Innovation in Extraterrestrial Service Systems - a Challenge for Service Science

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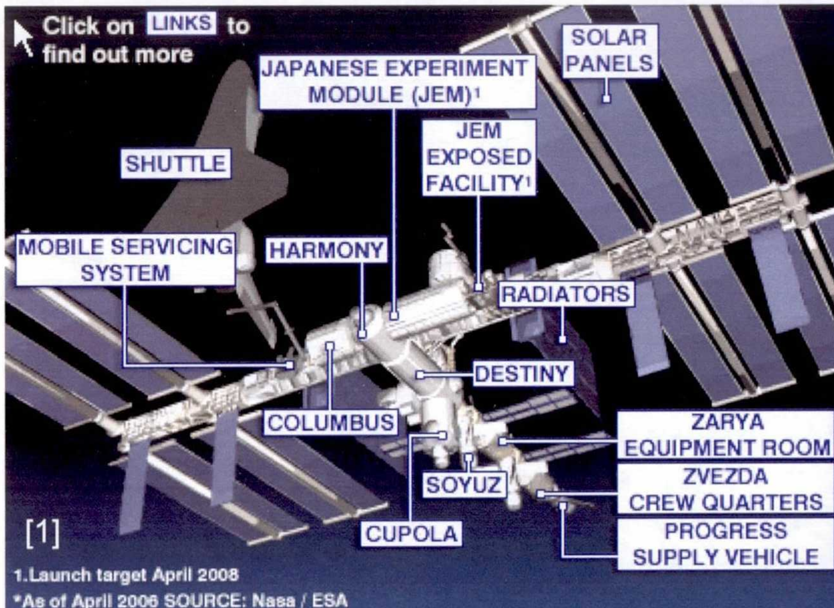
Title: Extraterrestrial Service Systems – A Challenge for Service Science

Abstract/Background: This presentation was prepared at the invitation of Professor Yukio Ohsawa, Department of Systems Innovation, School of Engineering, The University of Tokyo, for delivery at the International Workshop on Innovating Service Systems, sponsored by the Japanese Society of Artificial Intelligence (JSAI) as part of the JSAI International Symposium on AI, 2010. It offers several challenges for Service Science and Service Innovation. The goal of the presentation is to stimulate thinking about how service systems will evolve in the future, as human society advances from its terrestrial base toward a permanent presence in space. First we will consider the complexity of the International Space Station (ISS) as it is today, with particular emphasis on its research facilities, and focus on a current challenge - to maximize the utilization of ISS research facilities for the benefit of society. After briefly reviewing the basic principles of Service Science, we will discuss the potential application of Service Innovation methodology to this challenge. Then we will consider how game-changing technologies – in particular Synthetic Biology – could accelerate the pace of sociocultural evolution and consequently, the progression of human society into space. We will use this provocative vision to advance thinking about how the emerging field of Service Science, Management, and Engineering (SSME) might help us anticipate and better handle the challenges of this inevitable evolutionary process.

Agenda

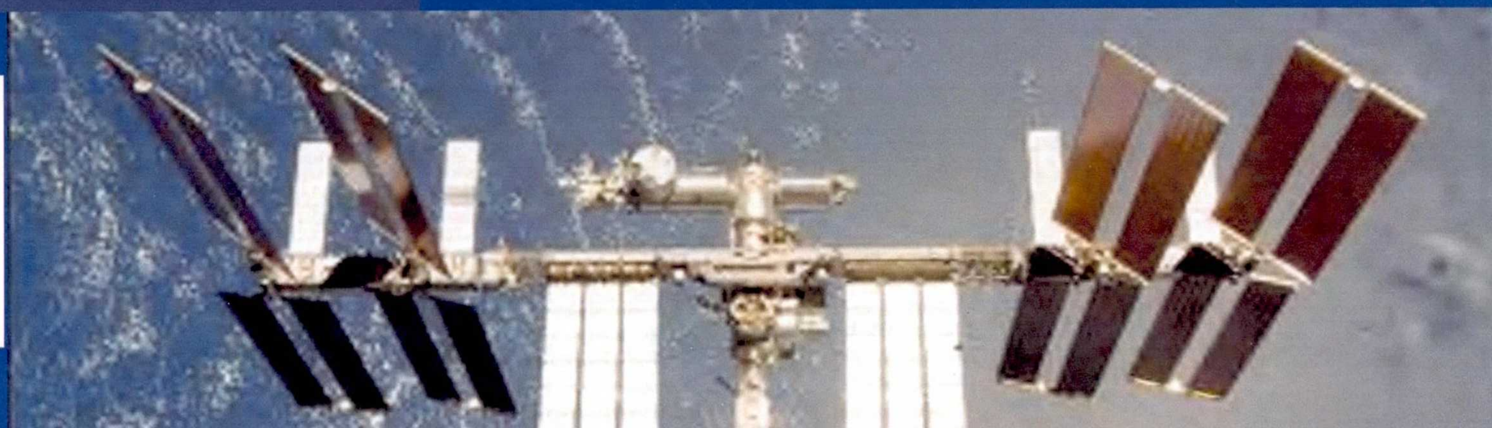
- A *Service System* in space: the International Space Station (ISS)
- Focus on a subsystem: laboratories aboard the ISS
- Discussion: How can *Service Science* be applied to tackle challenges in the utilization of these service systems?
- Extraterrestrial service systems of the future
- Synthetic Biology
- Discussion: *Service System* evolution
  - How will service systems of the future be different than those of today?
  - Can Service Science help us anticipate the course of service system evolution?

