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CAN A SPACE "MEGAFUND" MOVE HUMANITY CLOSER TO BECOMING A MULTIPlANETARY SPECIES?

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I. ABSTRACT

We present a case for funding space development projects -- commercially viable, and riskier projects -- with a financially engineered, risk managed "megafund". This work is partially inspired by the work of others who have explored the potential benefits of a megafund in achieving the development goals of capital intensive, very high risk, very high reward enterprises in other industries. Andrew Lo has argued (National Academies of Sciences, "How Financial Engineering Can Cure Cancer") that a $30 Billion megafund could help bring cancer drugs to the marketplace in a financially more efficient fashion. Could this kind of funding initiative accelerate space development? Our goal is opening energy and resource development of space, enabling the human race to become a multi-planetary species. Example opportunities include: the development of space elevators for cost-efficient access to orbit, resource extraction (asteroid mining), and space-based solar power generation for Earth-based consumption. In addition, we suggest funding the International Space Station (ISS) as a technology incubator: a properly utilised space laboratory in orbit such as the ISS has the possibility to accelerate microgravity research for the biotech, nanotech, artificial intelligence, robotics, material sciences, and other sectors. Indeed, immediate financial support and commercial use of the US Laboratory could be viewed as a prototype working example of how a larger megafund might work.

II. INTRODUCTION

"No Bucks, No Buck Rogers", Dr. Buzz Aldrin

"MegaBucks, Can Create Mega Buck Rogers", Michael Potter

The economic benefits of space development are often underestimated. Many people worry about money 'spent in space' without recognizing that 100% of expenditures are actually spent terrestrially. There are no cash machines in space (yet!). Further, they fail to see that space development represents a key segment of the global economy, because of the international satellite communications market. However, many other promising space development projects languish because of delayed or volatile funding. Our hypothesis is that with proper financing, a wider variety of commercial space activities will be successful, and will contribute to making humanity a multi-planetary species -- while simultaneously opening new frontiers of clean energy, and access to critical resources to serve the ever-growing population of Earth. This is likely one of the most important frontiers in human evolution, in terms of economic growth and the emergence of new market sectors, driving innovation and improving living standards for all peoples.

Satellite communications and remote sensing market segments, after being liberalised and privatised, have shown consistent returns on investment, enabling this segment to secure additional development capital. Guided by this success, we can ask several questions:

- Could the capital resources of a space megafund jumpstart development of our local space region (near-Earth and solar system)?
- Could a fund support commercial utilisation of the existing ISS as an economic proof of concept?
- Could a space megafund help create a new commercial ecosystem?
- What space-based industries are most promising for megafund investment? For example: space-based solar power, asteroid mining, space fuel depots, asteroid mining, etc.
- How does a proposed bio-technology megafund compare to a space megafund? And could biotechnology research benefit from experiments performed in unique microgravity environment on the ISS -- supported by the space fund?

Questions specific to forming and operating a space megafund include:

- How much historical performance data is needed to engineer a predictable and investable space megafund?
- How much capital should be raised?

- Can governments play a role in facilitating a space megafund?
- Is CASIS and its work aimed at incubating the US National Lab a template?

Other key issues are:

- Can we anticipate an emerging "space singularity", in which there is single moment in time when commercial and financial conditions create a "golden spike" opportunity?
- What ways can we measure the approach of a "space singularity"?
    - When suborbital flights cost a single-integer multiple of the median US income? ($50-250k?)
    - When future orbital flights are the inflation-adjusted price of 2014-priced sub-orbital flight?
    - When industrial-sponsored space-based experiments are economically viable and become commonplace?
- Can space development bonds be investment grade?
- Is ISS an appropriate commercial benchmark?

III. CALIFORNIA'S STEM CELL FUND AS A MODEL FOR A SPACE MEGA FUND?

Our thesis is a megafund would control and reduce financial risks of space development. This funding model may therefore encourage larger investment, and also enable projects with higher risk -- and higher reward -- thereby amplifying benefits to humankind.

There exist analogous, high risk investment objectives being served by megafunds. Have these efforts been successful? Can they provide insights into the viability of the megafund model to support space exploration?

Large pooled investment vehicles (similar to megafunds) have long been used by investment managers to reduce portfolio risk by incorporating diverse, uncorrelated holdings. Examples range from private equity funds investing in companies with diverse products in different industries, to securitized loan pools such as "asset-backed securitized bonds" (ABS) composed of loans in different industries and geographies.

Below, we discuss the California Stem Cell Initiative (CSCI), a public investment fund with economic and policy goals. This example may offer insight into formation and management of a space development megafund.

<u>Purpose of California Stem Cell Initiative</u>

Stem cell therapies have been identified as potential game changers for numerous injuries, diseases and maladies that are difficult to treat using current therapies, or which may be simply untreatable by currently available medical practices.

