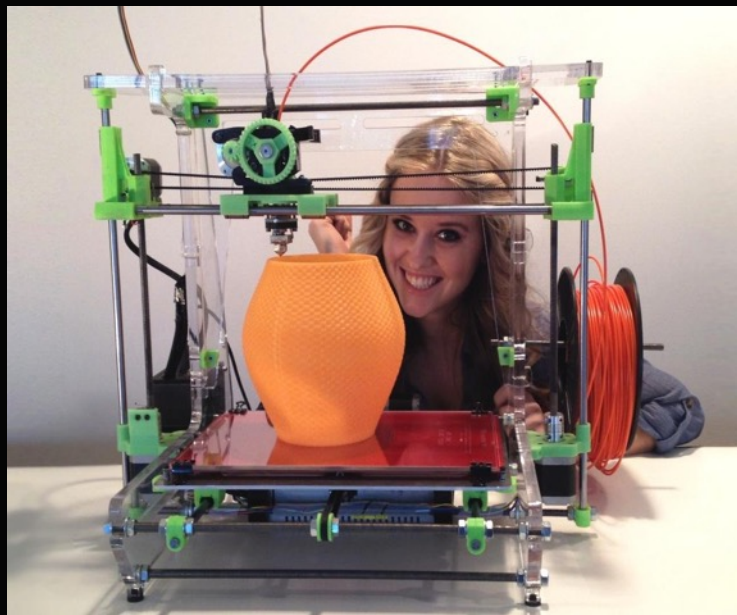


In-space Manufacturing (ISM): Make it, Don't Take it!

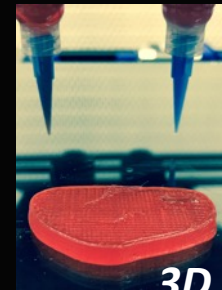


What is 3D Printing?

A 3D printer works a lot like printers which print out images on paper in two-dimensions, except a 3D Printer actually 'prints' three-dimensional objects by layering melted plastic or metals based on the electronic models (i.e. 'instructions') sent to the machine.



Oak Ridge National Labs 3D Printed Car



3D Printed Food



Prosthetics



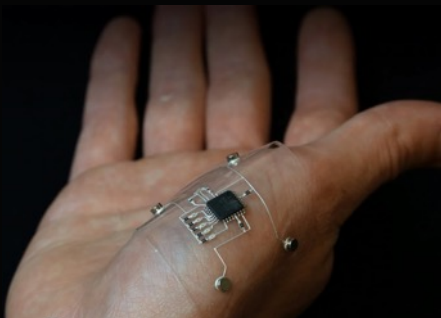
New Balance 3D Printed Shoes



Useful, custom tools

**What would YOU
3D Print?**

**Flexible
Electronics &
Wearables**



Why does NASA need 3D Printing?

- *When we live on the Moon or Mars, we will be much further from earth than we are on the International Space Station (ISS). Our astronauts won't always be able to rely on launches for resupply of consumables or spare parts.*
- *The International Space Station (ISS) is ~250 miles from the earth and it only takes hours for cargo launched from earth to reach ISS.*
- *The moon is ~240,000 miles away and takes around 3-4 days to travel to from earth.*
- *The average distance of Mars from earth is ~140 MILLION miles (closest recorded approach in history was 34.8 million miles) and it will take several months to get there with current propulsion technologies.*



MAKE IT,



DON'T TAKE IT!!

The current ISS resupply model relies on frequent launches from multiple countries.



The current ISS resupply model is not sustainable for long duration missions beyond low earth orbit.



