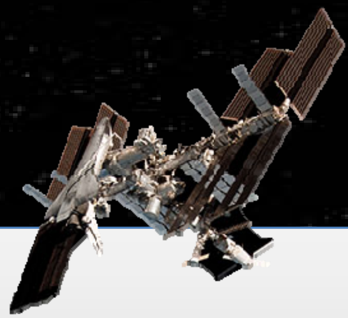

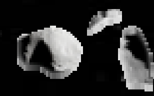

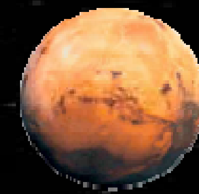

In-space Manufacturing: Exploration thru Innovation

AIAA/TEDx Salon

March 5, 2015

Niki Werkheiser
NASA In-space Manufacturing Project Manager
Niki.Werkheiser@nasa.gov
256-544-8406

What I thought I would get….

What I actually got

Images courtesy of Creative Commons

Image courtesy of Wikimedia Commons

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Printing Press

↓

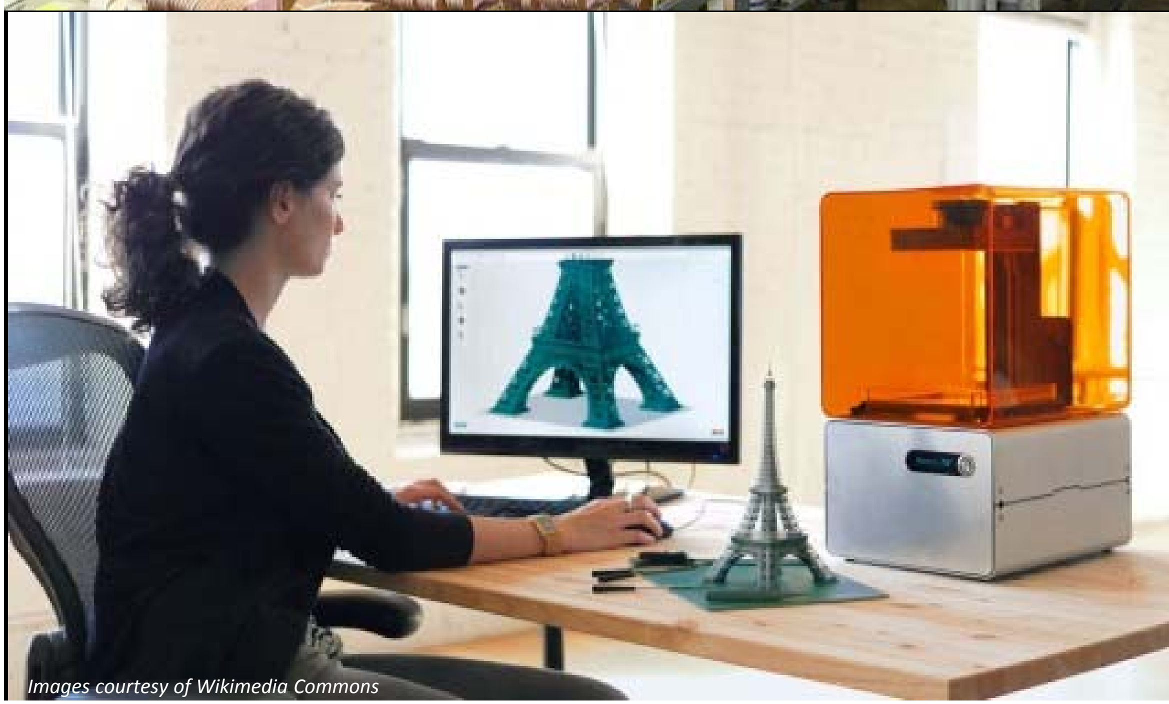
3D Printing, i.e. Additive Manufacturing