California's initiative was, in part, a reaction to U.S. Federal Government restrictions on research and funding in the arena of stem cell research. In 2001, the Bush administration restricted funding for stem cell research, making rules that allowed using only adult stem cells and a few existing lines of existing embryonic stem cells -- and categorically not allowing development of new embryonic stem cell lines. The existing embryonic lines of stem cells permitted for research were considered of poor quality and unfit for research by scientists. At the time, embryonic stem cells were also considered to hold more promise and significant benefits deemed unavailable from adult stem cells.

These restrictions were lauded by pro-life groups, but were met with dismay by patient advocates, stem cell researchers, and the biotechnology industry. Concerns ranged from the loss of potential life saving therapies, to damaging the competitiveness of the U.S. biotechnology industry.

California's response was Proposition 71, presented to the California electorate in November 2004 under the state's referendum process. The initiative was heavily promoted by patients, scientists, and industry. There were a number of highly emotional appeals by prominent celebrities afflicted by diseases or injuries considered potentially treatable with stem cell therapy.

Fifty-nine (59) percent of California voters approved the initiative, authorizing $3 billion in bonds, with funds to be dispersed over a decade at a rate of $300 million per year. This was the largest commitment of funding by any state or country in the world. For perspective, note that the total U.S. federal government spending for stem cell research in 2004 was only $25 million.

Grants were restricted to California universities and research facilities, and provided for creating research facilities, expanding existing research capacity, workforce development, and initiating stem cell therapies.

The proposition also directed the creation of a state agency to manage the $3 billion commitment and implement the intent of the initiative in the form of the California Institute for Regenerative Medicine (CIRM) with an oversight body, the Independent Citizens Oversight Committee (ICOC).

The CIRM directs grants and loans to research on therapies, diagnostics, and other life saving medical treatments of maladies such as amyotrophic lateral sclerosis, cystic fibrosis, spinal cord injury, liver disease and multiple sclerosis with additional applications in cancer, diabetes, arthritis and other diseases. Research is supported in tissue specific lines to test therapies, disease development and immunity enhancement along with cell replacement therapies.

While emotional appeals and the promise of life changing therapies from stem cells just around the corner motivated public support, in California policy-making, academic and industry spheres there was a strong element of economic development or industrial policy animating support for the initiative.

Economic motivations behind Proposition 71 were driven by strategic goals of protecting and enhancing the California-based biotechnology industry. There were significant concerns that the effect of the Federal Government restrictions on stem cell research would cause an exodus of talent and capital from California to nations more welcoming to stem cell research. The commitment of multi-year funding and increased research capacity by the state was designed to attract additional capital, industry, and talent to California, thus buttressing and promoting its leadership role in biotechnology.

While direct financial "return" is not the primary motivator of public policy initiatives such as the California Stem Cell initiative, there are potential economic benefits that could accrue to the state and California taxpayers. These include royalties from successful therapies developed from loans and grants, future state health care savings attributable to therapies and economic development benefits in the form of tax revenues from a growing biotechnology industry and increased employment

Success of the California Stem Cell "Megafund"

Has the California Stem Cell Initiative been successful? Answering this question is a challenge. It's not the intent of this paper to review potential or perceived flaws in Proposition 71 and the execution of California's Stem Cell Initiative. However, it will be helpful to have some context regarding the political challenges accompanying CIRM's genesis along with what might be considered some of its own self-inflicted wounds that potentially have inhibited performance.

There are numerous critiques of the state's effort. Some consider Proposition 71 and its commitment of $3 billion a wasteful boondoggle sold to the public in a disingenuous atmosphere of emotionalism and hyperbolic promises of lifesaving cures. Others, supportive of investments in regenerative medicine consider the money could have been better spent on basic research on stem cells to create the foundation for the therapeutic application of the science.

The ICOC and CIRM have been plagued by charges of conflicts of interest, given the presence on governing boards of senior administrators and deans affiliated with universities and research institutes receiving funding from the CIRM. The recent departure of a President of the CIRM and subsequent employment with a beneficiary of funding from the CIRM has fed this controversy.

Claims of poor contract management practices, poor fiscal management, and concerns that the agency is simply slow and bureaucratic in its evaluation and selection of potential research projects to be funded have tarnished the CIRM. The CIRM has taken, on average, two years to approve funding requests.

It should be noted that Proposition 71 was passed with vigorous opposition by powerful interests such as the Catholic Church, pro-life advocacy groups, and fiscal conservatives. This opposition did not cease with the public's passing of Proposition 71. Lawsuits were filed to challenge the ability of the CIRM to issue bonds. While the CIRM prevailed, the lawsuits and the sheer magnitude of effort involved in starting a new state agency delayed funding.