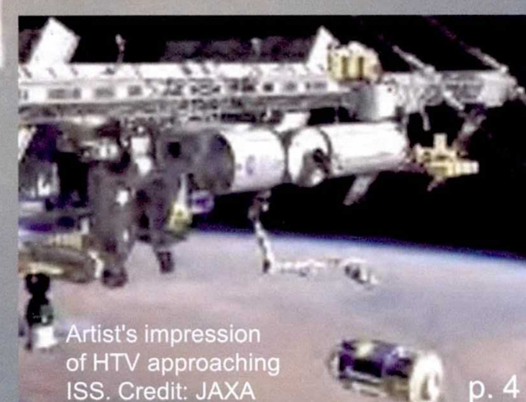


The International Space Station (ISS) is the largest space station ever built, the largest structure ever assembled in space, and one of the most complex international scientific projects in history. Now essentially complete, the ISS is more than four times larger than the old Soviet Mir space station and longer than an American football field (including the end-zones). It has a pressurized living and working space approximately equivalent to the volume of a 747 jumbo-jet, and can accommodate up to seven astronauts. The solar panels span more than half an acre [1].

ISS –

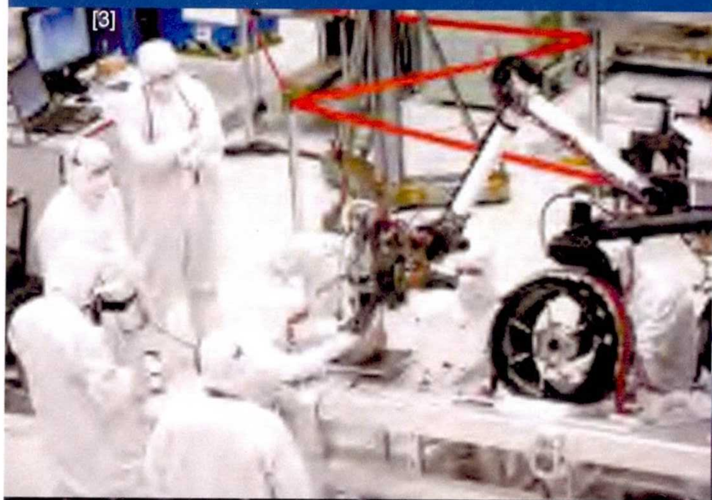
A "System of Service Systems"





Artist's impression of HTV approaching ISS. Credit: JAXA

Complex extraterrestrial systems have always required substantial terrestrial logistics and operations components



[3]

http://byricardomarcenaro.blogspot.com/2010/07/nasa-working-on-space-trabajando-en-el.html

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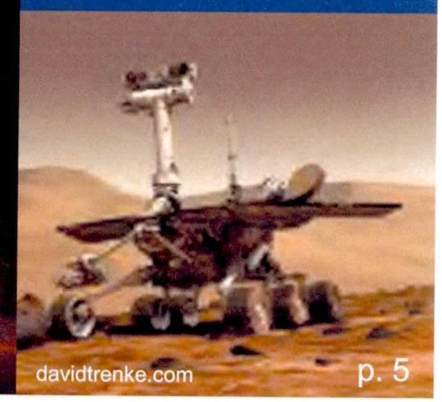
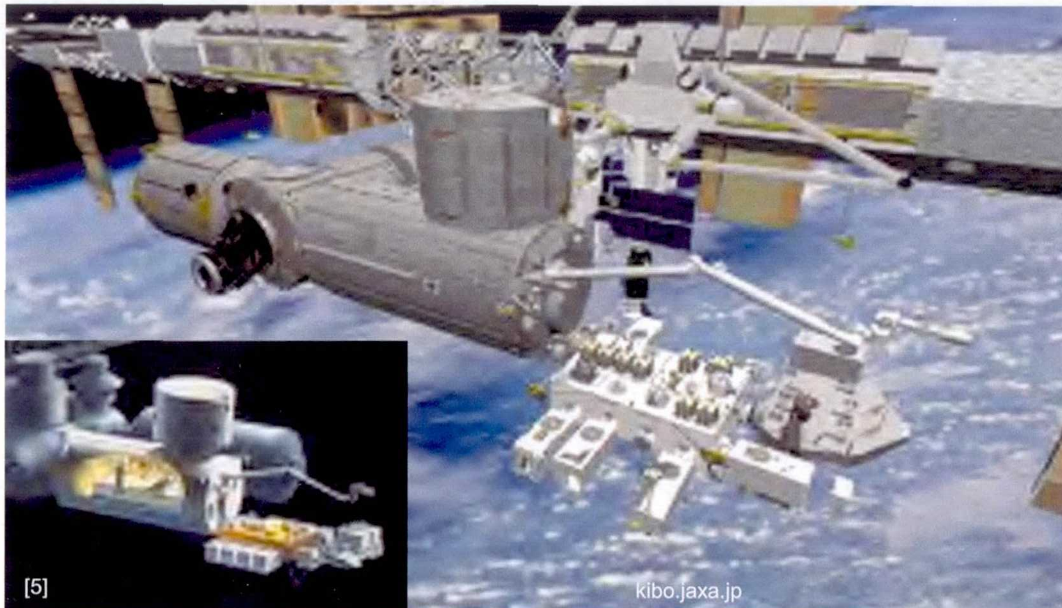
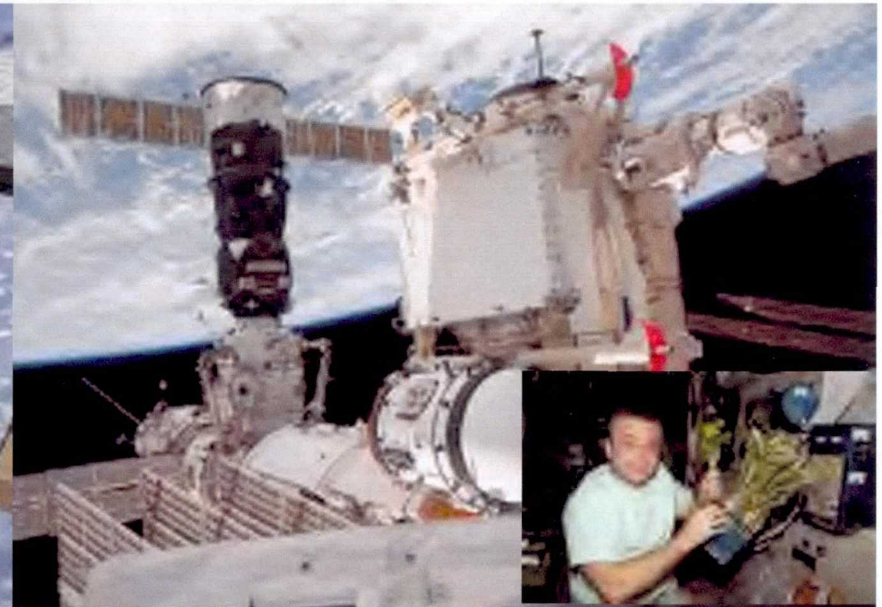
As we venture farther from Earth, autonomy becomes a key challenge