SPACE ↑

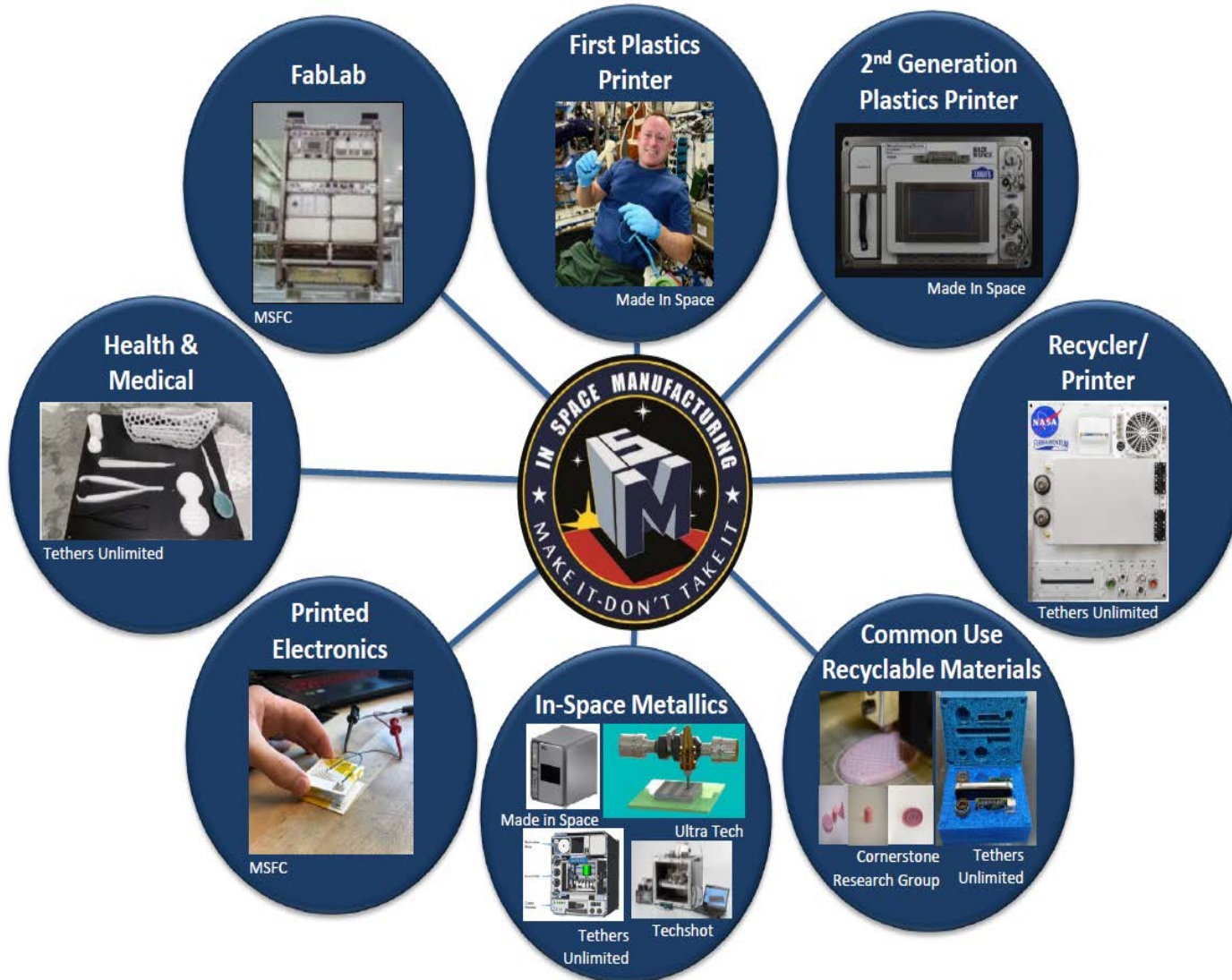


***One-of-a-kind Test-bed for exploration systems:
The International Space Station (ISS)***



In-Space Manufacturing (ISM) Project...