Also, the CIRM has been criticized by patient advocates frustrated by slow progress in developing therapies. As a public agency, the CIRM has had to balance the mandates of transparency and public accountability with the needs of confidentiality and propriety regarding scientific research and the potential creation of valuable intellectual property. There appears to have been significant cultural friction in reconciling these differences.

Many critics are biased. However, a number of criticisms are well founded and were addressed in separate reviews of the agency by both the California Little Hoover Commission and the American Institute of Medicine. Both provided recommendations to address the conflict of interest issues, improve governance and correct other deficiencies.

CIRM finds itself approaching the expiration of its mandate looking for a big "win" to convince the public to recapitalize the agency with another round of bond issues. This has motivated the "CIRM 2.0" initiative, an effort to reduce the grant application process to ninety days and attempt to accelerate demonstration of results. This highlights the challenge of doing science within the political arena. It is apparent that CIRM is now under pressure to justify its future existence, and its long-term effectiveness may be degraded.

Within the context of these challenges, has the State of California Stem Cell Initiative been successful in creating stem cell-based cures that will revolutionize medicine? To date, no. In fact, there have been no approved therapies derived from grants or loans provided by the CIRM. This is not intended to be a criticism; just a statement of fact.

So what has the public received for its $3 billion investment commitment and allocation of $2.2 billion in funding to date? The CIRM has not been idle. In the American Institute of Medicine's 2012 review of the agency it noted that the CIRM had awarded $1.3 billion to fifty-nine institutions in a manner consistent with its strategic plan of 2006. And, that the CIRM's investments in basic research, physical infrastructure, human capital and its collaboration with other national and international centers of excellence had positioned California as a center of activity in regenerative medicine.

The CIRM lists as benefits and accomplishments attributable to its funding the following:

- Ten therapeutic approaches currently in clinical trials
- Therapy pipeline with eighty-seven potential therapies funded with $600 million
- 1,750 published discoveries
- Training of 1500 individuals to work in the industry as technicians and researchers
- Attraction of 130 senior scientists who have established laboratories in California
- Development of 12 new buildings housing new state of the art research space and the leveraging of $543 million in addition to its $271 million awarded
- 38,000 new jobs projected to date
- $286 million in tax revenues to date

In fairness, it is simply premature to evaluate the California's Stem Cell initiative. The initiative is technically ten years old. But given legal and start-up delays, the initiative has only been operative for seven years. Further, given the nature of scientific research and the slow process of securing approval of therapies it would be unreasonable to expect demonstrable benefits at this time.

The initiative and its implementing agency the CIRM have flaws and critics. And, the execution of the initiative must occur within a political milieu where the expectations of stakeholders and the California taxpayers funding the initiative may simply be unreasonable, or at best uninformed. Notwithstanding its rocky start, the initiative appears to be on a path that may yield significant therapies and contributions to regenerative science. Unfortunately, it will take decades to determine how much the state's investment yielded for the public in terms of improvements in medical treatment.

In terms of the underlying industrial or economic development purposes of the initiative, it appears that it has been successful in positioning California, its top-level universities, and its biotechnology companies as leaders in the field of regenerative medicine. However, while the CIRM has levered a half billion dollars in co-investments in research capacity plus $283 million in taxes, it is also too early to see if these will result in tangible financial returns to the state and taxpayers at a level to justify the approximately $6 billion in principal and interest expense.

We could rely on the initial Economic Impact Report prepared by the Analysis Group in support of Proposition 71 to the voting public to speculate that California's Stem Cell Initiative will be a success and yield benefits that can be monetized creating economic returns far outweighing the investment the public has made toward this effort. The analysis' findings assert that Proposition 71 would, under a variety of scenarios, provide total economic benefits to the State of California between $6.4 billion and $12.6 billion during the thirty year payback period of the bonds.

These returns would accrue in the the form of taxes, royalties, and health care cost savings to the state budget representing a 120% to 236% return on investment. (It should be noted that this analysis was generated by a group affiliated with Stanford University. Stanford -- a private institution -- has been the largest single recipient of Proposition 71 funding, to the consternation of the state's top-tier public research universities.)

<u>Is the California Stem Cell Initiative a Model for a Space Exploration Megafund</u>?

What lessons from the CSCI experience apply to a space Megafund?.

A Space Exploration megafund is an equity-financed investment vehicle intended to diversify risk, while generating a high level of equity return for its investors. Capital placed in the fund would require a very high return and would be available immediately for investment in a limited number of pre-identified ventures of which any single successful project could potentially generate an extremely high rate of return to the total fund.

