

# Mars Campaign Office Life Support Systems

## *Development of the Miniature Total Organic Carbon Analyzer*

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**Session 406: Water/Air Quality: Maintenance and  
Monitoring**





# Need for water quality monitoring

- **Ensuring that potable water on ISS is safe for crew to drink is currently achieved through monitoring of water quality on orbit and analysis of down mass samples.**
- **Organic contamination level of potable water is monitored on-orbit on ISS using the Total Organic Carbon Analyzer (TOCA), which provides a sum-total number for organic carbon present in the water, termed Total Organic Carbon (TOC).**
- **SSP 41000 and the Spacecraft Water Exposure Guidelines (SWEG) establish a 3 mg/L and 5 mg/L (respectively) limit for TOC of potable water.**
- **Potable water and system water is also sent as down mass to be analyzed at the Toxicology and Environmental Chemistry (TEC) Lab at JSC.**
  - The TEC lab utilizes many different techniques to develop a “total water quality picture” for samples that are measured.
  - Air and water quality reports are published regularly and available publicly: [Toxicology Analysis of Spacecraft Air - NASA](#)



# Example of water quality results (Increment 68)

Data on this slide from “Toxicological Assessment of ISS Air and Water Quality: September 29, 2022-March 28, 2023 (Increment 68) Including NG-18, SpX-26 and SpX-27 Ingress,” E.S. Williams and V. Rider, Memo TOX-SW-2024-01. <https://www.nasa.gov/wp-content/uploads/2024/02/increment-68-report-ng18-spx26-spx27-ingress.pdf>, retrieved June, 2024.

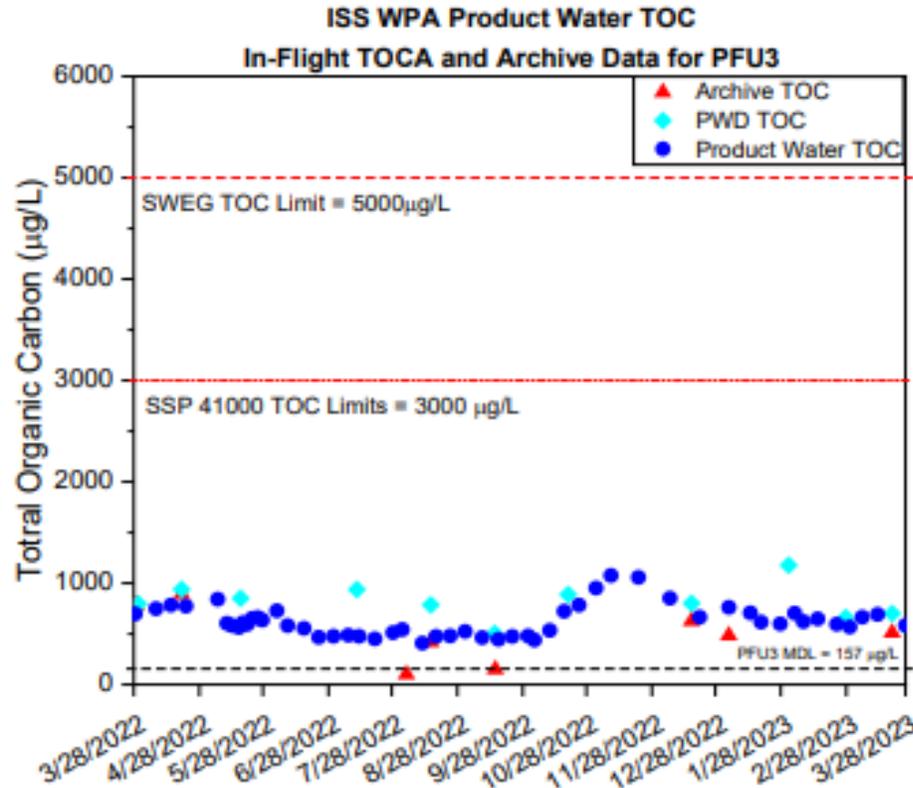


Table 3A. Analytical Summary of ISS Water Analyses for ChECS Samples (Increment 68)

Return Mission	Sample Location	Sample Date	TOC (mg/L)	DMSD (mg/L)	Methyl Sulfone (mg/L)	Conductivity (µS/cm)	Total Iodine (mg/L)
SpX-26	WPA PWD Ambient	12/16/2022	0.6	1.1	0.09	<1	<0.05
SpX-27	WPA PWD Ambient	3/21/2023	0.5	1.2	0.08	<1	<0.05

In-flight data provides trending for TOC.

Figure 5. Total Organic Carbon (TOC) trending in US Potable Water from Archive Water Samples and On-Orbit TOCA (PFU3) for March 2022 to March 2023



# Need for water quality monitoring

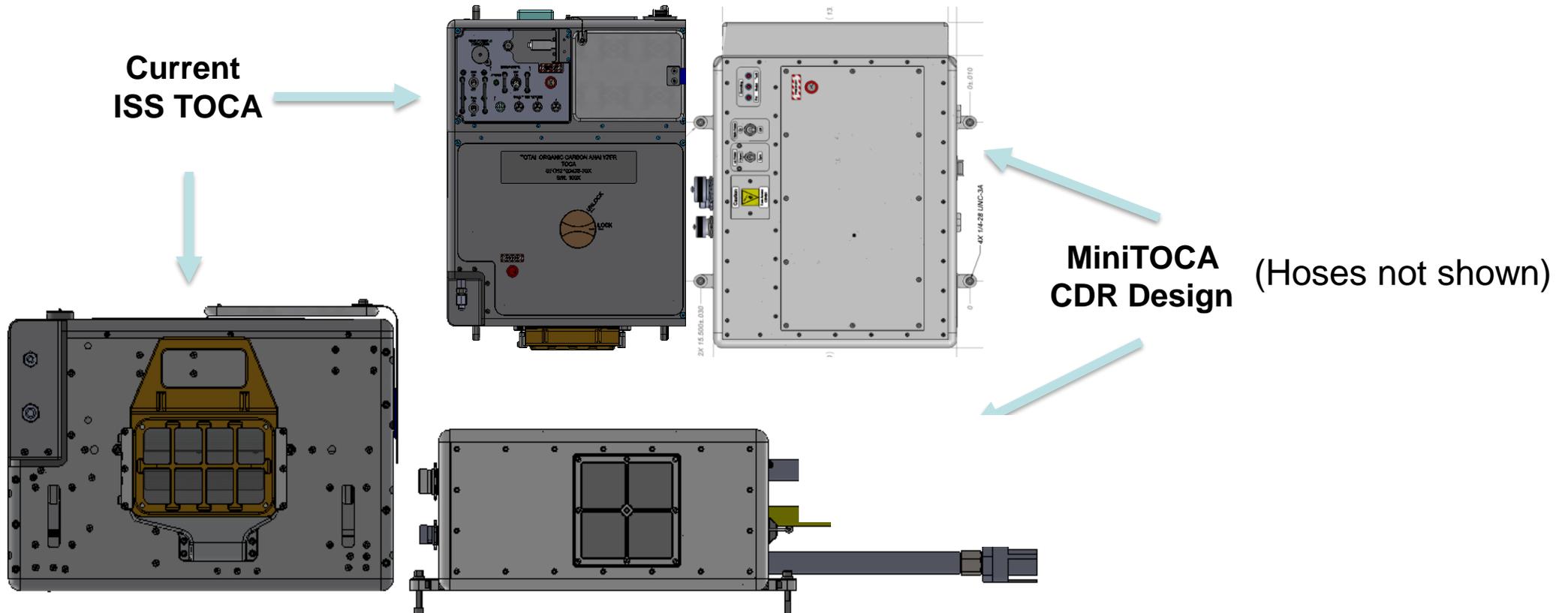
- **Water quality determined from samples collected at various points of the water recovery system informs system health / performance.**
  - Trending data from TOCA has been evaluated and used as part of decision process for maintenance of MF beds
- **Other systems, such as EVA suits need clean water because some components are more sensitive than others to contaminants, such as the sublimator.**