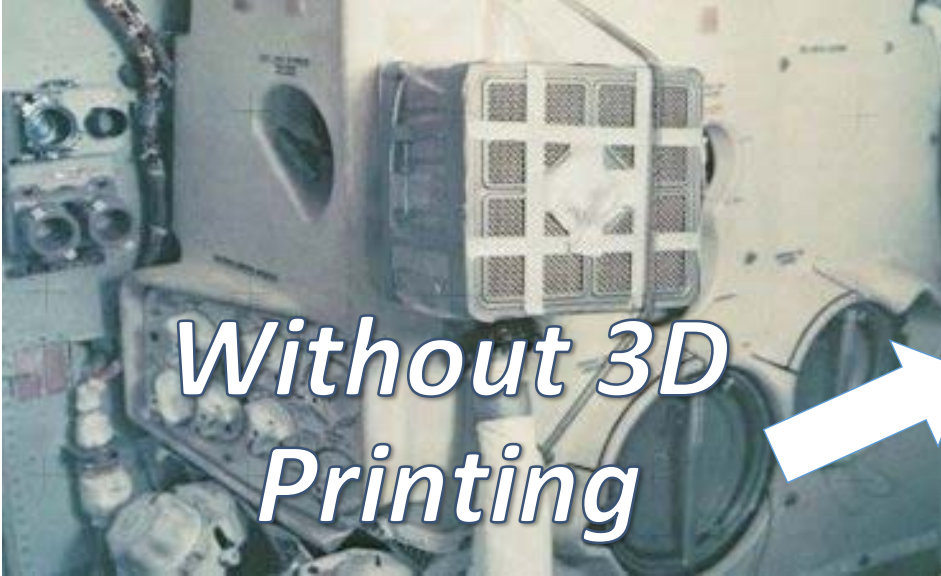
Make it, Don't Take it!



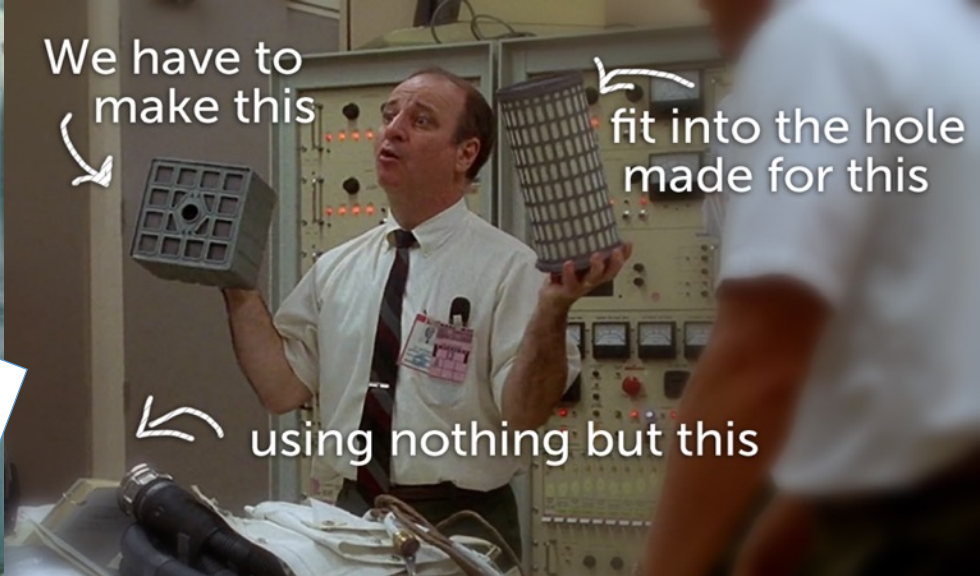
Objective:

To develop and demonstrate on-demand manufacturing, recycling, and repair capabilities for long-duration spaceflight missions.

