Advanced Organic Waste Gasifier

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NASA SBIR PHASE I CONTRACT NO. 80NSSC18P1958

– RECENTLY SELECTED FOR PHASE II AWARD

Identification and Significance of the Innovation

- The objective of the Phase I Advanced Organic Waste Gasifier (AOWG) project was to fabricate, test, and refine a reactor system capable of processing organic wastes to produce clean water for recycle during Mars transit to support human exploration missions.
- Wastes generated on Mars transit spacecraft are gasified in an oxygenated steam environment so that all organic matter in liquid and solid form (including feces and urine brine) is converted to vapor phase.
- The AOWG, which is designed for operation in microgravity, recovers water for recycle from the gasifier product gas while also producing a clean, dry gas suitable for venting. Only a small mass of sterile, solid inorganic waste remains from metallic packaging materials or other inorganic matter contained in the waste fed to the AOWG.

Key AOWG Phase I Conclusions

- The AOWG was shown to have significant mass leverage for Mars transit and Earth return missions as a result of its ability to recover water for re-use while generating clean, dry gas for venting from the spacecraft. The preliminary projection of 90 kg AOWG mass allows for recovery of between 500 to 900 kg of water while venting about 1250 to 2100 kg of dry gas (depending on the propulsion system and mission architecture). The mass estimates are based on a round trip assuming no operation during vicinity stay.
- A preliminary AOWG operating power estimate of up to 600 watts, including electrolysis to support production of oxygen for steam reforming, was established from evaluation of system requirements. About half of the system power is dedicated to electrolysis.

AOWG System Modeling

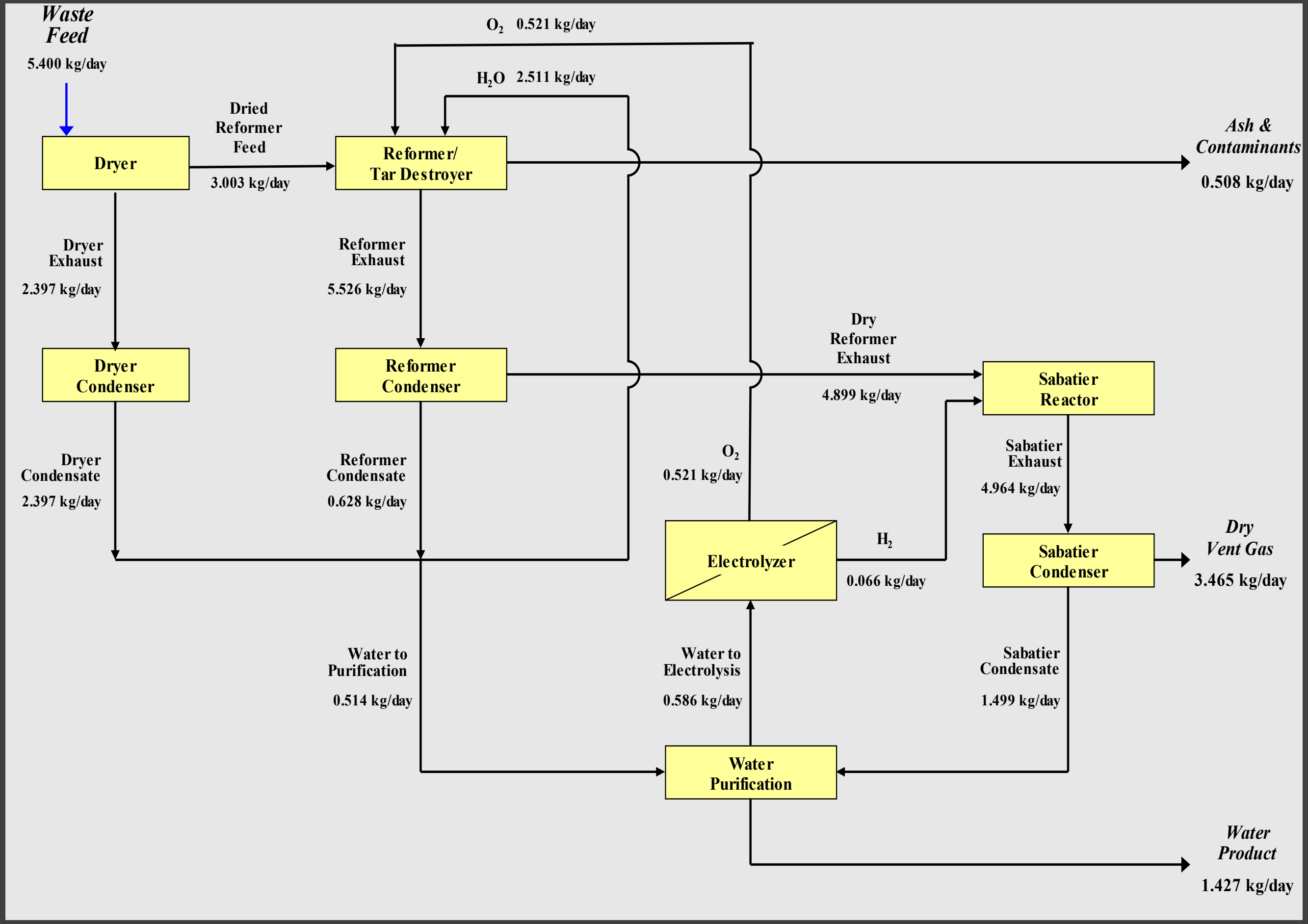
- Project observed laboratory results for a range of feed compositions and operating rates
- Crew of 4
- Integrated electrolysis
- 100% on-stream factor
- Waste composition (based on NASA High Fidelity Waste Simulant):