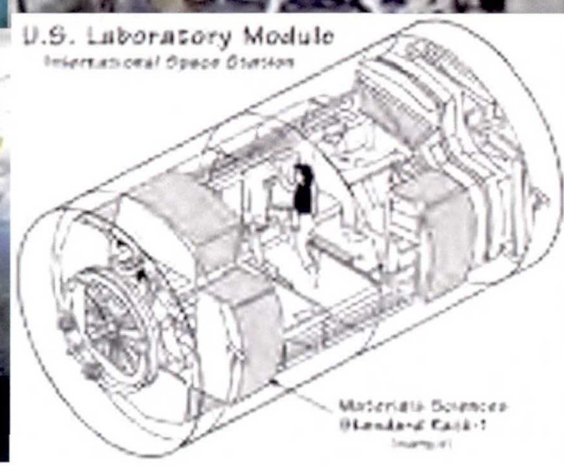


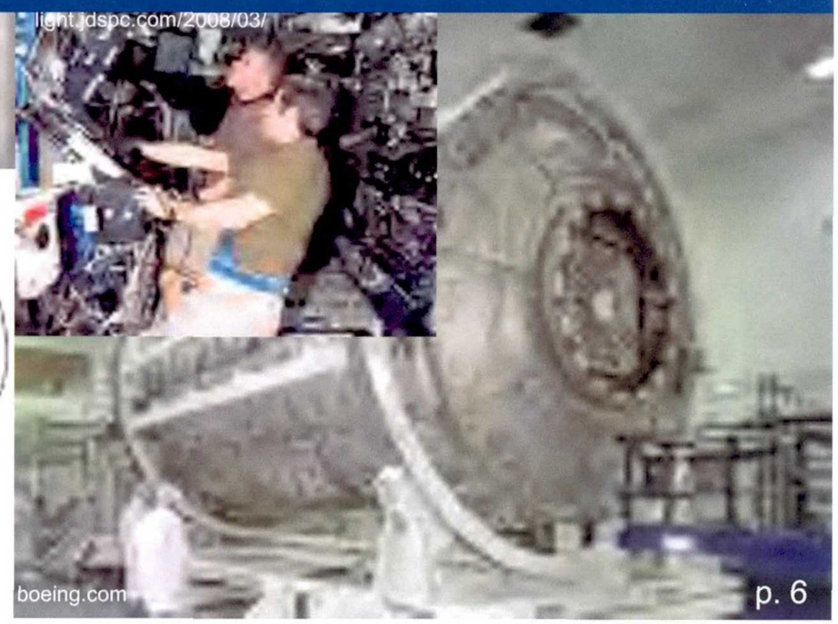
davidtrenke.com





ISS laboratories can create knowledge required to extend human presence into deep space and sustain life there





Tackling a specific challenge of ISS service management:

- The nations who built these lab in space intend for them to be used as facilities to generate knowledge for the benefit of society
- Managing these labs for a wide range of stakeholders and potential customer is very challenging
- Can *Service Science,* and in particular its subfield, *Service Innovation,* help us to utilize these systems more effectively, and to maximize their value to society?

Service Science

Service Science, Management, and Engineering (SSME) is a term introduced by IBM to describe Service Science, an interdisciplinary approach to the study, design, and implementation of *services systems* – complex systems in which specific arrangements of people and technologies take actions that provide value for others. More precisely, SSME has been defined as the application of science, management, and engineering disciplines to tasks that one organization beneficially performs for and with another.

An analogy can be made with Computer Science. The success of CS is not in the definition of a basic science (as in physics or chemistry for example) but more in its ability to bring together diverse disciplines, such as mathematics, electronics and psychology to solve problems that require they all be there and talk a language that demonstrates common purpose. *Service Science* may be the same thing, only bigger: an interdisciplinary umbrella that enables economists, social scientists, mathematicians, computer scientists and legislators (to name a small subset of the necessary disciplines) to cooperate to achieve a larger goal - analysis, construction, management and evolution of the most complex systems we have ever attempted to construct. [9]

Five core principles of Service Science*

1. Value is calculated from multiple stakeholder perspectives
    1. Customer
    2. Provider
    3. Competitor
    4. Collaborator
    5. Authority/Regulator
2. Value is *co-created* between entities through the fulfillment of mutually agreed to *value propositions* that define the parameters by which entities interact and allocate resources
3. *Service Innovation* entails the creation of *new value propositions,* normally, those that can be repeated or replicated in a system, which may be a new service system
4. Service Systems may be entities in higher order Service Systems (system of systems model)
5. Innovation in a given area can affect the system of systems in unanticipated ways

These principles are intended to provide a foundation for effective inquiry, dialogue facilitation, qualitative modeling, and quantitative modeling, as well as communication of insights generated by these activities

*based on interpretation and synthesis of defining literature from IBM/Cambridge [9,10]

Utilization Challenge

Price too high on space module for hire

The Yomiuri Shimbun (Sep. 22, 2010)

The Japan Aerospace Exploration Agency has received few requests from private corporations wanting to lease space in the research module Kibo on the International Space Station, with the high cost thought to be a major reason for the lack of interest.

