 2 characterizes a) the last century’s breakthroughs, and b) the types of things that might radically change the projected state (most likely beyond 2100).

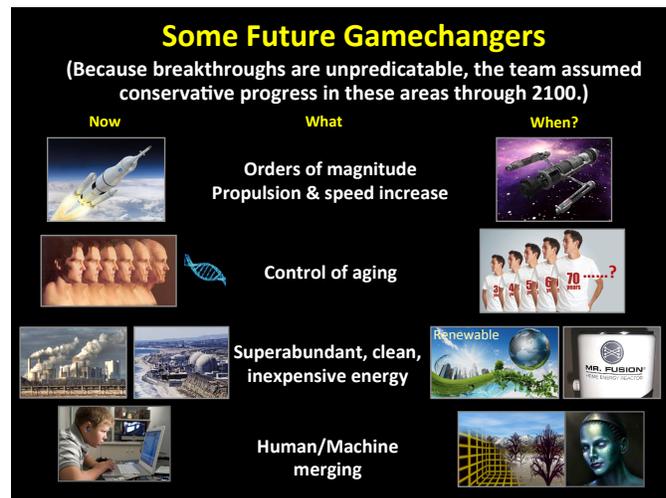


Figure 2 – Breakthroughs

NOTE - Though extremely high-end technologies like warp drive probably won't be available by 2100, 3D printing, which was on the low end of our big-ticket list, is maturing incredibly quickly, and will have a huge impact on progress in space exploration and colonization, because it will allow just-in-time manufacture of parts, reduce mass storage and transfer requirements, and will probably be able to use inks made from in situ materials. The first 3D printer in space was recently launched to ISS. In August 2014, MSFC tested a rocket engine injector that was 3D-printed and has been described as the most complex injector ever built. "The entire injector had only two parts," said Brad Bullard, a propulsion engineer at the Marshall Center. "If we had made it the old-fashioned way, 163 parts would have had to be built and then assembled together. This process saves us time and money and allows us to build a part that will enhance rocket engine performance and be less prone to failure" [2].

Results of the 2013 Sprint

The combined X and Y teams framed their predictions for 2100 in terms of four themes:

Earth Technologies – Abundant, clean energy; Distributed and additive manufacturing; Health and disease management; Artificial intelligence (AI) and robotics; Instant/immersive information technology

Earth Social - Environment (food, water, population, and climate concerns); Politics (global responsibility and cooperation); Security and privacy (individual empowerment and monitoring); Employment (robotics and AI reducing the length of the work week and/or increasing the breadth and quality of work endeavor); Education (highly tailored to individuals)

Space Technologies derived from Earth Technology - Energy (e.g., carbon-neutral, space-based solar); Manufacturing (based on in-situ resources and additive processes); Health advancements (including radiation/bone loss countermeasures, advanced life support); AI/robotics (including robotic assembly and highly autonomous missions); Space transportation (including nuclear systems and both human and robotic deep space missions)

Space Social - Economics (space resources becoming significant to the global economy); Exploration becoming more diverse through varied sponsorship of missions, utilization (significant industry operations in the inner solar system); Space colonization; International cooperation to enable large/costly missions.

Figures 3 and 4 illustrate Earth and Space themes and provide hints of interrelationships.

In the process of projecting the "what" of 2100, both independently and working together, the teams developed a sense of "how" NASA and MSFC might help these projections come true, as shown in Figure 5.

Based on these assessments, the combined teams synthesized their conclusions into Table 1, which is essentially an opportunity map driven by social trends and evolving technologies.