Waste Component	Mass % (as-received basis)	Mass, kg (average daily rate)	Mass % (contaminant-free basis)	Mass % (dry, contaminant-free basis)
Moisture	44.40	2.397	49.0	---
Total Organic Carbon	31.00	1.674	34.2	67.1
Total Organic Hydrogen	4.20	0.227	4.5	9.1
Total Organic Oxygen	11.00	0.594	12.1	23.8
Gaseous Contaminants	4.70	0.254	---	---
Solid Contaminants	4.70	0.254	---	---
Total	100.00	5.400	100.0	100.0

Modeling: Optimization of Water Recovery

- Methanation and Reverse Water Gas Shift (RWGS) reactions were evaluated as options to maximize water recovery from gaseous compounds present in the dry AOWG reformer exhaust
- Oxygenated steam reforming followed by a single-pass Sabatier methanation reactor was determined to yield nearly three times as much water as reforming followed by RWGS

AOWG-Methanation Mass Balance



AOWG-Methanation Vent Gas Composition

Gas Constituent	Volume %
H_2	0.0
CO_2	25.0
CO	15.3
CH_4	59.7
Total	100.0

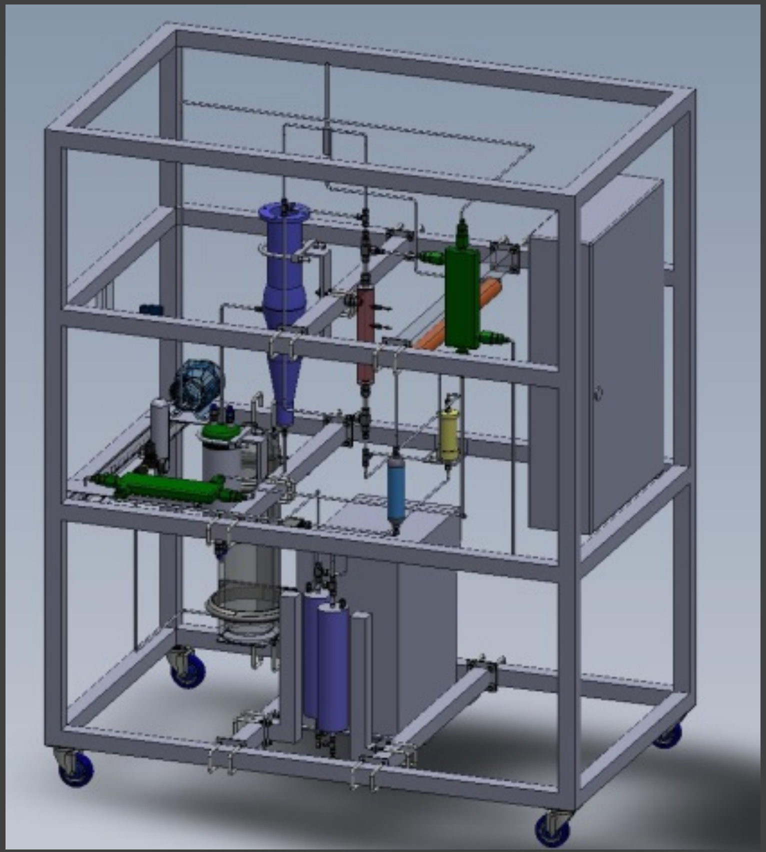
Final AOWG Phase I Baseline Design

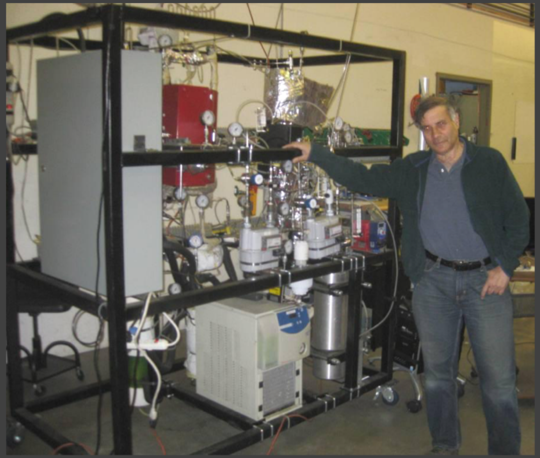
- Baseline integrated AOWG design was established on the basis of the Phase I modeling, design, and operation results. The baseline design includes features to enable operation in microgravity and include:
    - a shredder to reduce waste to a particle size suitable for a compact reforming reactor system,
    - a pneumatic assisted material conveying system,
    - a feed dryer using waste heat to remove most of the feed moisture (to minimize risk of reactor quenching in the event of the introduction of a high-moisture slug of feed, to minimize oxygen requirements, to improve control stability, and to reduce risk by allowing continued water recovery and purification in the event of reformer system failure)

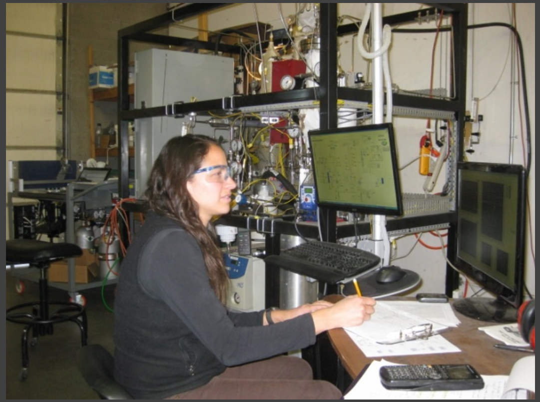
Final AOWG Phase I Baseline Design

- The baseline design includes features to enable operation in microgravity and include (continued):
  - actuated linear cylinders to ensure movement of material and to clear any adhered or bridged waste,
  - a catalytic tar destruction reactor to substantially reduce the amount of organic contamination in the reformer condensate,
  - a condensate purification system tailored to the AOWG to produce electrolysis grade water