Under a pricing system introduced by JAXA in June last year, corporations can pay 5.5 million yen per hour to have astronauts from Japan, the United States or other nations carry out scientific experiments or other activities in Kibo. JAXA expected to receive commissions for 10 to 30 hours per year, but orders have fallen well short of that, the agency said. Since JAXA began leasing space in Kibo in September 2008, just four commercial operations have been conducted in the module. They include the shooting of TV commercials for chewing gum and cameras, and a project that involved keeping seeds in space for several months and later distributing them to children on Earth.

The agency plans to work out measures to expand commercial use of the module, and will consult various companies in the near future.

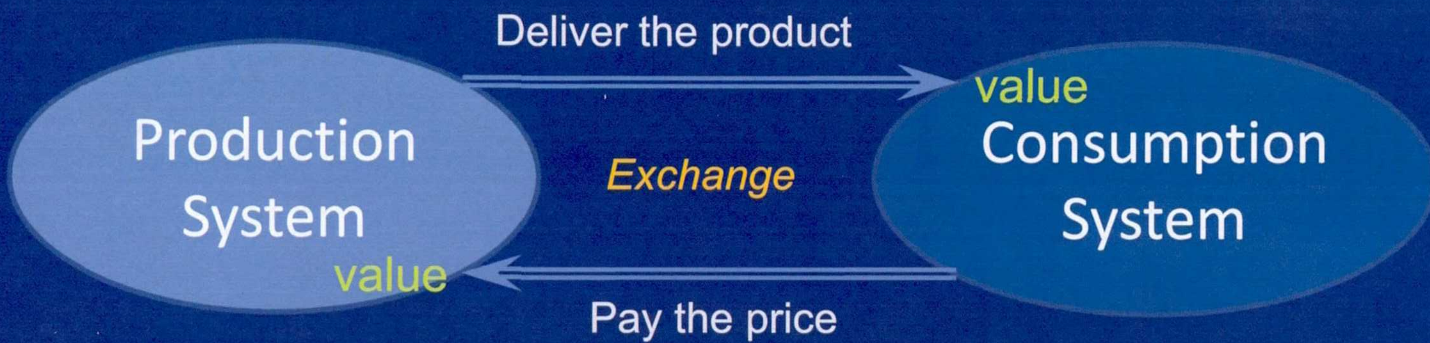
At first, JAXA employed a bidding system, offering set usage periods for purchase by companies via auction. However, it changed to a first-come-first-serve, hourly rate system after hearing from industrial circles that the bidding system was difficult to work with. The seeds-in-space project is the only one to have been commissioned since the hourly rate was introduced, and astronauts have been left with nothing to do.

"Amid a deep recession, 5.5 million yen per hour might've been too expensive," a JAXA official said.

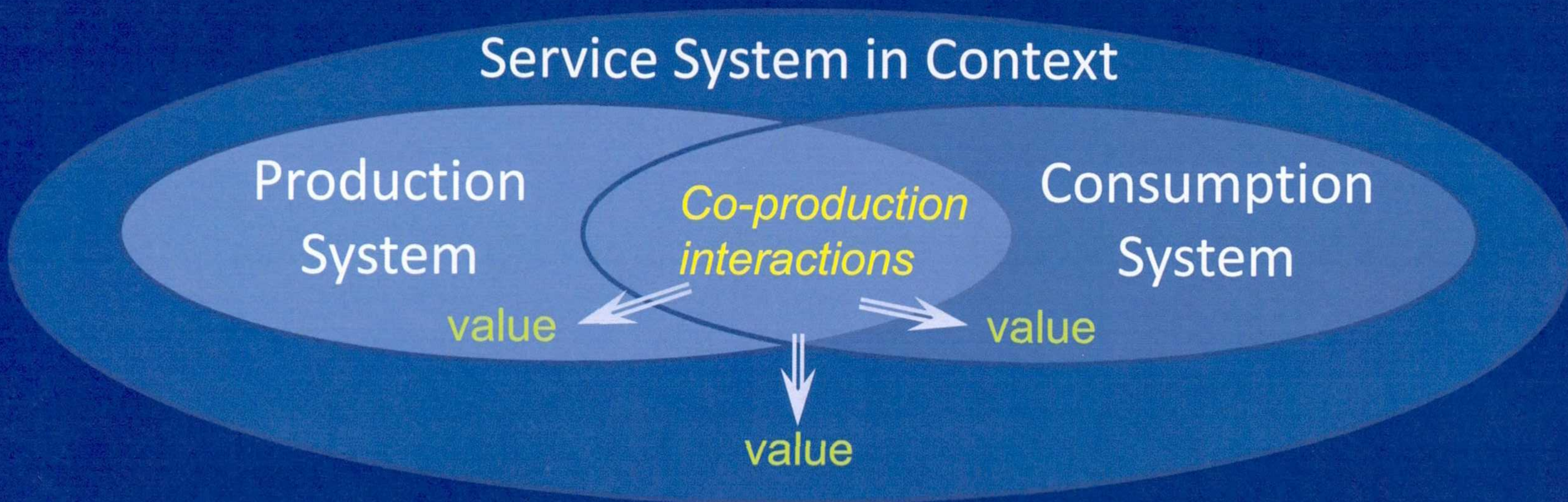
Is the *price* really the barrier?

- The United States has also faced challenges in achieving full utilization of U.S. laboratory resources on ISS [11]
  - The barriers and solutions considered have been more involved than "price for service".
  - The U.S. ISS National Laboratory was created to help address the utilization challenge
  - Upgrades in technology, as well as organization and governance, have been considered and implemented
- In the language of *Service Science*, the U.S. response has entailed broad consideration the *value propositions* that can made

Service vs. *Product* thinking



Product-dominant logic



Service-dominant logic

Adapted from [9], p. 20

Discussion

Challenge: full utilization of ISS laboratories for the benefit of society

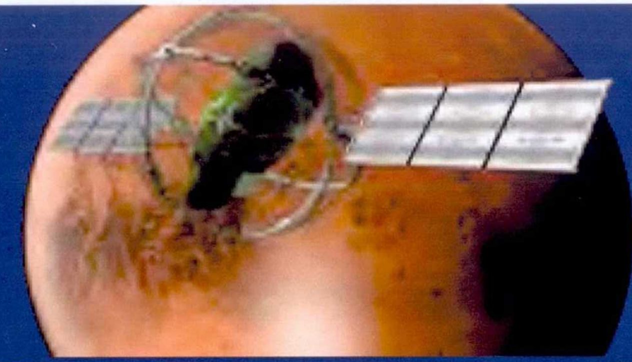
How can the language and modeling techniques of Service Science be applied to better describe, understand and model the problem?