- Replacement parts, repairs, new components from metals, plastics, electronics, and in-situ materials
- Recycling and reuse of waste materials & consumables



*Without 3D
Printing*

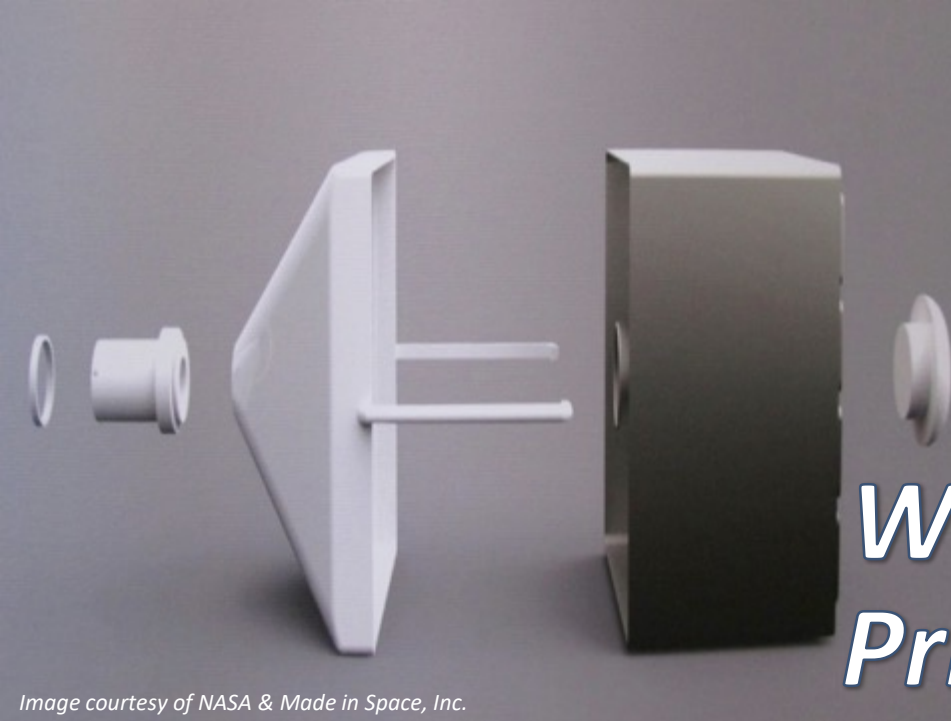


We have to make this

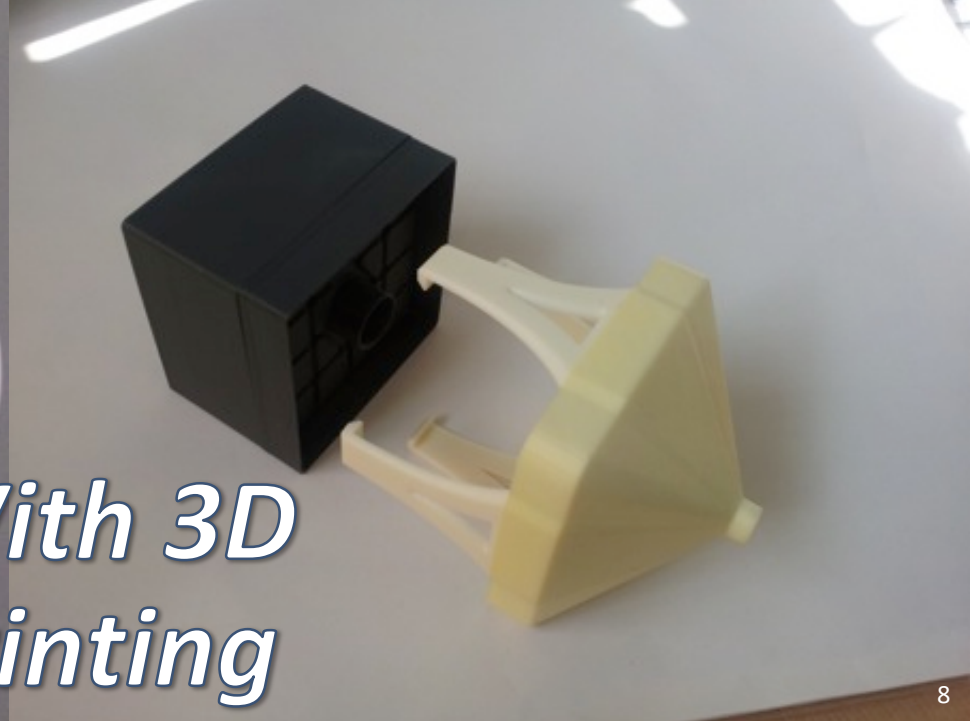
fit into the hole made for this

using nothing but this

Square peg in Round Hole? No problem!