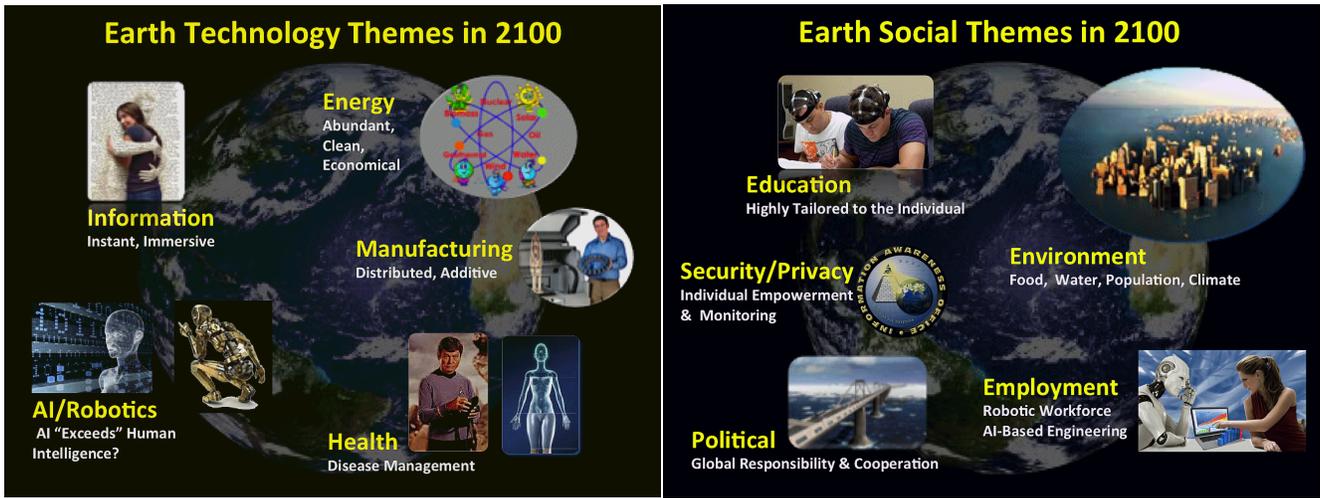


Figure 3 - Anticipated Earth Themes in 2100

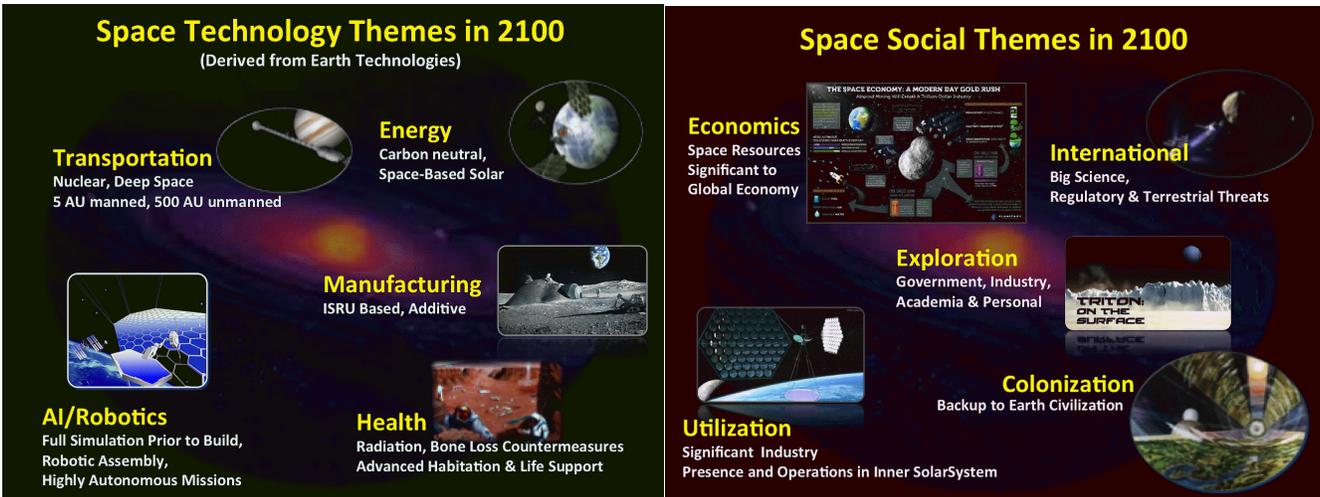


Figure 4 - Anticipated Space Themes in 2100

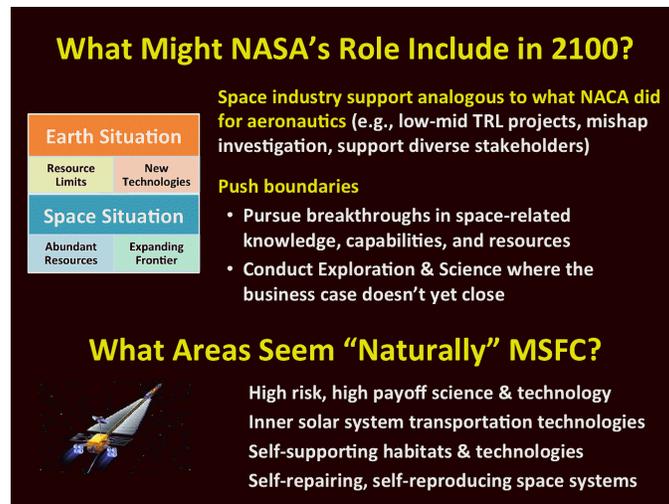


Figure 5 – Possible NASA and MSFC Roles in 2100

>> Social Trends and Evolving Technologies

- | | | | |
|---|---|---|--|
| <ul style="list-style-type: none"> • Government/International Cooperation • Additive Manufacturing • DIY / Open Source Movement • De-emphasis on Formal Education • Growth of Private Space Market | <ul style="list-style-type: none"> • Energy Independence • Streamlining of Government Processes • International Cooperation • Global Market/Bazaar (Bidding for Common Resources) | <ul style="list-style-type: none"> • Fusion Economy • Thorium power • Growing Infrastructure for Space Economy • Suborbital Flights for Intercontinental Travel | <ul style="list-style-type: none"> • Life-extending Medical Research and Technologies • Self-Sustaining Outposts for Research and Long Duration Missions • Space Colonization |
|---|---|---|--|

2000 - 2025

- Large Scale Launch Vehicles (SLS, SLS Block II)
- In-Space and Propulsion Technology Development
- Cooperation with DoD, DoE, NOAA
- Additive Manufacturing
- Support Private Space

2025 - 2050

- Renewable Energy Source and Production R&D
- International Collaboration on Large Scale Projects
- Asteroid Mining
- Build Cislunar Infrastructure
- Define Constraints of Global Marketplace (e.g. Earth Orbits, Radio Frequencies, & Patents)

2050 - 2075

- Leverage Advanced Space Propulsion Research for Power Generation Technology
- Provide Low-cost Access to Space for Academia and Small Business
- Build Rendezvous and Rescue Vehicles for Commercial Space Tourism/Commerce
- Launch Interstellar Robotic Probe

2075 - 2100

- Robotic Missions for Interstellar Space Colony Construction
- Enable Individual Research through Citizen Outreach and Partnerships
- Inflatable, Low-Cost Payloads for Individual Research Initiatives

>> Opportunities enabled by evolving technologies and social trends

Table 1 – Possible Evolution of Space Activities, 2000-2100

A few more notes are in order:

- As stated earlier, Team Y took a technology progression approach. At one point, a team member had a difficult time envisioning technology from their specific area of expertise advancing by the leaps and bounds presented here. The rest of the team had to convince him/her that the developments are plausible.
- Team X (the allegedly “less experienced” team) took a novel approach relative to the technical MSFC environment. They looked at the constitution and how U.S. frontiers developed, then predicted how space development might follow the same patterns.
- With respect to the X and Y approaches, did years of NASA service play a role in being more (or less) open to the creative approach? Was homogeneity good because it helped the contrasting approaches surface, or might it cause teams to miss opportunities?
- The two approaches produced nearly identical visions of the future and barriers/solutions related to achieving

it, which offers some degree of validation.

