The Future of Industrial Activity in Space

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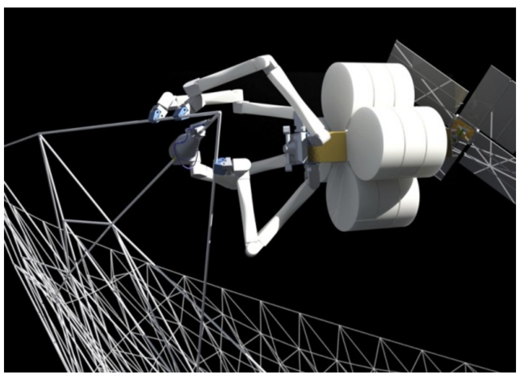
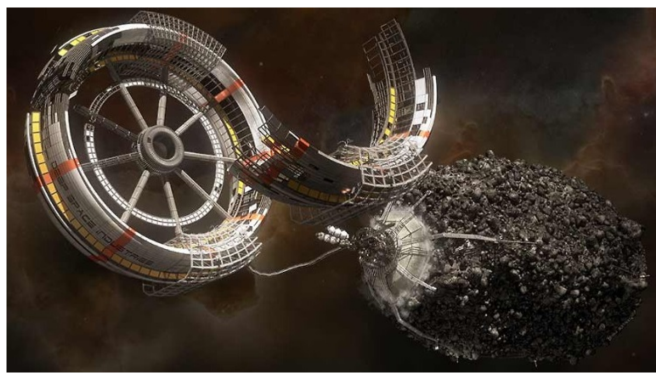
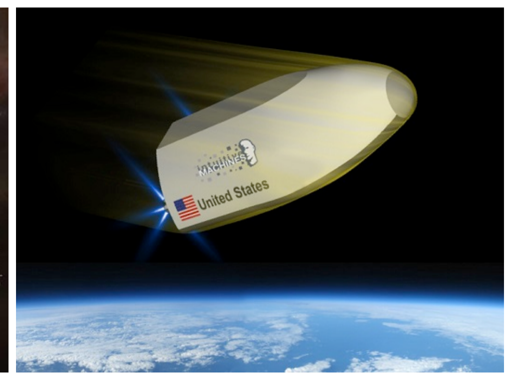






Introduction

Global society is at a crossroads when it comes to the development of space. For the past several decades, human activity in space has been dominated by national space programs, whether human or robotic, and commercial telecommunications satellites.

However, companies like SpaceX are beginning to drive the price of space launch down by applying the lessons learned in terrestrial industry to the manufacture and operation of rockets. As a result, NASA now procures cargo transportation to the International Space Station (ISS) through services contracts and will soon do the same for crew transportation.

The proliferation of CubeSats and small satellites (less than 500 kilograms in mass) using off-the-shelf components has made space technology accessible to even the elementary school classroom. Additionally, the US Congress designated the American section of the ISS as a National Laboratory, opening it to other government agencies, academia, and private industry pursuing the uses of space outside NASA's exploration missions.

This convergence of technology, accessibility, and policy may portend the emergence of new industrial uses of space and the growth of Low Earth Orbit as an economic development zone. In this analysis, using the University of Houston Foresight Framework, we will examine both how that future might take shape and plausible alternatives.

First, we will define the domain to provide focus. Second, we will examine the current state of affairs, key stakeholders, and their plans. With this information, we will then identify the five leading trends in the industrialization of space.

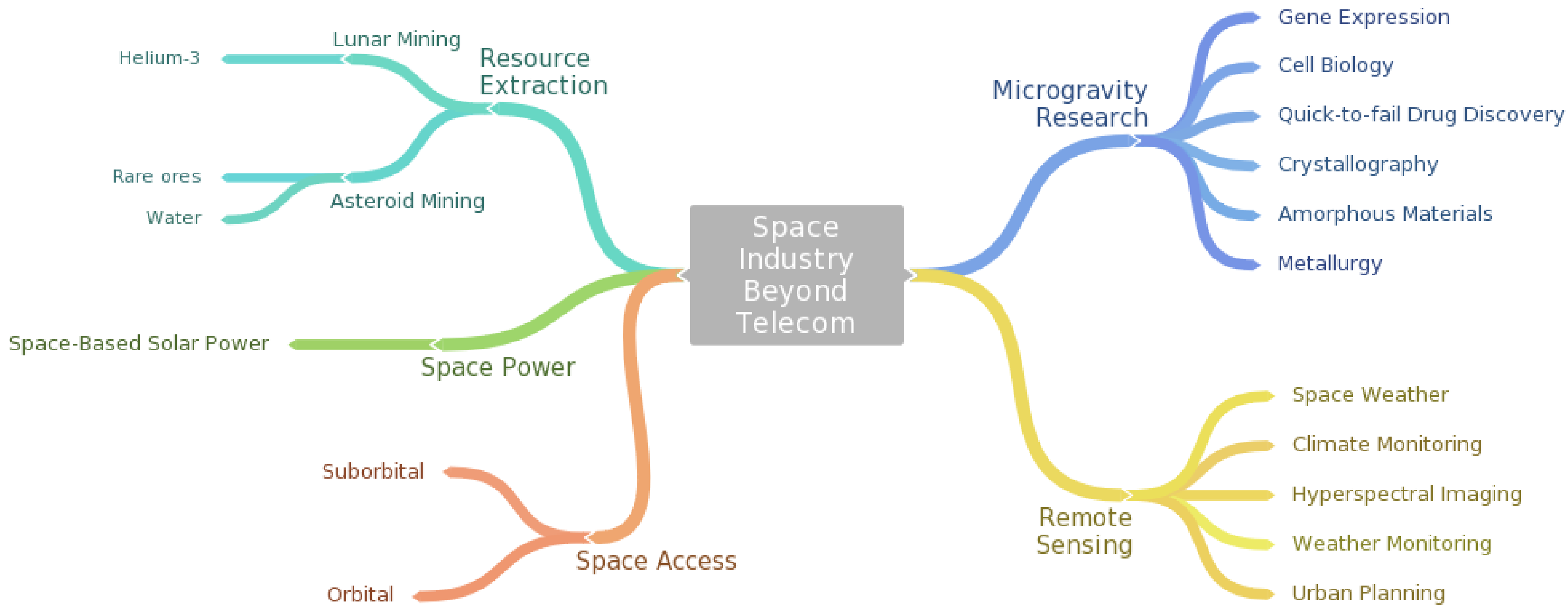
Our Baseline Future will illustrate a world where the focus of new activity is on microgravity industry for materials & biotech research and crew-tended Earth observation platforms. Government agencies – including a NASA taking its first steps outward since Apollo – are now customers of services in LEO, rather than owner-operators.