In contrast, the California stem cell investment is debt financed with investments of funds over a ten to fourteen year time frame; payments on the bonds over 30 years; and potential returns over thirty years. The cost of funds is extremely low relative to the risk in that the source of investment funds are a general obligation bond issue derived from the credit standing of California backed by the taxpayer. In essence, the investment is paid back to the source of funds notwithstanding the success or failure of the "stem cell venture". This creates a massive advantage for the public fund not likely available to a private equity megafund. Further, the potential "return" to the state is derived from multiple sources such as taxes and avoided health costs which are actually greater than the direct returns attributable to royalty payments to the state from successful therapies.

There are other examples where large sums of money, not in a structured megafund sense, are also being deployed. There is the wide encompassing field of "life extension" that is starting to attract large amounts of funding. In an April 14, 2015, article, "Tech titans' latest project: Defy death", the Washington Post reported, " the tech titans who founded Google, Facebook, eBay, Napster and Netscape are using their billions to rewrite the nation's science agenda and transform biomedical research. Their objective is to use the tools of technology — the chips, software programs, algorithms and big data they used in creating an information revolution — to understand and upgrade what they consider to be the most complicated piece of machinery in existence: the human body."

It is unlikely that investors in a space megafund could monetize "avoided" costs. Ideally, though unlikely, a megafund would have investors willing to place capital at costs commensurate with state general obligation bonds (perhaps in the 5% interest range); payable over thirty years; without recourse to the "fund" or its creators; with no oversight committees; and no distributive politics. But this fund already exists. It is called NASA.

IV. ARE COMMERCIAL ASTEROID MINING, AND SPACE RESOURCE MISSIONS CANDIDATES FOR A SPACE MEGAFUND?

Over the last decade a number of privately financed, space-related companies have been involved in pioneering research and development. Space-X and Bigelow Aerospace are just two examples of private companies venturing into areas that previously were mainly the domain of government-funded research facilities.

The drawback of this new development is that research and development are limited to the financial resources the individual companies are able to raise, meaning they have to concentrate on 'what they can afford'.

Where 'milestone' projects comparable to NASA's lunar missions are concerned, the overall financial requirements will be likely out of reach for most, if not all, individual companies. According to 'The Space Review', the total cost of the Apollo programme was, in today's money, about $110 billion, ESA gives the cost of the International Space Station (ISS) as €100 billion over its lifetime.

It is undeniable that both the Apollo project and the ISS have boosted the development of a wide range of technologies globally. Hence, if a space megafund were to identify and help finance and develop a similar 'milestone' project, the payback, if these benefits could be monetized, would likely outweigh the overall costs.

The question arises as to what would be a suitable project to pursue and the following options come to mind:

1. Asteroid Mining
2. Human Interstellar / Intra-solar system missions
3. Creation of a Space Elevator
4. Space based Solar Power
5. Mars habitations built by 3-D printers

The first two of these three 'shortlisted' options have in common that they require transportation into outer space.

Undertaking this transportation directly, the Apollo project's Saturn V rocket presents a good way of estimating costs. According to Nasa [1] the cost of a Saturn V including launch was $185m in 1969, which, when adjusted for inflation equates to approx. $1.2bn in 2015. The payload for a Saturn V was 118 tonnes to LEO and 48.6 tonnes to TLI (Trans-Lunar Orbit). This works out at a cost of $10.2k per kg for a launch to LEO. Since then, launch costs have been reduced significantly and Space X currently quote a cost of $1.6k per kg to LEO for the Falcon Heavy launch vehicle [2].

In 2004 Elon Musk estimated [3] that launch costs to LEO could be reduced to $1.1k per kg. However, a Falcon 9 v1.1 uses a total of 178k litres of liquid oxygen and 112k litres of kerosene (RP-1), which is a fossil fuel. It can and often is argued that this compares favourably with the amount of fuel used in aviation: A Boeing 757 uses approximately 12 litres of fuel per km, so over a 10 hour flight burns approx. 150k litres of kerosene. [4]

Therefore, it can be argued, that transportation to LEO has got little environmental impact. It furthermore, has to be stressed that traditional, rocket-based launch vehicles are a known technology, so development can be undertaken in discrete steps by improving efficiency from one launch vehicle generation to the next, while generating income from the current generation.

If asteroid mining or interplanetary travel were undertaken on a much wider scale, the number of required launches to LEO or beyond would have to increase drastically.

The above can be compared to modern motor car technology. Petrol and Diesel engines have been available for over a century and, due to lower manufacturing costs, fossil-fuel cars eventually overtook electric cars in sales. The current electric car revival is to some extend a result of environmental concerns regarding fossil fuels, but it cannot be denied that the initial revival was caused by government intervention (such as California's Zero Emission Vehicle Programme). Legislation had the desired effect of sparking a renewed interest in electric vehicles -- car makers were motivated by a desire to remain eligible to sell cars in California.

However, with regards to launch vehicle technology, it is unlikely that any unilateral legislation by a government would spark an interest in non-fossil-fuel based technology as launch vehicles are not something that is sold to a wide range of consumers.