- Even if the predictions are off by a few orders of magnitude, the relationships built during the exercise, both personal and cross-organizational, have already begun to pay off in terms of awareness and readiness to catch glimpses of insight applicable to short-, mid-, and long-term issues.

4. 2014 SPRINT - THE 2050 CIS-LUNAR ECONOSPHERE

The Ask:

The second year's activities were narrowed in focus to cis-lunar space, the area between the Earth and the moon and their vicinities. The framework was stated in two parts, with an overall theme of **"Space is open for business."**

- SCENARIO - It's 2050.
 - It's 2050.
 - Space tourism is thriving.
 - Multinational companies are mining space objects.
 - Commercial lunar outposts are under construction.
 - We are NASA.
- CHALLENGE - Outline NASA's role in the space economy of 2050.
 - How do we enable commercial activity in space?
 - What practices are needed?
 - How do they differ from those today?
 - Consider commercial agreements, international partnerships, intellectual property, safety, security, and regulations
 - We are committed to economic success.

Team Structure, Working Assumptions, Process Flow

Three teams were assembled for this exercise:

- Phase 1 - Composed primarily of 2013 Space 2100 participants
- Team A - A diverse mix of civil service and contractor engineers, business analysts, lawyers, project/branch managers, and additional technical and non-technical personnel. Very few 2013 participants.
- Team B - Same type of mix as Team A. Unlike the

2013 effort, there were no distinguishing criteria between the two teams (e.g., years of service).

As in 2013, all teams met jointly and agreed to

- Assume no major physical, political, or organizational calamities and no "magic wand" technological advances.
- Entertain all ideas, even those that seem "crazy" at first blush, allowing viability to make itself known over time.

Phase 1 was tasked with painting a picture or "snapshot" of the 2050 Cis-Lunar Econsphere in more detail than what came out of the 2013 Sprint. (The term "econsphere" and some early discussion seeds came from an article in SpaceNews [3].)

Teams A and B were to assume that the Phase 1 picture was "correct" and independently estimate

- The flow of events and developments needed for that picture to become a reality, and which parties (e.g., governments, large/medium/small industry, academia, private citizens) might accomplish them
- Major challenges, roadblocks, solutions, and processes
- How NASA can enable the econosphere in the long run
- Things MSFC might start doing now to help get the seeds planted (hence the title of this paper)

NOTE: To avoid bias or other undesirable influence, Phase 1 gave Phase 2 (Teams A and B) the snapshot and a small amount of rationale for some key items, but did not reveal their modeling of events, developments, challenges, etc. Also, Phase 1 participants were not involved in the independent Phase 2 work other than answering occasional requests for clarification of Phase 1 outputs.

Figure 6 summarizes how we conducted the 2014 Sprint.

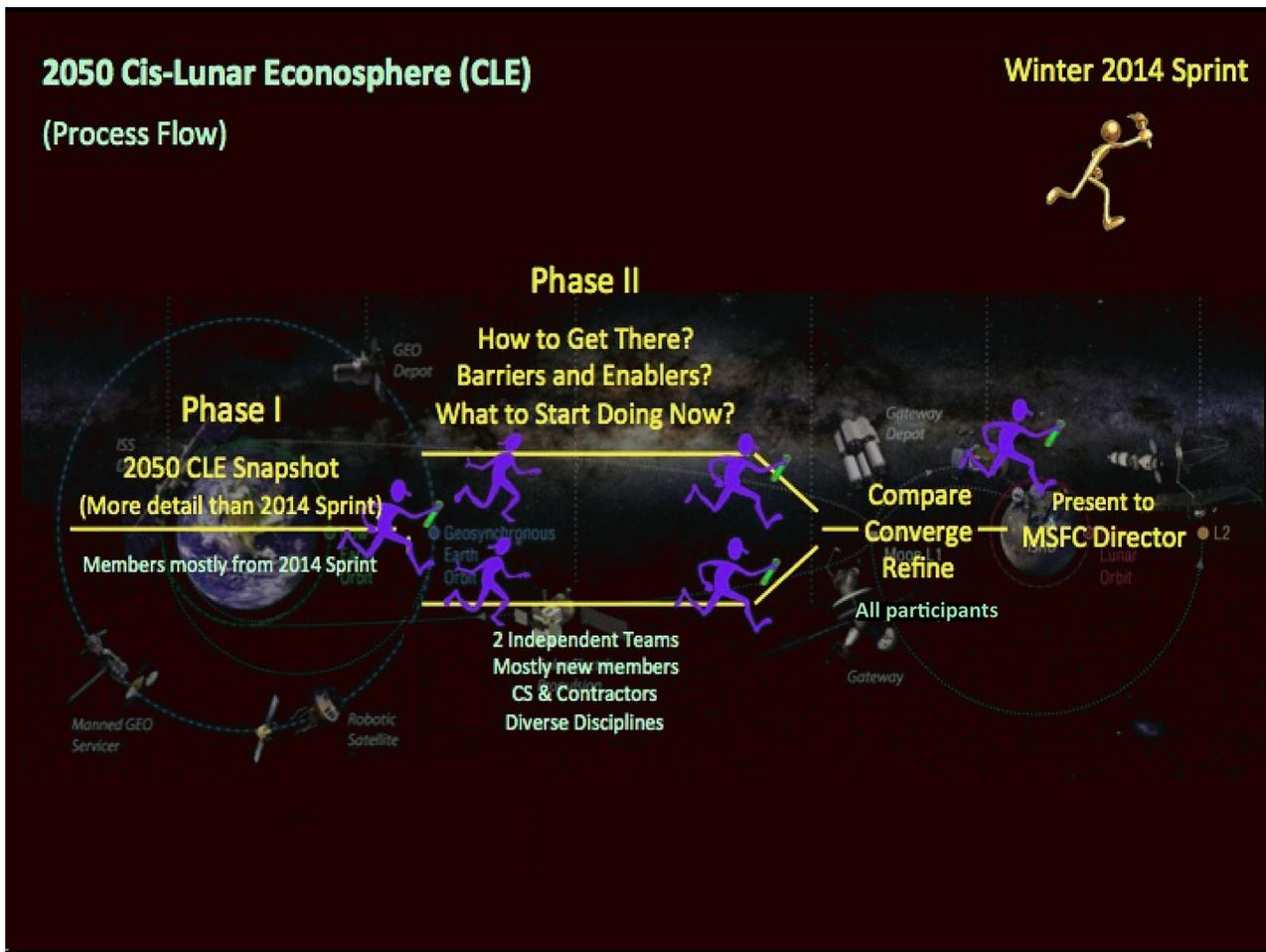


Figure 6 - Executing the 2014 Sprint

Phase 1 Results

Phase 1 took the following steps to develop their “picture:”