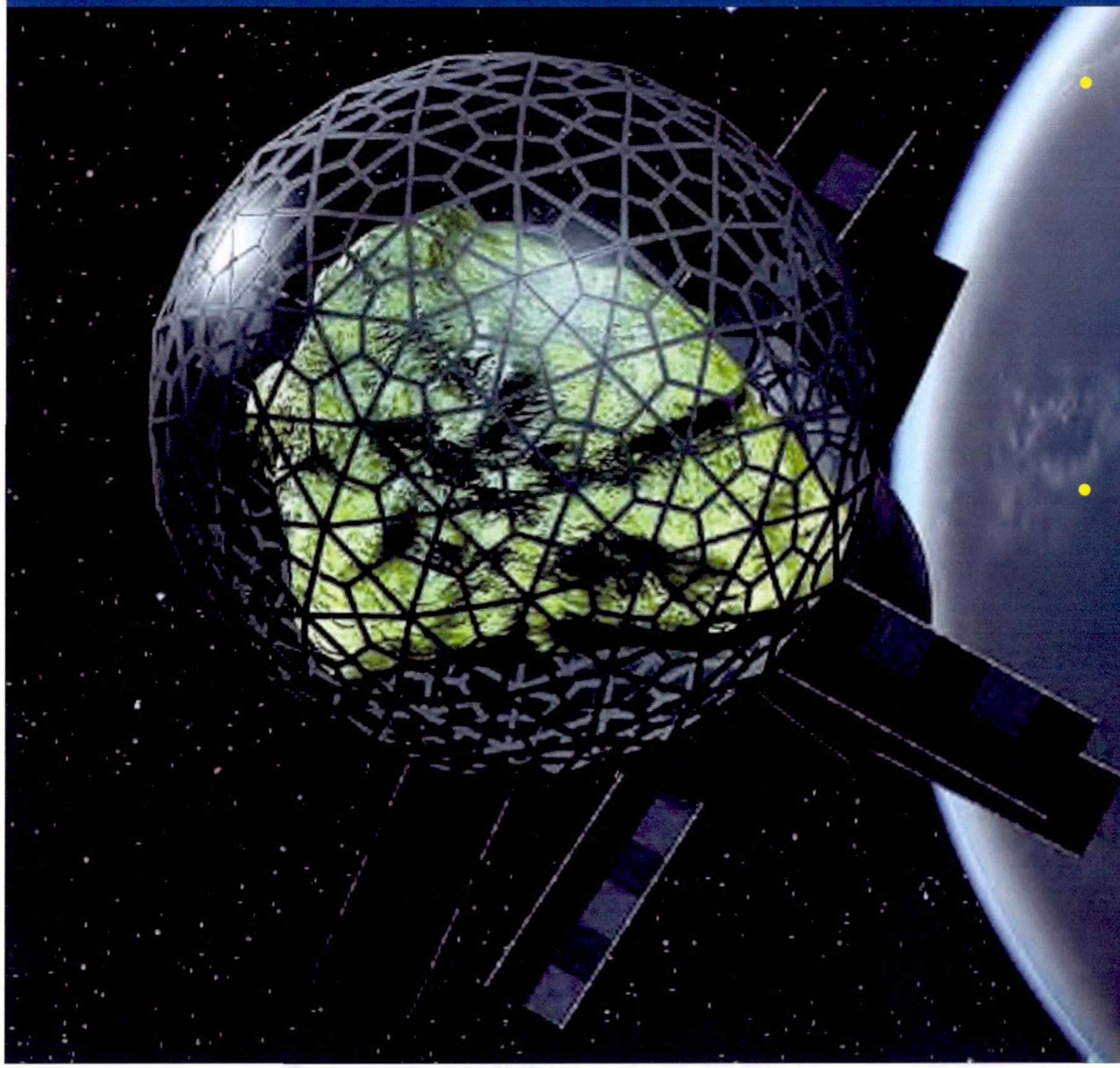
How can Service Science and Service Innovation help stakeholders tackle this challenge and develop better alternatives (new value propositions)?

U.S. Intentions for the future [12]

- LONG TERM GOAL.—The long term goal of the human space flight and exploration efforts of NASA shall be to expand permanent human presence beyond low-Earth orbit and to do so, where practical, in a manner involving international partners.
- KEY OBJECTIVES.—The key objectives of the United States for human expansion into space shall be—
  - to sustain the capability for long-duration presence in low-Earth orbit, initially through continuation of the ISS and full utilization of the United States segment of the ISS as a National Laboratory…
  - to determine if humans can live in an extended manner in space with decreasing reliance on Earth, starting with utilization of low-Earth orbit infrastructure, to identify potential roles that space resources such as energy and materials may play, to meet national and global needs and challenges, such as potential cataclysmic threats, and to explore the viability of and lay the foundation for sustainable economic activities in space;
  - to maximize the role that human exploration of space can play in advancing overall knowledge of the universe, supporting United States national and economic security and the United States global competitive posture, and inspiring young people in their educational pursuits
  - to build upon the cooperative and mutually beneficial framework established by the ISS partnership agreements and experience in developing and undertaking programs and meeting objectives designed to realize the goal of human space flight set forth [above].