Background:
Lunar Organic Waste Reformer
NASA SBIR Phase II Contract NNX11CA76C

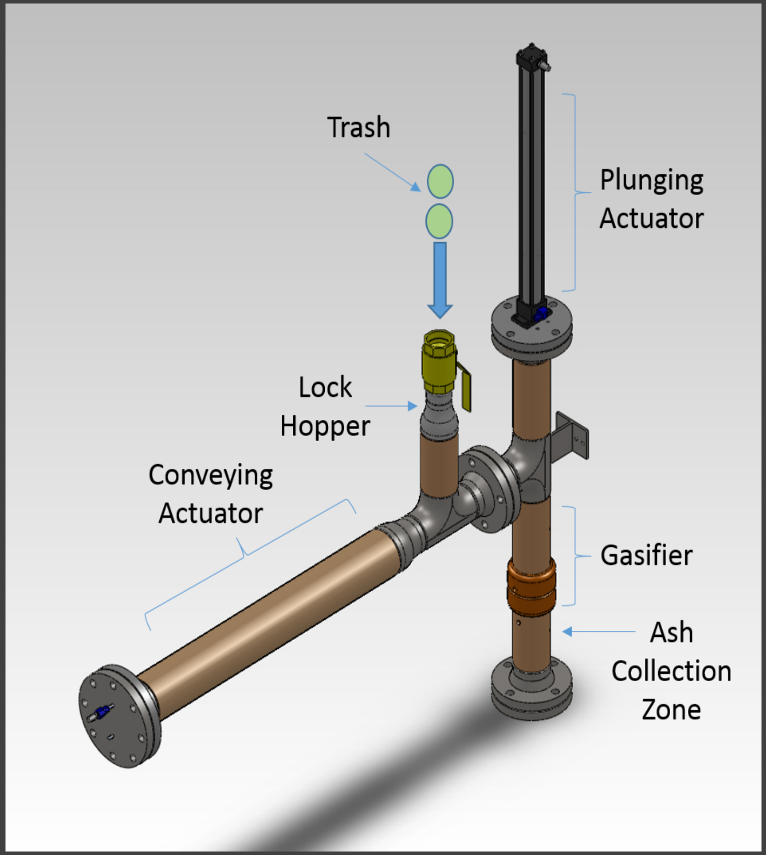


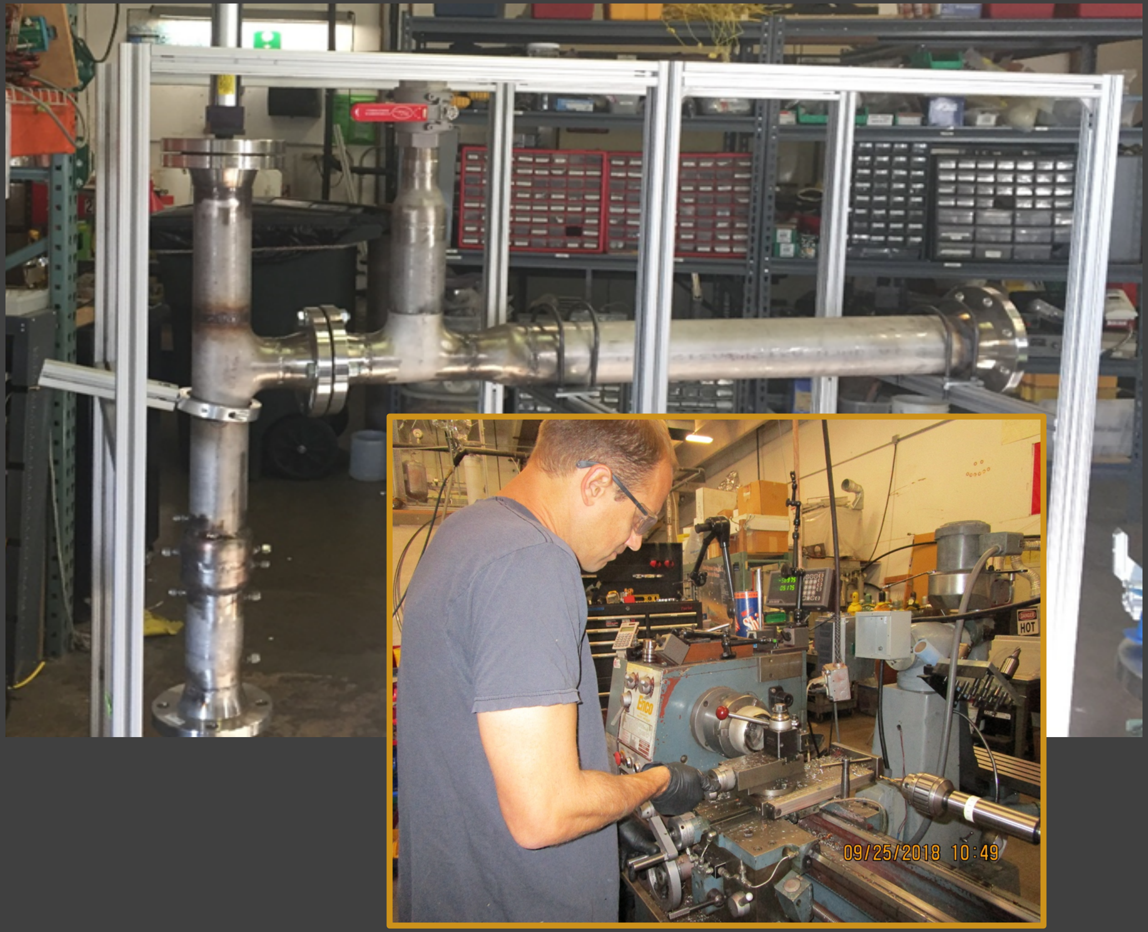




- Utilizes high temperature steam reformation to convert all lunar-base plastic, paper, and other organic waste materials into useful gases.
- At high temperatures, oxygenated steam reacts with organic materials to produce a gas mixture largely composed of hydrogen, carbon monoxide, and carbon dioxide.
- The exhaust gases are fed to a catalytic reactor where they are combined with additional hydrogen from electrolysis to produce methane along with oxygen as propellant.