Our Alternatives Analysis examines trend breaks and uncertainties in industrial uses of space, particularly a future where long-promised advances in atomic-precision manufacturing overtake global industry and dramatically shift humanity's interest in space from economic development to addressing social and environmental pressures.

1. *Domain Description*

1A. Domain Description Worksheet

Category	Description
Domain definition	The future of industrial activity in space With the designation of the US portion of the ISS as a National Laboratory, thus enabling access to space for non-NASA users at only their own costs, and the efforts by companies like SpaceX and Blue Origin to dramatically lower operational costs and disrupt the launch services market, we may be near the long sought tipping point for industrial activity in space leading to private R&D and product development beyond the comsat industry. What might this burgeoning industry look like in 2030? What factors and which stakeholders can accelerate or hinder its growth?
Client	The Center for the Advancement of Science in Space (CASIS) – Managing NGO of the ISS National Lab
Geographic scope	Cislunar space
Time horizon	2030
Domain Map	See image on next page
Key issue(s) or question(s)?	What rights will entrepreneurial ventures in space have? What will be the tipping point in the cost of access to space? What sector(s) will be the first to prove the value of space industry and why? How will the balance between corporations and governments play out?



Domain Map: Opportunities in Space Industry Beyond Telecommunications

2. ***Current Assessment***

2A. Current Assessment Worksheet

Category	Description
Current conditions (important facts and variables about the domain today)	There are currently three effective domains for space activity – military use, privately-owned telecommunications & remote sensing satellites, and government space programs, like NASA. The cost of launching anything into orbit currently hovers around $10,000/lb, thus limiting access to space to organizations with both resources and critical interests (military, space programs) and companies whose information products outweigh the high initial investment costs (telecoms, Digital Globe, etc.). However, the conditions for entry into the market are beginning to change. SpaceX has almost single-handedly brought the United States back into the commercial launch market and has the largest backlog in history. It was even reported that the Chinese space agency, which had been making progress in taking market share away from Europe and Russia, assessed they could not compete with SpaceX's prices. Owned by industrialist Elon Musk, SpaceX is turning its profits back into the company and developing both reusable stage technologies and a new heavy lift rocket – either of which could lower launch costs by an order of magnitude or more. Other companies, including Blue Origin and Reaction Engines (a UK company), are pursuing different technical approaches and are not as far along as SpaceX, but also have the goal of developing reusable launch systems with much lower user costs. Satellites themselves are also becoming increasingly affordable. Even as satellites built by prime contractors like Boeing and Lockheed Martin have become ever more complex, large, and expensive, the proliferation of CubeSat and small satellite technology means that even primary schools can now build their own payloads. However, opportunities to fly these smaller satellites often depend on grants from US government-sponsored launches or the largesse of launch providers. There are a few small companies, though, that are trying to break into this market with small disposable rockets specifically intended to deploy at relatively low orbital altitudes.

	NASA is also changing the way it operates. US cargo deliveries to the International Space Station are now conducted under a fixed-price contract system with SpaceX and Orbital Sciences Corporation (which recently began a merger with another aerospace giant, ATK) because the successful Commercial Orbital Transportation Services program enabled new companies to compete with the "big primes". Boeing and SpaceX are now competing in a similar development program to begin transporting US crews to and from the ISS within a few years. In the meantime, the Space Station itself has been opened up for non-NASA use. With its designation as a National Laboratory and the creation of a non-governmental organization, CASIS, to facilitate and manage access, other US government agencies, private companies, and academic researchers can conduct scientific research, product development, and applied R&D on the ISS for only the cost of building and flight-certifying their own payload. NASA can only review these payloads for safety, though, and cannot impose their own mission requirements on National Lab users. Cargo transportation, on-orbit power, data, and even astronaut crewtime are considered in-kind services, provided at no cost, because the US taxpayer has already paid for them. Established companies, like Proctor & Gamble, Merck, and Novartis, are already using the Station for pathfinder microgravity research that could lead to new products on the market. New services companies, like NanoRacks, have established a nascent market for helping people who haven't worked in space before build their own payloads. Startups, like Planet Labs, are combining the low cost of CubeSats with the low access cost of deployment from the Station to compete with industry giants, like Digital Globe, in the satellite imaging market by taking advantage of the rapid prototyping available to small, effectively disposable satellites. As the cost of access to space declines and more companies derive benefit from research or operations in space, the pieces are beginning to come together for the emergence of a self-sustaining space industry beyond telecommunications and remote sensing satellites.

