



EXPLORE MOON_{to}MARS

Plasma Applications for Space Biological Systems

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SURA Workshop on Space Biology

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1. Bennett Aerospace, Kennedy Space Center, Florida, USA
2. Astrion, Inc., Kennedy Space Center, Florida, USA
3. NASA, Kennedy Space Center, Florida, USA

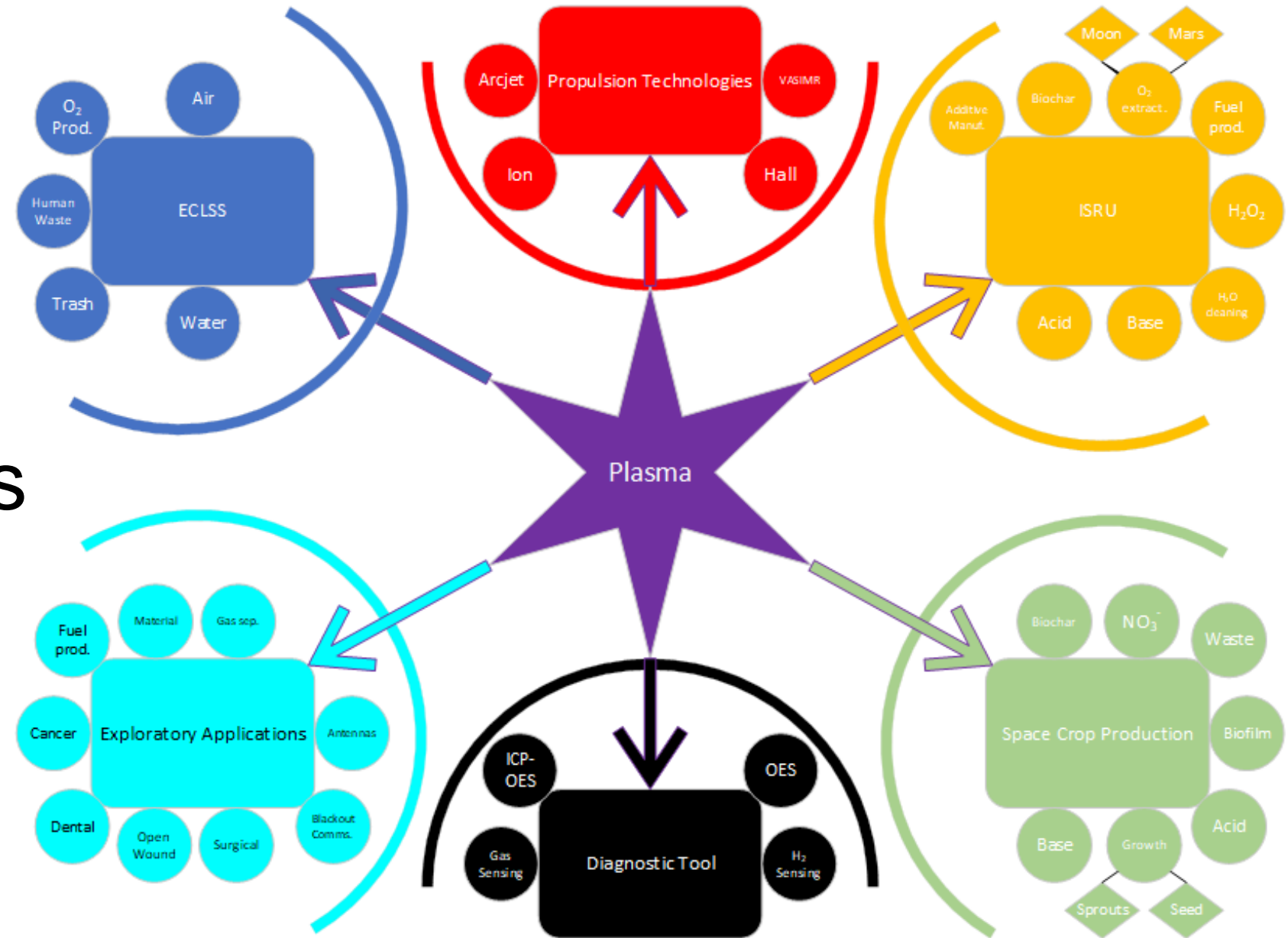
Plasma

Differentiate between thermal temperature and electron temperature (both are based on Boltzmann distributions)

- DC: Thermal $T = 3,000$ to $5,000$ K
- AC: Thermal $T = 1,000$ to $3,000$ K
- Pulse: Thermal $T =$ room temp
- Electron temp depends on plasma waveform (voltage, frequency, pulse width, etc.)



