Infrastructural Development Approach to the 100 Year Starship

19 November 2012

Marc M. Cohen marc@astrotecture.com +1 650 218-8119
Palo Alto, California USA http://www.astrotecture.com

and

Robert E. Beckerroberte.becker@prodigy.net +1 561 927-0632
County Antrim, Northern Ireland UK

Published:
In (Ed.) Alires Almon (2012). 100 Year Starship Symposium Conference Proceeding
http://100yss.org/symposium/2012

The Human Exploration Vision for the 100YSS

The human exploration *vision* for the 100YSS begins from an existential perspective; if humans are to control our own existence and fate, can we simply accept our status quo in the universe? Cosmology underlies all human belief systems. What is the universe? From where did everything in the universe come? What is our species' role in it and what does it mean for how we treat one another? For example, one of the earliest expressions of this linkage: cosmology – origins – ethics appears in Isaiah 66:1-2.

> . . . . '*The Heaven is my throne and the Earth is My footstool*. . . .
> *All this was made by my hand, and thus it all came into being*.
> *Yet to such a one I look; to the poor and brokenhearted,*
> *who is concerned about my word*.'

Written soon after the Babylonian exile ended in 537 BCE, the authors of these verses had the benefit of Babylonian astronomy, which achieved the first geocentric model of the solar system, with a proto-theory of the ecliptic and began making tables of ephemerides in cuneiform. Thus, this passage refers concretely to the Earth as a body in space.

This matrix of linkages applies regardless of an individual's or a society's particular belief, whether it is the Founding Fathers' "Nature and Nature's God;" nature without God (Laplace's "unneeded hypothesis"); or Felix Adler's *ethical culture* independent of nature or God. The variables are those values that people put in the cells of the matrix. Once humanity can understand that we all share this same matrix of Cosmology, Origins, and Ethics, our species will be ready to begin moving out into the Galaxy. As humanity faces the vastness and mystery of the Cosmos by venturing beyond our Solar System, we imagine that the internationalism of the original Star Trek series will prove prophetic. The differences among nations shrink to *de minimus* in comparison to the universe and what – or how—we may find there. Humanity can best embark upon the interstellar adventure united in our rich diversity.

Learning about our universe changes the status quo. Exploration is the most enduring and effective means of acquiring new knowledge – scientific, technical, and about us as a species, a society, and as individuals pushing the frontier of human experience. Therefore, in striving to control and direct our own existence, we need to learn by exploring and to explore by learning. Interstellar exploration and finding new forms of life or intelligence would be the most profound learning encounter in our species' short history. As this enterprise seeks deeper understanding of the universe and its origins, ethics will come to the forefront for the design of the 100YSS mission. We cannot expect the crew to survive and succeed up to a century in the confines of the Starship without a highly developed system of ethics and well-tuned concomitant governance framework. Upon arrival at the new planet, the ethics of planetary protection will come into play. Should the crew meet an intelligent civilization, ethical conduct may prove the key to establishing good relations with them, and even to ensuring the crew's and humanity's survival.

Why Explore?

Having stated the above, the justification for ***why*** we should explore - for our citizenry as a whole, not just space enthusiasts - must be found in the *short-term* socioeconomic and practical benefits of performing the project to the broader constituency of the nation. These benefits must be realizable during the developmental phases of the program to be "short-term." They cannot wait for decades or centuries until the program comes to fruition and is fully executed. Technology, social engagement, education, and financial development constitute the four major domains in which the 100YSS shall invest to enable and support the interstellar mission. This human exploration vision informs all aspects of these domains. The Human-Interstellar-100YSS vision will attract support to all these constituent endeavors, bringing people and funding into our collective effort. In turn, space infrastructure is the arena from which most of these benefits will be derived.

Science and Exploration

Science and exploration intertwine through thought, action, testing, and proof. Many great scientific journeys of discovery afforded practical demonstrations that established proof that something was not just a theory. For example, the ancient Greeks observed that the shadow the earth cast on the Moon during a lunar eclipse is always circular; the only object that could cast such a shadow is a sphere. How big was this spherical Earth? Eratosthenes was the first to calculate the circumference of the Earth. He learned that at the summer solstice in the south Egyptian town of Syene (Aswan), a stick standing vertical from the ground cast no shadow at noon. He arranged to measure the distance from Alexandria to Syene, 7°12'in latitude to the south. By measuring the length of shadow a stick cast in Alexandria, he used geometry to calculate the circumference of the earth to the remarkably accurate value of ~39,690km (~25,000 miles), with an error of less than 2%.