AOWG Phase I 'Bolt-action Rifle' Feed Delivery System



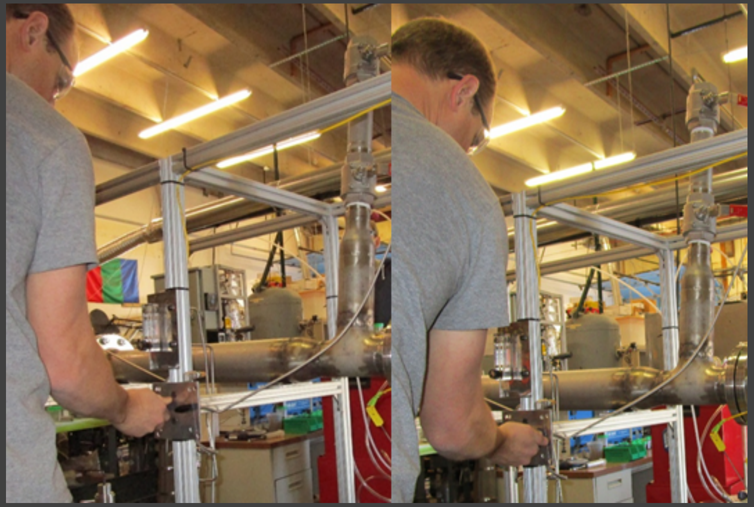


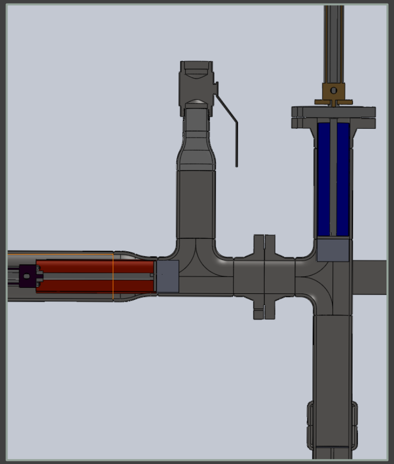
Phase I Feed Delivery System

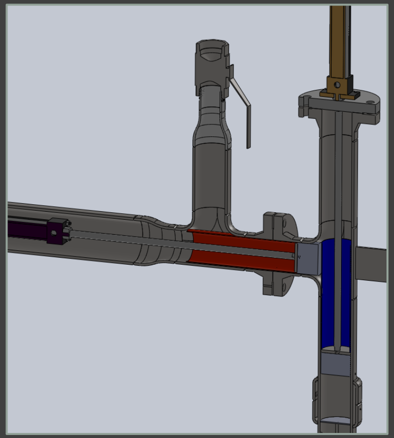
Feed Introduction Procedure

- Set valves to default position
- Open V1 (upper lock hopper valve)
- Load 1 waste football
- Close V1
- Open V2 (lower lock hopper valve)
- Close V2
- Open V1
- Inspect exposed lock hopper to ensure waste football has entered AOWG
- Close V1
- Operate feed movement system/repeat as necessary to feed for continuous operation