Large Facilities

Mass Production

Time

Big Workforce



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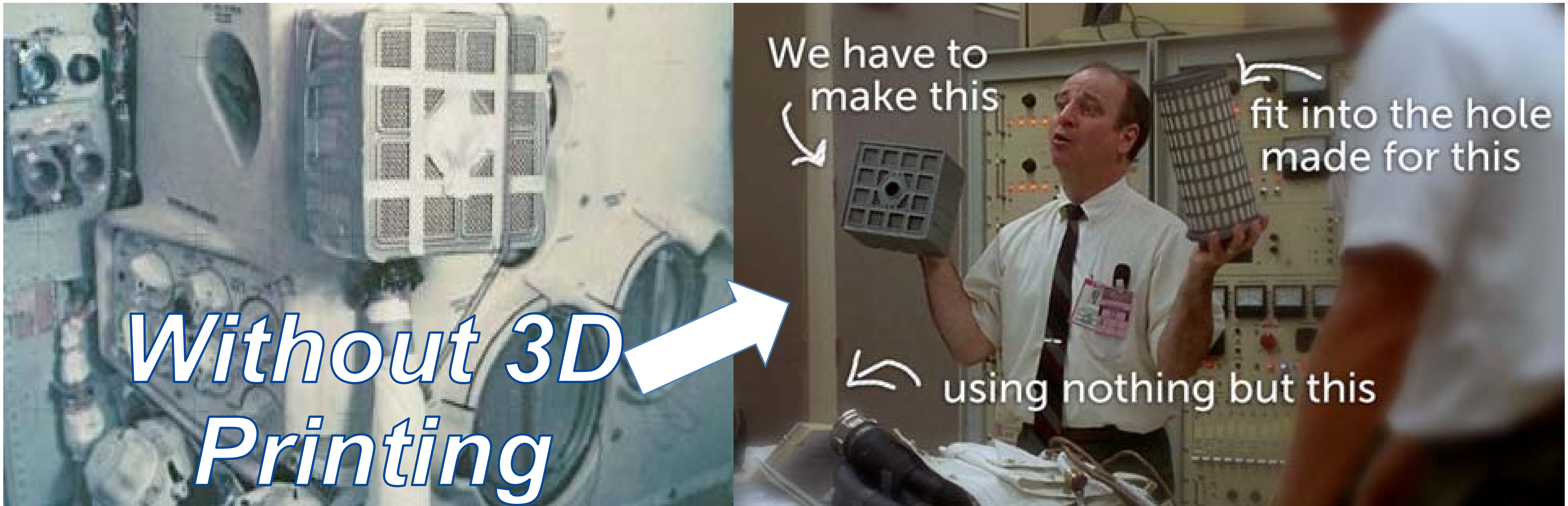
Independence


Can be here.....
Images courtesy of Wikimedia Commons


Or here


SPACE
FEASIBLE
Images courtesy of Creative Commons



Square peg in Round Hole? No problem!

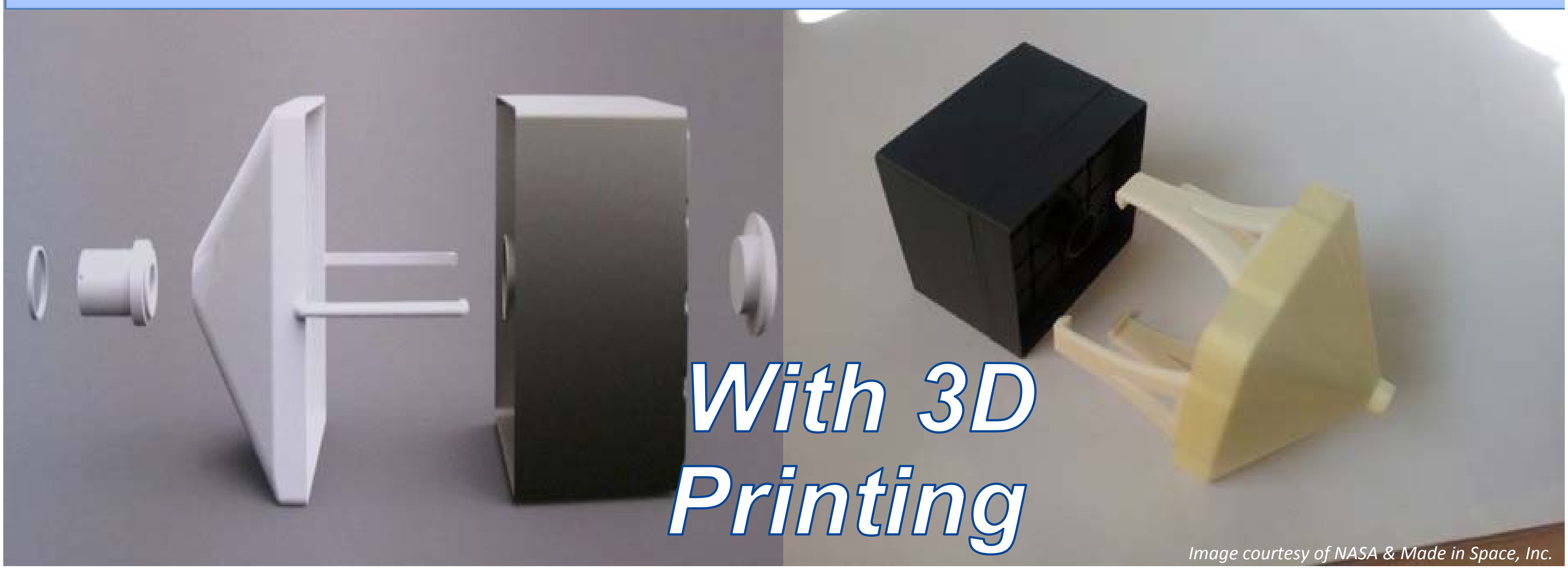


Image courtesy of NASA & Made in Space, Inc.

In-space Manufacturing Platforms

ISS Technology Demonstrations are Key to 'Bridging' necessary Technology Development to Full Implementation of the Required In-space Manufacturing Capabilities for Exploration of this Critical Exploration Technology.