Extraterrestrial service systems of the future

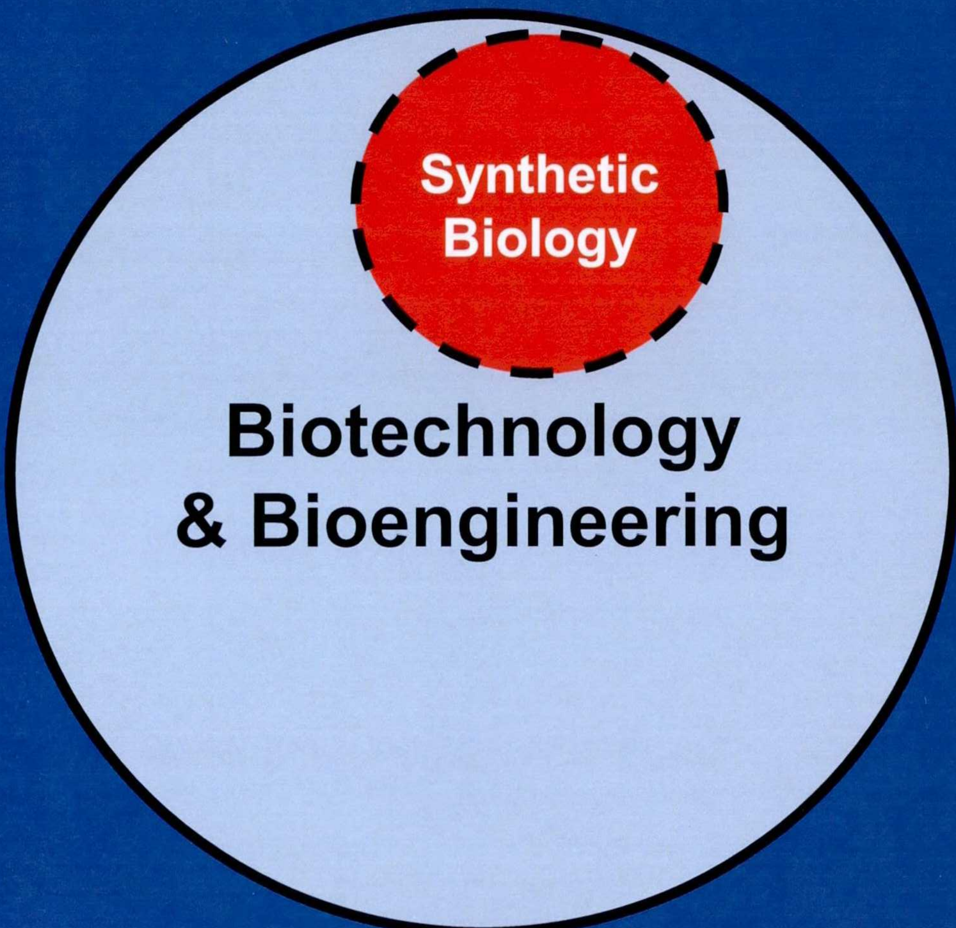




- We've shown we can cooperate, live, work, build complex systems, and do scientific research in space – What next? Where are we going?
  - Deep space missions (beyond LEO)
  - Permanent human presence in deep space.
- What's coming
  - Emerging commercial space sector
    - Tourism
    - What else?
  - Globalization of human space flight capabilities
  - Emerging technologies will change the game, e.g.:
    - 3D printing
    - Synthetic Biology with in-situ DNA writing

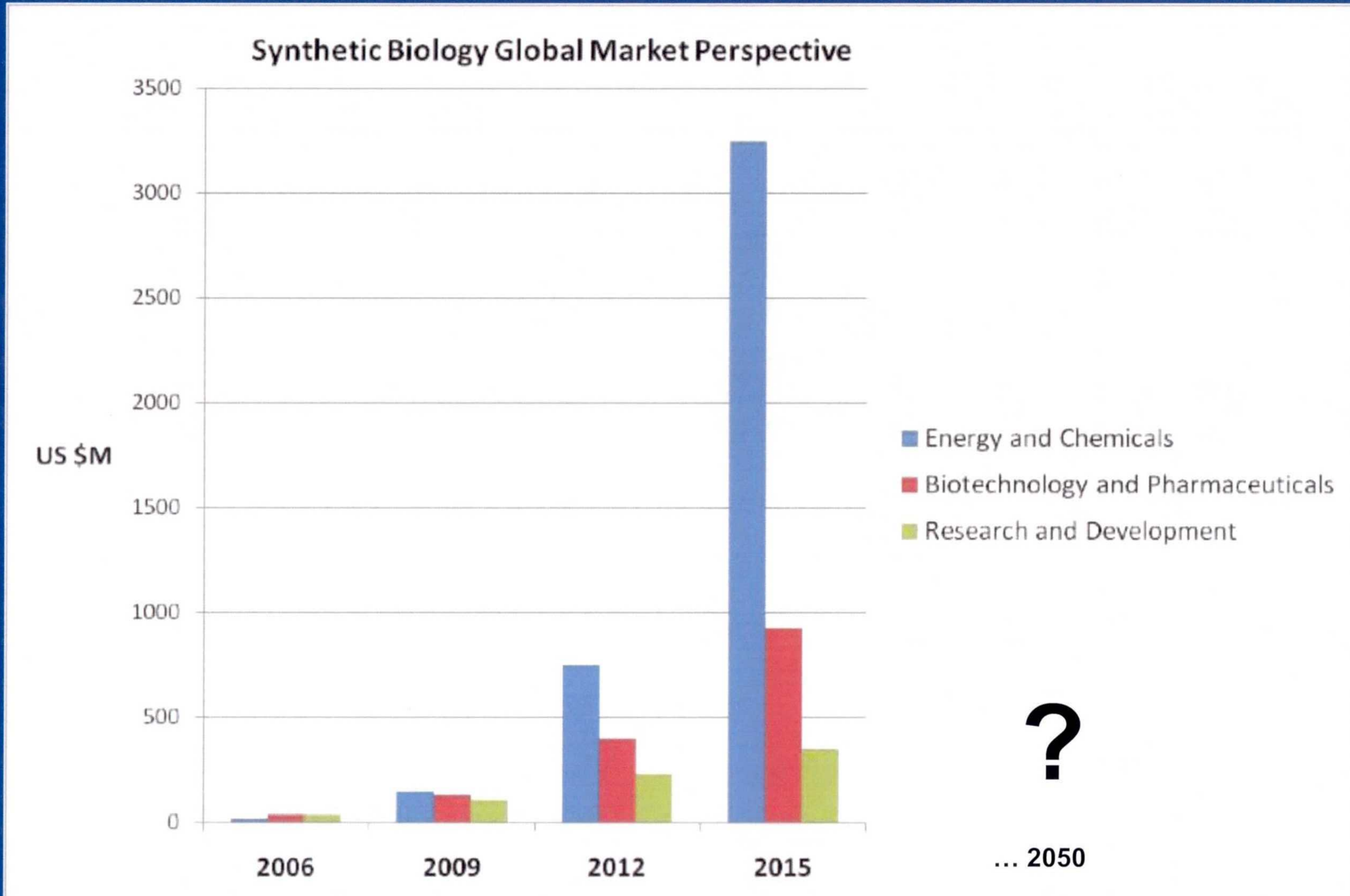
What is Synthetic Biology?