Given the above cost arguments and especially the fact that launch vehicles can be developed in discrete steps, providing a much better cash flow even at a fairly early stage, it is unlikely that any single player in the launch vehicle market will look at the concept of a space elevator.

In a paper published in 2000 [5], B. C. Edwards states clearly that with current or near-future technology none of the potential problems in the construction of a space elevator have been found to be unsolvable. With carbon-nanotubes being a major element in the construction of the elevator it has to be emphasized that since 2000 much progress has been made in this field.

In a later report [6], Edwards estimates the construction costs of a space elevator to be around $6.5bn (+/- $0.5bn), though he emphasizes that the non-technical costs could be much higher as they depend on how the programme is run. Given that these are 2003 figures they have to be adjusted for inflation. Furthermore, experience from other large-scale programmes shows that costs are generally underestimated. Initial costs for the Apollo project were estimated at around $7bn, but this figure was famously (by James Webb) increased to $20bn.

It is exactly this uncertainty on a large financial scale that will most likely deter any private companies to risk the development of a space elevator (a paper published in 2004 [7] cites financial cost overruns as a major risk). Applying the same financial estimates as for the Apollo programme, one could argue that the overall sum of money required for the development of a space elevator is around $20-$25bn. Hence, it lends itself to a project being undertaken by a space megafund.

Once on a relatively secure financial footing, the risks regarding a space elevator are relatively small as most of the technology required is already available or within reach of development.

The launch costs of conventional launch vehicles to LEO are currently around $1.6k per kg, but it is estimated that depending on the financing structure, the launch and lifting costs to LEO can be reduced to $150-$1100/kg, and eventually as low as $10/kg. The latter figure would require more cost efficient production methods of a space elevator components such as nanotubes, but this is something that is already happening. The cost reduction histories of computing and data storage are instructive, as costswere reduced as technology became more widely and regularly used, providing financial incentives for manufacturing cost reductions.

Technologies such as carbon nanotubes also find application in many other areas of technology (batteries, solar cells, biomed to name but a few) so a technological boost could also be expected for these applications which would clearly provide a huge societal benefit.

Furthermore, a reduction of launch cost to LEO by a factor of 10-50 would also spark much more interest in interplanetary travel and asteroid mining. For both projects, the predominant cost is launching the equipment. With a drastic reduction in these costs, more commercial interest would be generated and much progress would be achieved.

In 2012, Space.com published and article about asteroid mining [8], referring to a study undertaken by the Keck Institute for Space Studies and also referring to Planetary Resources, Inc. In the article it is claimed that for a cost of $2.6bn it is possible to identify, capture and place into a lunar orbit an asteroid weighing about 500 tonnes.

Once in lunar orbit, the asteroid could then be mined, but here lies the crucial element. The cost of regular journeys to a lunar orbit are still very high, but a space elevator would be revolutionary, since the cost of mining material and returning it to Earth would significantly reduced, making it possible for private enterprises to successfully operate in this market.

The report published by Edwards identifies 20 potential legal issues , ranked from very broad to very specific, but none of these is seen as a definite 'show stopper'.

The three major issues were that were identified were:

1. Right of way of existing satellites to avoid collisions

2. As the space elevator will go through geosynchronous orbits, relevant orbital position slots would be required.

3. Liability insurance would be required.

The report found none of these issues insurmountable.

Once established, the space elevator would provide an important piece of infrastructure with regards to human exploration and colonisation of space. It has been argued that given the uncertainty in overall finance required and the cash flow considerations make it an unlikely project to be undertaken by any private company.

At the same time, the technological and legal risks and uncertainties for a project of this size are comparatively minor while the societal and technological impacts are potentially large. This makes a space elevator a well suited candidate for a space megafund.

NASA recently issued a grant challenge to stimulate the development of 3-D printer technology for building habitation structures on mars [9]. The concept is still under development, but the basic premises include a) processing local mars or lunar rocks (such as basalt) into a form usable by 3-D printers, b) developing robotic-enabled machines which can operate independently, building structures prior to the arrival of human inhabitants, c) the structures could be thick, air-tight, and provide radiation shielding, and d) the system could be fully demonstrated on Earth (basalt is plentiful on Earth), before installation on the lunar or martian surface.

This initiative has many of the characteristics of projects appropriate for a megafund portfolio, including:

- Developing revolutionary technology
- Project can start now -- does not need to wait on other enabling technology
- High probability of stimulating spin-offs -- for example, improvements in mainstream housing construction techniques.
- Relatively low cost, and potentially very high reward.