The spherical geometry and size of the Earth remained in dispute for nearly two millennia until Magellan's crew circumnavigated the globe. Since Magellan, there have been innumerable repetitions of this cycle: observation, theory, measurement, calculation, then practical demonstration leading to acceptance of the proof and socioeconomic benefits that follow.

Exploration enables science. Conversely, science enables exploration, although this reciprocal principle is not well recognized in the human spaceflight community. The Principal Investigator has witnessed or participated in the following Socratic dialogue numerous times:

<u>Planetary Science Advocate:</u> Why won't you provide sufficient science payload capacity in that: a) lunar crew lander, b) habitat, c) rover, d) human Mars Mission, e) all of the above?

Human Spaceflight Program Advocate: We don't need any of *that* stuff; it just takes up mass and volume that we could use for consumables.

Planetary Science Advocate: But aren't we going there to do great science?

Human Spaceflight Program Advocate: Naah! We're just going to see what's there!

Planetary Science Advocate: But how will you *KNOW* what you are seeing without science?

The ***same principles,*** exploration enabling science and science enabling exploration, apply to exploring other star systems and their planets. At present, we observe but dimly through a glass the exoplanets in our search for a habitable candidate in the "Goldilocks Zone." What must we do to determine if that planet is habitable? Surely, we will need to send a robotic probe to take measurements and return data to the Earth. But what will be the practical demonstration, the proof? How can we obtain it without sending people to explore the new planet? How can we prove that it is habitable without settling and inhabiting it?

Interstellar travel may achieve another proof. Suppose the search for extraterrestrial intelligence (SETI) "solves" the Drake Equation, finding evidence of an intelligent civilization out there in the Milky Way. ***So what?*** Can we obtain the practical demonstration of communicating with an alien species? After we send them a carefully planned set of signals and hopefully have a two-way conversation, what next? Are we going ***out there*** to meet them?

Ethics of Exploration

What will we do when we arrive on the new planet? How will we treat this new home? The prevailing – one could almost say – the romantic paradigm of exploration is the "Conquistador Model:" find a civilization that is not as advanced as you are, kill or enslave them, take their gold, and colonize their country. This paradigm tends to dominate in the popular (e.g. commercial) imagination, as evidenced by the video-gamers at the 100YSS Public Symposium, who were eager to have the ultimate space shoot-em-up with genuine aliens. Of course, the ethical problem with the Conquistador Model is the experience of the conquered, displaced, enslaved, exiled, and murdered populations. Furthermore, the Conquistador Model does not produce good science or learning.

In the Human Interstellar Exploration Vision, ethics are an essential component of the technology development effort, Starship construction, crew training, mission operations, and practices upon arrival at the new planet. Planetary protection policy and practices constitute an essential defense against forward contamination to new planets or other celestial bodies. Since it is highly unlikely that there will be return missions from the stars to Earth, absent Faster Than Light (FTL) technology, there is much less concern for 100YSS with back contamination of the Earth itself. However, contamination of the crew and the Starship itself remains a major issue. A priority approach to ethical questions will be to engage social scientists to advise the 100YSS from the perspectives of Anthropology, Economics, Human Factors, Psychology, and Sociology on all aspects of the mission.

What should 100YSS do for Human Exploration?

The WHAT -- The primary métier of the 100YSS is to establish policies, practices, and standard procedures for the myriad challenges and tasks to produce the Starship, or some part thereof, the flagship deliverable for the organization. However, the 100YSS must accomplish this predictably and with stability without becoming bureaucratic or ossified. Combining these two goals requires careful design of the 100YSS organization(s) and their operations.

A top priority for the 100YSS organization should be to determine the desired scope of the Project. Is the terminal goal development of technology and infrastructure alone? Is it launch and execution of robotic missions to the stars? Or is it the majestic vision of sending an inhabited ship off to the stars? Herein is taken the view that this last objective should be the one chosen. The first two options then become necessary and nearer-term phases leading to the overarching goal.

The WHEN–The choice of an human interstellar expedition immediately implies a very long timeline, one that stretches well beyond a “mere” century, yet one that incorporates the prior two more proximal objectives.