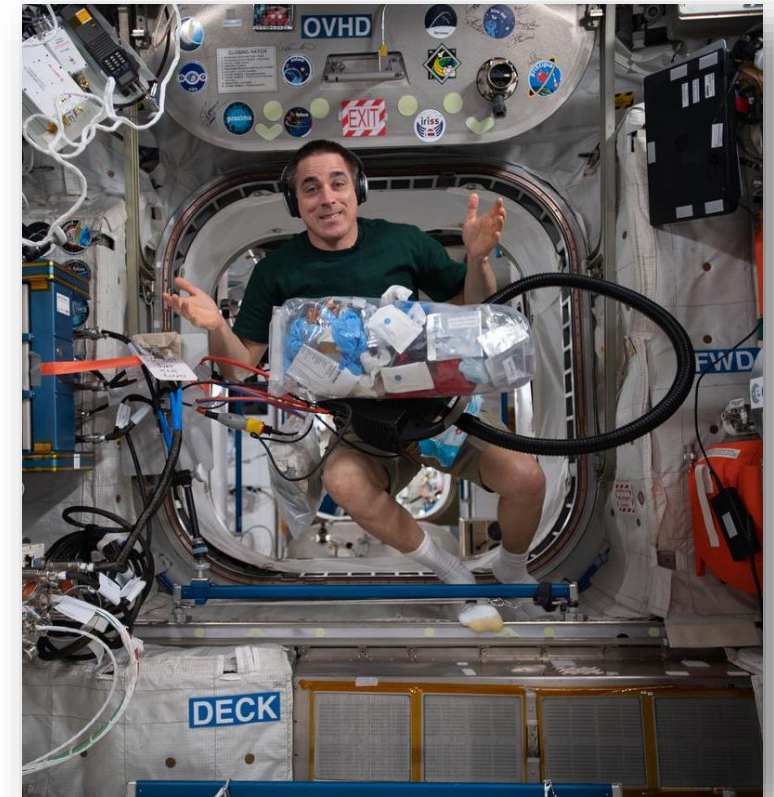
Plasma in Space Applications



Trash is a Problem in Space

- Represents mass with little to no benefit.
- Mass requires fuel, not only for launch, but for transit insertion and orbit injection burns (multiplicative).
- Occupies spacecraft volume.
- Produces odor.

*Note: Astronaut waste is a complex mixture that includes textiles, food and food packaging, metabolic wastes (feces and urine), various and sundry wastes (toothpaste, rubber gloves, duct tape, paper, tissues, etc.).



NASA Image ID: iss063e066984 (Aug. 8, 2020) --- NASA astronaut and Expedition 63 Commander Chris Cassidy collects trash for disposal during weekend housekeeping activities aboard the International Space Station.

One Astronaut's Trash Production

550 days (Mars mission)
800 kg of waste
2536 'footballs'



1 day
1.5 kg
5 'footballs'

7 days
10 kg
32 'footballs'

30 days
43.5 kg
138 'footballs'

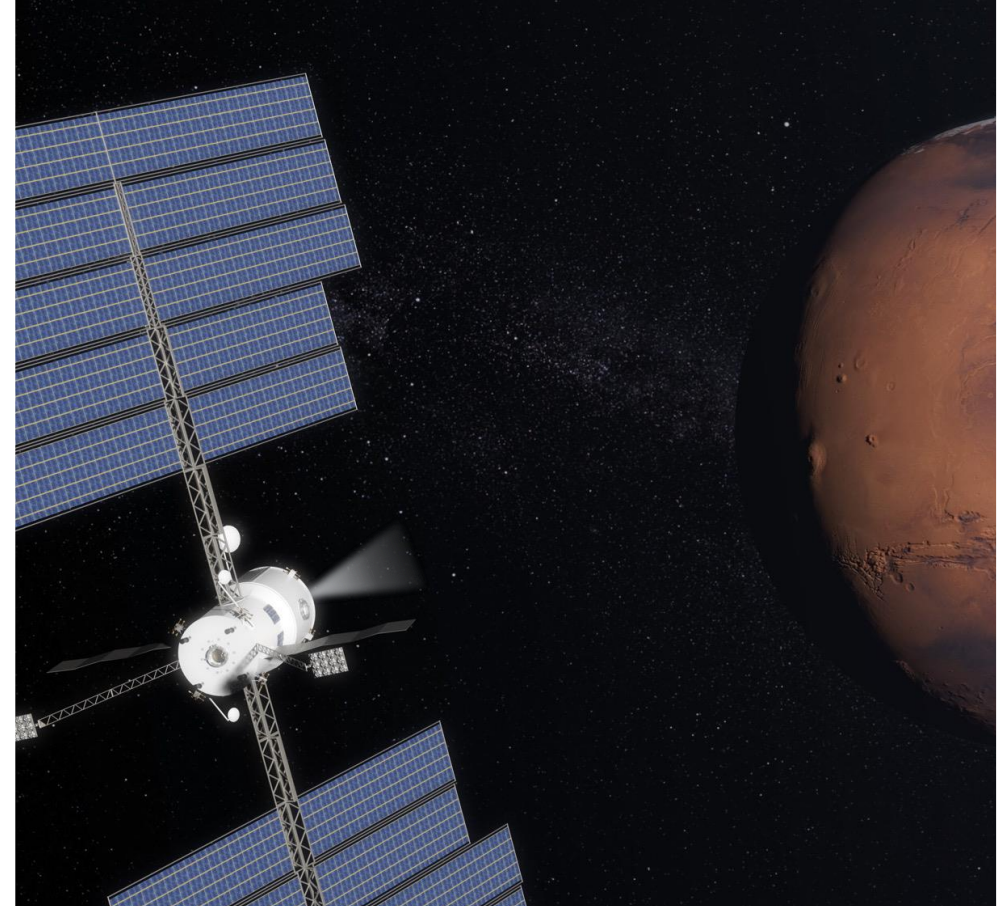
Trash-to-Gas Model

Thermal process to convert solid to gas (combustion, incineration, steam reforming, pyrolysis, torrefaction, etc.).

Produces gases such as CO_2 , CO , H_2 , CH_4 , additional hydrocarbons.