V. THE INTERNATIONAL SPACE STATION (ISS) & CASIS: A PRECURSOR TO A SPACE MEGAFUND?

How will we judge the success or failure of any future megafund for Space? What metrics will we use? Return on investment? Jobs created? Scientific discoveries? Additional commercial investment spurred by the megafund? What benchmarks will we use? Further, is there a potential that we can examine today that a megafund for space might work and how it might function? The authors would argue that, yes, such a precursor example exists today in the form of the Center for the Advancement of Science in Space (CASIS) and its work on the International Space Station (ISS).

In 2011, CASIS was awarded the management of the US National Laboratory on the ISS by NASA and the US Congress [10] with a mission to maximise the use of this unique asset in Space. CASIS is a not-for-profit entity tasked with managing the non-NASA science on the ISS for the US Laboratory. The award to CASIS was in response to the mandate in the 2005 NASA Funding Act to put aside a portion of the US Laboratory for development. CASIS is funded at $15m per annum. Further, part of the award to CASIS from NASA includes upwards of $3m in Congressional mandated funds for CASIS to use in the selection, develop, and support of experiments and partners to use the US National Laboratory and also to encourage matching or more commercial investment in the use of the same. [11]

In this regard, CASIS can be seen as a space 'mini fund' focused on the development of the US Laboratory on the ISS and in this aspect can been seen as a working precursor of merit for a larger future space megafund. The CASIS development of the US National Laboratory is comparable to the envisioned megafund.

How is CASIS performing? What metrics are being used to determine its effectiveness, success, or failure? How is CASIS measuring its own activities in response to reporting back to its stakeholders? CASIS provides a benchmark for any future megafund in Space.

From 2012 through to the end of the first quarter of 2015, CASIS has enabled over 182 experiments to the ISS to utilise the US National Laboratory, with a further 33 pending projects and 5 new in development.[12] Yet, what was the use of the US National Laboratory before the advent of CASIS? Figures are difficult to find.

So though impressive, the number of experiments to the ISS from CASIS is not yet perhaps a key indicator of success. However, when the commercial investment level matched to these experiments is examined, a different metric emerges. From 2012 through to the first quarter of 2015, CASIS has awarded $13,843,016 [13] in development grants for experimenters to utilise the US National Laboratory. In turn, this investment of funds CASIS has received matching commitments of $12,106,425.00 from its partners in the form of "cash, gifts, pledges, in-kind gifts, and other types of support that have a monetary value in support of the CASIS mission". [14] For every US$1 of grant monies awarded, CASIS to date is seeing a matching investment from its partners on the ratio of near 1:0.87. Almost parity.

CASIS has stated that it will track the number of scientific papers published resulting from experiments funded by grant awards. [15] At present CASIS is tracking media impressions, web site visits, and social media activity.

It would appear that CASIS is still a work in progress, yet, it's very existence serves as an example for a future megafund for Space. It's work and chosen milestones will be seen as a benchmark for any future megafund. How CASIS tracks its results and how it performs for its stakeholders will have an impact on the viability of any future megafund in Space and for this reason CASIS serves as a modern day example of a precursor to any future megafund in Space.

VI. PURCHASE OR LEASE OF ISS IN 2024?

Current plans call for NASA and international partners to slam the ISS into the ocean in 2024, as part of a decommissioning and deorbit plan of the space station. A space megafund could potentially intervene.

In a recent Wall Street Journal article it was reported, “During a presentation to the Milken Institute Global Conference here, William Gerstenmaier, an associate NASA administrator, said “there’s a tremendous new environment” in space programs because “the private sector wants to do this.” He also said the agency’s own plans past 2025 anticipate the use of privately funded orbiting facilities for some of its own research.” [16]

ISS itself is perhaps the greatest international technology project of all time. Which implies two things. One, that there is probably some value in the asset, in terms of orbital salvage, repurposing and recycling. Two, that trying to formulate a coordinated, coherent, international plan to repurpose ISS may in fact be nearly impossible.

The fully loaded cost of ISS will probably reach around $200 billion dollars before the Station is to be deorbited. Preserving this investment is alluring. A commercial sale of the ISS is unlikely, based on the assumption it would be very difficult to get a timely consensus among all of the space stations partners. A lease of the space station, or perhaps a portion of the space station, might be more achievable.

The legal mechanisms used to transfer decommissioned Space Shuttles to museums are worth considering. The legal authority for conversion of NASA assets to private use is through the sale program authorized under the Federal Property and Administrative Services Act. This includes conversion of assets to private contractors, collectors, or museums. Property may not be loaned to private contractors, individuals, collectors or museums -- unless the loan satisfies a NASA programmatic requirement.