Phase I Feed Delivery System





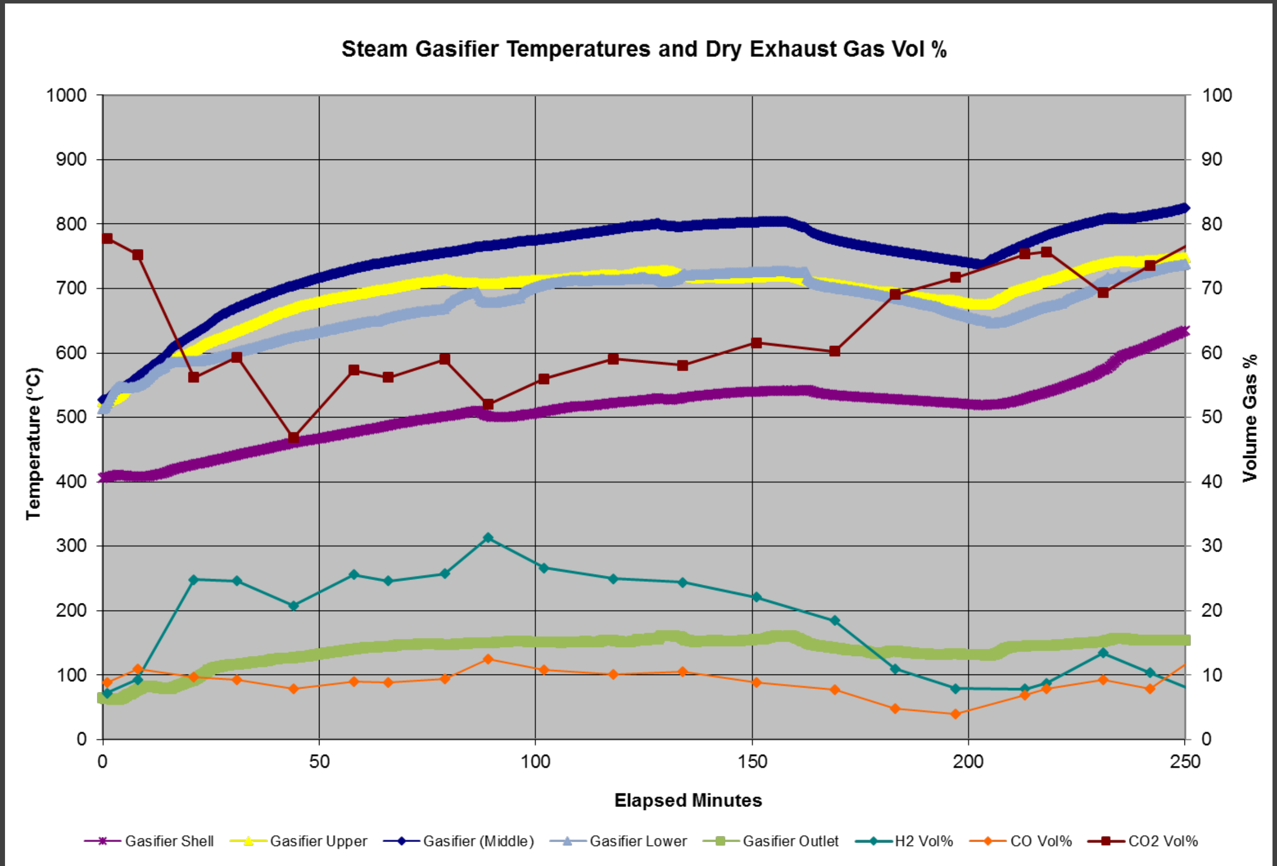


Feed Movement Procedure (while operating reformer)

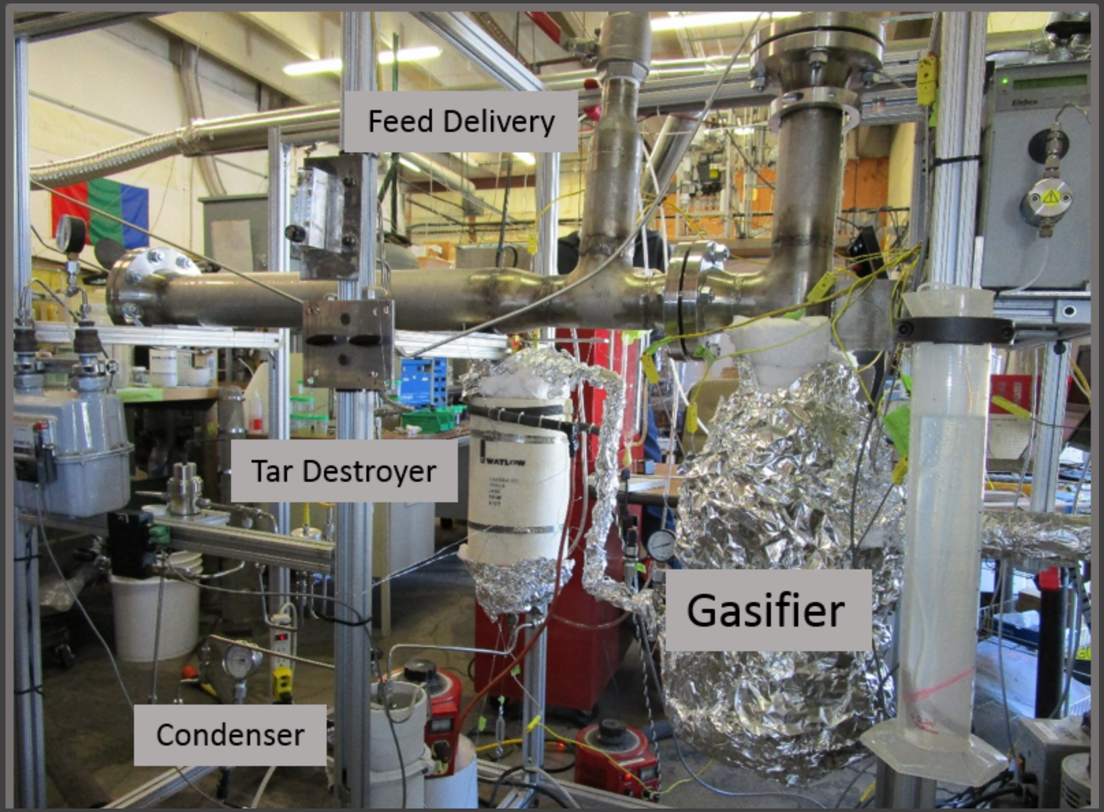
- Set actuators to default position
- Retract AS (horizontal feed plunger)
- Follow feed introduction procedure
- Ensure that V1 and V2 are closed
- Retract AT (vertical reactor plunger)
- Extend AS
- Retract AS
- Extend AT
- Retract AT
- Extend AS (seal for lock hopper)
- Extend AT (weight)

Duplicate operations performed in Phase I to ensure all feed was delivered.

Oxygen-enhanced Steam Reformation



Tar Destruction Reactor



- Minimizes contamination of gasifier condensate by organic matter
- Contains olivine catalyst
- Located downstream of gasifier
- Operates at ≥ 700°C