ISS Platform

- *3D Print Tech Demo*
- *Qualification/Inspection of On-orbit Parts using Optical Scanner*
- *Additive Mfctr. Facility (AMF)*
- *In-space Plastic Feedstock Recycling*
- *Utilization Catalogue*

Planetary Surfaces Platform

In-situ Feedstock Test Beds and Reduced Gravity Flights Which Directly Support Technology Advancements for Asteroid Manufacturing as well as Future Deep Space Missions.

- Additive Construction
- Regolith Materials Development & Test
- Synthetic Biology: Engineer and Characterize Bio-Feedstock Materials & Processes

Note: Blue italics indicate AES ISM FY15 Activity Defined

Earth-based Platform

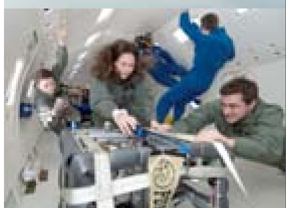
- *Certification & Inspection of Parts Produced In-space*
- *In-space Characterization Database*
- *Printable Electronics & Spacecraft*
- *External In-space Manufacturing (not currently funded)*

Earth-based Platform (cont.)

- *In-space Metals Manufacturing Process Study (not currently funded)*
- *Additive Repair Ground Testing*
- Self-Replicating/Repairing Machines
- In-situ Feedstock Development & Test: See Asteroid Platform

In-space Manufacturing Technology Development Vision

Earth-based



Pre-2012

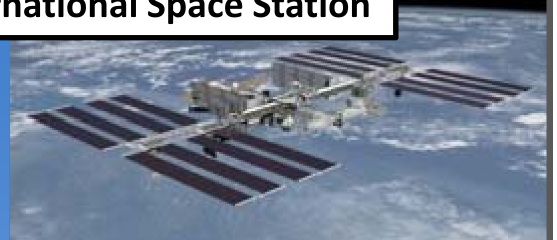
Ground & Parabolic centric:
- Multiple FDM Zero-G parabolic flights
- Trade/System Studies for Metals
- Ground-based Printable Electronics/Spacecraft
- Verification & Certification Processes under development
- Materials Database
- Cubesat Design & Development

International Space Station

3D Print Tech Demo

2014

- **In-space:3D Print: First Plastic Printer on ISS Tech Demo**
- **NIAC Contour Crafting**
- **NIAC Printable Spacecraft**
- **Small Sat in a Day**
- **AF/NASA Space-based Additive NRC Study**
- **ISRU Phase II SBIRs**
- **Ionic Liquids**
- **Printable Electronics**



Metal Printing

Optical Scanner

Printable Electronics

SmallSats

Recycler

Add Mfctr. Facility

Self-repair/ replicate

2015 2016 2017 2018

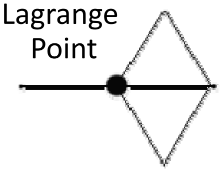
- ***3D Print Tech Demo***
- ***Future Engineer Challenge***
- ***Utilization Catalogue***
- ***ISM Verification & Cert Process Development***
- ***Add. Mfctr. Facility (AMF)***
- ***In-space Recycler SBIR***
- ***In-space Material Database***
- ***External In-space 3D Printing***
- ***Autonomous Processes***
- ***Additive In-space Repair***

ISS:
Utilization/Facility Focus
- In-space Recycler Demo
- Integrated Facility Systems for stronger types of extrusion materials for multiple uses including metals & various plastics
- Printable Electronics Tech Demo
- Synthetic Biology Demo
- Metal Demo Options

Exploration

Asteroids

Lagrange Point



Lunar

Mars

2020-25

Lunar, Lagrange FabLabs
- Initial Robotic/Remote Missions
- Provision some feedstock
- Evolve to utilizing in situ materials (natural resources, synthetic biology)
- Product: Ability to produce multiple spaces, parts, tools, etc. "living off the land"
- Autonomous final milling to specification

2025

Planetary Surfaces Points Fab
- Transport vehicle and sites would need Fab capability
- Additive Construction

2030 - 40

Mars Multi-Material Fab Lab
- Utilize in situ resources for feedstock
- Build various items from multiple types of materials (metal, plastic, composite, ceramic, etc.)
- Product: Fab Lab providing self-sustainment at remote destination

ISS Technology Demonstrations are Key in 'Bridging' Technology Development to Full Implementation of this Critical Exploration Technology.