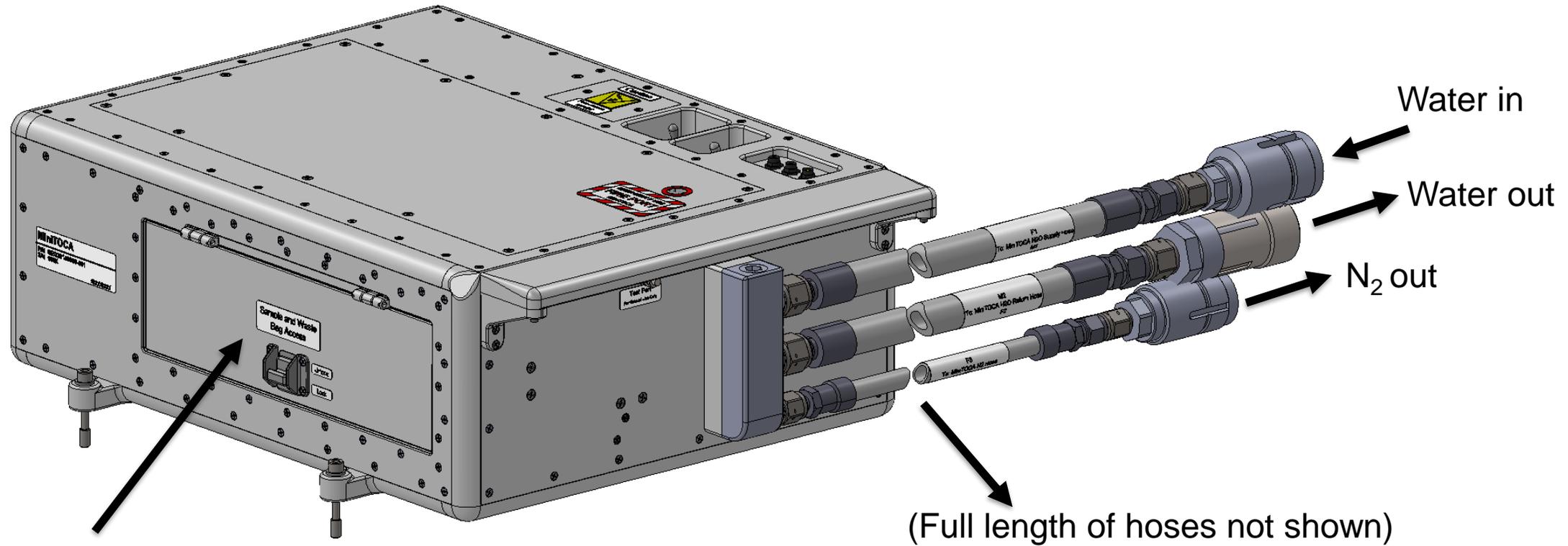
Verifying whether water meets flight rule limits for crew consumption or use with hardware requires monitoring instrumentation.

**MiniTOCA is the next generation TOC monitor.**

# TOCA (State of the Art) vs MiniTOCA (new development)

- MiniTOCA is smaller than ISS TOCA.
- MiniTOCA does not use a buffer chemical (no associated resupply).
- MiniTOCA requires calibration packets, sample bags, and waste bags (as does TOCA).





Sample and waste bag compartment

- **MiniTOCA plumbs into the potable water bus, and can accept bag samples.**



# Characteristic Requirements for MiniTOCA

Mass / Power / Volume & Environment Requirements		MiniTOCA Notes
Volume	<0.03 m <sup>3</sup>	0.03 m <sup>3</sup>
Mass	<20 kg	20 kg
Power	<175W average	<60W, average 45W as tested with EDU
Microgravity Performance	Not sensitive	To be tested on ISS
Ambient CO <sub>2</sub> compatibility	Up to 0.52% CO <sub>2</sub>	Tested to 3.9 mmHg ppCO <sub>2</sub> with EDU (0.52%)
Sampling Interface	Bag samples & interface to potable water system	Samples bags & continuous connection to potable water
Sample Compatibility Requirements		
Gas content	Up to 5% free gas in water	Uses a degasser
pH	4.5-9	Does not require buffer chemicals
Silver biocide	Up to 0.4 mg/L	Not used in US segment
Iodine biocide	Total iodine up to 4 mg/L	Verified through EDU performance testing
Total inorganic carbon (TIC) interference	Up to 2.5 mg/L TIC as dissolved CO <sub>2</sub>	Verified through EDU performance testing
Performance Requirements		
TOC Analysis Range	0.6 ppm – 10 ppm TOC	Verified through EDU performance testing
TOC Accuracy	+/- 25% over TOC range	Verified through EDU performance testing
TOC Precision	+/- 25% RSD for a series of 3 replicates, over TOC range	Verified through EDU performance testing



# Background: Generalized TOC Analysis Sequence



- **For many TOC analyzers, generally the analysis sequence is as follows. Multiple options are listed for each step.**
- **Receive sample water**
  - Sample bags
  - In-line plumbing
- **Oxidize TOC**
  - Ultraviolet light
  - UV / Persulfate
- **Transfer CO<sub>2</sub> out of sample water (phase separation)**
  - Choice of sweep gas
- **Measure CO<sub>2</sub> (Detection)**
  - Infrared is typical (NDIR)
  - Other technologies