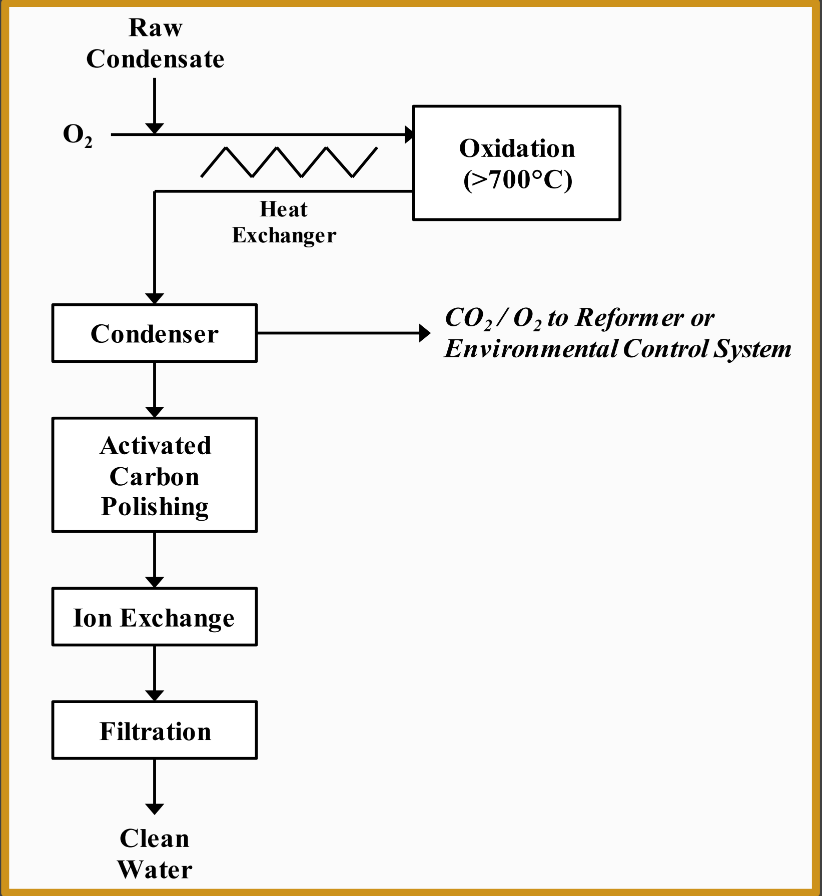
Tar Destruction Reactor

No Tar Destroyer

With Tar Destroyer

- Raw condensates produced before and after catalytic tar destruction reactor was installed.
  - Two samples on left = no tar destroyer
  - Two samples on right = with tar destroyer
- Significant improvement in condensate quality which reduces purification requirements while protecting hardware from plugging with tar

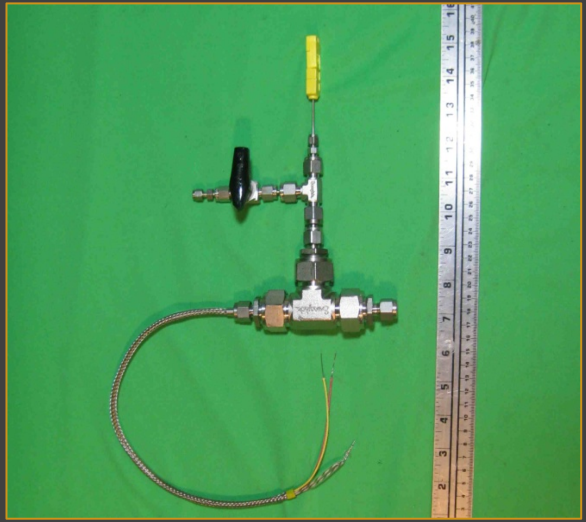
Condensate Purification Flow Diagram & Results



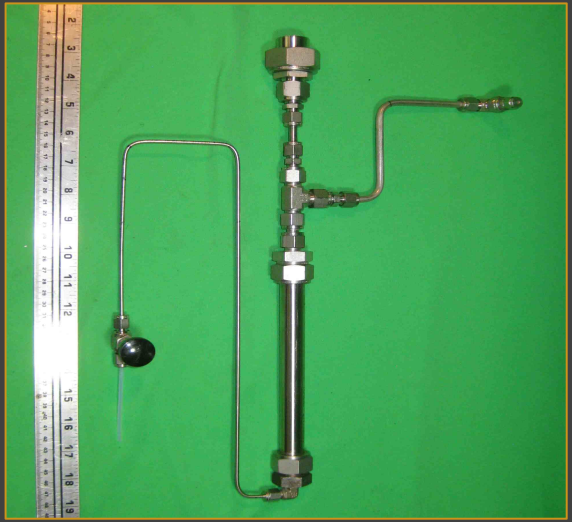
Measurement Parameter	Condensate Sample ID			
	12/13/18	12/18/18	1/3/19	1/8/19
Conductivity, mS/cm	7.34	1.60	7.77	11.64
ORP, mv	29	38	137	180
pH	8.9	9.0	9.6	9.7

Treatment Step	Measurement Parameter		
	Conductivity, µS/cm	pH	ORP, mV
Raw Condensate	11,640	9.7	180
After Oxidation at >700°C	1,903	10.1	163
After 0.5 micron Filtration and Ion Exchange	1.3	8.0	127
After Second Ion Exchange	1.6	8.4	137