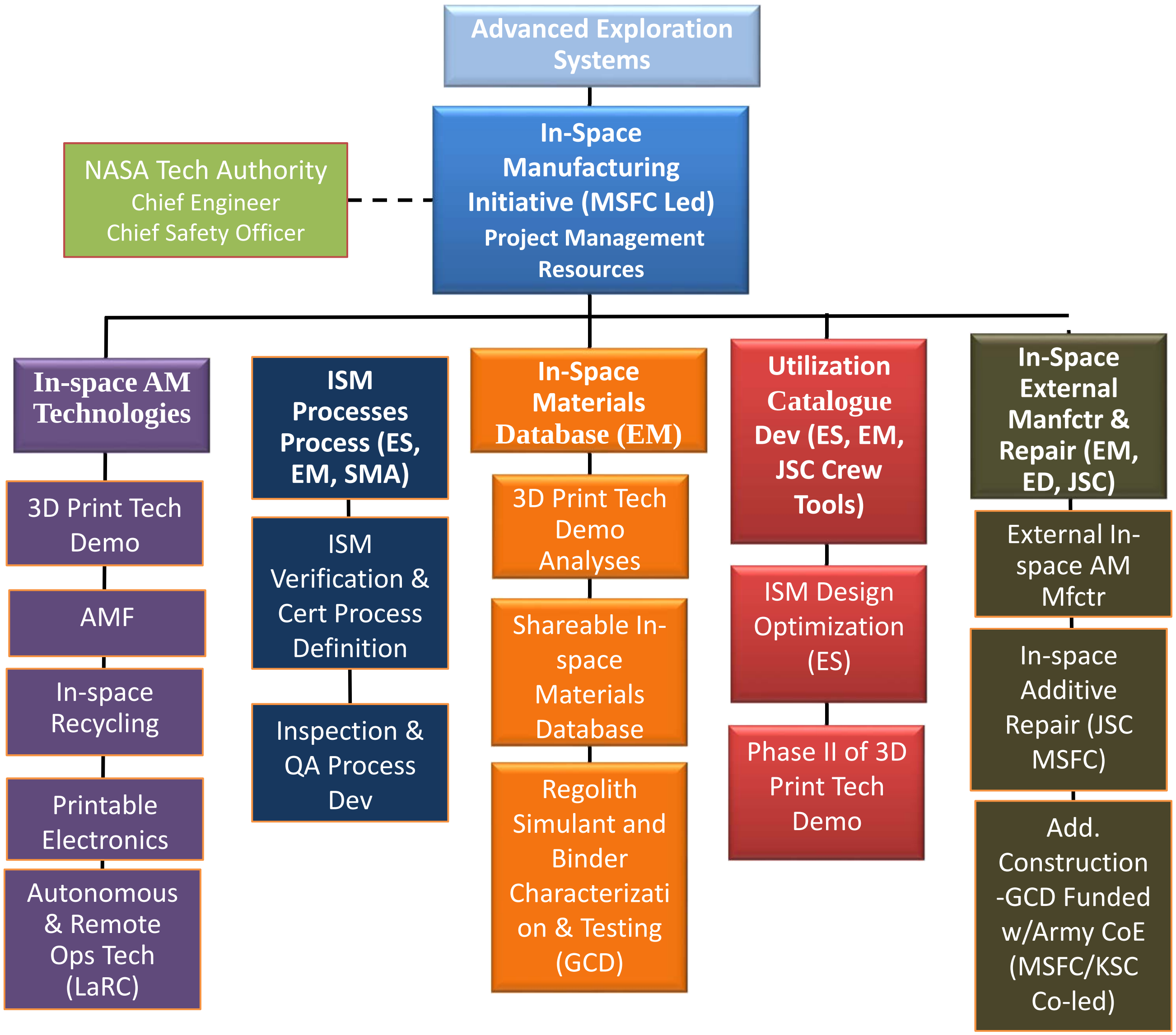
National Research Council (NRC) Report on Space-Based Additive Manufacturing (AM)

- The AF Space Command, AFRL Space Vehicles, the NASA Chief Technologist Office & STMD requested the NRC to:
  - (1) Evaluate the feasibility of the concept of space-based AM of space hardware, (2) Identify the science & technology gaps, and (3) Assess the implications of a space-based AM capability
  - Report delivered in July 2014

Key Recommendations

- NASA should ***quickly identify AM experiments for all areas of ISS*** utilization planning & identify any AM experiments worthy of flight that it can develop & test aboard the ISS during its remaining 10 years of service and determine if they are worthy of flight.
- Agencies need to do ***systems*** & ***cost benefit analyses*** (CBA) related to the value of AM in space. Analyses should not focus just on how AM could replace traditional manufacturing but how it can enable ***entirely new structures & functionalities that were not possible before***. For example, a CBA would be helpful is in the manufacture of smaller satellites on the ISS.
- Targeted investment is needed in areas such as **standardization, *cert, & infrastructure***.
- Decrease stove-piped parallel development, it is critical that there be ***cooperation, coordination and collaboration within and across agencies, sectors, and nations***.
- NASA should ***consider additional investments in the education and training*** of both ***materials scientists*** with specific expertise in AM & ***spacecraft designers and engineers*** with deep knowledge of the use and development of AM systems.