An emerging, innovative, game-changing bioengineering discipline.



- An engineering approach that seeks to construct new biological parts, devices and systems, as well as to re-design existing components to do useful work
- A new discipline that distinguishes itself from conventional genetic engineering with a heavy emphasis on developing foundational technologies that make the engineering of biology easier and more reliable.
- A rapidly growing area of biotechnology that can be employed to manipulate chemicals, fabricate materials and structures, produce energy and fuel, provide food, drugs, and nutrients, and maintain and enhance human health and our environment.

Synthetic Biology is rapidly growing in global economic significance



Synthetic Biology will radically alter our ability to extend human society into space

"Over the next 20 years, synthetic genomics is going to become the standard for making anything. The chemical industry will depend on it. Hopefully, a large part of the energy industry will depend on it. " [8] - J. Craig Venter, 2007

"Any change that alters the way a society obtains the material necessities of life generates pressure for change in virtually every part of the sociocultural system... When a society experiences a major change in its technology, it is as if there had been an important modification in the genetic makeup of its members" [7]

<u>The Past</u>

We took familiar, terrestrial, biological systems into space, and engineered environments to suit them.

<u>The Future</u>

We will engineer biological systems to make them suited to extraterrestrial environments, and employ these systems in new kinds of missions

Why is this technology so critical to extraterrestrial systems?

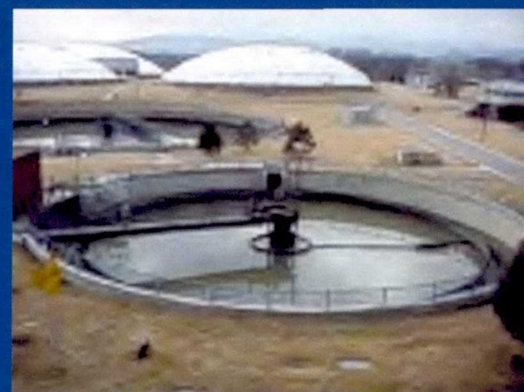
Biological systems have unparalleled potential to translate small upmass into enormous value (e.g., materials, manufacturing, processing), given suitability of the biological system to the extraterrestrial environment

Self replication with exponential growth

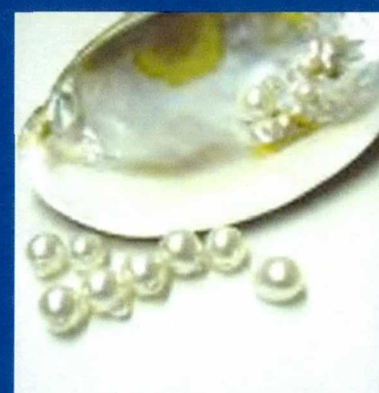
Synthetic Biology will offer unprecedented ability to capitalize on this potential, to sustain human presence in extraterrestrial environments

People have been using biology to do chemistry for thousands of years on Earth.

Process chemistries:



Materials chemistries:



Synthetic Biology will enable people to do this far from Earth.

Synthetic Biology for Sustaining Life In Space – Biological In-Situ Resource Utilization (BISRU)

<u>Materials Utilized</u>

- Terrestrial (transported upmass)
- Acquired in transit (e.g., biomined asteroid, repurposed upmass from other missions)
- Acquired in situ

⟹ **Synthetic Microbial Bioreactor** ⟹

<u>Useful Products</u>

- Foods
- Drugs
- Fuels
- Gasses
- Materials
    - Polymers
    - Fibers
- Heat

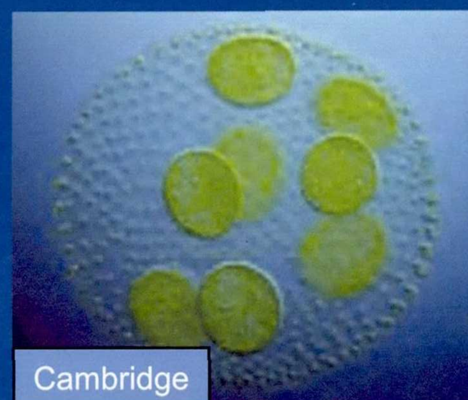
<u>Potential advantages of synthetic bioprocessing over physical/chemical processing</u>

- Facilitates closed loop life support and reduced upmass, reduced consumables, and reduced re-supply
- Reduced power required; potential for direct capture of solar energy by biological systems
- Facilitates *in-situ* manufacturing and processing with reduced reliance on hazardous/toxic chemicals
- As compared to physical/chemical processing, Synthetic Biology has much greater potential for game-changing breakthroughs for sustaining life in space, as well as economically significant terrestrial applications

Bio-Photovoltaics

- Harness photosynthetic machinery to generate electricity
- Also for oxygen production and hydrogen production
- Intact cells or extracted P-synthetic complexes can be used

Gold nanowires directly inserted into the chloroplasts of algae to collect electrons—6 mA per cm^2



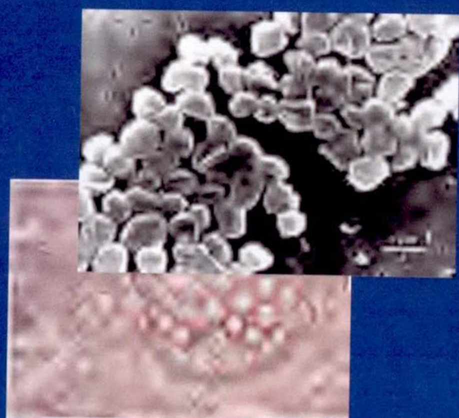
Green algae photocell can power a clock—
platinum nanoparticles help capture electrons.