Effluent passed through Sabatier reactor to recover oxygen (as H_2O).

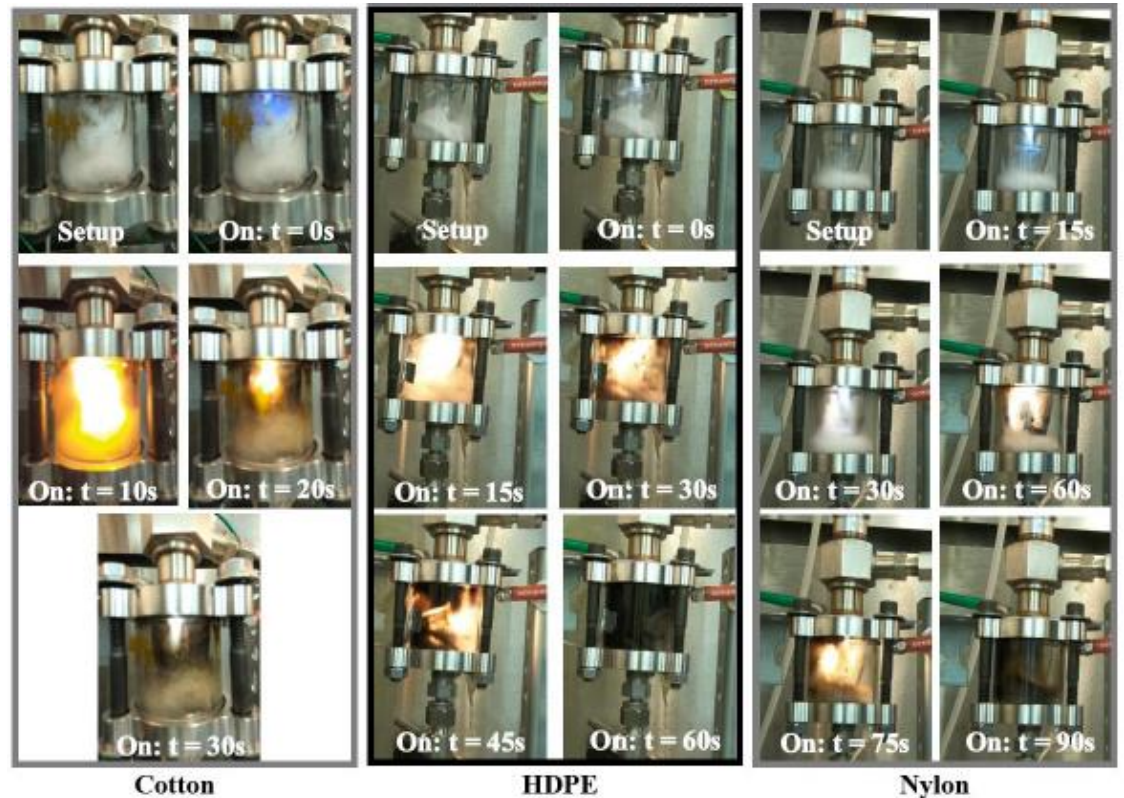
Resulting gases vented to space = mass reduction.



Plasma Waste Gasification

- DC plasma (to provide thermal breakdown).
- 87% solid to gas conversion.
- Also directly produces oxygen due to presence of CO₂.
- For a mission to Mars, expected launch mass savings = 6,151 kg (~2%) compared to trash stowage.
- Not yet optimized (low TRL).

DC, waste gasification of astronaut materials.



A. Meier, et al., ICES-2019-128.; J.A. Olson, et al., ICES-2021-282.; J.A. Olson, et al., ASCEND 2021, 4080.

In-Situ Resource Utilization (ISRU)

Additive Manufacturing via Plasma-based Chemical Synthesis
Point-of-use conversion of waste and/or benign materials into useful (but more hazardous) chemicals.



DC, nitrogen plasma torch in a quartz cell.

In-Situ Resource Utilization (ISRU)

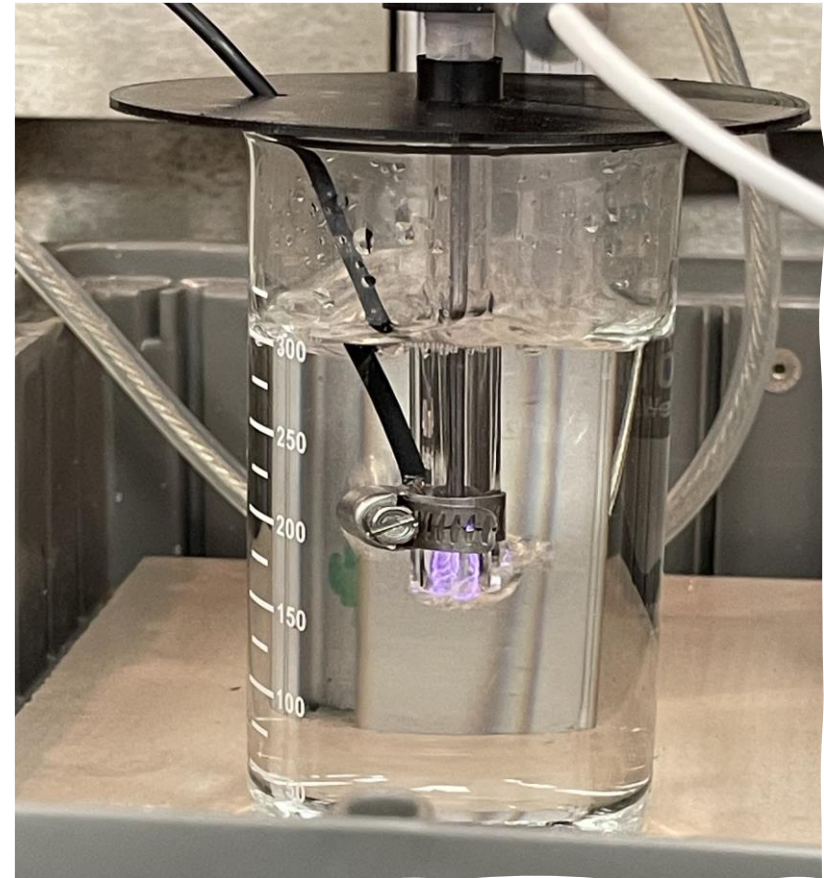
Plasma-Activated Water (PAW)