One legal mechanism for the disposition of the ISS as a surplus asset could be an Enhanced Use Lease. This is a cooperative arrangement between a government entity and a private sector developer. The government can negotiate a long-term lease of an underutilized property (land, buildings and other structures) to the private developer or a private enterprise. Under this model the government receives cash or in-kind services from the enterprise while retaining ownership of the asset. Congress provided NASA authority in 2007 to enter into enhanced use leases at all Centers. Later amendments in 2008 clarified how the funds should be expended and established percentages of the revenue that were to remain at the Centers versus being placed in an Agency capital asset account. The Enhanced Use Lease might be a suitable mechanism for commercializing the International Space Station.

VI. CONCLUSIONS

In this paper we have introduced for the first time the concept of a megafund for financing the commercialization of outer space. The authors have looked at the concept of a proposed megafund for financing cancer drugs, and have examined the California Stem Cell Agency & the California Institute for Regenerative Medicine for models that could provide lessons and insight into large investments in other technical, science and commercial frontiers. In addition, we have considered possible commercial candidates for a space megafund including the space industrial sectors of asteroid mining, space elevator transportation, intra-stellar missions, and space solar power business.

A de facto megafund-like process exists in private equity investing for biotech R&D. Sophisticated investors evaluate risks, technology, IP, scientific talent, potential markets, and rewards. It seems that capital does aggregate around risky pharma research, with some drug companies built around specific drugs that have potential, market and talent and as these drugs gain value by moving through the approval process they are monetized based on their higher probability of success where big pharma buys the company or drug etc. Or, part of the original capital structure of the single drug research company is owned by big pharma with options on the drug.

One of the concerns is that while there is an investor "sweet spot" for the yields these analysts are projecting, that is also the sweet spot for "dumb" money. Biotech investors expect high yields, because risks are high. The question is, does the megafund wind up with a higher percentage of "dogs" in its portfolio? Would a company like Google or SpaceX, if they felt passionate and confident about a project, really consider seeking to draw investment from a megafund? Or conversely, would they be more likely to take the projects, that they might not feel confident about to a megafund, trying to "outsource" their risks?

The proposed biotech megafund model shows initial and early cash flows generating yield or payout to bond investors, while it is still saddled with the challenge of R&D and maintaining the development pipelines. How likely is it that early cash flows (in the first five years) will manifest, unless there is a sizable capitalized interest component of the issuance to pay early dividends?

One of the main purposes of this paper is to define the outer boundaries of this new investment fund concept. Perhaps this paper can inform and inspire the development of a template or the document, that would be handed to a Space megafund investment committee year 2020, as they prepare to look at financial options and strategies for preparing for the private reuse of the International Space Station.

The usual "financial-engineered securitized bond" is an example instrument, with steady, early cash flow (people paying their monthly mortgage into a MBS pool, for example) -- and clearly the pharma and space funds would not have this prompt payment feature. So there would need to be a higher reliance on modeling speculative future cash flows. And, of course, there's is also the problem of how it is decided which projects get funding -- and the process could potentially be susceptible to manipulation.

Possibly a capitalized interest component to account for the negative cash flow at the front end for the first couple of years could be considered or capital appreciation bonds (CAB) if bonds are a viable instrument. A possible strategy could be layered financing in a senior-subordinate structure, with the subordinate being in essence an equity tranche. The are examples of triple tranche financing with the A (senior) piece being packages as a conventional bond; the B piece being CABS or high yield and the C being an equity piece. There are examples of exotic financings such as “champaign” bonds that are based on financing the bottling or accelerating the receipt of the discounted value of the beverage in anticipation of the future value of the champaign. But, there is extensive data out there in terms of growing time, aging and value to discount the future value and cash flows of the sale of the beverage to structure the bonds. A space megafund remains both risky and speculative, so a big piece of the puzzle will still have to be some sort of equity structure.

Establishing humanity as a multiplanetary species is as much about financial engineering as it is about traditional notions of science, technology and engineering. A financial megafund, or a fund with similar characteristics may be one of the most important innovations that is necessary in facilitating humanity’s evolutionary movement into the heavens.

It would perhaps be premature to dismiss the concept of large financial funds for the development of space as too distant, or too visionary in conception. As we have argued in this paper, there is a mid-term, large-scale, decadal challenge that space agencies of the world have created by announcing the destruction of the $200 billion dollar International Space Station in 2024. This may give financial fund architects a little more than a half decade to conceptualize, develop, and operationalize a funding mechanism that could potentially play a critical role in allowing the commercial re-use of one of humanity’s greatest science and technology assets, the International Space Station.

A megafund could be an interesting mechanism for financing an innovative extension of the ISS life cycle. Rather than deorbiting ISS, perhaps ISS could be moved to a Lagrange point, a lunar orbit, or perhaps ISS modules could be landed on the lunar surface for future habitation. NASA has recently launched an innovative 3D printed habitat challenge for Mars. It is possible to envision an ISS recycle strategy integrated with a lunar or Martian 3D habitat research.