The Timeline in FIGURE1 presents the longest-term view of 100YSS, starting from 2011 through to arrival at a new planet. Although the title of this Program is 100 Year Starship, the Timeline reflects the considerably longer development trajectory that will be entailed to design and construct a habitable starship. This infrastructural research and development will be necessary to build the Starship and send a human crew to an exoplanet and settle them there safely and successfully. The key milestones across these timelines appear in FIGURE 1. They are:

1. Set up the Starship Organization to undertake the 100YSS,
2. Develop and Launch a robotic probe to Proxima Centauri.
3. Develop and launch a swarm of robotic probes to candidate habitable planets within 20 light years to verify their habitability, safety, and suitability for human settlement.
4. Return data via radio from the Proxima Centauri probe, ***major milestone.***
5. Design, build, and test The Starship on a mission into extra-solar deep space and return.
6. Return data via radio from the probe from the candidate planets, ***major milestone.***
7. Develop and Launch one or more crewed Starships to the selected habitable exoplanet or exoplanets, and
8. The crew arrives at the new planet, lands, and settles, ***major milestone.***

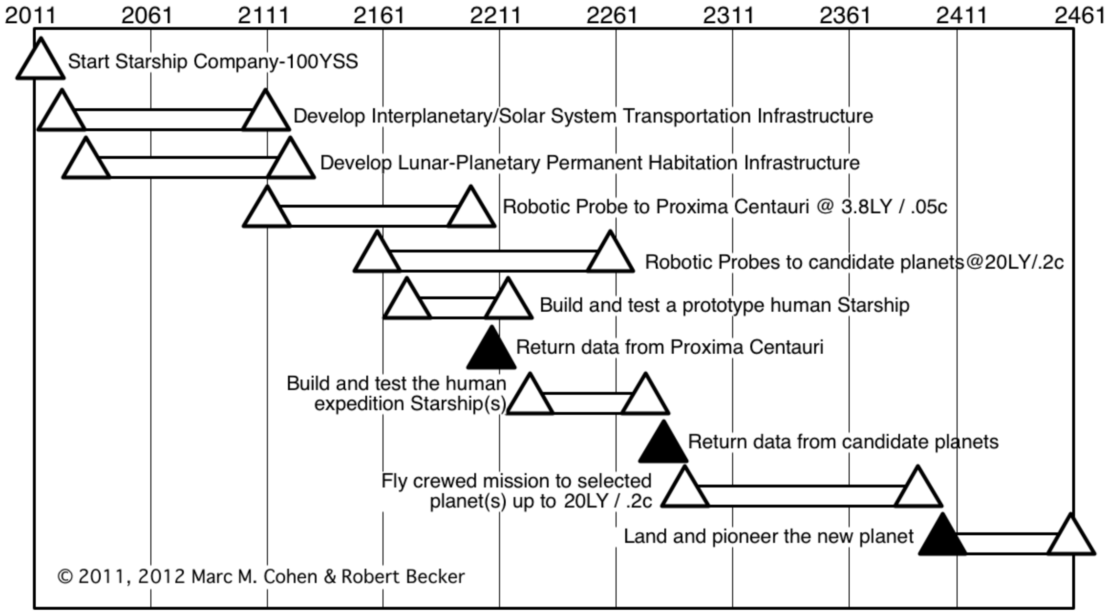

FIGURE 1. Human Interstellar Exploration- Sample00YSS Long-Term Timeline.

Long Range Plan – One approach to the analysis of the scale, topicality, and longevity of 100YSS is to develop and work through the Challenge Matrix in TABLE 1. This methodology starts with questions on the final goal, and then works backwards through the milestones to the start of 100YSS to determine how each goal-state levies demands upon the preceding activities and investments, including the Solar System Infrastructure development that will be essential for the 100YSS mission and any human follow-on missions.

It often seems taken for granted that a large-scale Solar System Space Infrastructure will be in place by the time 100YSS needs it. This assumption is not necessarily so. While 100YSS itself may prove to be driver in the development of that Infrastructure, it is not clear at this early juncture that an Interstellar mission will hold that much sway over the public. Indeed, traditional visions of the expansion of humanity into deep space hold the reverse to be true: Start with the Solar System, particularly the Moon and Mars, and only then expand into the depths of space as it gradually becomes feasible. Whether 100YSS itself must add development of Solar System Infrastructure to its abundance of challenges delineated in Table 1, or if forces external to 100YSS (e.g. increased commercialization of space or a major government finally recognizing Solar System Exploration and its concordant development [2] as valid national goals), this hurdle must be surmounted at some point. Thus, a concept for this Infrastructure development bears closer examination.