Feedstocks: Nitrogen/Oxygen plasma through water.

Products: Nitric acid (pH as low as 1.8).

Feedstocks: Inedible Biomass

Products: Biochar (activated carbon), ash (pH as high as 11.5)



Plasma jet in water

In-Situ Resource Utilization (ISRU)

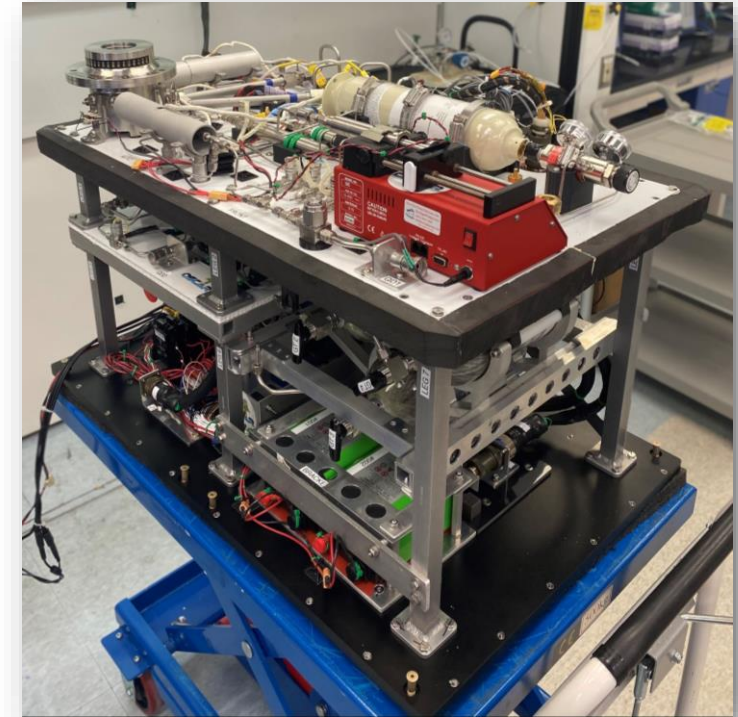
pH-balanced PAW nitrate solutions were demonstrated to enhance plant growth.



R.P. Gott, et al., ICES-2023-234.

Plasma VOC Abatement

- Volatile Organic Compounds (VOCs) are common byproducts of important systems
 - Hygiene Products
 - Mechanical Lubricants
 - Trash to Gas technology
- The current state of the art for reduction of VOCs relies on consumable scrubbers
 - Plasma reduces logistics and uses only electricity (~50 W)



OSCAR – Orbital Syngas Commodity Augmentation Reactor
Launched 8/2021 Blue Origin NS-17

Plasma VOC Abatement

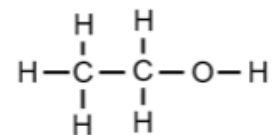
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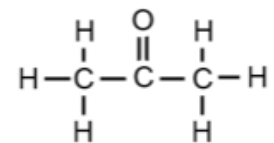
SMAC List

73 individual species that are ubiquitous to space operations and pose a hazard to crew health