# Exploration TOC System Selection

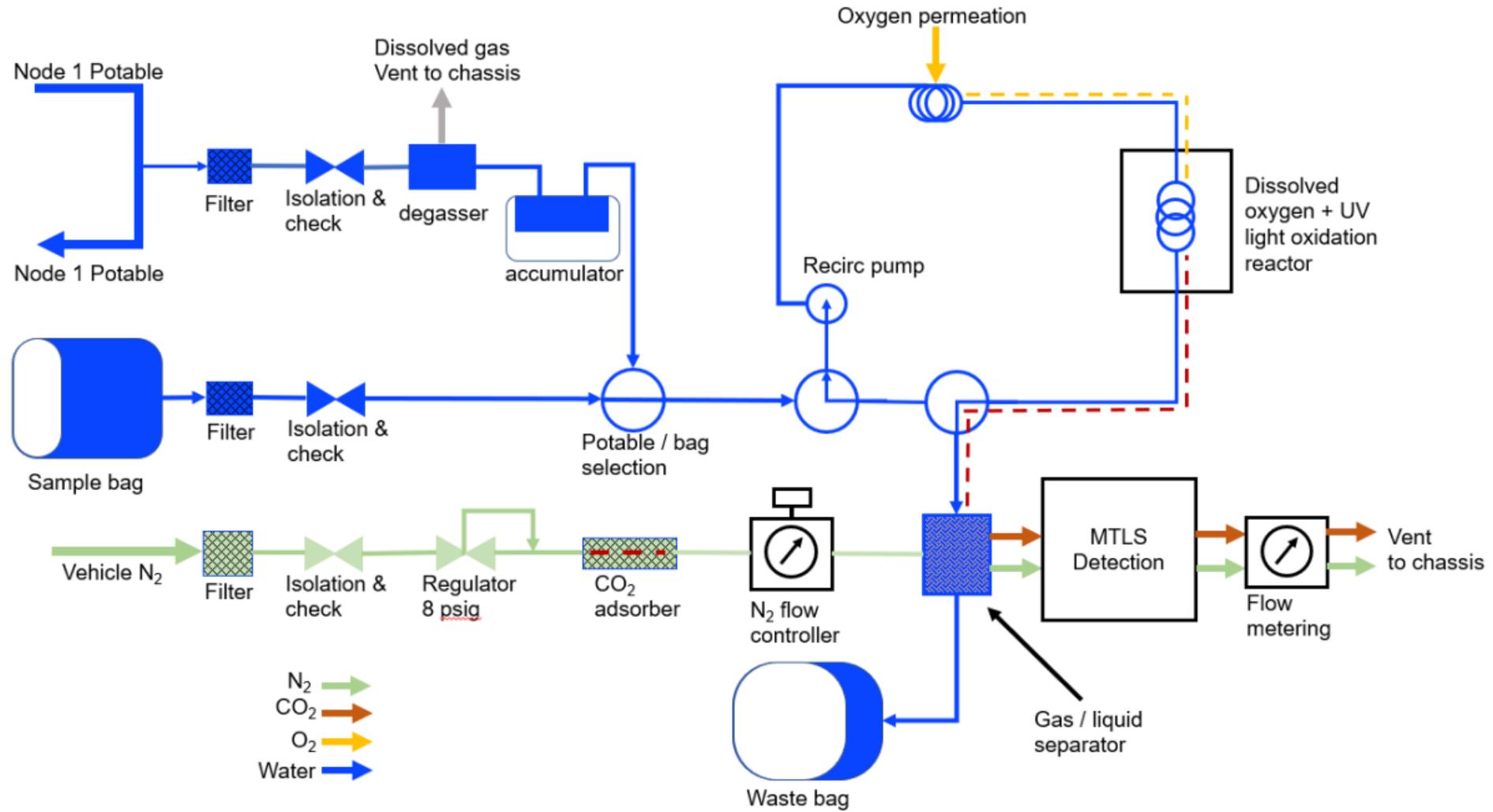


- Trade space for the general sequence, and the selection made for MiniTOCA, is shown below.
- A breadboard / technology development phase was completed during 2018-2020 and the technology suite for MiniTOCA (green) selected in 2020.

Technology Architecture Options for Sample Oxidation & TOC Determination			
Oxidation	Phase Separation	Carrier	Detection
Ultraviolet (UV) w/ recirculation + electrolyzer	Membrane	Deionized Water	Conductivity
UV w/ recirculation + electrolyzer	Membrane	Nitrogen Gas	Tunable Laser Spectroscopy (TLS)
UV w/ recirculation + electrolyzer	Membrane	Water Vapor	TLS
Catalytic Combustion	Evaporation on hot catalyst	CO <sub>2</sub> -free air / gas	“Hot” TLS