As former NASA Administrator Michael Griffin recently pointed-out in an International Astronautical Congress paper: “Once set aside, the nascent interplanetary exploration infrastructure of the Apollo era was as difficult to re-establish as private spaceflight has been to create. To be effective, public policy makers must heed the old investment advice – go big or stay home.” [17]

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ABOUT INTERNATIONAL INSTITUTE OF SPACE COMMERCE IISC

The International Institute of Space Commerce, or simply 'the Institute', has been established on the Isle of Man through a partnership between the International Space University (ISU) and the Manx Government.

The Institute's mission is to become the leading think-tank in the study of the economics of space. It is intended to be the intellectual home for the Industry and Space Academia around the world for which it shall perform studies, evaluations and provide services to all interested parties with the ultimate aim to promote and enhance world's space commerce to the general public.

The vision is for the Institute to act as a resource for all, being an international and non partisan 'Think Tank' drawing upon new ideas and solutions to existing and future problems the space industry faces by drawing together experts from academia, government, the media, business, international and non-governmental organizations, most notably those from the ISU and its extended network of people and resources.

The aim of the Institute is to broaden the professional perspective and personal understanding of all those involved in the study, formulation, execution, and criticism of Space Commerce.

The Institute is a Not for Profit Foundation and has been located at the International Business School (IBS) on the Isle of Man to capitalize on the Isle of Man's growing importance and position in the world's space industry.

END NOTES

1. "The Space Shuttle Decision", NASA History, Chapter, "Economics & the Shuttle."

http://history.nasa.gov/SP-4221/ch6.htm (accessed January 2015)

2. SpaceX Website

http://www.spacex.com/about/capabilities

3. Prepared Statement by Elon Musk at a Senate Hearing on Space Shuttle and the Future of Space Launch Vehicles, May 5, 2004.
http://www.spaceref.com/news/viewsr.html?pid=12774

4. "How much fuel does an international plane use for a trip?"

http://science.howstuffworks.com/transport/flight/modern/question192.htm

5. Edwards, Bradley C, "Design and Deployment of a Space Elevator," Acta Astronautica, Vol 47, No. 10, pp. 735-744, 2000

6. Edwards, Bradley C., "The Space Elevator," NIAC Phase II Final Report, March, 1, 2003, Eureka Scientific

7. Raitt, D and Edwards, B.C., "The Space Elevator: Economics and Applications," ISC-04-IAA.3.8.3, 55th International Astronautical Congress 2004, Vancouver, Canada

8. Is Asteroid Mining Possible? Study Says Yes, for $2.6 Billion, by Leonard Davd, Space.co, April 24, 2012

http://www.space.com/15405-asteroid-mining-feasibility-study.html

9. The 3-D printer challenge for martian and lunar habitation is discussed in https://americamakes.us/challenge . Other references include: a) B. Kading, J. Straub, "Utilizing in-situ resources and 3D printing structures for a manned Mars mission," Acta Astronautica 107 (2015) 319, b) G. Cesaretti et al., "Building components for an outpost on the Lunar soil by means of a novel 3D printing technology," Acta Astronautica 93 (2014) 438., and c) "Housing

Designs on Mars: 3-D Printing on the Red Planet," Inside Outer Space, By Leonard David, September 13, 2015
http://www.leonarddavid.com/housing-designs-on-mars-3-d-printing-on-the-red-planet/
One of the authors (C. Milner) wishes to acknowledge Alexandra Binder, a student in his Southern Methodist University course "Writing for Science", who originally brought this subject to his attention in a research paper.

10. CASIS Metrics http://www.iss-casis.org/Dashboard.aspx

11. CASIS Awards First Space Station Research Grants, by Dan Leone, November 12, 2012.http://spacenews.com/32217casis-awards-first-space-station-research-grants/

12. CASIS MetricsCASIS Annual Report 2014.
http://www.iss-casis.org/Dashboard.aspx

13. CASIS MetricsCASIS Annual Report 2014.
http://www.iss-casis.org/Dashboard.aspx

14. CASIS Metrics CASIS Annual Report 2014.
http://www.iss-casis.org/Dashboard.aspx

15. CASIS Metrics CASIS Annual Report 2014. http://www.iss-casis.org/Dashboard.aspx

16. "NASA Official Lays Out Vision of Privatized Space Stations", WSJ April 29, 2015. By ANDY PASZTOR,
http://www.wsj.com/articles/nasa-official-lays-out-vision-of-privatized-space-stations-1430363264

17. "5 Reasons Why The International Space Station Should Really Orbit The Moon," by Bruce Dorminey, Forbes/Tech, SEP 11, 2015 @ 04:19 AM.
http://www.forbes.com/sites/brucedorminey/2015/09/11/5-reasons-the-international-space-station-iss-should-orbit-the-moon/