- Reviewed the 2013 Sprint results
- Partitioned Cis-lunar space into eight location bands from Suborbital to Lunar Surface, and added one for Beyond Cis-lunar
- For each band, identified technologies/industries anticipated for 2050. Visually speaking, the bands and tech/industry topics could be considered columns one and two of a spreadsheet.
- For each technology and/or industry, estimated progress/milestones from 2014 to 2050. We mapped this on a timeline (e.g., each decade an additional column in the spreadsheet metaphor), which provided insight on relationships and critical paths among various developments.

- In some cases, prepared conservative, optimistic, and very optimistic estimates to seed discussions that led to consensus.
- As noted previously, this map was not shared with the A and B Teams that performed Phase 2. When it was all over, we were pleased to note that they had derived essentially the same elements and progressions.

Figure 7 illustrates the 2050 state of affairs, cis-lunar space in 2050, driven primarily by economic endeavors, hence the term ecosphere as opposed to technosphere or astrosphere. (As the old saying goes, “Follow the money!”)

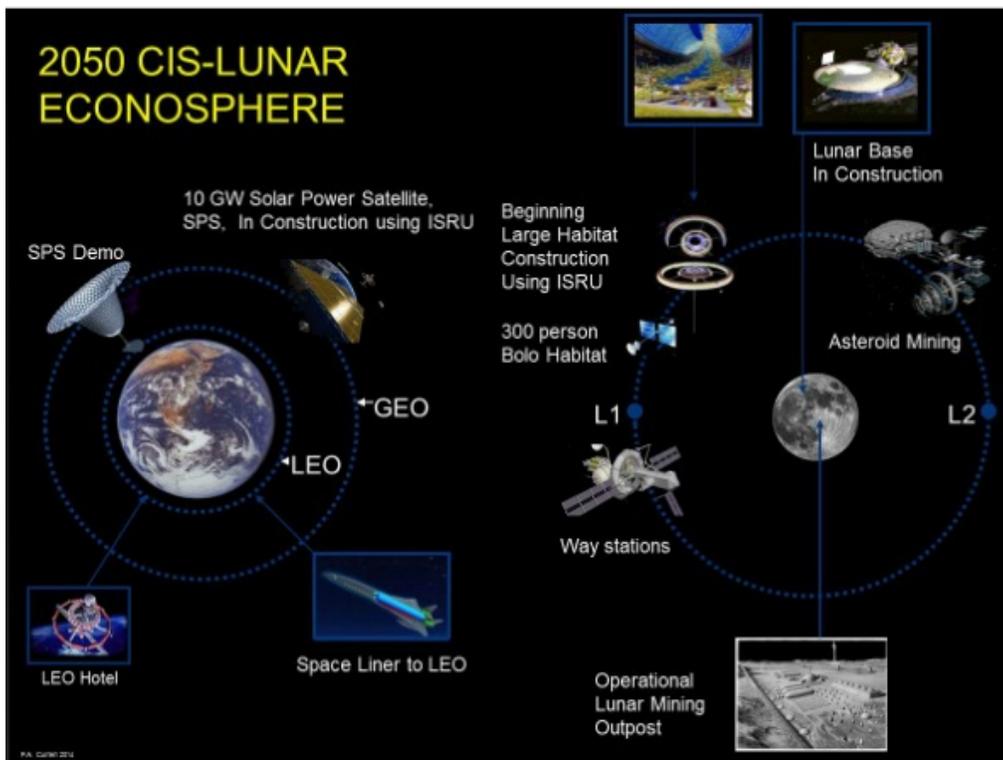


Figure 7 - 2050 Cis-Lunar Econosphere Snapshot

Here are some significant concepts and details underlying Figure 7:

- Though the focus of the exercise is the cis-lunar environment, there will have been at least one manned mission to Mars by 2050, and perhaps a settlement there. This will impact the cis-lunar economy, e.g., deep space lessons learned are applied “locally,” or cis-lunar experiences and enterprises affect or develop vehicles, products, processes, etc. for deep space endeavors.
- Just about everything in Low Earth Orbit (LEO) will be done by commercial firms rather than space agencies.
- Much of the space activity near the moon will also be commercial, though governments may be involved where the business case hasn’t yet closed.
- Governments will play a major role in developing methods and negotiating standards and policies so that vehicles and settlements owned/operated by a variety of entities can operate, co-operate and support each other via a flexible, collaborative infrastructure, even though they may both compete and team with each other economically. The Space 2100 team refers to this as “building the fire department” and other infrastructure.
- As cost decreases, increasing demand will make space tourism a very viable industry.
- The economic viability of Solar Power Satellites (SPS) or other space-based power generation will have been demonstrated, and large-scale production generators will be under construction.
- The cost of fighting earth’s gravity to get finished products into space will remain excessive, so In Situ Resource Utilization (ISRU) and on-site, 3D manufacturing will be critical technologies.
- Mining operations on the moon’s surface or on asteroids that have been placed in lunar orbit will be robotic in nature, with human oversight.
- The 300-person habitat in the moon’s vicinity will house personnel to run mining operations, way stations, and construction of a large habitat. This habitat will provide radiation shielding and artificial gravity. It will demonstrate food production and other technologies, using in situ space materials to achieve near self-sufficiency.
- The large habitat (thousands or tens of thousands of residents) might be used for a lunar civilization or become the initial instance of portable communities for colonizing other parts of the solar system.
 - Building the first such habitat/community in lunar orbit would provide easy access to space and opportunities to prove assembly techniques and self-sufficiency, yet maintain the safety factor of having Earth resources and personnel available.
 - The Space 2100 team concluded that radiation-shielded, off-surface 1G living environments would help humans maintain Earth-compatible physiology (e.g., bone mass and other vital parameters that will be identified and characterized in coming decades). Duration of sojourns to lower or higher G-gradient

surfaces/zones could be adjusted to preserve long-range health, and nominal, 1-G based exercise protocols would suffice for extensive transits through zero/micro-G space.