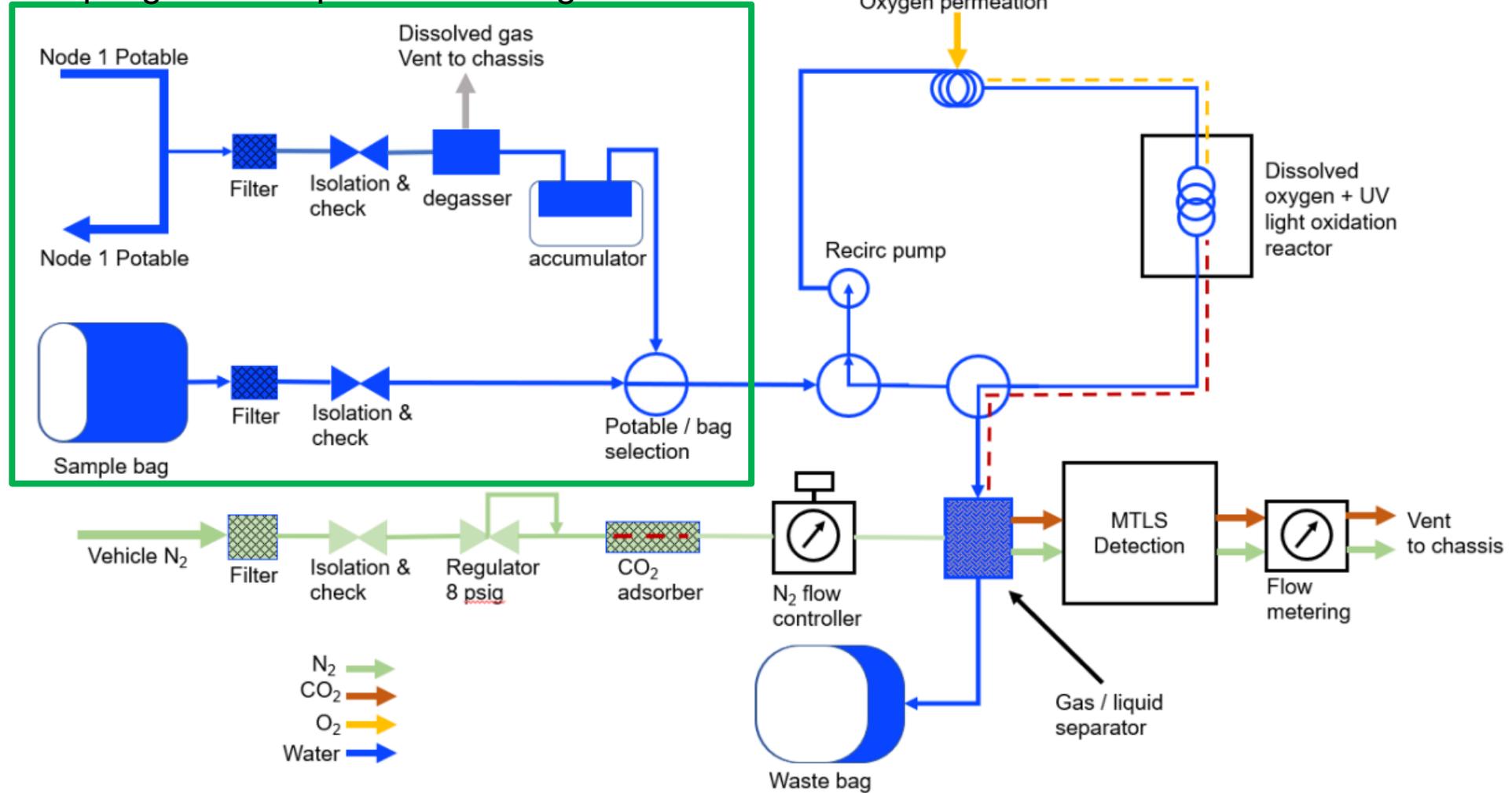
# MiniTOCA System Schematic





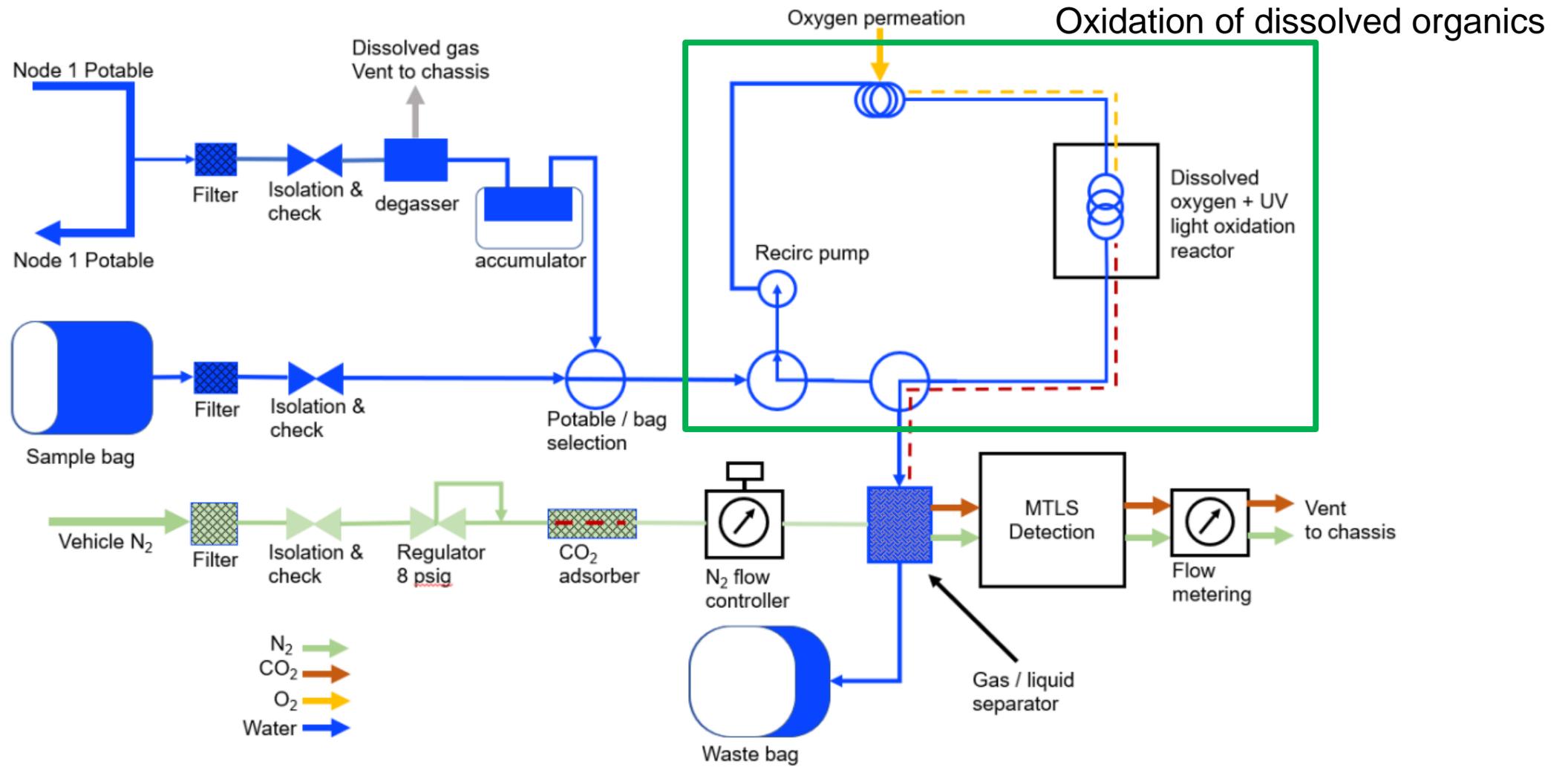
# MiniTOCA System Schematic

## Sampling and sample conditioning



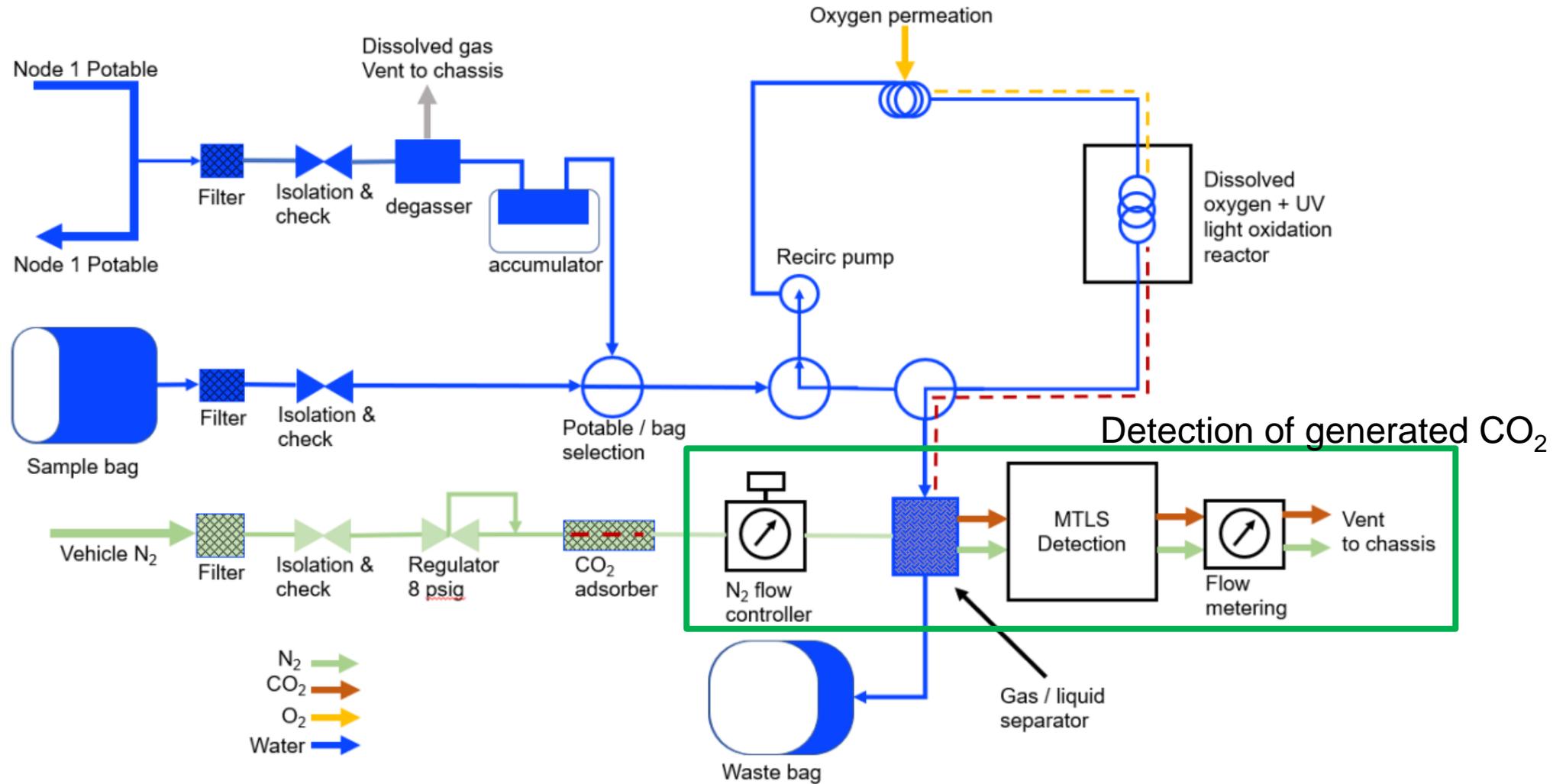


# MiniTOCA System Schematic





# MiniTOCA System Schematic





# MiniTOCA Technology Demonstration

- **Path to Technology Demonstration:**
    - SRR: January 2021
    - PDR: April 2022
      - MiniTOCA EDU (flight-like) was built and tested before CDR, with test results reported at CDR.
    - CDR: November 2023
    - Delivery: Planned 9/2025, NG-24 to ISS.
    - Operate 1200 day technology demonstration on ISS integrated in Node 1.