Stakeholders (individuals or organizations that can influence the future of the domain)	Government space agencies: inc. NASA, ESA, JAXA, Roscosmos, UK Space, ISRO, CNSA Regulatory agencies: FAA Launch providers: Arianespace, Energia, United Launch Alliance, SpaceX, Blue Origin Aerospace contractors: Boeing, Lockheed Martin, Orbital ATK, Sierra Nevada, Aerojet Rocketdyne Customers: Telecom operators, energy companies, biotech companies, materials companies, infotech companies, imagery customers New players: Planetary Resources, Shackleton Energy Company, Deep Space Industries, Planet Labs, UrtheCast, Firefly Space Systems, ACME Advanced Materials, Intuitive Machines, Made in Space

History (past event(s) that began the current era)	The Space Shuttle was promised by NASA to be the beginning of a new era of reusability, repeatability, and lower cost access to space. However, compromises in its design meant that it was never optimized for life cycle cost. The Challenger disaster in 1986 also led to the military withdrawing from using the Shuttle as a satellite delivery vehicle and the loss of commercial satellite deployments. The Orbiters also required extensive refurbishment and repair between each flight. As a result, the life-cycle cost per Shuttle launch turned out to be $1.5 billion per flight and the marginal cost per flight was $450 million. Compare this to initial goals of $54 million (in FY11 dollars) per flight. Because of the higher than expected costs and infrequent launch, much of the promised advances in microgravity and space science research were not realized. Many of these experiments were in basic physics and biology that would need later development before they could be applied. These research programs and attempts by NASA at developing commercial centers of excellence, to draw in companies & researchers who would apply this knowledge for Earth benefit, were stymied by unstable funding, two Shuttle disasters, competition for resources during the construction of the Space Station, and the outright termination of most of the NASA microgravity research program in 2004 as resources were directed to the now-defunct Constellation lunar exploration program.

	In the meantime, the US military pursued its own assured launch capability through the Evolved Expendable Launch Vehicle program. Boeing and Lockheed Martin began as competitors, but eventually created the United Launch Alliance joint company to offload the significant costs and development risk each company had taken on in agreeing to the US Air Force's terms. This arrangement also ensured the military would have redundancy in space access by retaining both Boeing's Delta IV and Lockheed's Atlas V rockets. These boosters are extremely reliable, but their costs – along with Congressional regulations intended to prevent technology transfer overseas – effectively priced them out of the international launch market. It can be noted that only SpaceX has successfully challenged ULA in recent years by working towards Air Force certification to compete on future bids. Sensitive to political concerns over American dependence on Russian engines and the rising competitive threat from SpaceX, ULA has announced a strategic partnership with Blue Origin to provide all-new engines for a new rocket. Earlier attempts at breaking the dominance of Arianespace (European) and Energiya (Russian) over commercial launches only met with limited success. The Sea Launch venture, which launches a Russian rocket from a converted Norwegian oil platform operated from California and sailed to the equator, went bankrupt after some notable launch failures, but has reemerged as a minor launch provider. China and India have launch programs of their own and have won some customers, but no one has yet broken the current price stratum, though SpaceX is poised to do so if they can perfect their R&D program aimed at creating a reusable version of their Falcon 9 rocket.

2. *Current Assessment*

2B. Stakeholder Plan Analysis

Name of the domain: Industrial Activity in Space

Selected Stakeholders	***Interests, goals, values, fears, positions***	***Plans, Intended actions***	***Assumptions***	***Implications***
1. NASA	Increased commercial use of space for benefits here on Earth	NASA selected an NGO to manage the non-NASA use of the ISS in 2011 (NASA, 2011)	National Lab user IP is protected; Regular ISS access on launch vehicles; The cost of conducting experiments goes down	When private entities begin making products that directly result from microgravity research, there will be a demand for new platforms that can exceed the ISS' capacity.
2. SpaceX	Dramatically lower the cost of launching to orbit	Build a commercial spaceport that is not subject to NASA or US Air Force control (Tillman, 2014)	FAA accepts the environmental assessment & provides a launch license	SpaceX's competitors will be under pressure to match their flight rate and lower operating costs, thus driving true market competition.
3. Planetary Resources	Mine asteroids for valuable metals & volatiles	Crowdsource asteroid detection through a partnership with NASA (Planetary Resources, 2013)	NASA & Planetary Resources incentivize enough people to use the open-source tools they will release	An immense open-source database of asteroid information will be available for science, exploration, and commercial ventures.

3. Trends in Industrial Activity in Space

List the five most important trends in the domain.