- Such space habitats would provide great depth of support for building infrastructure on solar system surfaces. When construction is finished, they could remain to provide redundancy or move to somewhere else.
- There could be interesting implications for the space real estate industry!

Phase 2 Results

In addition to creating their own timelines and milestone maps for reaching 2050, Phase 2 participants sought insight and advice from experts outside of MSFC. A highlight of this effort was a 3-hour meeting with Dr. Joanne Gabrynowicz, Professor Emerita of Law at the University of Mississippi (Ole Miss), who has specialized in space law for 30-plus years. For brevity, the rest of this paper will refer to this meeting as “The Legal Talk.” (Phase 1 participants also took part in this event due to its unique nature and because

Phase 1 assisted with preparation of the final the Phase 2 report.)

To seed what turned out to be a most lively and enlightening discussion, Dr. Gabrynowicz explained several major legal and economic issues central to large-scale exploration and development of space, then mapped them to technologies and endeavors highlighted by the 2014 Sprint. The next page of this paper includes highlights from the discussion

The first working chart in The Legal Talk stated “Warning! You will leave here with more questions than answers” (a suitable caveat for this entire paper).

After pondering the ideas gleaned from The Legal Talk and the technology issues explored via timeline and milestone projection, the teams converged on a model in which NASA and MSFC’s role in fostering the 2050 CLE could be embodied in four primary enablers or drivers, Figure 8 illustrates this concept, and has become emblematic of the Space 2100 effort.

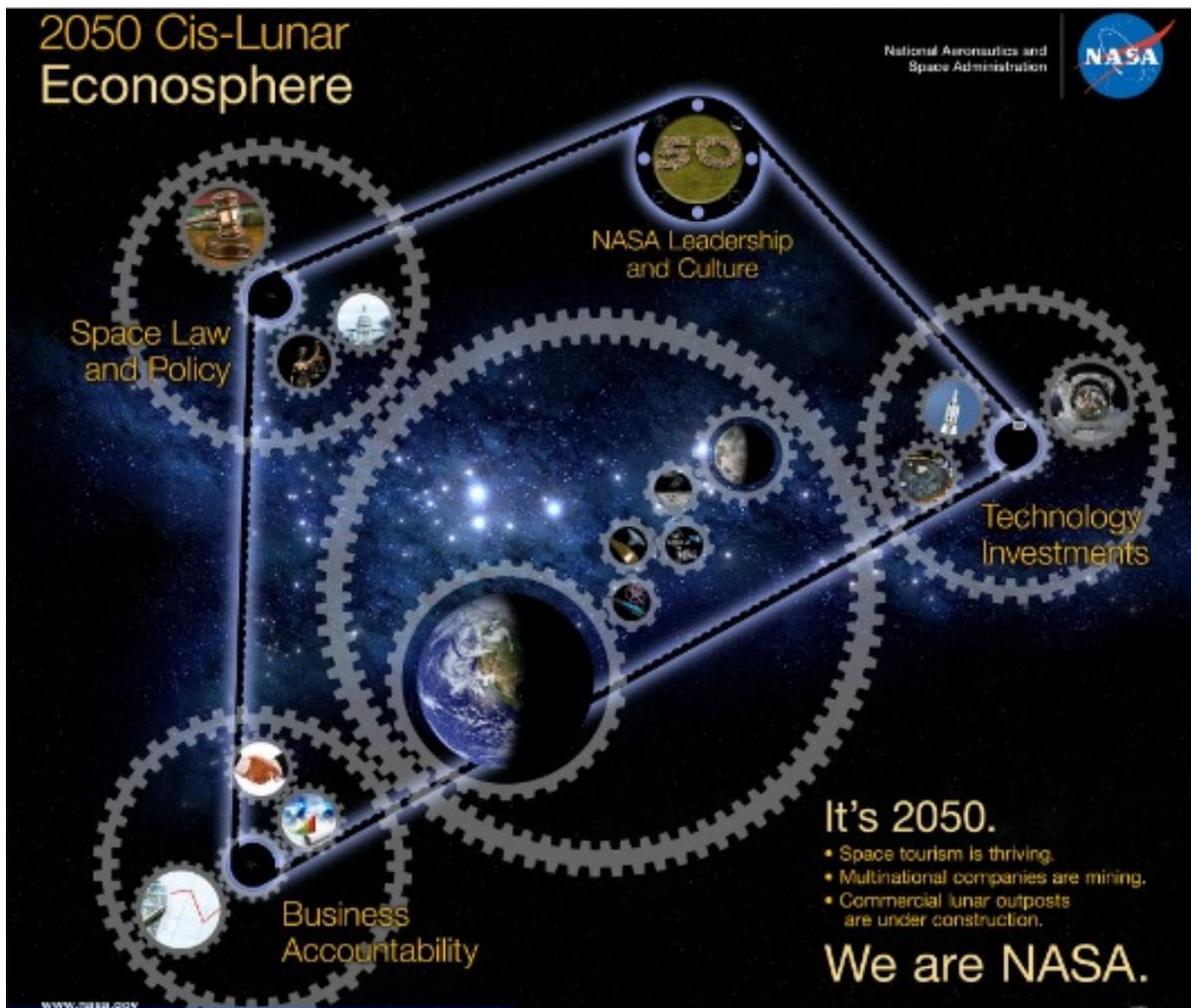


Figure 8 - 2050 CLE Enablers and Drivers

The “Big Four” 2050 CLE enablers or drivers are:

Technology Investments. One of NASA’s traditional specialties. While the actual work is challenging, there appears to be no “Unobtainium” needed to evolve the technologies needed for 2050. In other words, given that past tends to be prologue, our current approaches combined with normal acceleration in computing and manufacturing capability will be sufficient to mature 2050-supporting technologies in a timely manner:

An important takeaway point is that exercising the capability we already have to evolve technologies will be relatively easy compared to cultural and procedural changes needed in other areas.