Transportation as the Essential Infrastructure

Transportation is the ***sine qua non*** of space exploration and space development. It is the leading infrastructure in much the same way that the Erie Canal and the transcontinental railway were the leading infrastructure for the opening the American West to settlement and development.

The 100YSS does not provide for creating the larger space infrastructure, without which the 100YSS will not be achievable. Aiming for a Starship as a first goal may prove too ambitious in isolation from a larger expansion of spacefaring capabilities. Thus, a more manageable first level for space infrastructure creation would be to build and operate a transportation and settlement infrastructure within our Solar System, with a view towards developing Starship technology,, in much the same way as the Moon could serve as a testing ground for Mars capabilities and infrastructure. Providing the robust and reliable transportation infrastructure is the *Sine Qua Non – the necessary precondition* of Space Development and Settlement.

TABLE 1. Human Exploration Challenge Matrix for the 100YSS

Discipline	On the New Planet	The Interstellar Journey	Building the Starship	Developing Technology
Vision	What does the crew do to explore: Astrobiology, Planetary Science, SETI, etc.?	What does the multigenerational journey teach us about spacefaring civilizations?	What should be the performance requirements for the Starship throughout the Mission?	What technologies will we need to develop for the Solar System Infrastructure, the Starship, and the arrival on the new planet?
Systems Engineering	Define landed surface systems vs. what to make at destination.	Determine functions & processes on board the Starship	Identify capabilities, & support systems to build & test the Starship.	Define new technologies to develop for the Starship and its associated segments (e.g. Solar System Infrastructure).
Ownership, Legal, & Governance	Who owns the landed equipment and supplies? The settlement? The land?	What is the economy and government on the multigenerational Starship? Who owns the Starship and its infrastructure?	Who owns the means of production to build the Starship? How to decide "Make/Buy?"	Who owns the Intellectual Property? Is a 17 year patent long enough? Can 100YSS commercialize it?
Management & Organizational Structure	How does the management and organization grow from the 100YSS to the Starship to the new settlement?	What is the best social and managerial organization for a multigenerational journey in a closed society?	What project management and contract structures for the construction phase?	What is the best approach? Non-profit owning for profit companies? Make/Buys?
Sources of Income & Fundraising	The management/ governance will need some kind of revenue or tax to provide services	Does the Starship need an on-board revenue regime? Services or taxes?	How to secure a cash flow to finance the building of the Starship?	How to raise funds for technologies? How to use them for income?
Investment Approach (financial, technology, and social)	What technologies will the crew need on the new planet? How much can they make or develop after landing on the surface?	How much development and manufacturing can they do during the journey?	What are the criteria for selecting and implementing new technologies in the Starship?	How should the 100YSS give grants, contracts, or open its own labs to do "in-house" R&D? Commercialize it?

Example of Infrastructure Development, Based on the Aldrin Cycler Concept

The Aldrin Space Cycler-Orbiter concept offers a model for an important segment of space transportation infrastructure. We need to understand the cycler first on functional and conceptual levels rather than as a literal and specific design. The Cycler, depicted in FIGURE 2, means reliable and repeatable space transportation to destination platforms or settlements and return to Earth. The Cycler would be reusable, refuelable resuppliable, repairable, and maintainable *in space*. The scheduled service will be round trip, even if the schedule itself is somewhat irregular because of the "motion of the spheres." The Orbiter aspect of the Aldrin concept is a mission-specific capability; some applications and levels of infrastructure development do not require an orbital insertion or departure.