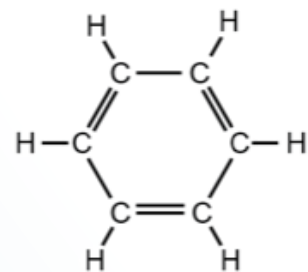
Ethanol



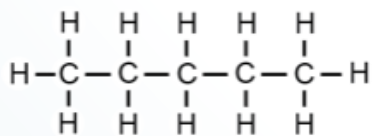
Acetone



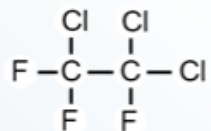
Benzene



Pentane



Freon 113



JSC 20584

Spacecraft Maximum Allowable Concentrations for Airborne Contaminants

Human Health and Performance Directorate

Biomedical Research and Environmental Sciences Control Board
(BRESCB) Controlled

Revision B

November 2022

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Houston, Texas

www.nasa.gov/wp-content/uploads/2023/03/jsc-20584-rev-b-final-rev-b-signed-0.pdf

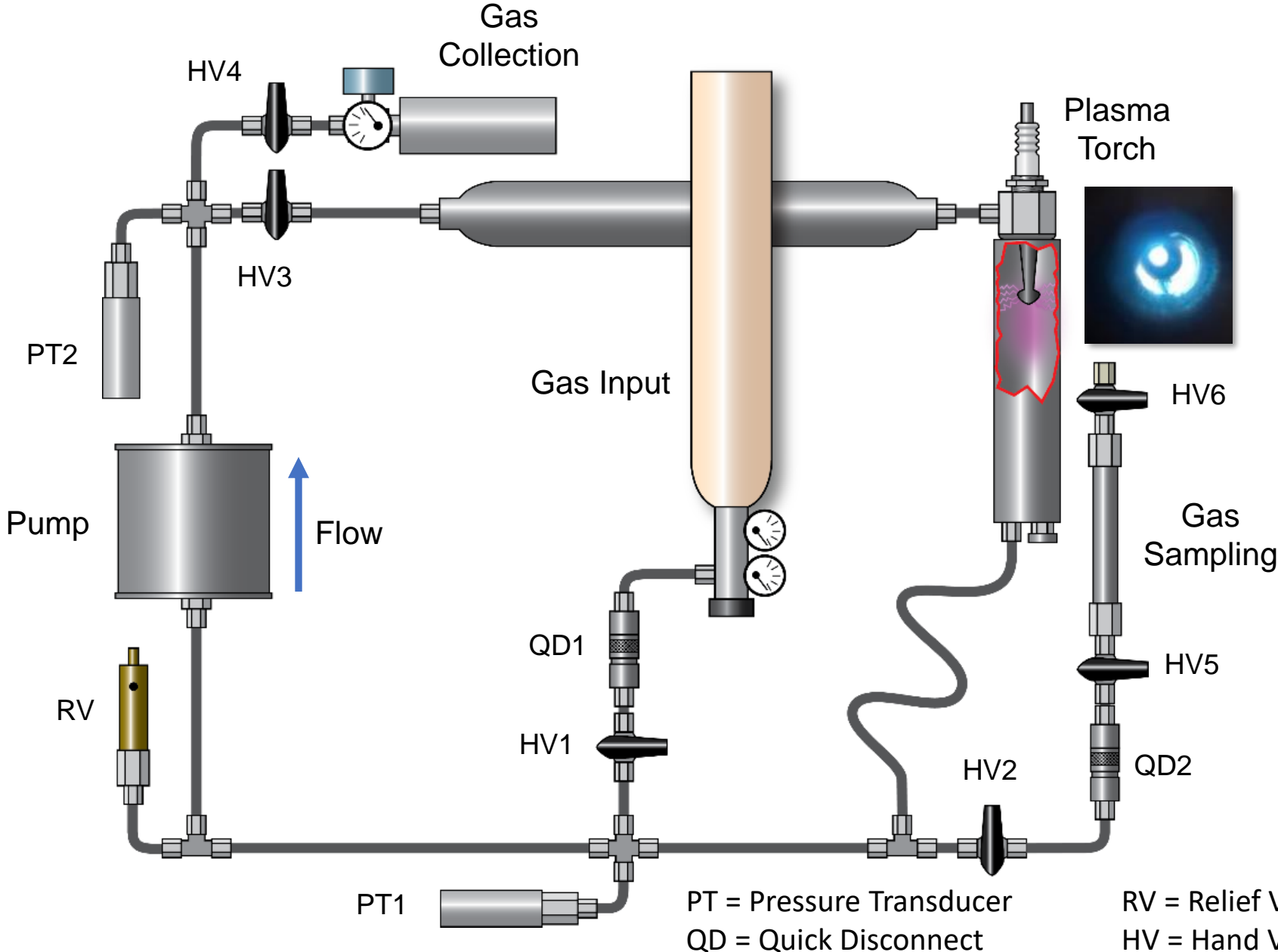
SMAC List

Analyte	1 hr	24 hr	7 day	30 day	180 day	1000 day
Acetone	500	200	22	22	22	Not Set
Pentane	150	80	60	20	3	Not Set
Benzene	10	3	0.5	0.1	0.07	0.013
Ethanol	5000	5000	1000	1000	1000	1000
Freon 113	50	50	50	50	50	Not Set