  - **This presentation covers EDU testing results, both environmental testing results and performance testing.**
- **The MiniTOCA EDU shows a valid design approach and good performance leading towards a successful tech demo on ISS.**

# Key Technology – Detector

- MiniTOCA Tunable Laser Spectrometer (MTLS)
- Provided by JPL
- Uses room-temperature Nanoplus interband-cascade lasers emitting around 4285 nm and room temperature HgCdTe detectors from Vigo.
- Single pass analysis beam from laser to detector 5 cm long.
- Optical cell controlled to 40 C.
- Measures CO<sub>2</sub> in Nitrogen. A calibration curve correlates that signal to TOC concentration in the sample.

Optical cell

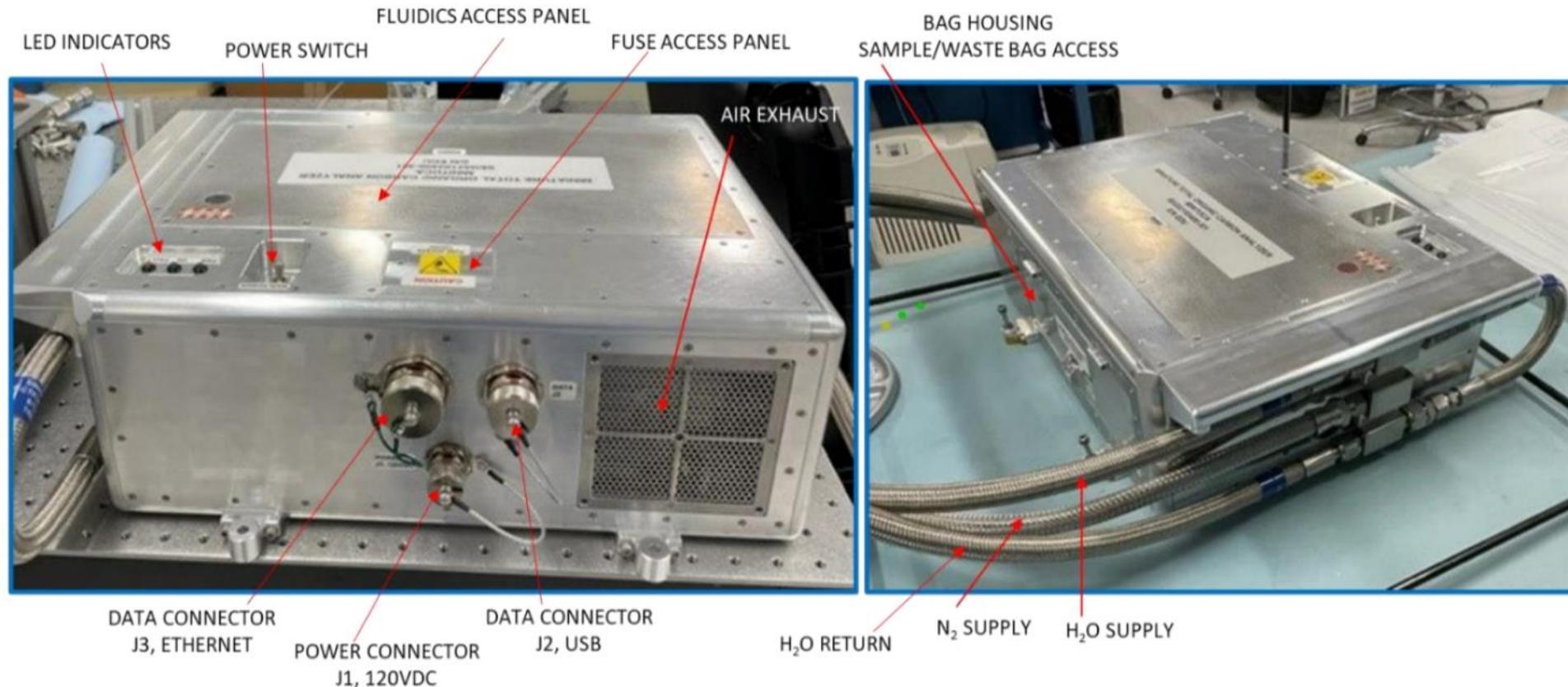
Chassis: 5.9 x 5.1 x 1.7"