ISM Organization (Functional)



ISM MSFC Core Team

- Project Manager: Niki Werkheiser (ZP30)
- Add. Construction Lead: Jennifer Edmunson (ZP30)
- Project Assoc.: Mallory Johnston (ZP30)
- Project Support: Diane Risdon (ZP30)
- Resource Lead: Dana Solomon (ZP02)
- Chief Engineer: Rick Ryan (EE05)
- Principal Investigator: Quincy Bean (EM42)
- ISM Design Leads: Jason Waggoner, Bobby Atkins (ES21)
  Lead Systems Engineer: Erick Ordonez (ES13)
- Chief Safety Officer: Terry Jones
- Payload Safety Engineer: Gordon Deramus (QD22)

ISM Task 1: First 3D Printer in Space!

3D Print Flight Unit with the MSG Engineering with ABS Plastic Parts

3D Printing in Zero-G Tech Demo Objectives

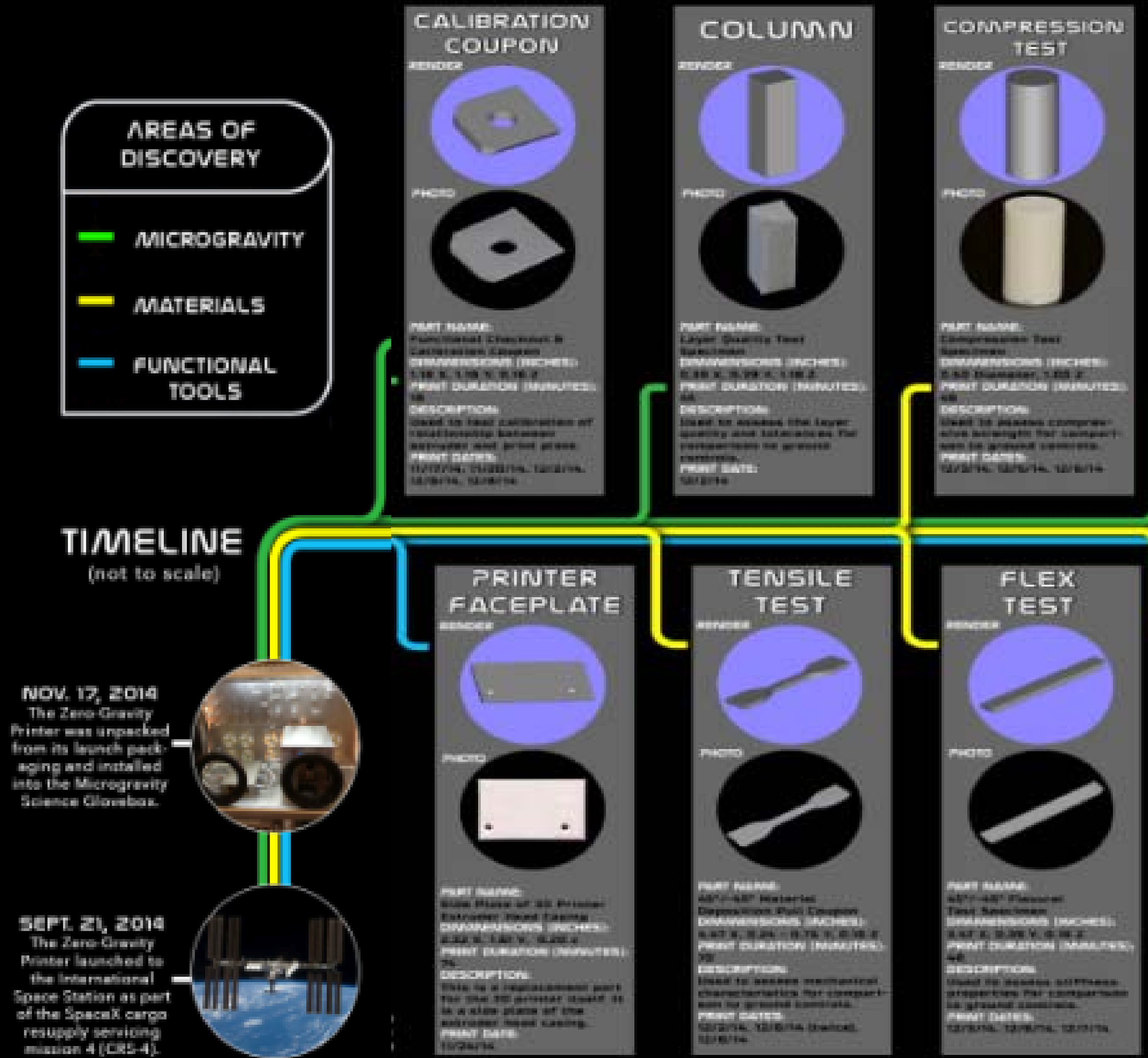


Image courtesy of MIS

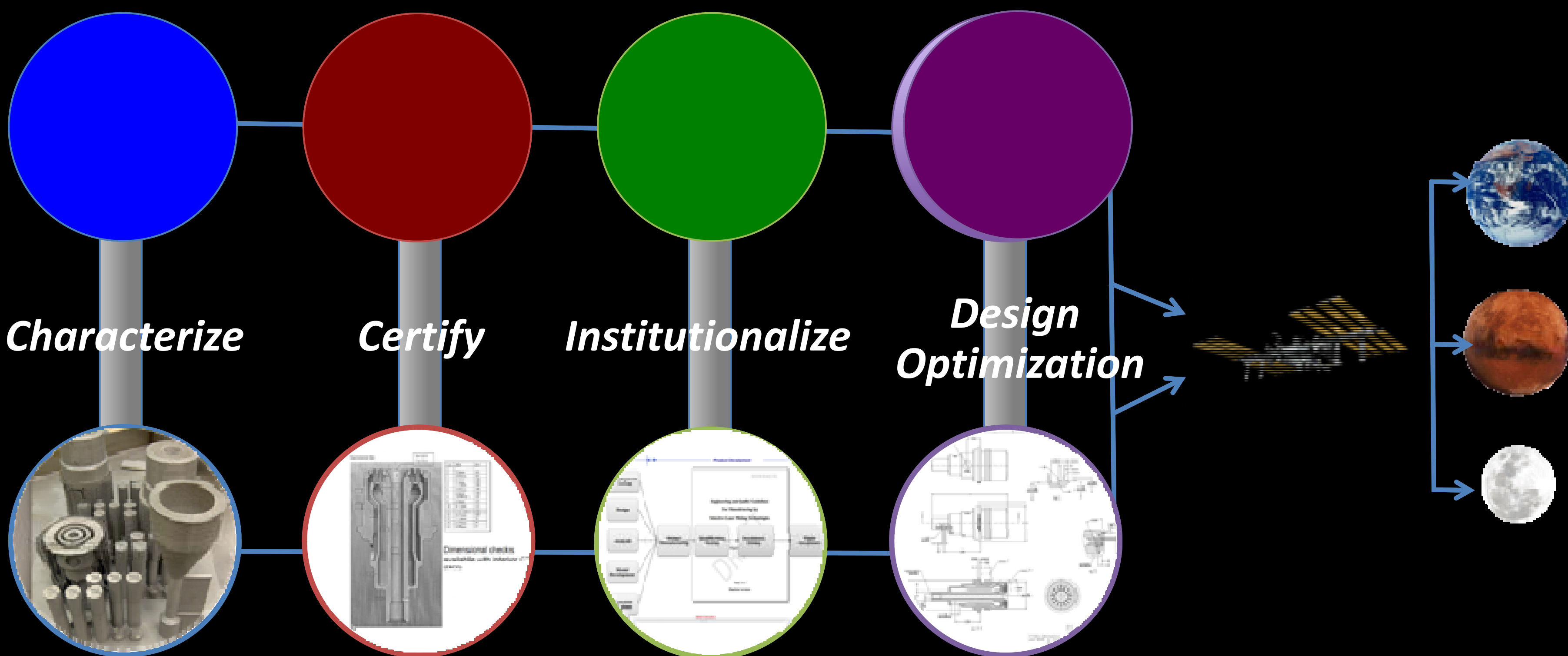
- The objective of the first phase of the technology demonstration is to confirm that ***Printer and Processes work in microgravity*** via printing of Test Articles & post-flight analyses.
- The objective of the second phase is to ***Demonstrate functionality of utilization parts*** such as crew tools and ancillary hardware.
- First parts printed returned on SPX-5 and will be sent to MSFC for detailed analyses and testing. All results will be published.

3D Printing in Zero-g Tech Demo Status