> The Cycler system alters the philosophy behind a Mars program. It makes possible the dream of regular flights to the Red Planet and a permanent human presence there. That's the only way we'll ever succeed in taking mankind's next giant leap: a subway-in-the-sky between our planet and our future second home. – Buzz Aldrin [3]

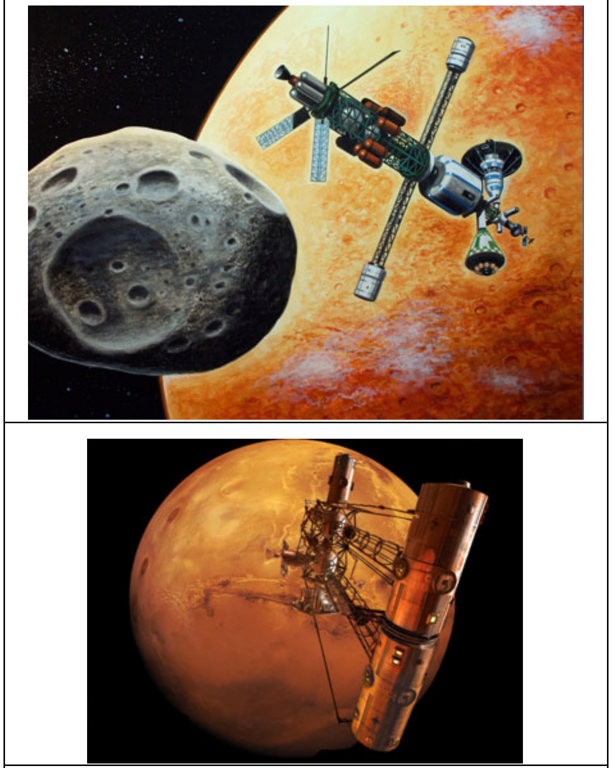

FIGURE 2. Spacecraft Design Concepts for the Aldrin Cycler. Courtesy of http://buzzaldrin.com/space-vision/rocket_science/aldrin-mars-cycler/

FIGURE 3 illustrates the hierarchy of developing the essential space infrastructure to acquire the know-how and capability to build and operate a human interstellar vehicle: a Starship. Levels 1 thru 6 of this Infrastructure development process fit in between the first two major timelines for 100YSS in its broadest conception as depicted in FIGURE 1. Implementation of this Infrastructure need not be conducted under the ambit of 100YSS, but someone must do it, or something very much like it. In accordance with this Timeline, Levels 1 thru 6 should be accomplished within 50 years of 100YSS inception to prepare the way for Levels 7 and 8, which are definitely in the domain of 100YSS. As such, the Infrastructure progression laid out in FIGURE 3 is quite ambitious in its schedule milestones. But then, so is the concept in FIGURE 1: A robotic mission is to be launched to the stars only 50 years after inception of 100YSS. Realistically, technology preparation for the Interstellar missions, as well as solidification of the Solar System Infrastructure, may well require closer to 100 years, which is not at all inconsistent with the very name of this program.

8. Earth-Exoplanet Mission to another star. . .

7. Robotic Precursor Missions to Stars
6. Mars-Europa Cycler staged from Phobos/Deimos. . . .
5. Mars-Main Belt Cycler staged from Phobos/Deimos. . .
4. Earth-Mars Cycler staged from a Lagrange Point. . . . .
3. Earth-Phobos/Deimos Cycler staged from a Lagrange Point . . .
2. Earth-NEO Asteroid Cycler staged from a Lagrange Point . . . .
1. Earth-Moon Cycler staged from Low Earth Orbit (LEO) to Low Lunar Orbit(LLO). . . . .

FIGURE 3. The Feasibility Theme begins from capabilities that are possible today and builds on them successively

The Ladder of Feasibility

At each step in the Feasibility Ladder, the infrastructure development must address the following three questions:

1. What are the requirements to accomplish this level of capability, including the space development it enables and supports?
2. What do we need to do to fulfill those requirements?
3. Once we accomplish this level of development, what will be the sustaining foundation of architecture, design, engineering, function, technology, and operations?

1. Earth-Moon Cycler staged from LEO to LLO to build and support a lunar base, using conventional propulsion. The lunar base will expand to support the "Lunar Shipyard." The space vehicles defined in the remainder of the Feasibility Ladder would be built -- at least in part -- on the Moon, with final assembly of modules at a Lagrange point.

2. Earth-Asteroid Cycler staged from a Lagrange Point to conduct prospecting and mining operations and to return to the Lagrange Point to conduct smelting and refining operations. Near -Earth Asteroids are the logical initial targets. Using a breakthrough in propulsion (e.g. Solar Dynamic/Solar-Thermal) will enable sustained logistics and transportation.