**MTLS EDU Delivered Spring 2023**

# MiniTOCA EDU

- **Form, fit function to the flight hardware design**
  - Samples water from bags or water bus simulator
  - Oxidizes without reagents
  - Uses same single board computer, same support electronics designs as flight design
  - Detects with MTL5 detector in a flight-like implementation.
  - Runs the software we plan to use for flight, including Arcturus software.





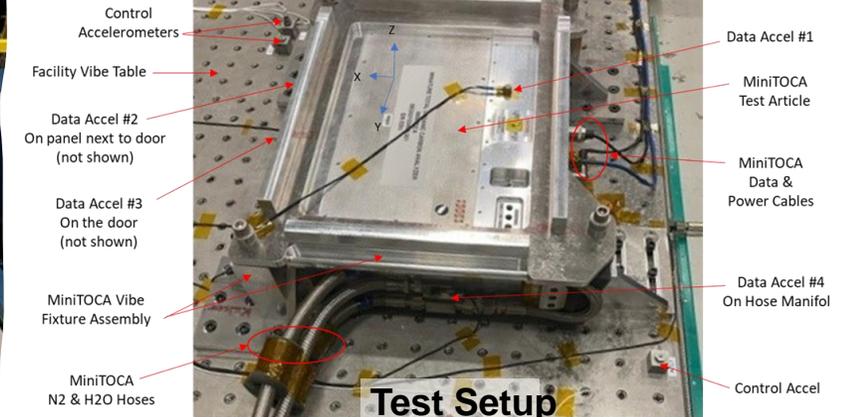
# Engineering Evaluation (Test) Program



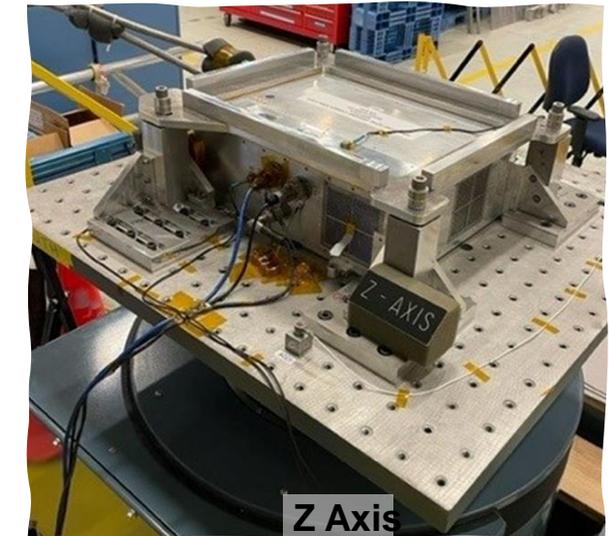
- **The completed EDU was put through a series of tests for the purposes of engineering evaluation of the design and EDU build.**
- **The EDU underwent tests the flight hardware would normally encounter.**
- **The EDU passed the tests performed, and some information was learned that will be useful for the flight build.**
- **Following slides capture testing activities and results.**

# Random Vibration Testing

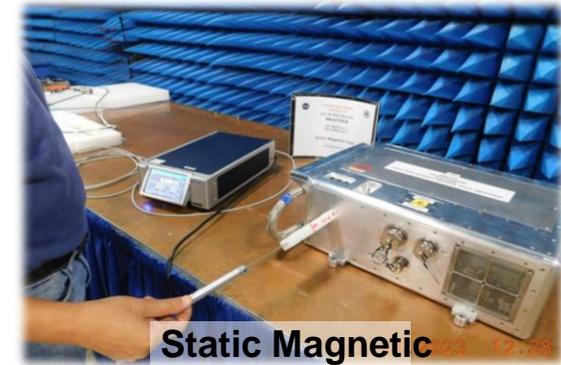
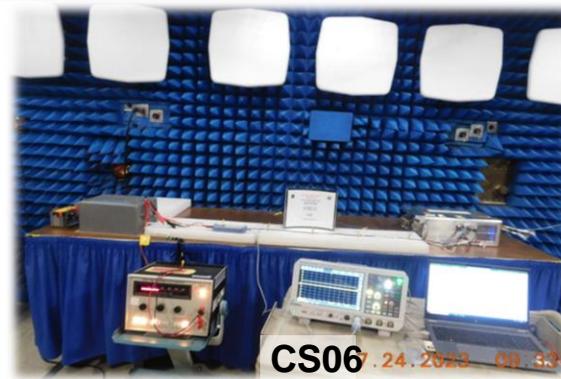
- Random vibration testing was completed successfully in three orthogonal axes to  $8.7 G_{rms}$  for 1 minute (protoflight duration) in each axis
- Two fasteners from COTS items were found out after testing. Project noted it and we will stake these particular fasteners on the COTS item before integration into higher assembly.



All Data Accelerometers are Tri-axial



- MiniTOCA EDU was tested for compliance with EMI/EMC requirements (conducted emissions, conducted susceptibility, radiated emissions, radiated susceptibility, static magnetic fields).
- EDU was found in compliance on all tests and also functioned nominally before and after testing.