Trend	***Assumptions*** *(up to three)*	***Implications*** *(up to three)*
1. The cost of orbital launch is decreasing towards a tipping point.	1. Demand for access to space will increase to keep flight rates higher than today. 2. Regulations will not eliminate the cost savings.	1. The cost of access will be low enough for non-government orbital platforms to emerge. 2. Individual customers will spend more on payloads & platforms than launch costs, thus tipping the cost/benefit analysis more favorably.
2. Economy and survivability in space systems are increasingly prioritized over raw performance.	1. Government customers are more concerned with life cycle cost than immediate mission success (i.e., "Live to fly again another day".) 2. Commercial customers will be comfortable with recoverable abort scenarios.	1. The cost of sustained activity in space will decrease over time and increase potential returns from space-based platforms. 2. More customers will be willing to take R&D risks in space because of decreased opportunity costs.
3. Growth in space technologies being used to catalyze other industries.	1. ISS National Lab pathfinders will demonstrate enough value in space research for commercial benefit to draw other users. 2. Complimentary platforms will be created to meet the demands.	1. Space will be seen as place to solve terrestrial problems and create new products. 2. Commercial investment in space activity will surpass even military spending.
4. Space resources become increasingly competitive with terrestrial resources.	1. Fossil fuel market & opportunity costs (pollution, scarcity, land use) continue to rise. 2. Rare earth element market & opportunity costs (pollution, scarcity, land use) continue to rise.	1. Space property rights will need to be defined for both companies & nations. 2. The conservationist movement could support space industrialization as a form of ecosystem protection.

5. Demand for remote sensing data increases in both total volume and granularity.	1. Existing sensor platforms are insufficient to meet demand. 2. Terrestrial and/or airborne solutions are insufficient to meet demand.	1. Small-sat, CubeSat, and, perhaps, PicoSat solutions will proliferate to address individual customer needs. 2. Space debris management will become an issue requiring active controls, not just passive self-regulation or simple avoidance.

4. ***Baseline Future***

4A. Baseline Future Inputs Worksheet

Category	**Description**	**Citation**
Constants	1. NASA purchasing power will remain flat	1. (Planetary Society, 2013)
Trends	1. Launch costs will continue to drop 2. More companies will do business activity in space	1. (Fernholz, 2013) 2. (David, 2014)
Plans	1. NASA will not directly replace the ISS, but instead purchase services on private LEO platforms 2. Bigelow Aerospace will operate LEO habitats for private and government customers 3. SpaceX will operate reusable vertical-launch, vertical-recovery vehicles from its own spaceport 4. ISS operates until at least 2024	1. (Smith, 2014) 2. (Bergin, 2014) 3. (Tillman, 2014) 4. (Holdren & Bolden, 2014)
Projections	1. An order of magnitude more companies will do business in space 2. Microgravity research and private space platform management will emerge as strong market verticals	1. (David, 2014) 2. (David, 2014)

4B. Baseline Future Summary Worksheet

Title & 1-line description	**It's an LEO World, After All** – As NASA continues to piece together a deep space exploration program, private entities in Low Earth Orbit take over routine launch, servicing, and platform operations to meet the demand of the growing industrial research and remote sensing markets.

Abstract (brief narrative summary)	Having demonstrated benefits in pharmaceutical, materials, and technology R&D, the ISS has reached the end of its service life to see the mantle picked up by newer, cheaper, purpose-built private stations. Bigelow Aerospace is the undisputed leader in crew-tended stations, while robust competition is emerging from small, autonomous, reusable platforms that can be launched and refurbished on the ground.
Key Drivers	1. Launch costs 2. Availability of privately-owned in-space transportation 3. ISS National Lab successfully demonstrates value of on-orbit research 4. ISS allowed to serve out its safe lifetime

4C. Baseline Future Narrative

In 2030, we see the bulk of new space activity in the emerging microgravity industry. NASA has shifted its focus towards exploration of the Moon, Mars, and Jupiter's moons (though it struggles under political constraints to take full advantage of private sector innovations) and established cooperative agreements with private space station operators, like Bigelow Aerospace, to provide zero-g training and research space for its exploration programs. Fierce competition between SpaceX, Blue Origin, United Launch Alliance, and Reaction Engines and the rapid growth of small-scale launchers like Firefly Space Systems and Rocket Lab has dropped launch prices to the point that some companies are now considering purchasing their own modules outright, rather than rent or sublet.

Microgravity-enabled materials that cannot be produced on the ground have taken the exotic materials market by storm, but are only recently being produced in mass market quantities because of the time taken to scale up to industrial-level output. The viability of these ventures were first proven with testbeds on the ISS National Lab, along with a slew of new pharmaceuticals that were brought to market faster because of discoveries only possible in microgravity. Fortune 500 companies in the tech and industrial sectors took notice of these successes and accelerated sector growth by using the ISS National Lab as a field station for applied research in materials, metallurgy, and the physical sciences. Bigelow Aerospace opened their first private research station in 2022, with a for-profit spinoff from CASIS as its research management partner, to meet the needs of companies that had invested in microgravity research, but were ready to move on from what the NASA-controlled ISS could offer or feared the loss of political will to sustain it past 2024.

Distributed satellite networks of smaller, cheaper, replaceable units that can be launched on the new low-cost, high-volume rockets or deployed as secondary payloads from either big cargo rockets or the private stations themselves have also made remote sensing and Earth observation available to the masses. Digital Globe has retained dominance with its federal agency, military, and intelligence community clients and their high performance needs, but has found itself outmaneuvered in the civilian markets by a cottage industry of smaller Earth sensing companies that can cheaply provide “good enough” imagery.