3. Earth-Phobos/Deimos Cycler staged from a Lagrange Point to build and support a base on Phobos or Deimos (no Lander needed).Using a Solar-Thermal or equivalent breakthrough will reduce transit times to three months each way.

4. Earth-Mars Cycler staged from a Lagrange Point to build and support a base on Mars. Using a Solar-Thermal or equivalent breakthrough will reduce transit times to three months each way. It requires a Mars Ascent/Descent Vehicle (e.g., a Lander) that is reusable and refuelable on Mars.

5. The Mars-Main Belt Cycler will afford regular transportation to the asteroids that promise the richest trove of exploitable minerals in the solar system. Staging will occur from a Phobos or Deimos base in near-microgravity. This architecture helps to beat the "**When** you go determines **where** you go" constraint on asteroid exploration.

6. The Mars-Europa Cycler will afford regular transportation to the outer planets. Mars-Europa Cycler staged from Phobos or Deimos to build a base on the ice or even under the ice on Europa (e.g. covered by the ice). Europa is one of the most promising targets for Astrobiology. Using nuclear-fusion or equivalent propulsion, the cycler will make the transit in six months or less each way.

7. Robotic Precursor Missions to the Stars constitute the necessary reconnaissance and interstellar transport technology testbed. Twin priorities for the robotic missions are to demonstrate the feasibility and functionality of whatever interstellar propulsion technology is chosen for 100YSS and to reconnoiter habitable exoplanets previously identified by astronomical observations from Earth and its environs. While some degree of testing of aspects of an interstellar drive may be possible within the confines of the Solar System, the only true test prior to launch of a habitable Starship must come in visiting another star. Several precursor missions should be planned because it would be irresponsible to launch a Starship with only one conceivable target (assuming the Universe has cooperated and there are in fact more than one habitable exoplanet within striking distance). Identification of multiple targets also helps ameliorate the "Wait Problem" (e.g. [4]) of propulsion technology marching forward faster than Starships can reach their destinations. Additional target exoplanets can serve as potential fallback options for a single human mission, and in order of increasing distance, as the primary targets of subsequent human Starship missions.

8. Earth-Exoplanet Mission to another star within 20 light years. Staging can occur from any suitable location in the Solar System. The Starship requires several orders of magnitude advances in propulsion to achieve fraction of c velocity (e.g. 0.05 to 0.1c) for a multi-generational journey. It further requires radical advances in human factors, habitation, life support, food production, etc. Initially, it must fly one-way in terms of an individual's lifetime. Inasmuch as it is unlikely that the Starship itself will land on the exoplanet, eventually, the Starship becomes another *Cycler* within the targeted stellar system.

The Technology Assessment Model

The inevitable and necessary investment area for the Starship and its surrounding infrastructure is technology development. 100YSS might conceivably produce the Starship without social or educational expenditures, but it is impossible without technology. Although in conventional orbital and solar system exploration technologies, the areas of investment and research may seem self-evident, that is not necessarily the case for Interstellar travel. The extremely long duration flight and constant exposure to GCRs and μG, plus the isolation and confinement of such a "closed society" and its ecosystem may have far-reaching effects that we have yet to observe. According to the reports from the Institute for Biomedical Problems in Moscow (IBMP), the Mars500 simulation of 520 days in confinement and isolation has been particularly grueling for the volunteer crew. On a previous closed chamber test, the subjects experienced assault and violence. The Biosphere2 crew went through some very difficult problems that left them exhausted and ready to leave at the completion of their two-year mission.

Simulation technologies, in particular, will need to advance very much further than they are today, including complete ecological life support that includes growing food. Funding has been spotty at best within NASA for this type of study.

TABLE 2 presents the Human Exploration analytical matrix for the approaches and "modalities" of investment in technology development, which will emerge by far as the largest effort. This matrix frames the scrutiny for each potential technology – which approach is the best and which model of development is the most suitable for ***that*** specific technology.

A. Top-Down System-Driven Approach

This approach starts from the Systems Engineering methodology that a top-level analysis can generate the clarity and precision to select the key technology innovations to achieve the goals of a project. Once a project is going into final design, when done properly, this approach will prove efficient, timely, and essential to stable development of the system. The cautionary is that, if made too ossified or bureaucratic, this methodology in the earliest stages of the project could run the risk of always selecting existing constructs and proven systems instead of truly innovating.