- To date, 25 parts have been printed of 14 unique objects. These included engineering test coupons, a microgravity test coupon, & utilization examples.
- Engineering Test Coupons:
  - Column: layer quality & tolerance
  - Tensile: mechanical characteristics
  - Compression: compressive strength
  - Flex: stiffness properties
  - Hole & Feature Resolution: geometric accuracy & tolerances for positive & negative range
  - Torque: torque strength
- Overhang Structure: would be difficult, if not impossible, to print in gravity w/out supports
- Utilization Examples:
  - Crowfoot Tool
  - Sample Container
  - Cubesat Clip
  - Ratchet (test of on-demand capability)

In-space Manufacturing Tenets

In-Space Additive Manufacturing



SLM manufactured injector, mechanical property and microstructure test articles

CT Scan Nondestructive Inspection and Dimensional Verification

Process Standards documentation for qualification/certification process

Design for Additive Manufacturing Process

Note: Example is of Ground-Based Additive Manufacturing of Propulsion Components for Spaceflight

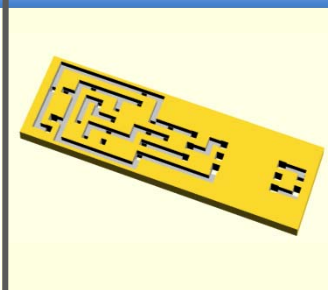
Characterize→ Certify→ Institutionalize→ Design for AM

In-space Manufacturing Technologies

RECYCLER

Recycling/Reclaiming 3D Printed Parts and/or packing materials into feedstock materials. This capability is crucial to sustainability in-space.