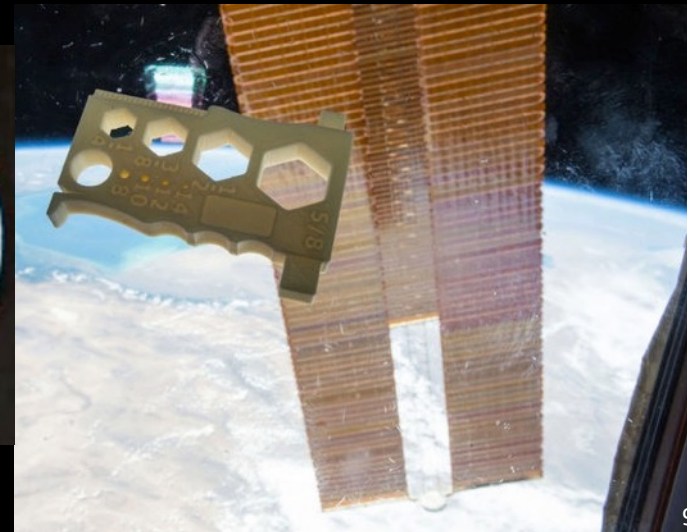


*With 3D
Printing*



First Step: Does 3D Printing Work in Space?

- In 2014, NASA and the company Made in Space, Inc. (MIS) sent the first 3D Printer to the International Space Station (ISS) .*
- There were 55 parts printed on ISS and then returned to Earth. Scientists and engineers at NASA tested and analyzed the returned samples to compare them to the ground samples.*
- It was determined that you can 3D print plastic parts in space the same way you do on Earth.*



Can you electronically uplink a part to space?



1. Design Part



2. Uplink to ISS



4. Make it on ISS



Captain 'Butch' Wilmore holding the first 3D Printed Wrench in Space on the ISS. The design file for the wrench was "e-mailed" (i.e. uplinked) from the ground to the ISS.

And then...the Additive Manufacturing Facility (AMF) by Made in Space, Inc.



- The second 3D Printer, the Additive Manufacturing Facility (AMF), has been operating on the International Space Station (ISS) since 2016.
- This printer is owned and operated by Made in Space, Inc. through agreement with the ISS National Lab.
- NASA is one of the customers, as well as other government agencies, industry, and academia.
- AMF can print with three types of plastic: ABS, ULTEM and High-density Polyethylene.

Examples of Parts Manufactured on the ISS AMF



*SPHERES Free Flier Tow Hitch: This part joins two of the ISS free-fliers together in tandem
Printed 2/21/17*



*Radiation Enclosure Module (REM) printed in different thicknesses to hold monitors for radiation testing
Printed 3/20/17, 5/30/17, and 6/16/17*



Antenna Feed Horn which is being tested with various printed coatings for in-space use Printed 3/9/17 and returned on SpaceX-10 3/20/17



*Oxygen Generation System (OGS) Adapter attaches over air to obtain a consistent and accurate reading of airflow through
Printed on 7/19/2016.*



Let's Talk Trash...

Did you know....on the International Space Station, astronauts currently squeeze their garbage into trash bags (known as “trash footballs”) and, for temporary periods of time, store up to **2 metric tons** of trash on board before burning it up on re-entry!!