B. Bottoms-up "Let a Thousand Flowers Bloom"

Rather than dictating focused objectives, this opportunistic approach lets the technologies spur the development and human interest in 100YSS Project and Mission. Deriving primarily from basic research, this approach allows the researchers wide latitude to try many things. An example of this modality comes from Thomas Edison's famous 10,000 experiments to find the carbon filament for the incandescent light bulb that can burn brightly for hundreds of hours without burning itself up. The paradox turns back upon itself in realizing how hyper-focused on the light bulb Edison was while testing 10,000 alternate solutions.

C. Holistic Approach.

This strategy involves performing all levels of technology development at the same time in the same lab. Instead of handing off basic research from the Basic Research Team to the Applied Research Team and then to the Focused Research team, the Holistic Team does all three and more. This approach helps to ensure that products advance all the way through the development sequence so that nothing drops -- forever lost -- into the Technology Readiness Level (TRL) "Valley of Death" between TRL 4 and TRL7.

Specific criteria for undertaking investments/activity,

The conventional TRLs provide a starting grammar for technology, but they are hardly sufficient for the 100YSS enterprise where many of the requirements have yet to be determined. A better analytical toolkit for technology assessment is needed. TABLE 2 presents part of this toolkit, an analytical matrix. It allocates the Investment Approaches defined above to the Development Models defined in the following, and identifies a likely time horizon for the applicability of each such combination of Investment Approach and Development Model.

NASA started out doing bold new endeavors, taking risks, and achieving great advances. However, the last big, concerted technology push was the Space Station Advanced Development Program in the 1980s. Now, the culture of technology development has decayed in NASA human spaceflight and NASA's in-house capabilities have atrophied in many areas. This history tells a cautionary tale for the 100YSS organization 50 years out. In this Technology development analytical matrix, there are five models that factor into the evaluation trade studies:

1. "Legacy-driven" Systems Model

This approach derives from the doctrine that the only way forward is to reuse older, nostalgic systems that have an industrial base established in certain key congressional districts and states. Although this approach tends to make technology advancement slow and expensive, it has the virtue of maintaining the work force and preserving the corporate memory, both of which will be an important consideration for an enterprise that could take several hundred years. An example of this *Legacy* would be the late, unlamented NASA Constellation Program's dependence on hardware designs to be recycled from the Space Shuttle program such as the transformation of the Solid Rocket Boosters into the Ares I "stick."

2. The Aeronautical Sure-Bet Technology Model

In aviation, small improvements in performance can lead to significant savings in operating costs that translate into competitiveness of a new airliner design. This assured economic incentive creates a culture that looks to safe returns on investment instead of taking risks. For example, a technology program that will produce an assured 2% improvement in fuel efficiency stands a much better chance of funding than a riskier program to produce a potential 20% improvement. An example of an *Aeronautical Sure Bet* would be the introduction of winglets at the end of jet liner wings to minimize edge vortices, thereby reducing aerodynamic drag and improving fuel consumption.

3. The Space Technology Performance Improvement Model

Performance improvement in space technology follows the aero precedent of incremental improvement with one major difference: it looks for much larger increases in performance to justify the investment instead of the certainty of a small return, often on the order of 50 to 100%. This approach entails greater risk for greater rewards; the challenge is to balance risk against reward. An example of such Performance Improvement would be the steady progress in the development of solar cells and solar arrays, such as the circular "fan" type on the Orion-Multipurpose Crew Vehicle compared to the conventional rectangular arrays.

4. Order of Magnitude Improvement

Sometimes the solution may be to strive for an order of magnitude improvement that transforms the whole technology. An example of *Order of Magnitude* improvement would be the Suitport EVA Access facility as an alternative to the conventional airlock. To conserve more atmosphere in the Extravehicular Activity (EVA) airlock, the only choices were to make it tighter and more conformal or to greatly increase the size and power of the pump-down capability. The Suitport [5] achieved order of magnitude improvements in atmosphere conservation and savings in crew time, power, and pump-down cooling.

5. New Capability Model

All systems in space emerged at one time as a new capability. For example, Cosmonaut Alexei Leonov's first EVA afforded the practical demonstration of which science fiction writers dreamed for decades. Another leading example of *New Capability* would be the invention of digital computers as part of the Apollo Program. Potential *New Capabilities* lead to the questions:

a. What transformative results will the new capability bring about?
b. How can one benchmark a new capability when there is no comparable system that it is replacing or succeeding?
c. What are the criteria for choosing among new capability options?