With the cost of launch in 2030 under $1000 per pound and the ability to produce industrial-quality materials on-orbit, ventures to harness space-based solar power and mine asteroids are suddenly being taken much more seriously than in years past. In no small part, this is because they offer the promise of environmentally-friendly energy independence to nations weary of fossil fuel geopolitics and the increasingly chaotic consequences of climate change. In the first example of this culmination of technologies and capabilities, Google is leading a consortium of space systems companies to capture a small asteroid, bring it back to Earth orbit, and harvest it to directly replace defunct units in their global satellite broadband network.

The International Space Station itself has held up better than the conservative estimates suggested, but the new privately-owned platforms are just that much cheaper to sustain and upgrade. It served well as a pathfinder for microgravity industry, established the global collaboration network for deep space exploration, and answered many questions about basic science, even winning a Nobel Prize for the Alpha Magnetic Spectrometer team’s characterization of dark matter. However, its era has passed. NASA has put out a bid for it to be scrapped on-orbit and recycled.

5. Alternative Futures

5A. Alternative Future Inputs Worksheet

Category	**Description**	**Foundation, rationale, weak signals**
Trend Breaks	The cost of launching to orbit plateaus because competitors to SpaceX are unable to materialize and it begins exhibiting monopolistic behaviors to try to squeeze out the legacy contractors, like ULA.	Blue Origin has yet to launch or book customers; Reaction Engines is still on the drawing board; SpaceX has sued the Air Force over sole-source bids to ULA
Unfulfilled Plans	Planetary Resources is unable to find customers because atomic-precision manufacturing (APM) decreases the demand for exotic minerals and NASA does not yet fly deep-space missions enough to justify fuel depots.	Current NASA budgets do not include funds for human deep space missions; Advances in molecular research and atomic-precision tooling suggest APM is on the horizon
Wildcard Events	Asteroid Devastates Spokane! – In 2017, an undetected super-bolide destroys most of Spokane, WA. Including the surrounding region, casualties are over 250,000 people injured or killed. The US initiates a massive international impact defense program in response.	2013 airburst over Chelyabinsk region of Russia; 1908 Tunguska event
Issues	SpaceX vs. Arianespace: SpaceX finds itself in an unexpected trade war with Arianespace after the latter files WTO complaints, alleging NASA contracts allow SpaceX to unfairly lower its commercial prices. SpaceX countersues against direct financing provided by Arianespace's host countries.	Boeing vs. Airbus WTO lawsuits; Arianespace executives recently made these accusations in public

Ideas	Colonization Takes Off – Elite investors, disillusioned with traditional philanthropy and the degradation of the environment, invest in the construction of O'Neill habitats to retire to and build new societies.	Google CEO Larry Page recently said he'd rather leave his billions to Elon Musk to change the world, than go to charity.
Key uncertainties	1. We don't yet know what the tipping point in space industrialization will be. What will be the product(s) that make it go mainstream? 2. We don't know if something else will come along that could make space industrialization moot, like APM/nanotechnology.	

5B. Alternative Future Summary Worksheet

Title & One-line Description	**Because It's There** – The nanotechnology revolution finally hit, for better and for worse, and it's left a lot of people with nothing better to do than look up and out.
Abstract (brief narrative summary)	The future is here – it's just not evenly distributed. Eric Drexler's predictions of the revolution enabled when we can manipulate matter in the same manner as computers manipulate information have come to pass. With economic scarcity on the decline, "radical abundance" upending the global economy, and existing power structures struggling to adapt, some people that have the means have decided they'd rather go find their own corner of the Solar System and try something different.

Key Differences from Current Conditions and the from the Baseline	1. The baseline is a world in which current assumptions about economic generation and the predictions of the limits to growth hold true. Thus, the baseline illustrates an attempt to address those limits – and evade the trap in Tainter's theory of civilizational collapse by accessing new sources of energy to solve problems – through harnessing the resources and scientific discovery available in space. 2. The alternative scenario is one where Drexler's predicted revolution in manufacturing through atomic precision comes to pass either in parallel with or ahead of space commercialization. In a world where local materials can be used to produce almost anything with orders of magnitude higher quality, speed, and cost efficiency, people may go to space not for its resources – but to simply get away from the world's problems, because they can. Elon Musk has repeatedly said that he intends to retire on Mars and many of his fellow travelers in the Silicon Valley upper strata would love to join him.

5C. Alternative Future Narrative

Even at Eric Drexler's conservative estimate of 30 cents per kilogram for each product built by atomic-precision manufacturing, the real nanotechnology revolution changed everything in the world economy. Why buy from Southeast Asia when you can print household products in your garage? Why dig up conflict diamonds when your local nanofab can synthesize a stone that will fool even DeBeers? Why burn coal or uranium when you can print solar panels that will outlast your lifetime? The machines can build anything we can think of from only as much sand, water, and organic material as your design needs.

Buckminster Fuller, and others, tried to prepare us to think about how to live in such a world, but we still weren't really ready for it. We also didn't count on how much damage was already done to the global ecosystem after the Industrial and Information Revolutions. Authoritarian governments around the world are using nanofabrication to hold onto power even more tightly – cheap, ruthlessly efficient weapons and ubiquitous surveillance are ugly things when combined. Of course, that hasn't stopped insurgents and terrorists from fighting back just as nastily.