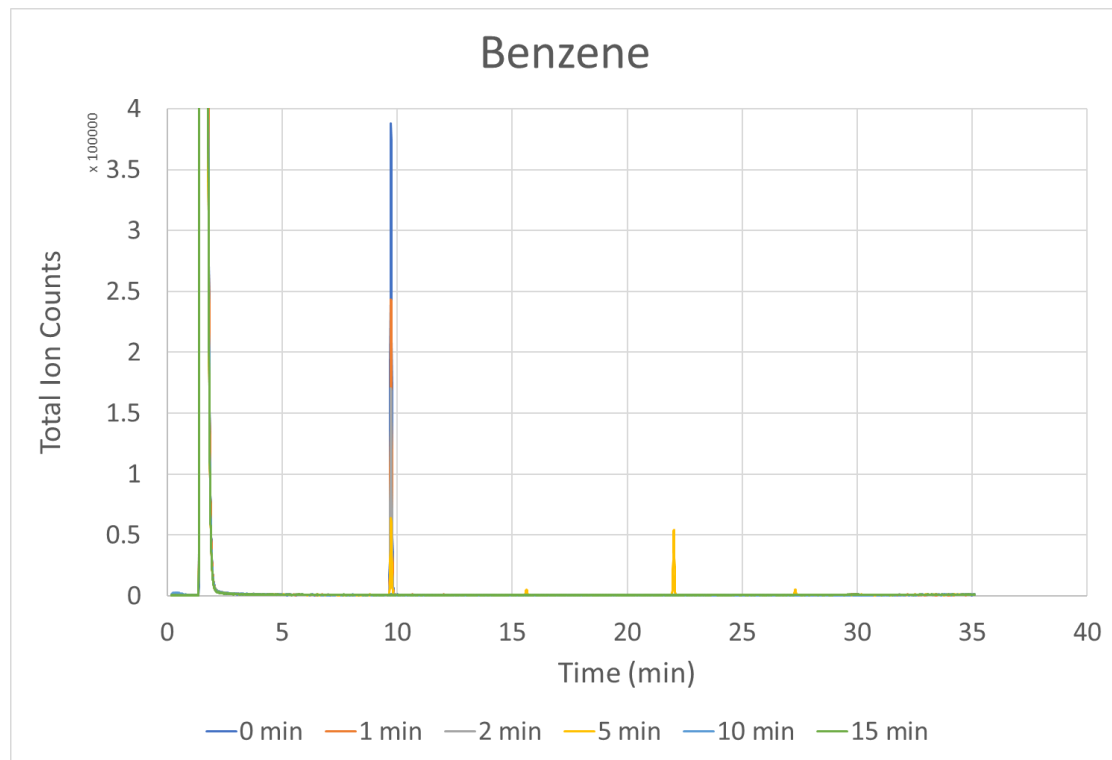
Spacecraft Maximum Allowable Concentration limits are shown in ppm.

Experimental

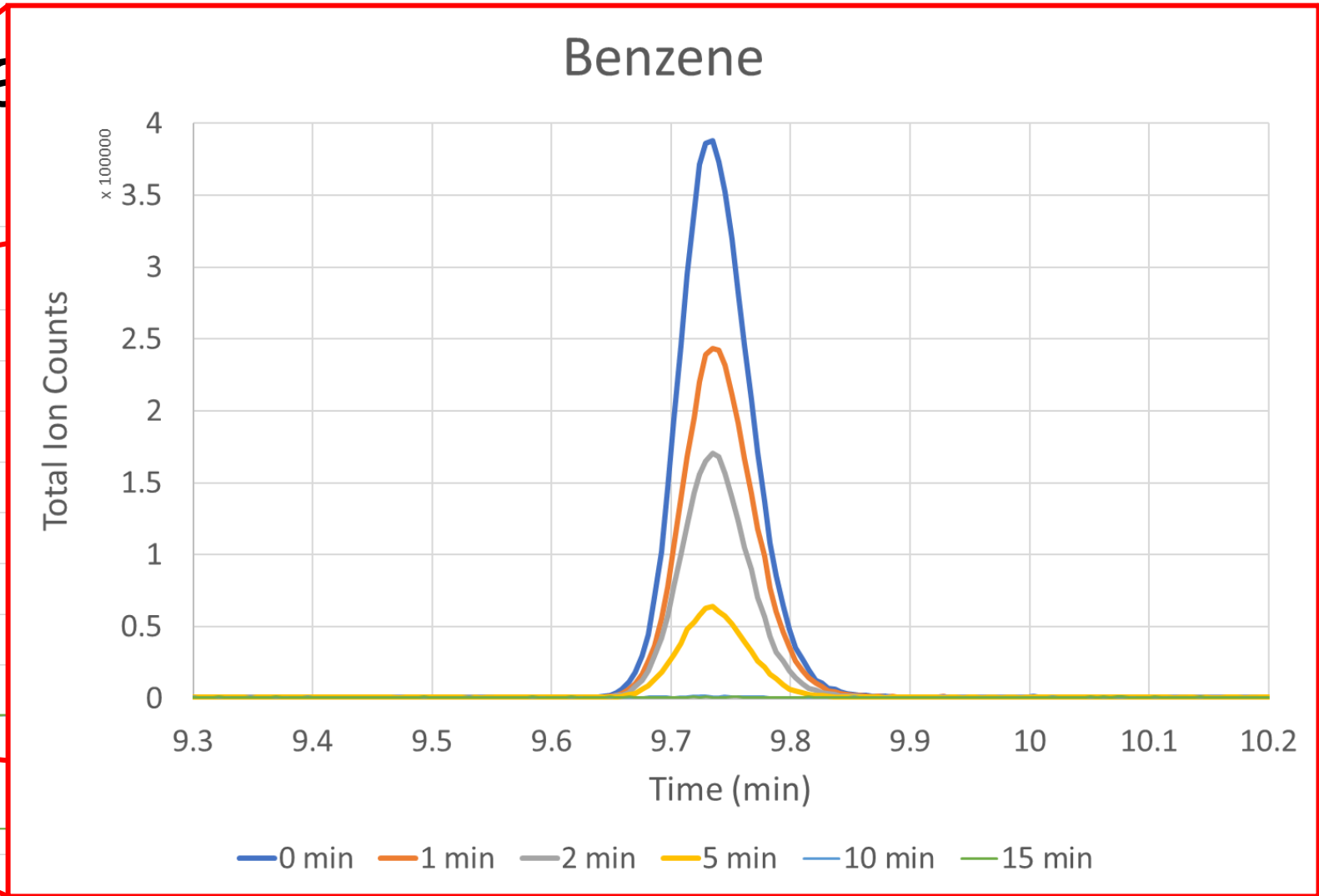
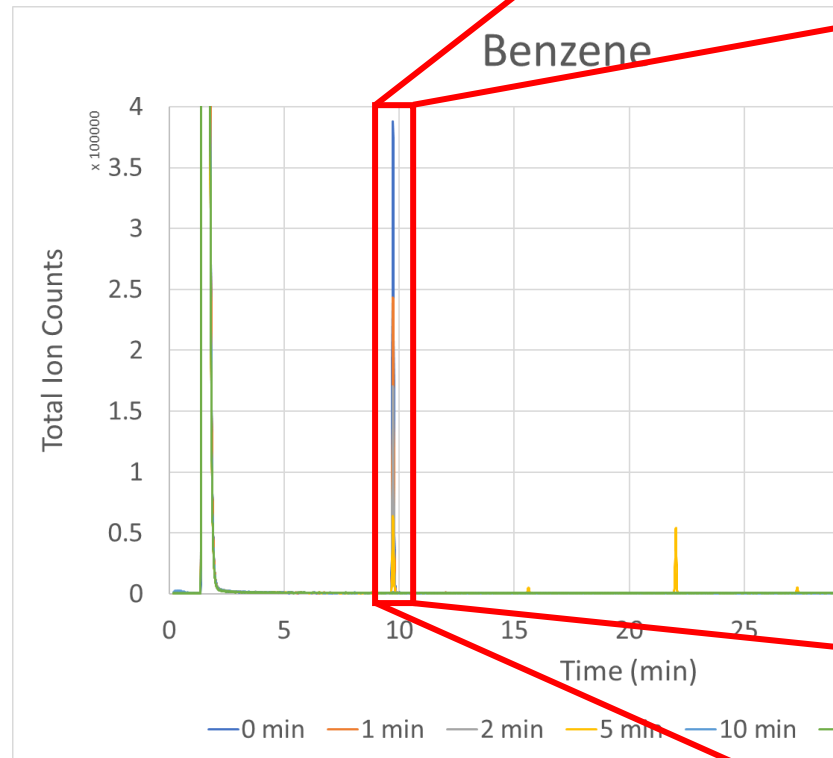
1. Introduce 100 ppm of a select VOC.
2. Recirculate and sample gases at 1, 2, 5, 10, and 15 minutes.
3. Quantify VOC via gas chromatography mass spectrometry (GCMS).