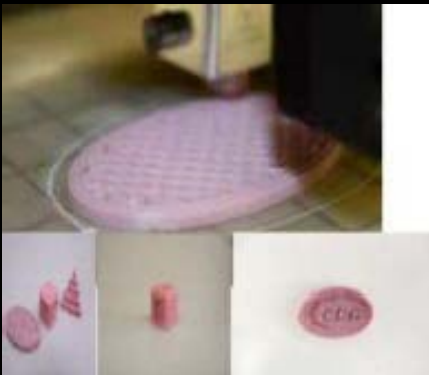


What if we could recycle materials in space?

- **By recycling parts, NASA won't have to launch as much material or spare parts. We can even recycle plastic bags, packing foam, and food containers into new items!**
- **On Earth, this technology could use old water bottles and plastic bags to make filament to 3D print with!**



ReFabricator payload from Tethers Unlimited.



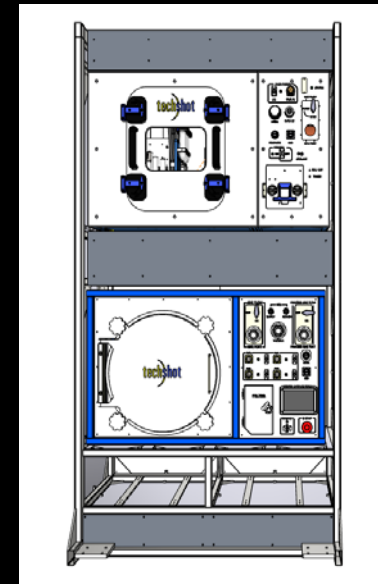
Recyclable packaging material developed by Cornerstone Research Group (CRG). Image provided by CRG.

Coming Soon: 3D Printing of Metals in Space!

- Many of the parts we may need to manufacture on long duration space missions are metal.
- NASA uses ground-based 3D printing of metals to produce components for rocket engines. 3D printing of metals can accelerate development and testing for engines by reducing lead times and cost for complex parts.
- Most 3D metal printers use metal powder and lasers to fuse the powder together layer by layer.
- For space, we are considering processes which use feedstock in wire (rather than powder) form.
- Another process being considered is solid state (i.e. does not melt metal material during the printing process).
- In the early 2020s, ISM is working toward deploying a **multi-material manufacturing facility for ISS** (approximately the size of a refrigerator) which can print with common metals used in space systems.

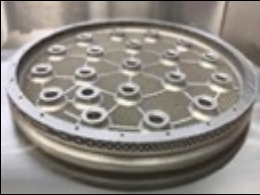


*Vulcan unit from Made in Space, Inc.
(phase II small business contract)*



*Rendering of
Techshot, Inc.
Fabrication
Laboratory for
ISS (image from
Techshot)*

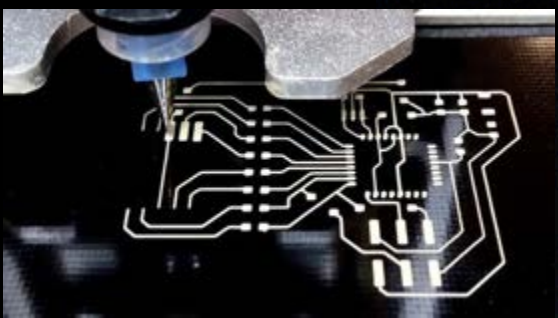
Stay Tuned - Coming to a Mission (not) Near You....