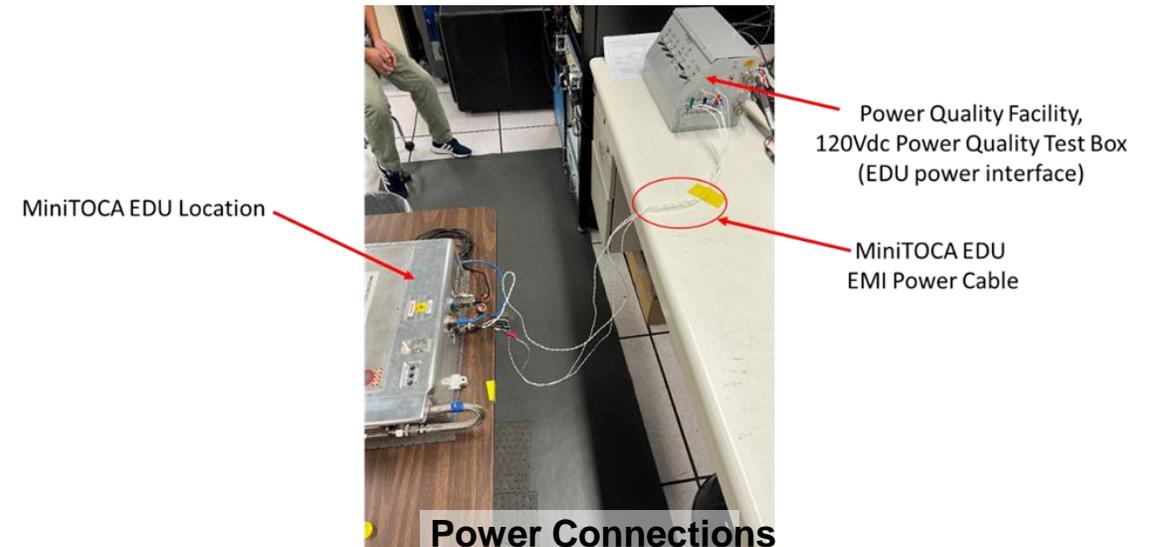
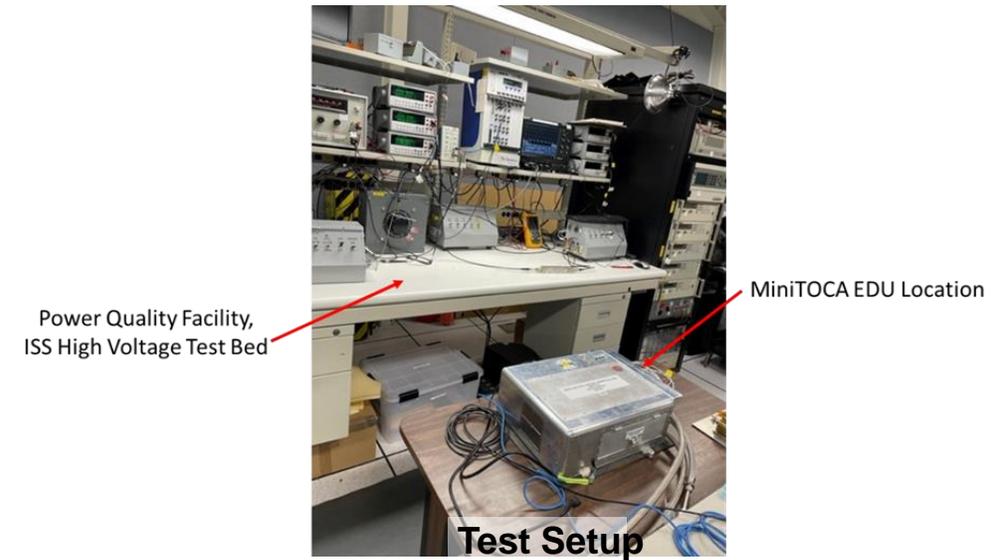
# Acoustic Emission Testing

- **MiniTOCA acoustic emissions testing was performed in the JSC B241 Acoustics and Noise Control Laboratory (ANCL)**
- **MiniTOCA EDU met the 8-hr intermittent noise level.**
- **Exceeded the NC-40 continuous noise limit, but feedback from the acoustics lab is it was close enough that variation s/n to s/n in a fan could make the difference on pass/fail. Flight build may perform different from EDU.**

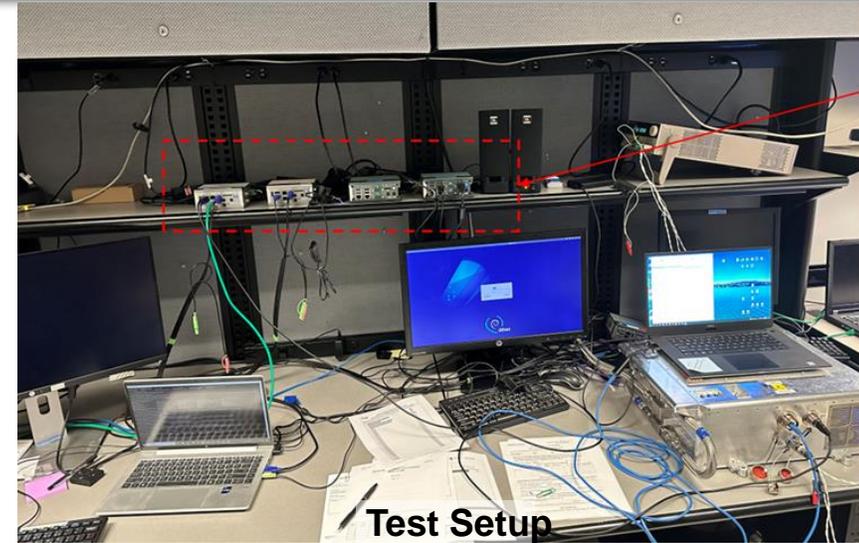


ANCL Test Setup

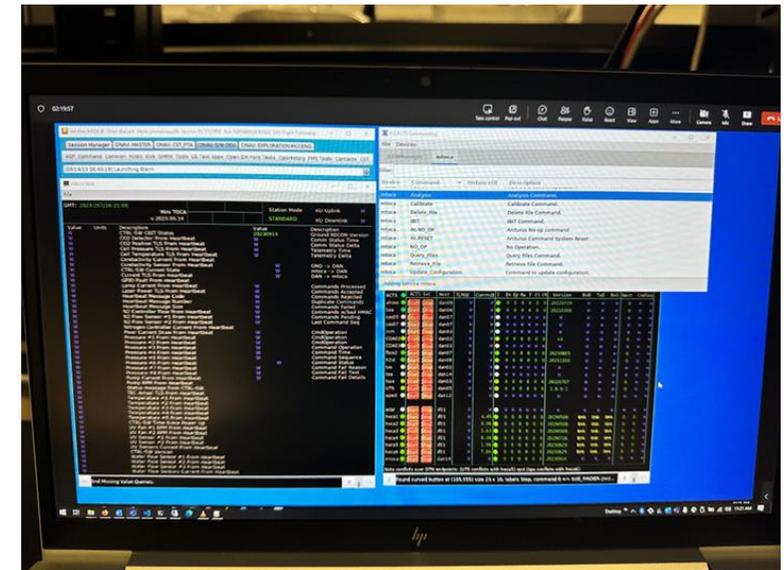
- Tested SSP 52051 scenarios
- Objective was to demonstrate ability of MiniTOCA design to operate in compliance with ISS 120 VDC power requirements
- EDU completed testing and post-test functionals and functioned nominally.