Even though fewer people are dying than in the past, make no mistake about it – the homeworld is constantly at war now in both the virtual and the physical realms. Why ***not*** resort to force when we can focus violence such that it only kills when absolutely intended? People are fighting for your mind, your soul, and your control. For what purpose do you live when anything material or virtual is as easy to come by as breathing? Everyone has their own answer and too many people are still willing to do anything to prove they are right.

I decided to stop wasting time in meme-war over who has the best idea for cleaning up the North Sea. The universe beckons. Our group – and we're far from the only "enclave" to pop up – pooled our cryptocurrency into launching some fabbers at a big rock halfway to the Moon. Once the machines were done reprocessing the raw material into a spin habitat, all we had to do was move in. We've got writers, animators, coders, modders, gene-splicers, designers – people who create content. Selling our ideas doesn't just cover the upkeep… we've got enough security to make even Czar Putin think twice.

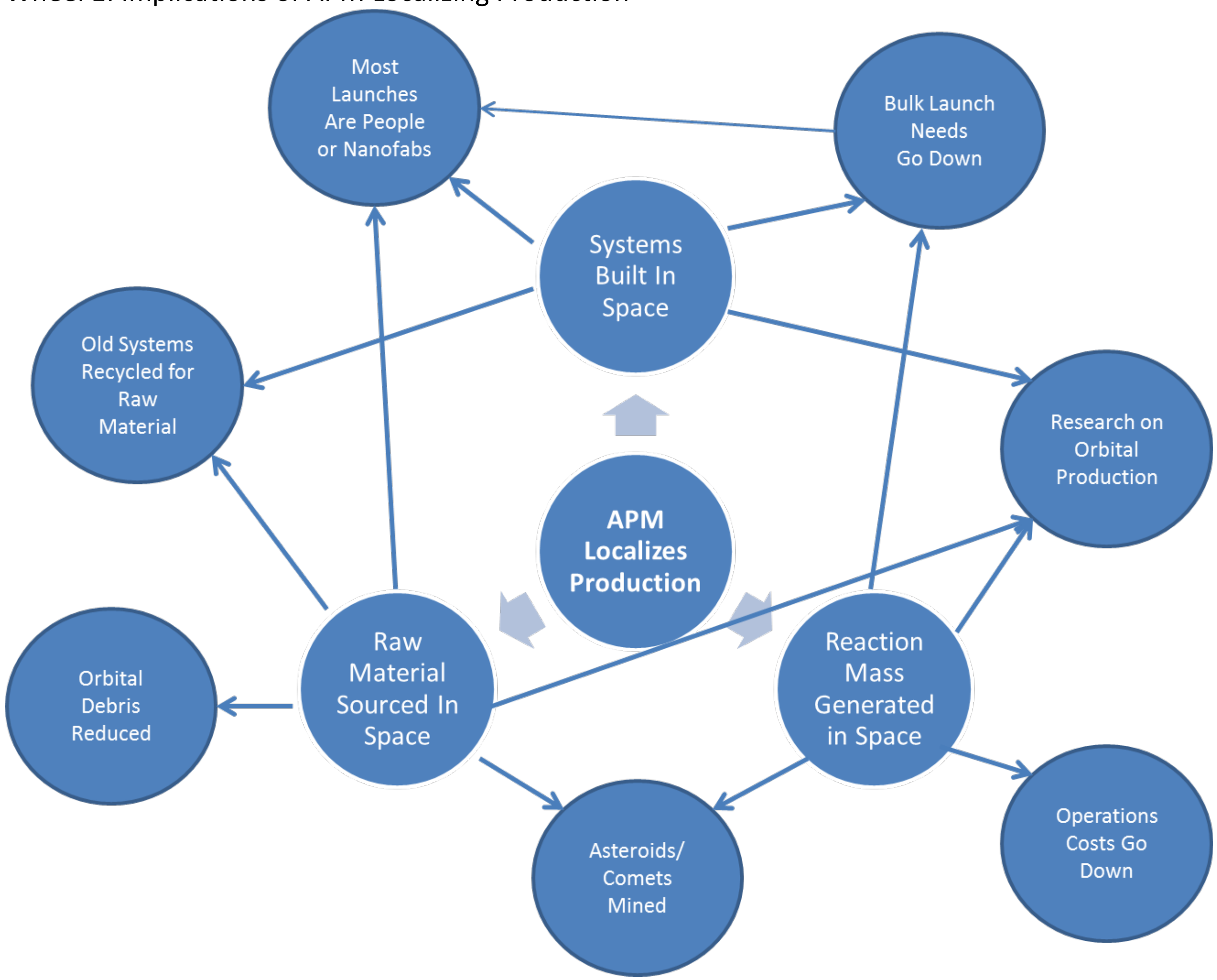
The rest of the time? Science, philosophy, cooking, my own little bubble looking out on the vast stars. Why not? It's our own little gated space community. No plague. No global warming-induced sea rise. No overcrowding. No NSA. Everyone passed psych screening. We're all here because we like the people we're around. If we get tired of the current view, we have a mass driver and enough fuel (read: construction slag) that we can just push off to another planet.

I hear National Geographic is sponsoring an expedition to look at the thermal vents at the bottom of Europa's ocean and they're looking for an enclave willing to make the move. That could be fun.