PRINTED ELECTRONICS

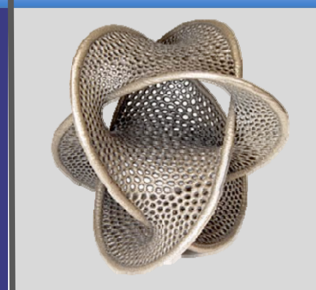


Leverage ground-based developments to enable in-space manufacturing of functional electronic components, sensors, and circuits.
Image: *Courtesy of Dr. Jessica Koehne (NASA/ARC)*

PRINTABLE SATELLITES

The combination of 3D Print coupled with Printable Electronics enables on-orbit capability to produce “on demand” satellites.

METALS



Additively manufacturing metallic parts in space is a desirable capability for large structures, high strength requirement components (greater than nonmetallics or composites can offer), and repairs. NASA is evaluating various technologies for such applications. Image: *Manufacturing Establishment website*

EXTERNAL STRUCTURES & REPAIRS

Astronauts will perform repairs on tools, components, and structures in space using structured light scanning to create digital model of damage and AM technologies such as 3D Print and metallic manufacturing technologies (e.g. E-beam welding, ultrasonic welding, EBF3) to perform the repair. Image: *NASA*

ADDITIVE CONSTRUCTION

Contour Crafting Simulation Plan for Lunar Settlement Infrastructure Build-Up B. Khoshnevis, USC

Illustration of a lunar habitat, constructed using the Moon's soil and a 3D printer. Credit: Foster+Partners

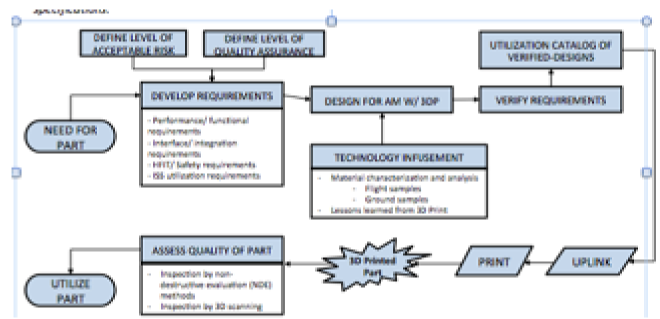
Technologies Under Development for Sustainable Exploration Missions

In-space Manufacturing (ISM) Activities

- **3D Printing in Zero-G Operations and Analyses:** Print first parts on-orbit and conduct analyses of Flight Parts compared to ground samples, publish results
- **In-space Materials Characterization Database:** Utilize MAPTIS to develop materials characterization database for in-space materials. FY15 focus on ABS, Ultem, & PEEK. *RP+M Task*
- **In-space Verification & Certification Process:** Develop verification and certification process for utilization of in-space manufacturing capability
- **Utilization Catalogue Development :** Develop a catalogue of approved parts for in-space manufacturing and utilization. Parts might include crew tools, payload components, medical tools, exercise equipment replacement parts, cubesat components, etc. JSC Crew Tools Office Co-PI. *GrabCAD Challenge*
- **In-space Recycler Tech Demo (*FY14 – 15 SBIR*):** Objective is to recycle 3D printed parts back into useable feedstock. Two Phase I SBIRs completed. Phase II Recommendations underway. Goal is to fly an In-space Recycler Tech Demo on ISS in 2016.
- **Future Engineers Program *(SAA)*:** National, multi-year STEM program via a SAA b/w NASA and American Society of Mechanical Engs (ASME). First 3D Printing in Space Challenge implemented this year. Winning student design will be printed on the ISS Tech Demo.
- **AMF *SBIR* Phase 2E** – next gen printer to incorporated lessons-learned from 3D Print Tech Demo & additional capabilities.
- ***Xhab* "Design of a Carbon-fiber/FDM Spacecraft Structural Fabrication System"**
- **Additive Repair Testing (JSC)**
- **Automation & Sensor Development (LaRC)**
- **Printable Electronics (MSFC, ARC, JPL)**
- **Additive Construction Project (*GCD & CoE*)**

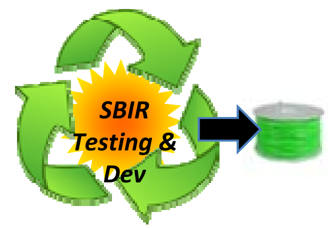
Post-flight Analyses

Utilization Catalogue



Verification & Certification

3D Printing in Space Challenge



In-space Recycler Tech Demo

Additive Construction (GCD w/CoE)

Additive Repair

In-space Manufacturing Summary

In order to provide meaningful impacts to Exploration Technology needs, the ISM Initiative Must Begin to Influence Exploration Systems Design Now.