Chromatogram



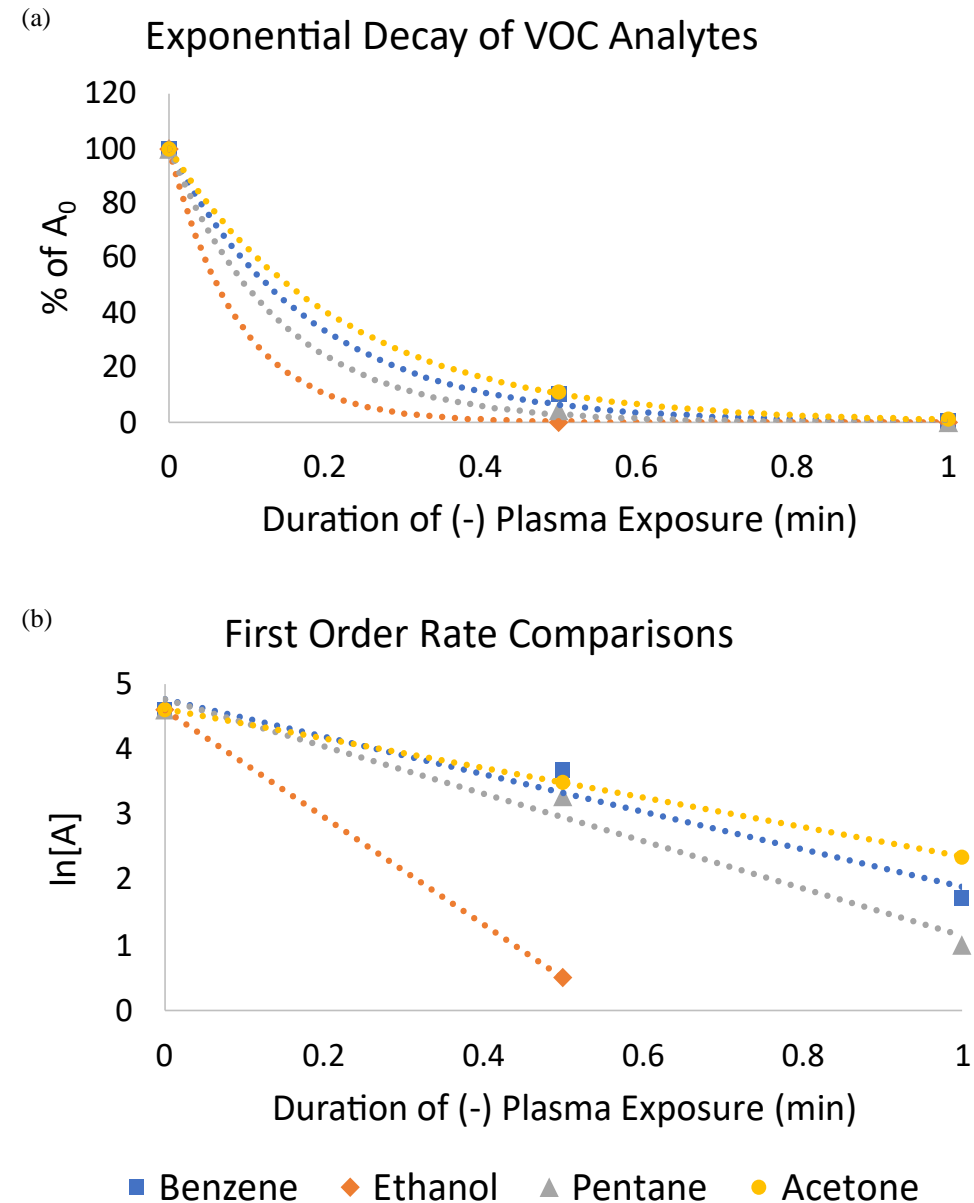
Chromatogram



Results

CO₂ Balance Gas, (-) plasma

Analyte	k (min ⁻¹)	t _{1/2} (min)
Ethanol	9.43	0.074
Acetone	3.94	0.176
Pentane	6.88	0.101
Benzene	5.90	0.118

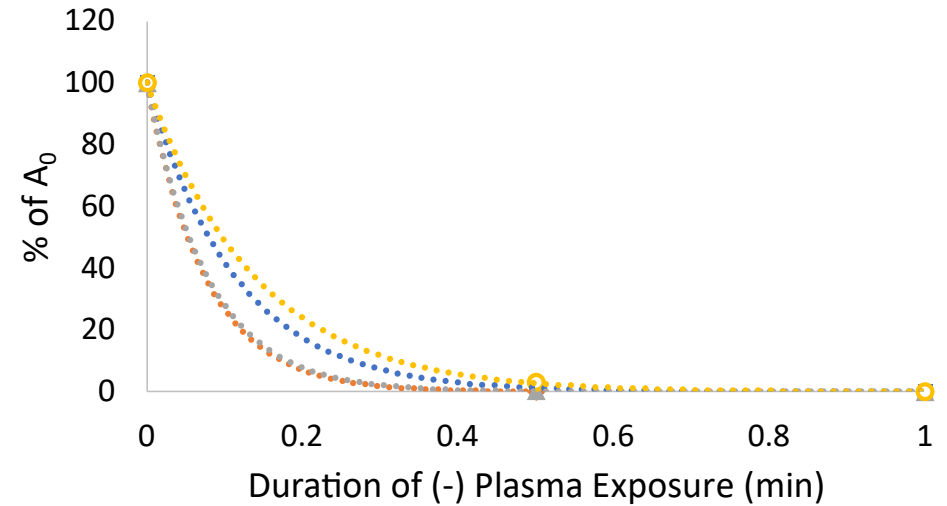


Results

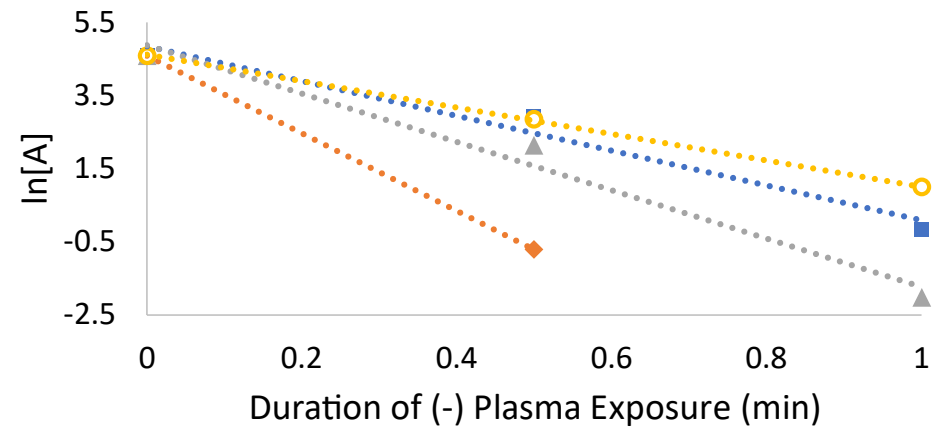
N₂ Balance Gas, (-) plasma

Analyte	k (min ⁻¹)	t _{1/2} (min)
Ethanol	7.99	0.0868
Freon 113	7.47	0.0928
Pentane	11.13	0.0623
Benzene	7.52	0.0921

(a) Exponential Decay of VOC Analytes



(b) First Order Rate Comparisons



■ Benzene ◆ Ethanol ▲ Pentane ● Freon 113

Capabilities Under Investigation at NASA's Kennedy Space Center

Space Crop Production

- Enabling of crop nutrient production
- Further close the space crop loop
- Nitrogen fixation (Mars*)
- Nutrient recovery of inedible biomass
- Hydroponic pH stability

Water Processing

- Treatment of contaminants in water
- Oxidative reactions
- pH stability
- Breakdown of chemicals
- Conductivity control

Capabilities Under Investigation at NASA's Kennedy Space Center

Logistics Reduction

- Fertilizer resupply reduction
- Acid-base production
- Soap for sanitation
- Mitigation of inedible biomass waste handling

In-Space Manufacturing

- Acid-base production
- Ash generation for potential additives

ISRU

- NO_3 in-situ on Mars
- Oxygen extraction from regolith
- On-Demand, point-of-use fuel production
- Electricity and air as consumables

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- NASA Postdoctoral Program/Oak Ridge Associated Universities
- NASA's OSTEM Internship Program

Thank you!

Any questions are welcome.
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