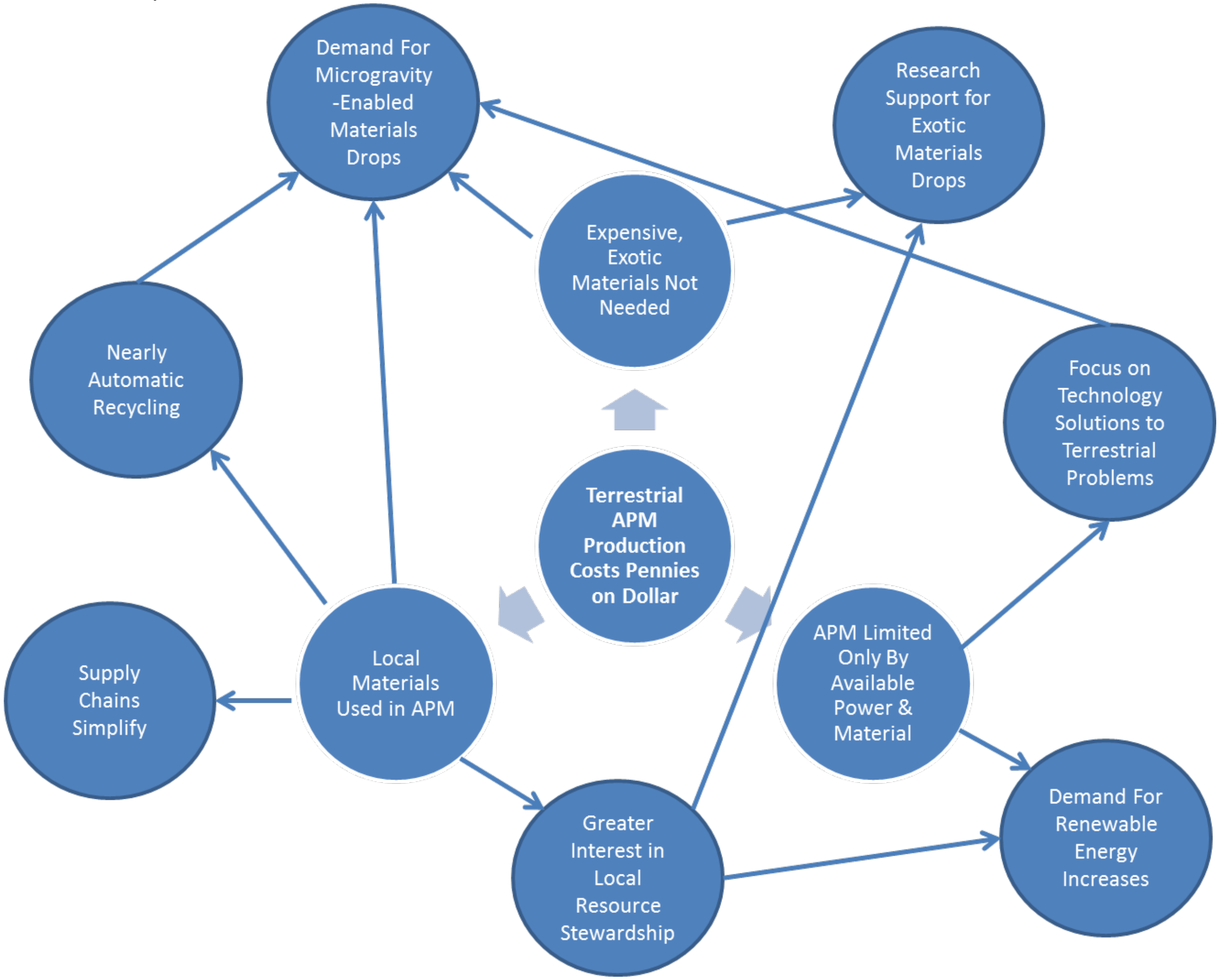
5D. Alternative Futures Implications
Futures Wheel Prep Worksheet

1. Pick either Baseline **or** Alternative Future	Alternative Future – Space Industry in the APM Revolution
2.Pick a category to focus the implication on	Microgravity Research would be most consequential to CASIS because that is the cornerstone of their mission.
3.Do 3-5 futures wheels of impacts of your scenario for the category.	See below.
4a.Single Most Important Implication (from Futures Wheels)	Microgravity research will likely shift focus on the industrial side to supply and manufacturing in-space for in-space projects, rather than terrestrial benefit, while basic science only needs enough people to want to do it.
4b.Single Most Provocative Implication (from Futures Wheels)	General-purpose nanofabricators mean you only need to launch & ship that which can't be fabricated – people & the first nanofabs. Anything else can be produced at the destination.