- **In-space Manufacturing offers:**
  - Dramatic paradigm shift in the development and creation of space architectures
  - Efficiency gain and risk reduction for low Earth orbit and deep space exploration
  - New paradigms for maintenance, repair, and logistics will lead to sustainable, affordable supply chain model.
- **In-space Manufacturing Vision established which serves as input to Agency Technical Areas and Roadmap for Exploration**
- **TRL advancement to application-based capabilities evolve rapidly due to leveraging of significant ground-based technology developments, process characterization, and material properties databases**
  - NASA-unique Investments are required primarily in applying the technologies to microgravity environment.
- **We must do the foundational work – it is the critical path for taking these technologies from lab curiosities to institutionalized capabilities.**
  - Characterize, Certify, Institutionalize, Design for AM
- **Ideally, ISS US Lab rack or partial rack space should be identified for In-space Manufacturing utilization in order to continue technology development of a suite of capabilities required for exploration missions, as well as commercialization on ISS.**
- ***But the moment when we will truly know that we have reached our goal is when we can just push a button and say…..***

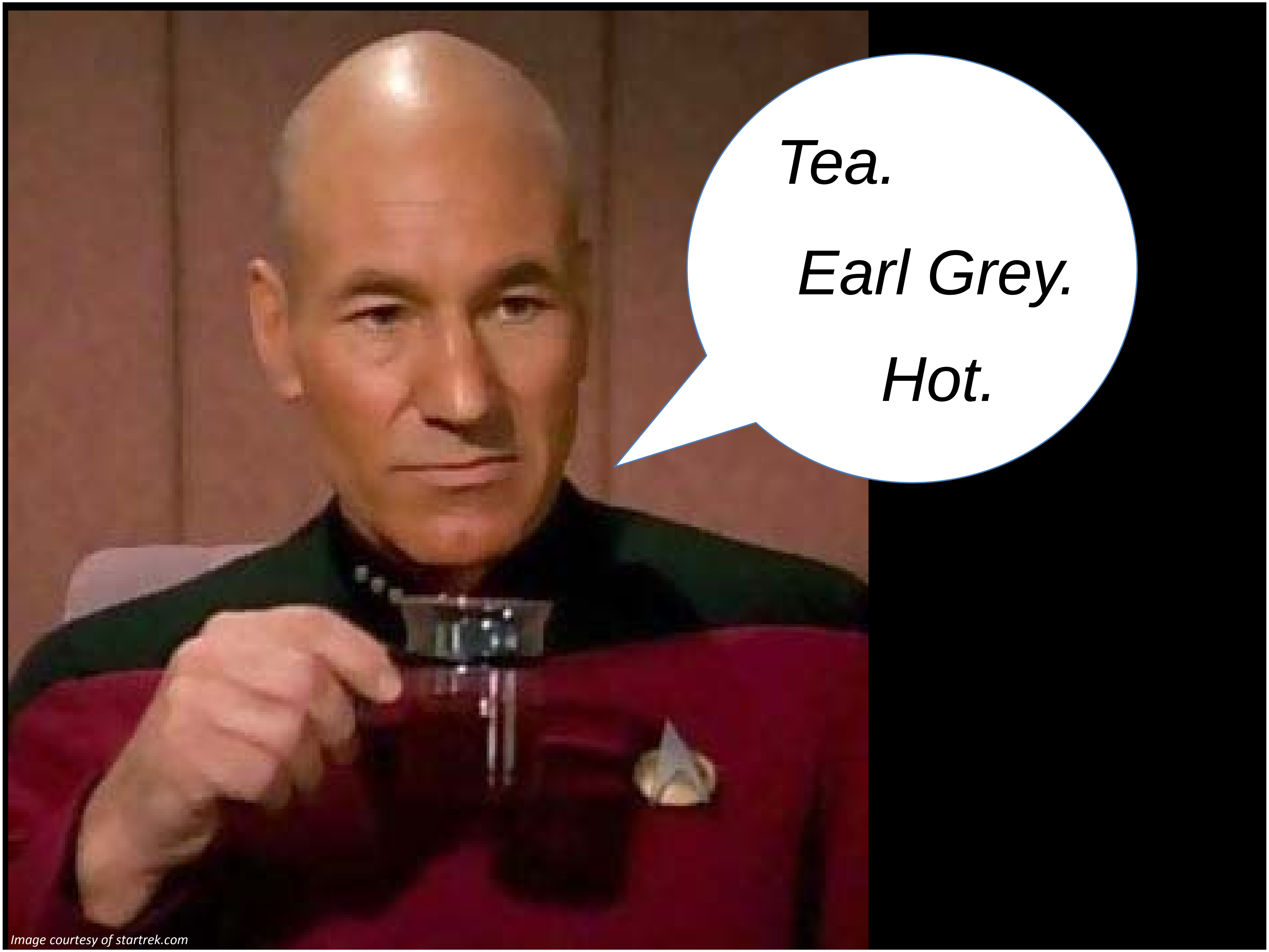


Image courtesy of startrek.com