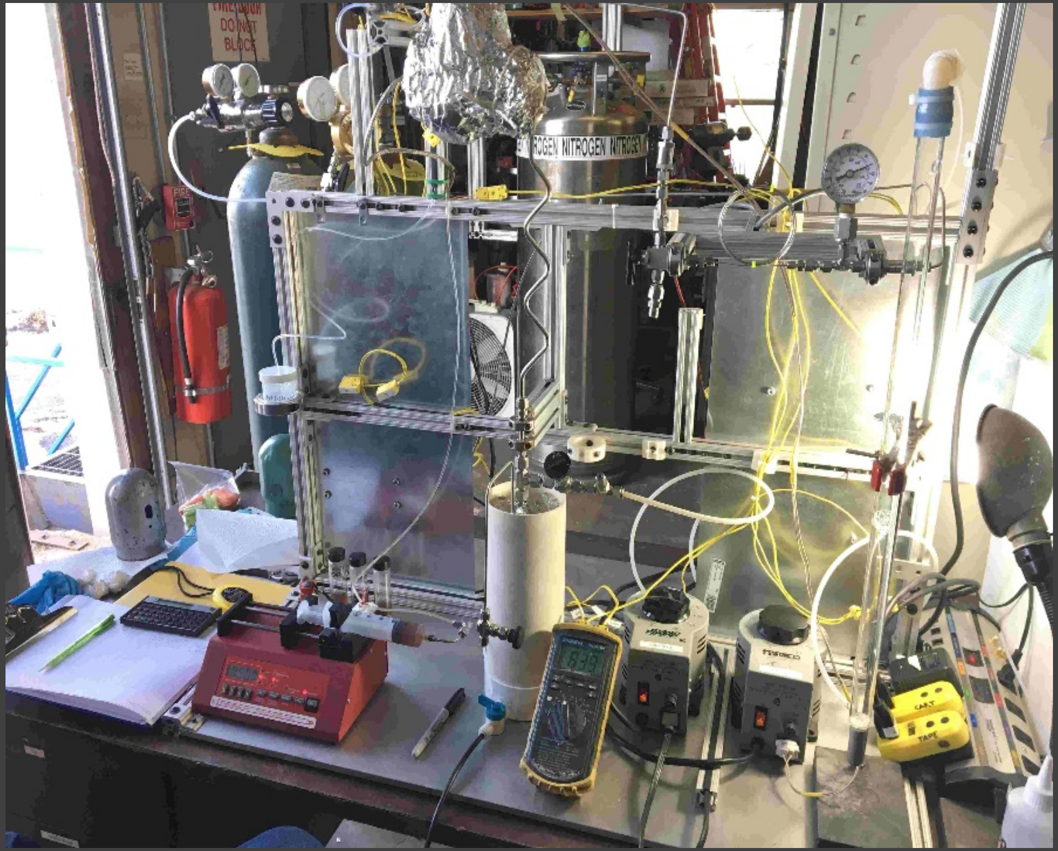
Condensate Oxidation Reactor System



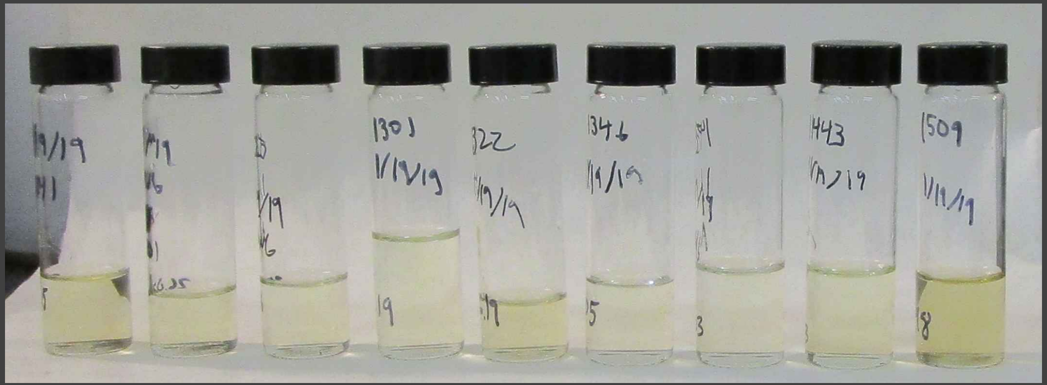
Condensate
Oxidation Reactor



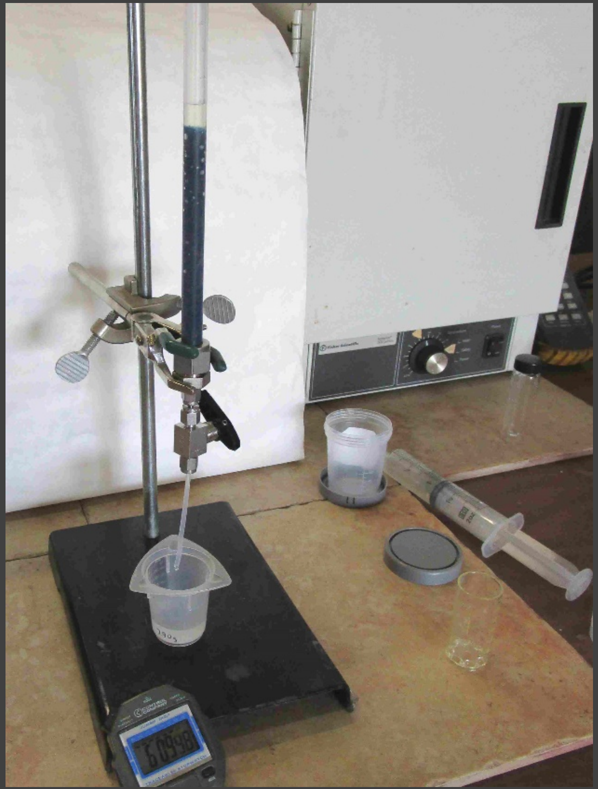
Condenser



Condensate Purification



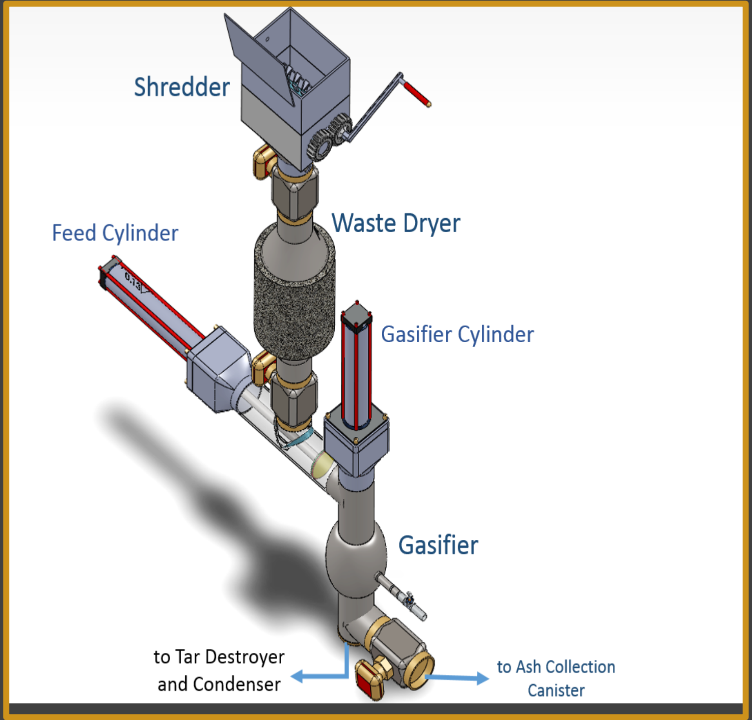
Condensate Oxidation Products



Mixed-Bed Deionizing Column

Phase II Approach

- *Feed System:*
    - Feed hopper with hatch to provide crew safety and odor containment
    - Shredder sized to the relatively low throughput suitable to reduce all potential waste components to a particle size suitable for material transfers and reforming
    - Feed dryer using system waste heat and gas filtration/recycle based on ISS waste management systems
    - Pneumatic assisted material transfer through each unit operation with an actuated linear cylinder to ensure a clear path to the reforming reactor