The investment/research portfolio projections for short, medium, and long term

The technology investment/research portfolio will start out with mostly long-term technology programs, while striking a balance with short-term and intermediate-term technologies or products that offer the potential for commercialization. As the 100YSS and its Infrastructure development effort progress, the portfolio mix will shift more towards intermediate and short-term investments/research. The shorter-term focus will serve two purposes:

1. To create commercial technologies, operations, and products that can produce the income stream necessary to pay for the monumental undertaking of actually building the first Starship.

2. Throughout the technology development and Starship design and construction process, the 100YSS organization will need to deliberate many “make/buy” decisions. Consistent criteria and procedures for making such selections will need to be developed and applied completely and consistently.
3. To focus on producing the prototype hardware, software, and operational techniques needed to design, engineer, build, and test the Starship.

TABLE 2. Analytical Matrix of Technology Investment Approaches and Development Models and Time Horizons

Development Models	**Investment Approaches**		
	A. Top-Down	B. Bottoms-Up	C. Holistic
1. Legacy-driven	Short Term		Short Term
2. Aeronautical Sure-Bet	Mid-term, Short-term		Short Term
3. Space Technology Performance Improvement	Mid-Term	Mid-Term	Mid-Term
4. Order of Magnitude Improvement	Long Term	Mid-Term, Long Term	Mid-Term, Long Term
5. New Capability		Long Term	Long Term

Due to the requirement at once altruistic and pragmatic that 100YSS not only fulfill its primary objective of achieving interstellar transport technology and infrastructure, but also provide socioeconomic benefits beyond the typical financial, technological, and scientific returns, what can characterize Return on Investment (ROI) for 100YSS is unusually broad and in some cases, non-monetized. This precept, in turn, demands that in order for this process to be managed effectively, metrics for measuring non-pecuniary ROI must be developed.

Potential FIGUREs of Merit (FOMs) for non-pecuniary ROI include:

- Science results,
- Engineering advances for system performance,
- Crew human support benefits and outcomes,
- Crew productivity,
- Crew health and safety,
- Social benefits and outcomes, and
- Educational outcomes, including the stream of highly trained young people into the Starship.
- Job creation in the broader, non-aerospace, economy.

These metrics may be derived from the corresponding FOMs in the manner described in Cohen, Houk (2010). [6]

Conclusion

100YSS presents the grandest vision of human destiny ever conceived and proposed to be made a reality. Throughout history grand schemes have been scuppered by overlooking details. Solar

System Infrastructure is not a mean detail. If forces external to 100YSS cannot be counted on to develop that Infrastructure independently, the 100YSS program must prepare to undertake this massive effort itself. Daunting as this task may appear, in scale at least as large as 100YSS itself, it fits well within the rubric under which 100YSS will manage construction of a ladder to the stars. Neglecting it could lead to spectacular technologies with no place to go, or just spectacular failures. The hierarchy of Solar Infrastructure development defined herein, utilizing a Cycler as a core technology, is one cogent approach to surmounting this obstacle.

References

1. Jewish Publication Society (1978 edition, republished in the 1985 Tanakh (Bible)). The Prophets – "Neviim", Philadelphia PA: Jewish Publication Society.

2. R. E. Becker, "Is There a Short-Term Economic and Social Justification for Human Exploration and Settlement of Mars", in *Proceedings of the Founding Convention of the Mars Society, August 13-16, 1998, Part I,* eds. R. M. Zubrin and M. Zubrin, Mars Society, Lakewood, CO, 1999, pp. 85-100, Paper MAR 98-011.

3. Aldrin, Buzz, *Popular Mechanics*, 2005.

4. Kennedy, Andrew, "Interstellar Travel: The Wait Calculation and the Incentive Trap of Progress". *JBIS*, 59, 239-246. 2006.

5. Cohen, Marc, US Patent 4,842,224.

6. Cohen, Marc M.; Houk, Paul C. (2010). Framework for a Crew Productivity FIGURE of Merit, Human Spaceflight Program Advocate: for Human Exploration, AIAA-2010-8846. http://www.astrotecture.com/Human_System_Integration.html.