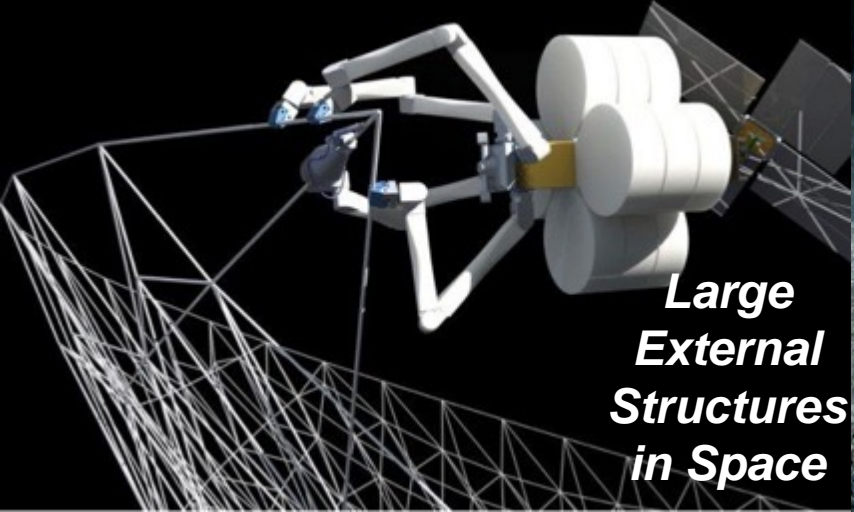
**The FabLab
Multi-
material
Printer for
Metals**



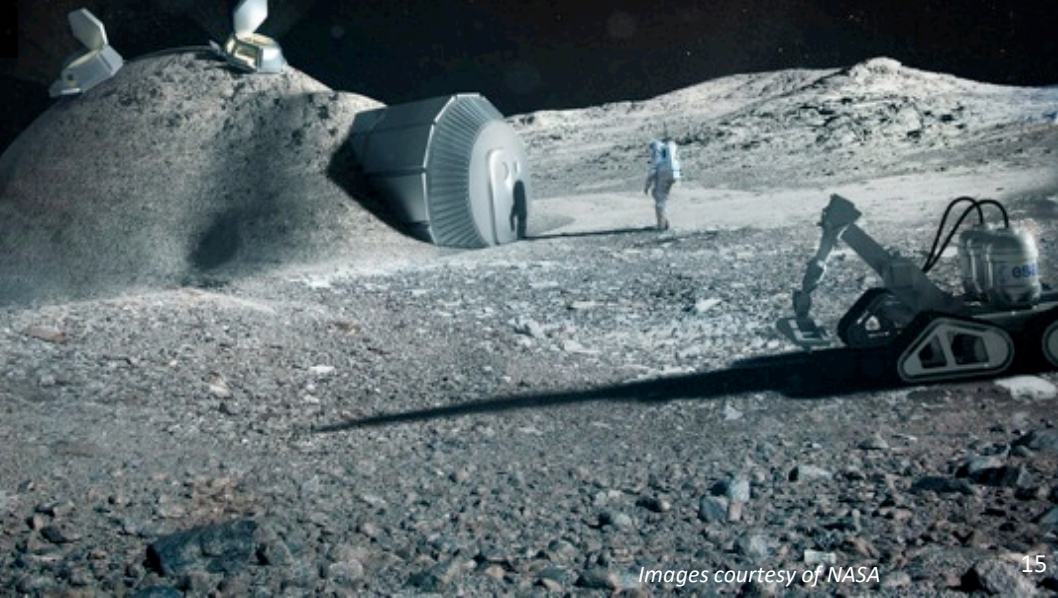
**3D Printed
Electronics
&
Wearables**



**Additive Construction
of Habitats Using In-
Situ Resources (i.e.
Moon or Mars "Dirt")!!**



**Large
External
Structures
in Space**



Questions

“Every revolutionary idea seems to evoke three stages of reaction:

- 1. It’s completely impossible.*
- 2. It’s possible, but it’s not worth doing.*
- 3. I said it was a good idea all along.”*

-Arthur C. Clarke



*Tea.
Earl Grey.
Hot.*

“If what you’re doing is not seen by some people as science fiction, it’s probably not transformative enough.” -Sergey Brin

Acknowledgments

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 - **Christopher Roberts**
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 - **Made in Space**
 - **Techshot, Inc.**
 - **Tethers Unlimited**
 - **Cornerstone Research Group**
 - **Ultra Tech Machinery**
 - **Fabrisonic**