- Testing was performed with the EDU in the SWDFSH lab at Sonny Carter Training Facility (SCTF)
- Overall objective was to verify that MiniTOCA is capable of interfacing with the Arcturus system by transferring data between MiniTOCA and the mission control center (MCC)
- Testing was successful, MiniTOCA software could be commanded by MCC, could perform updates remotely, and could send and receive data through the Arcturus network.



DAN Box for connection to Arcturus Network



MiniTOCA CTRL Software Interface with Arcturus Network



# Engineering Eval Testing Summary

- Summary of engineering evaluation performed on EDU

Test	Results of EDU Engineering Evaluation	Notes related to flight build
Random vibration	Pass	Identified some COTS assemblies that need fasteners staked
EMI / EMC	Pass	Test identified some required schematic changes to power board
Acoustic Emissions	Intermittent: Pass Continuous: Fail	Test identified continuous noise due to cooling fan is a concern, but magnitude of exceedance plus variability in fans is considered in forward risk assessment
Power Quality	Pass	None
Arcturus	Pass	None
Thermal Testing	Pass	None; thermal cycling not performed on EDU but thermal testing shows that experiment agrees with modeling and that component temperatures do not exceed limits, with margin.



# EDU Performance Testing



- **After the engineering evaluation testing, the EDU performed a series of tests to check performance of the design with respect to the detection requirements.**
- **A series of samples was tested which bracket the requirements ranges for sample composition, sample concentration, use of iodine biocide, and carryover testing.**



# Performance Testing Conditions & Calibration Comments

- MiniTOCA was operated inside an environmental enclosure which allowed variance of ambient CO<sub>2</sub> concentration.
  - Purpose was to be able to test over possible range of background ppCO<sub>2</sub> up to 3.9 mmHg (CO<sub>2</sub> requirement limit).
- Instrument was initially calibrated closer to Earth background CO<sub>2</sub>, approximately 0.4 mmHg (500 ppm).
- Subsequent testing at a background CO<sub>2</sub> level of 3.9 mmHg CO<sub>2</sub> led to reporting high (+% Error) for some samples.
- Re-calibration at higher CO<sub>2</sub> background, closer to the limit where we are testing, resulted in accurate reporting across the sample concentration range. *Calibration conditions for background CO<sub>2</sub> matter for MiniTOCA.*
- For the flight cert, we will calibrate at a background CO<sub>2</sub> between 2 and 3 mmHg, and verify requirements on the ground at the flight rule limit of 3.9 mmHg. On-orbit re-calibrations will be in an operational environment on ISS and therefore we expect MiniTOCA to report accurately initially, and especially after on-orbit re-calibrations during the tech demo.



# Performance Testing – Precision & Accuracy – Information

- **Each MiniTOCA measurement is an average of 3 successive determinations of the TOC value of a sample.**
  - For 1 given sample, the instrument sequence determines TOC 3 times on that same sample, and averages the 3 numbers to report one single “answer” for one sample.
- **Accuracy is determined as a percentage difference for what the instrument reports versus the true TOC of the sample.**
  - True TOC of the test samples was determined by the Toxicology and Environmental Chemistry (TEC) lab at JSC.
  - Negative % error = instrument reported low relative to the true sample value.
  - Positive % error = instrument reported high relative to the true sample value.
- **Accuracy requirement is +/- 25% of the true sample value over the range 0.6-10 mg/L (ppm)**
  - Note that 25% of 0.6 ppm is 150 ppb. Meaning, if the sample is 0.60 ppm, the instrument shall report it to be 0.45 ppm – 0.75 ppm.
- **Precision is the % relative standard deviation (%RSD) for the 3 replicates used to determine the single average value.**
- **Precision requirement is %RSD  $\leq$  25%.**



# Performance Testing Results

Test	Sample TOC (mg/L)	Sample TIC (mg/L)	Constituents	Test Purpose	Date Completed	EDU Accuracy (% Error)	EDU Precision (%RSD)
1	10	<0.5	TOC as KHP	Max TOC Range	8/24/23	-1%	+6%
					8/29/23	0%	4%
					9/6/23	2%	-7%
2	0.6	<0.5	TOC as KHP	High/Low Carryover, Minimum range	8/25/23	-27%	+22%
					8/30/23	+22%	+11%
					9/7/23	-4%	+11%
3	0.6	2.5	TOC as KHP	Minimum requirement range with max TIC	10/10/23	+17%	+12%
					10/12/23	+21%	+12%
4	1	2.5	TOC as KHP	Minimum CHECS TOC range with max TIC	10/9/23	+9%	+5%
5	5	<0.5	TOC as KHP	Flight rule health limit TOC	8/17/23	+4%	+5%
					9/7/23	0%	+3%
					10/12/23	-10%	+4%
6	3	<0.5	TOC as Ethanol	Calibration check TOC with ethanol + iodine	8/30/23	+21%	+5%
					9/5/23	+12%	+11%
7	10	<0.5	TOC as Ethanol	Max TOC range with ethanol and iodine oxidation challenge	8/25/23	0%	+8%
8	0.3	<0.5	TOC as KHP	Engineering evaluation at 0.3	8/29/23	+8%	+6%
					10/13/23	-19%	+6%



# Conclusions



- **The MiniTOCA tech demo project built and tested a high-fidelity engineering development unit (EDU) during the CDR phase of the project.**
- **Environmental testing on the EDU, as an engineering evaluation, shows the design is sufficient to meet the environmental requirements. Important information about COTS components and validation of the electrical design for the flight hardware were achieved.**
- **The EDU testing shows the design is sufficient to meet the performance requirements.**
- **MiniTOCA is planned to deliver to ISS in late 2025 with a 3-year technology demonstration on orbit following.**



# Acknowledgments



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