Business Accountability and Business Practices. Improvements the Space 2100 Team suggests include:

- Streamline information transfers, approvals, and procurements
- Embrace instead of avoid the concepts of “market”

and “marketing.” Traditionally, NASA has not been allowed to sell or market itself. Given that the U.S. military advertises for recruits, there’s probably a way to arrange for NASA to ethically do what makes good business sense.

- Market the benefits and gains of doing business in cis-lunar space, and how it can benefit the U.S. economy
- Reshape the meaning of “government space” and “commercial space.” A major revelation from The Legal Talk was that the U.S.’s relationship with industry is unique; the other spacefaring nations have much more flexibility in partnering with commercial ventures. To be both collaborative and competitive, we’ll need to find a way to be more compatible with these entities (and maybe some new organizations who will only have offices in space) while remaining true to the spirit and letter of U.S. Law (which may also have to evolve, within the bounds of the Constitution).
- Discern when it makes sense to partner and when it

doesn't (e.g., depending on Russia for all engines) and make decisions strategically for the best, balanced benefit to NASA, the country, and mankind. The Space 2100 team believes that NASA priorities will continue to include a) pure science, and b) path-finding in arenas where the business case doesn't yet close.

Space Law and Policy.

The Legal Talk with Dr. Gabrynowicz, which included a number of NASA legal team members, highlighted a number of issues that need to be addressed:

- Basics - Space is a global commons, analogous to Antarctica and the High Seas; Sputnik I and fear of nuclear weapons led to 5 treaties, the Outer Space Treaty of 1967 being the strongest
- Outer Space Treaty - – “Outer space including the Moon and other celestial bodies, shall be free for exploration and use by all States.”
 - No national appropriation or claims of National Sovereignty extend to space.
 - The Treaty doesn't discuss commercial claims and rights. Most space lawyers agree that freedom of use should include resource utilization similar to multinational fishing on the high seas, and that governments must authorize/supervise non-governmental entities.
 - **How does one define “national” in light of various partnership types?**
- Moon Treaty (U.S. did not sign) - Introduced the concept that while a celestial body may not be appropriated, a natural resource, once extracted, might be subject to appropriation, with possible governance and limitation by an international body.
- Space Tourism - Doesn't fit legal definition of Commercial Human Spaceflight; Liability and jurisdictional issues are poorly defined if at all, and have not been tested in court (which court?)
- Mining - HUGE national and international legal, economic, and political issues are involved
- Commercial Space Markets - U.S. = “private sector,” most other countries = “generates revenue” and governments can actively participate; Level playing

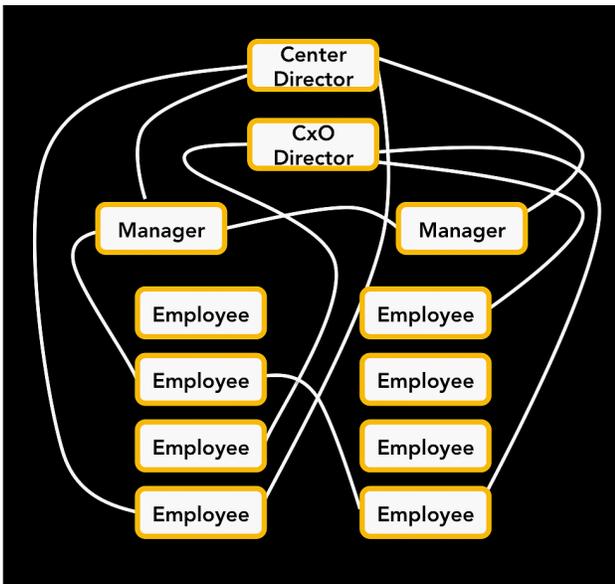
field in a highly subsidized industry?

There is good news in that public discussions about resolving such issues are already taking place, such as the September 2014 Space Subcommittee (U.S. House of Representatives) hearing related to issues facing planetary exploration and potential commercial interests, including the American Space Technology for Exploring Resource Opportunities In Deep Space (ASTERIODS) Act, H.R. 5063. Representative Posey noted that there are U.S. companies who are ready to mine asteroids now, not in the distant future.

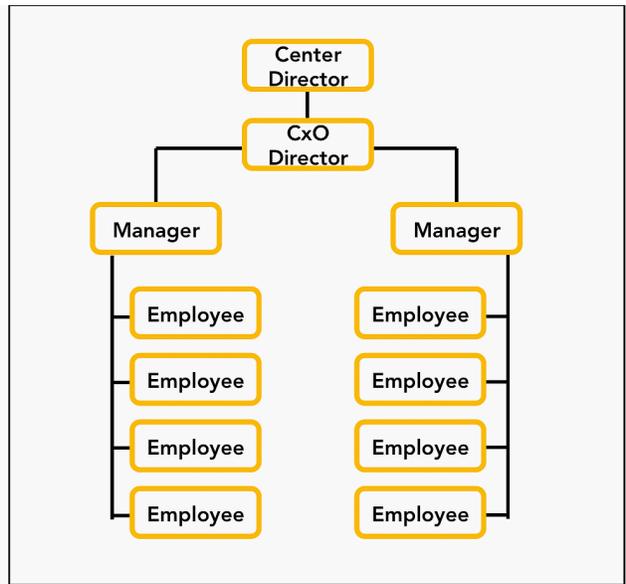
NASA Leadership and Culture

While Technology Investments, Space Law and Policy, and Business Accountability will exert a lot of power in enabling CLE 2050, NASA Leadership/Culture serve as both a driver and a tensioner in the “drive belt” visual metaphor of Figure 8. Some characteristics of this enabler may be:

- Ideas and changes in cultural practices need to flow laterally (e.g., employee-to-employee across organizations) and vertically (e.g., reverse mentoring) for the evolving culture to seep through organizations and be accepted.
- NASA won't always be the logical entity to lead the foray into a given aspect of the new frontier. Our roles may fluctuate, sometimes within different phases of a single project. We probably will fill gaps in TRL development when the business case doesn't close for commercial/private entities, often with help from other agencies (U.S. or International) and/or unique consortiums
- Strong following will be as important as strong leading.
- Organizations will need to transition quickly between free form and hierarchical modes (just as light exhibits wave and particle characteristics), perhaps shape-shifting their structure at times. Figure 9 shows how these modes complement each other.



Free Flow, Inspiration, Creativity, Boldness
 Generate/Identify Ideas, Crowd-Source
 Build Consensus



Stability, Accountability, Traceability, Diplomacy
 Refine Ideas, Resolve Conflicts, Design/Engineer Things
 Make Decisions

Figure 9 - FreeForm and Hierarchical Thinking, Communicating, and Acting

The Space 2100 exercises have produced some projections of the future and have identified related issues, challenges, and potential solutions. Just as significantly, the way the exercises were run yielded some immediate benefits to the participants. As the scale of the conversation grows, we

think the improvements shown in Figure 10 can permeate and invigorate the culture, providing skills and strengths that equip us to do better work.

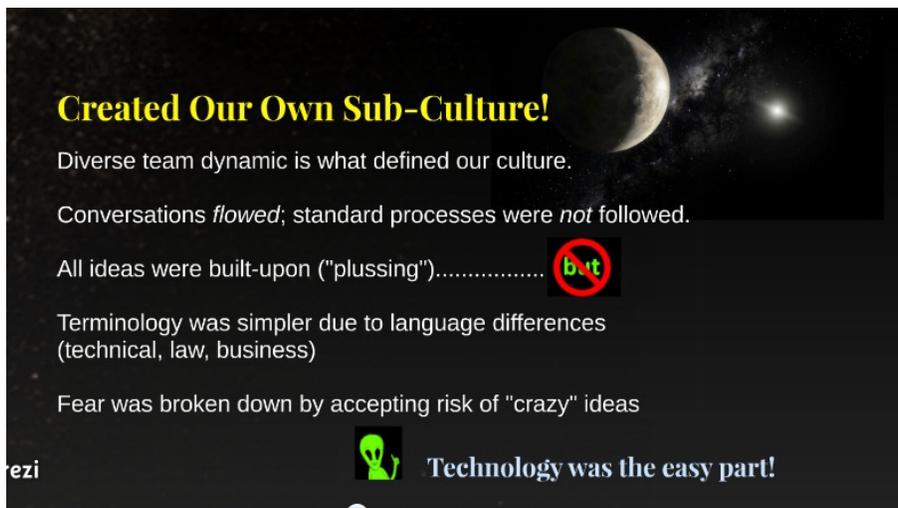


Figure 10 - Cultural Takeaways from Space 2100 Activities to Date

Two items from the figure merit a bit more coverage:

- “Plussing” involved a conscious effort to stay positive and solution-oriented by using “and” in situations where “but” might ordinarily appear. “Doing ABC will provide this-and-that benefit and it will cost XXX per cent of the budget” acknowledges both conditions

without negating them or setting them up as hostile parties.

- We had to simplify language when talking across disciplines, which brought us to the core of issues and concepts rather quickly and improved clarity in our own areas of expertise. Short words have power!

5. GROWING THE DISCUSSION

Results of the 2013 exercise were not immediately circulated outside of MSFC Center management, as the effort was new. They have been folded into presentations of the 2014 exercise as foundations on which we have built.

In addition to Center management, we have engaged with these groups:

- MSFC Executive Forum (top level direct reports)
- MSFC Chief Knowledge Officer
- Summer 2014 NASA/MSFC Interns
- MSFC Innovation and Information Technology Forum (I & TIE)
- 100 Year Starship 2014 Symposium
- 2015 IEEE Aerospace Conference

We've chosen the term "engaged" deliberately. Instead of presenting in the traditional manner, we have, whenever possible, asked those we met with to share their ideas about space in 2100 or the 2050 Cis-lunar econosphere before we reveal our conclusions. This really energizes the room, and most of the time, the ideas match up pretty well. This further validates the results and injects new food for thought.

6. CONCLUSIONS

As noted in the Introduction to this paper, **Space 2100 predictions and suggestions are nothing more than that, and do not constitute official NASA/MSFC policy or intentions.** The authors, on behalf of the Space 2100 Team, thank MSFC management for allowing and encouraging us to be freewheeling and frank about where we think we're headed and how to get there.

Here is a "shrink wrapped" version of our conclusions thus far:

- Patterns of the past provide useful modeling tools for projections of the future.
- Key enablers of the 2050 Cis-lunar Econosphere are:
 - Space Law and Policy
 - Business Accountability
 - Leadership and Culture
 - Technological Investments(In very informal terms, keep the geeks and bring on the three-piece suiters!)
- Very significant changes in the relationships between U.S. Government entities and U.S./Internat
- Leverage what we know, questioning it frequently
- There is no technological unobtainium
- Know when to lead and when to follow.
- Continue to retool our culture to creative-collaborative when appropriate

- Break down barriers (process, communication, etc.)
- Having the conversation and how we have the conversation are often more important than the resulting predictions, as they sensitize our antennas so that we'll be perceptive and receptive of good and great ideas as they present themselves.
- Engage across internal and external organizations. Grow the conversation.