Phase II Approach

- *Gasifier/Reformer:*
  - Size a compact oxygenated steam reformer for the target throughput (possibly as small as two-inch diameter) packaged in a configuration with other system components to provide maximum heat recovery and isolation of the relatively small hot zones from crew exposure
  - Incorporate a tar destruction reactor to minimize contamination of reformer condensate by organic matter
  - Integrate a single-pass methanation reactor to maximize water recovery while producing dry vent gas

Phase II Approach

- *Condensate Purification:*
  - Optimize condensate purification protocol to produce ultra-clean water from reformer and methanation condensates using a minimum of consumables
  - Identify and implement the use of catalysts and sorbents to minimize the amount of sulfur, halide, nitrogen, and phosphorus compounds in the gasifier condensate and methanation feed gas.

Overall Recommendations

- Develop collaborative relationships to establish the full range of expertise to set specifications for an integrated AOWG system for clean water generation and clean gas suitable for venting.
- Expand the level of detail for both primary and ancillary AOWG systems with respect to mass, volume, and power in the context of a Mars or long-duration space mission.

AOWG Phase II Design

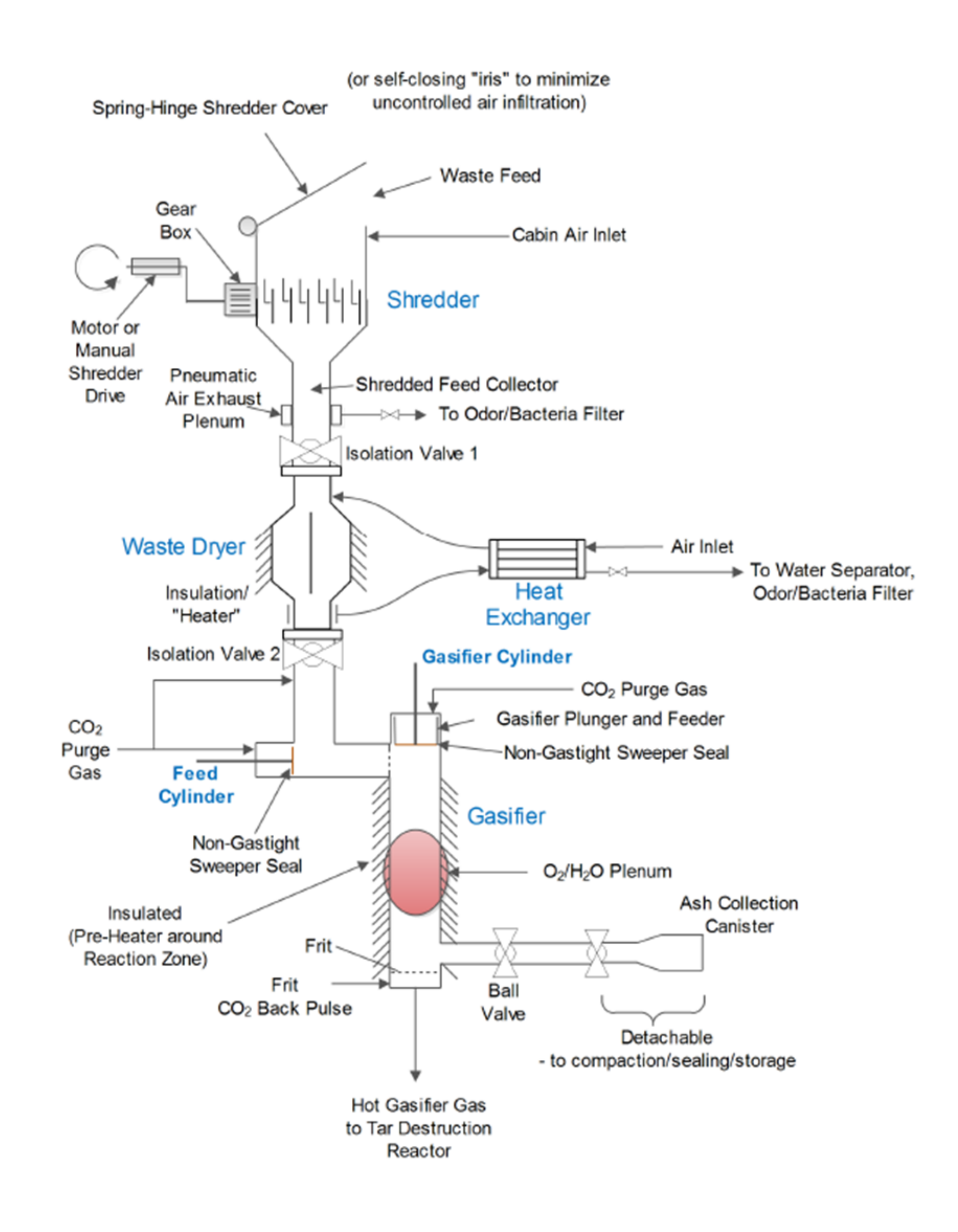
Shredder – Enables compact reactor
- Avoids channeling in reactor

Dryer – Provides more uniform feed
- Smoother process control
- Eliminates possibility of reactor quenching
- Allows ongoing H_2O recovery in event of downstream upset

Feed Delivery System – Pneumatic Actuators

Gasifier – compact reactor

Not shown – Tar destroyer & Sabatier Reactor



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