Simple robust photocell uses "light reaction centers" from purple bacterium *Rhodobacter and can self-repair.* Nanotubes direct current flow.

Syn Bio can advance these technologies for space applications

Astrobiology and Exobiology provide a strong foundation for Synthetic Biology-based technologies

Extremophiles:
Study of the chemical and physical limits of life (astrobiology research)



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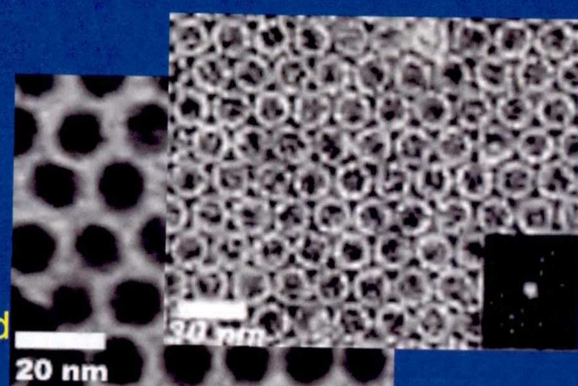
Chemical sensors for environmental monitoring and space science

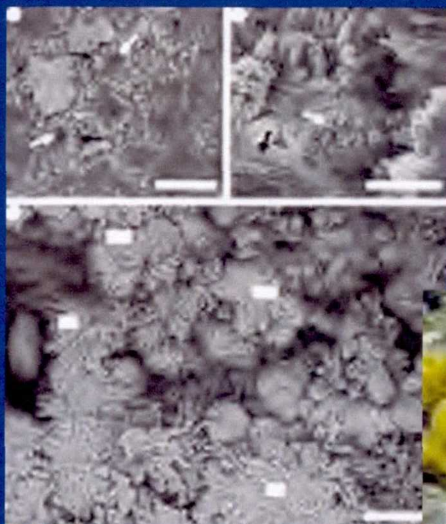
Robust scaffolds for biotechnology and nanotechnology

Enzyme complexes for efficient conversion of cellulosic biomass to foods and fuels

Metallic nanoparticle arrays with potential applications in information technology, and alternative energy (e.g, memory, engineered photosynthesis)

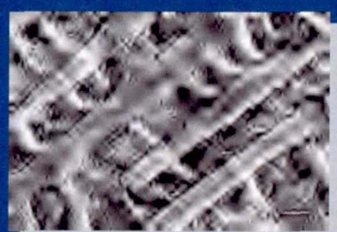


Strong, radiation resistant materials via biomineralization?



Research area: microbial biomineralization

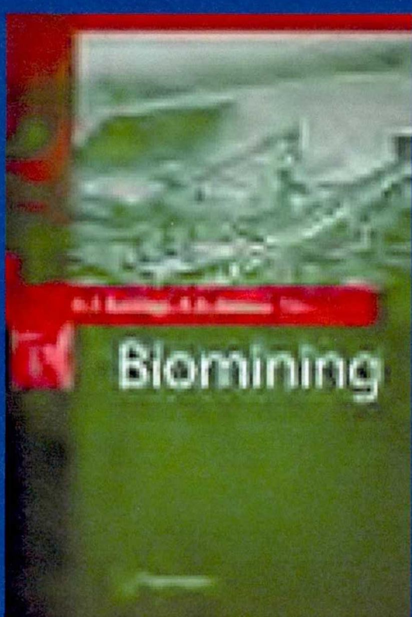
Research area: bone, teeth, enamel and programmed pattern formation.



Development, Function and Evolution of Teeth - M. Teaford, et al., (Cambridge, 2000)

Biomining

- Extremophiles generate acid to dissolve valuable metals in dilute ore
- Dissolved metal recovered via electroplating
- Produces ~ 25% of global copper supply
- Could Humans one day employ biomining on asteroids, the Moon, and on Mars?



Synthetic Biology to engineer plants…

… for food, materials, air/water processing?

Dwarf Tomato/Rice

Vitamin A Enriched Rice

Wavelength Experimentation

Super Dwarfs
- Increased yield
- High harvest index
- Reduced volume
- Reduced nutrients/H_20

Enhanced Nutrition
- Increased vitamins
- Complete protein source
- Improved taste
- Longer storage capacity

Precision Metabolism
- >2x growth rates
- Precise wavelength use
- Radiation use/tolerance
- Disease resistance

Syn Bio provides the foundation to revolutionize plant growth systems for space exploration and terrestrial utilization…

Synthetic Biology to engineer plants …

… for self-building habitats?

Flickr: exportw0nnl5, plantwerkz.blogspot.com

Potential synthetic biology applications in extraterrestrial systems

- Life Support
- Environmental Monitoring
- Biological In-Situ Resource Utilization
- Advanced Biomaterials and Manufacturing
- Human Health
- Space Power and Energy Storage Systems
- Advanced Sensor Systems
- Habitation Systems
- Astrobiology Research

Service system evolution

- Lenski argued that the rate of change in sociocultural systems accelerated non-linearly as human symbol systems overtook the genetic code in significance for the accumulation and passage of information to future generations.
- Yet we are still "tethered" to our genetic predispositions and limitations, as are the living things we depend on for our well being.
- Synthetic biology offers the ability to break this tether, potentially adding another radical non-linear factor to the socio-cultural change equation, and raising fundamental ethical questions.

How will service systems of the future be different than those of today?

Can Service Science help us anticipate the course of service system evolution?

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