Fellow crew members of Spaceship Earth: Snug your harnesses (and have your tray tables up and your seats in the full upright position)... It's going to be a fantastic ride!

REFERENCES

[1] Turner, Frederick Jackson (1920), *The Frontier in American History*
<http://xroads.virginia.edu/~HYPER/TURNER/>

[2] NASA Press Release 14-233, August 28, 2014
<http://www.nasa.gov/press/2014/august/sparks-fly-as-nasa-pushes-the-limits-of-3-d-printing-technology>

[3] Murphy, Ken (2012), "The cislunar ecosphere", *The Space Review*
<http://www.thespacereview.com/article/2027/1> (Part 1)
<http://www.thespacereview.com/article/2033/1> (Part 2)

BIOGRAPHIES



David W. Scott, alias "Scotty," is currently developing innovative interfaces and applications for the Huntsville Operations Support Center (HOSC) at NASA's Marshall Space Flight Center in support of ISS payload operations. He was a Payload Communications Manager for the International Space Station from

1999-2007. He has spearheaded several console technology projects, especially in space-to-ground videoconferencing and audio archiving. He was a payload communicator for the ATLAS-1 Spacelab mission in 1992, and helped design the payload training program for Space Station. He spent 6 years as a U.S. Naval Officer, including flight duty in F-14s, and holds a B.S. in Physics and Mathematics from Principia College.



Peter Curreri has been a scientist with NASA since 1981. He was the Mission Scientist for three Spacelab Missions, United States Microgravity Payload missions 2, 3, and 4, for which he was awarded the NASA Exceptional Achievement Medal. His past positions at NASA include

leadership of Marshall's Biological and Physical Space Research Laboratory, and Lead Scientist for Exploration. He served as technical lead for the Exploration Development Technology Friction Stir Weld Spin Form Dome project and as manufacturing lead on a NASA Engineering and Safety Center Alternate Heat Shield Carrier project for Orion.



Cynthia 'Tia' Kaiser Ferguson graduated from Tulane University in 1989 with a Bachelor of Science in Mechanical Engineering, and from the University of Alabama in Huntsville in 2003 with a Master of Science in Electrical Engineering. She has been a Professional Engineer since 1998

and holds a patent for a Micro-Electro-Mechanical-Systems (MEMS) translation stage. Ms. Ferguson has worked at NASA for almost 25 years. Her current position is Project Manager for SERVIR, and she has also served as Assistant Manager for the MSFC Science and Technology Office, Branch Chief of the Structural and Mechanical Design branch for the Space Systems Department, Project Manager for Cargo Element Integration of the Multi-Purpose Logistics Module (MPLM) for ISS during the development phase, and Structural and Mechanical Design engineer for space and ground hardware, and as an integration and test engineer at KSC. She currently lives in Huntsville with her husband and two teenage children



Mark Nall is the Technical and Administrative Support Manager for the Joint Army, Navy, NASA, Air Force Propulsion Committee. Prior to that he was manager of the NASA Lunar Mapping and Modeling Project at Marshall Space Flight Center. Earlier, he was manager of NASA's Space

Partnership Development (SPD) Program at Marshall Space Flight Center. This program, comprised of 12 Research Partnership Centers, specialized in industry, academia and governmental research partnerships that bring the best talent and resources to bear on problems of common interest. These partnerships enabled the SPD Program to conduct 30% of the U.S. research on the International Space Station on 5% of the research budget. Before moving to MSFC, Mark spent 5 years at NASA Headquarters in Washington DC, where he was Program Manager of the Commercial Middeck Augmentation Module Program that made it possible for private industry to provide accommodations for 200 middeck lockers on the Space Shuttle. Before joining NASA in 1989, Mr. Nall spent 9 years in the U.S. Air Force, first as a KC-135 Aircraft Commander, then as an EC-18B Research Pilot. Mr. Nall holds a Bachelors of Science Degree in Aerospace Engineering from West Virginia University, and a Master of Science in Systems Management from the University of Southern California. The recipient of numerous awards, he holds the Air Force Meritorious Service Medal, and was inducted into the Space Technology Hall of Fame.



Mike Tinker is currently serving as the MSFC Deputy Center Chief Technologist, where he is responsible for promoting creativity and innovation in the center workforce, and advising center management and the Chief Technologist on technologies the center should pursue. Previously, Dr. Tinker was Assistant Manager for the Systems Development, Integration, and Test Division of the MSFC Space Systems Department from November 2011 to June 2013. He also served as Branch Chief for the Thermal and Mechanical Analysis Branch in the same department, from February 2008 to November 2011. Earlier in his career, Dr. Tinker extensively supported development of test methods for Shuttle payloads and International Space Station hardware. He also led pioneering research of inflatable space structures, and received a patent for Foam-Rigidized Inflatable Structural Assemblies in June 2010. He has approximately 70 technical papers and reports, including NASA Technical Papers, conference papers, workshop presentations, and archival journal papers. Dr. Tinker is an Associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA), and was previously Chair of the Greater Huntsville Section.



Gregory M. Wright, is currently the Operations and Engineering Verification Manager for NASA's Chandra X-Ray Observatory. He has held this position since the beginning of the Program., being responsible for all areas of ground operations development, test, verification, and on orbit support. In 2012, Mr. Wright also became responsible for the flight operations aspects of the Program as well. Prior to Chandra, Greg also supported the initial data management planning functions for the International Space Station and Spacelab missions in 1992. In addition, Mr. Wright served as the assistant to the Director of Orbital Verification for the Hubble Space Telescope Program. He holds a M.S in Mathematics and Computer Science from the University of Alabama Huntsville.