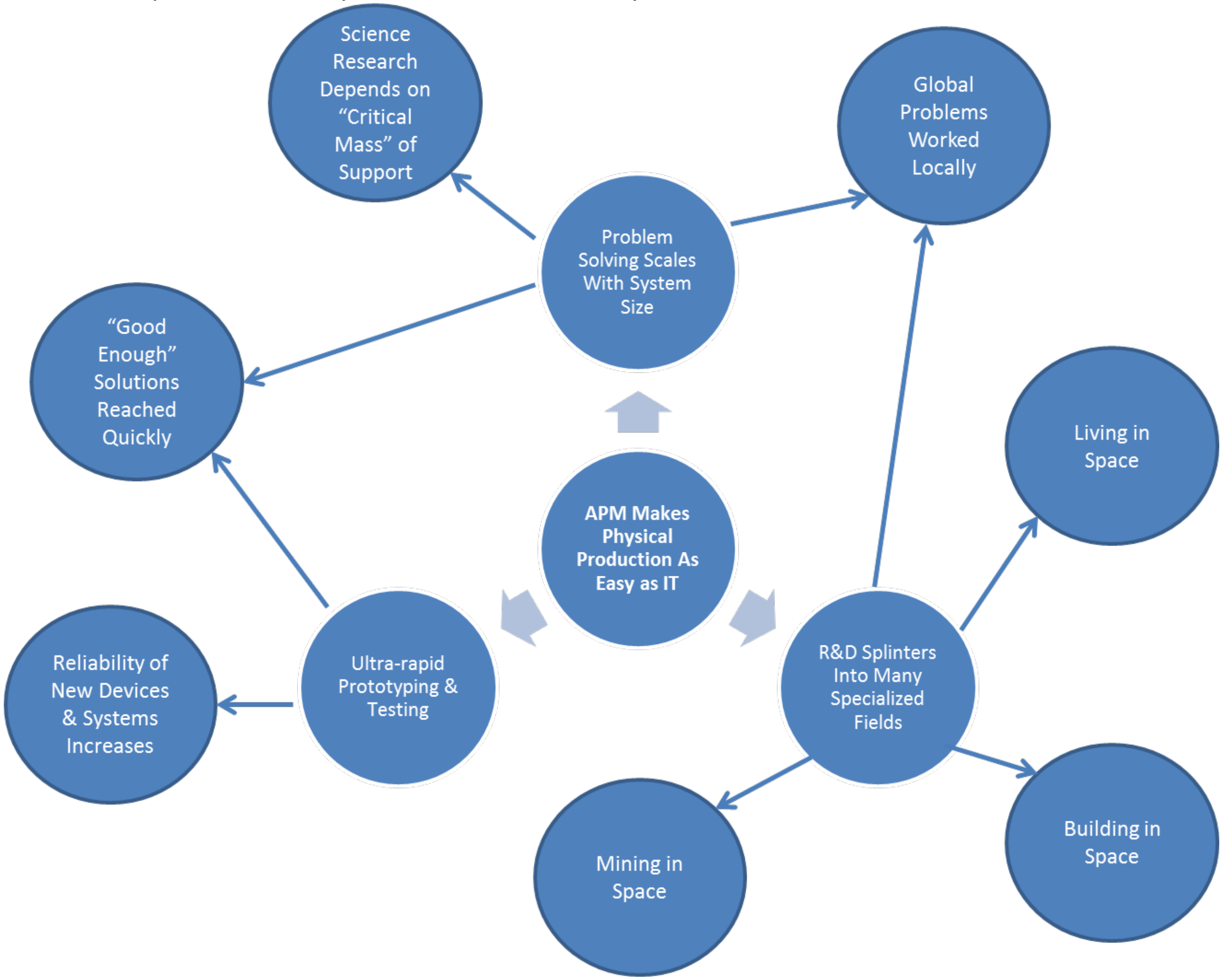
Wheel 1: Implications of APM Localizing Production



Wheel 2: Implications of Terrestrial APM



Wheel 3: Implications of Physical Production As Easy As Information Production



The View Ahead

After decades of following Wernher von Braun's model of exploration – Space Shuttle, Space Station, & Mars – NASA is beginning to realize that times have changed. Even visionary Gerard K. O'Neill depended on NASA's Space Shuttle to implement his plans in the 1970s to build cities in space. On December 11th, 2014, the Agency hosted a workshop on Low Earth Orbit commercialization intended to discuss not how NASA can buy products and services, but how to help drive demand for access to space and (just as importantly) know when to get out of the way.

With the ISS National Lab serving as a proving ground for new products and services enabled by access to Low Earth Orbit and the democratization of space technology well underway, industrial space activity in 2030 is likely to be focused on microgravity-enabled exotic materials and services for research customers. These services can be expected to include launch, on-orbit operations, and cargo return to the customers' nearest controlled airspace. While crew-tended stations are likely for government customers interested in exploration, basic science, and elevating national prestige, the continued growth and increasing cost-effectiveness of small satellite technologies suggests that automated, reusable platforms will be of prime interest for full-scale industrial production.

However, this outcome could be disrupted by trade disputes between launch industry companies that forestall continued innovation, policy failures that prevent private companies from owning the products of their labor in space, or advances in terrestrial manufacturing technology that leapfrog the terrestrial value of microgravity-enabled materials and research. Of these alternatives, the revolution in atomic precision manufacturing could still take humanity to the stars, but the focus would be on expanding the nature of the human experience and relieving social tensions that ramp up in the struggle to adapt to the new economic base.

In the coming years, CASIS must decide what kind of future it is working to create. The time horizon in this foresight model actually exceeds its current agreement with NASA to manage the ISS National Lab by nine years. If the emergence of space-based industry is to be part of that future, CASIS must create and foster strategic partnerships with companies, investors, and development organizations that will lead to proof-of-concept demonstrations of microgravity-enabled materials and support services in the next two to five years. Otherwise, the nascent industry will not have time to iterate and generate market solutions before political will runs out.

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