MELISSA MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

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8-9-10 NOVEMBER 2022

CREATING A CIRCULAR **FUTURE**

Nitrogen gas and water recovery using the Nitrogenisor bioreactor for crewed Mars mission: A feasibility study based on stochastic mission scenarios.

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University of Antwerp | Sustainable Energy, Air & Water Technology

eawag aquatic research

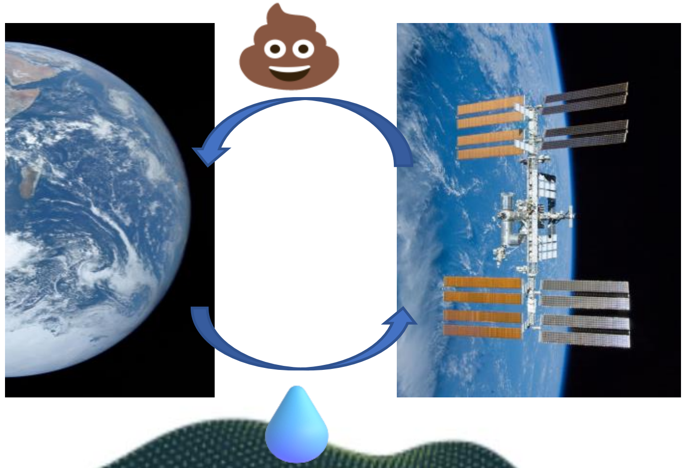
esa European Space Agency

90

650

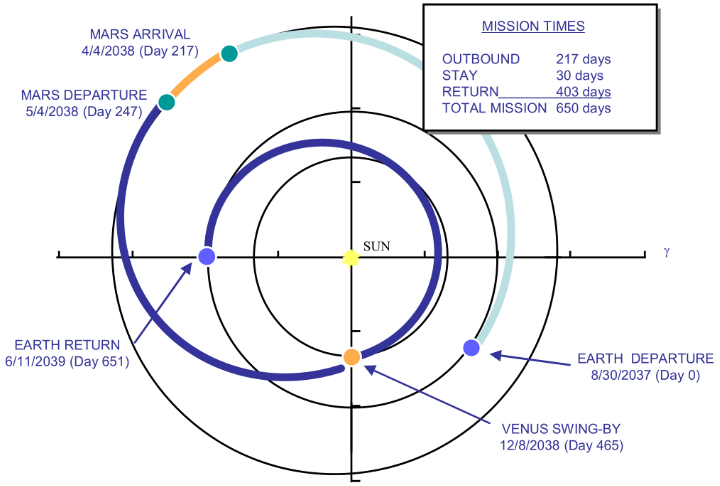
90 days

Average resupply time to ISS



650 days

Current estimated crewed mission time to Mars

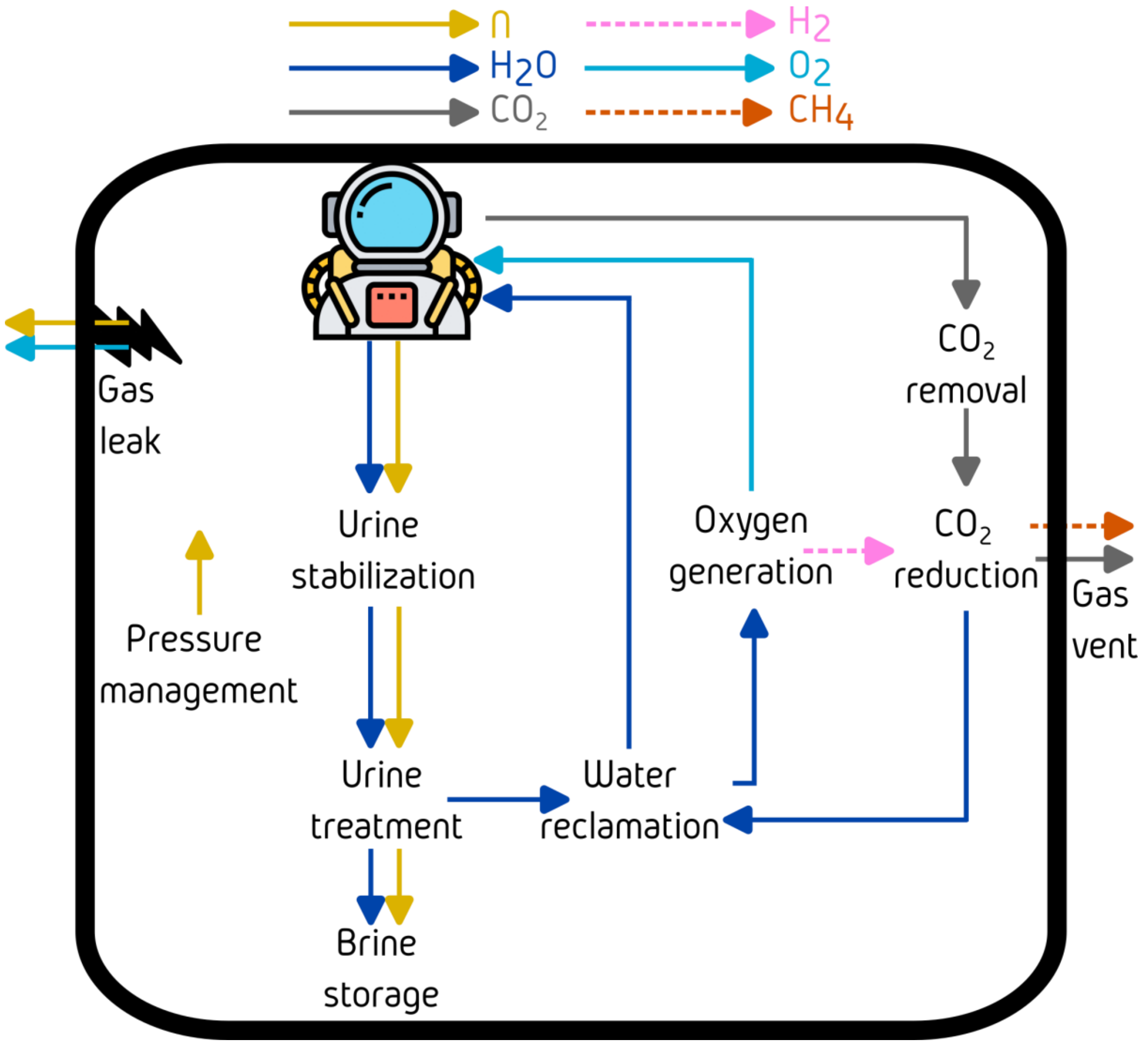


a) Opposition Class: Short-Stay Mission

Drake, B.G., Hoffman, S.J. and Beaty, D.W., 2010, March. Human exploration of Mars, design reference architecture 5.0. In *2010 IEEE Aerospace Conference* (pp. 1-24). IEEE.

State-of-the-art regenerative life support at the ISS

- ECLSS = environmental control and life support system
- ISS ECLSS = open loop



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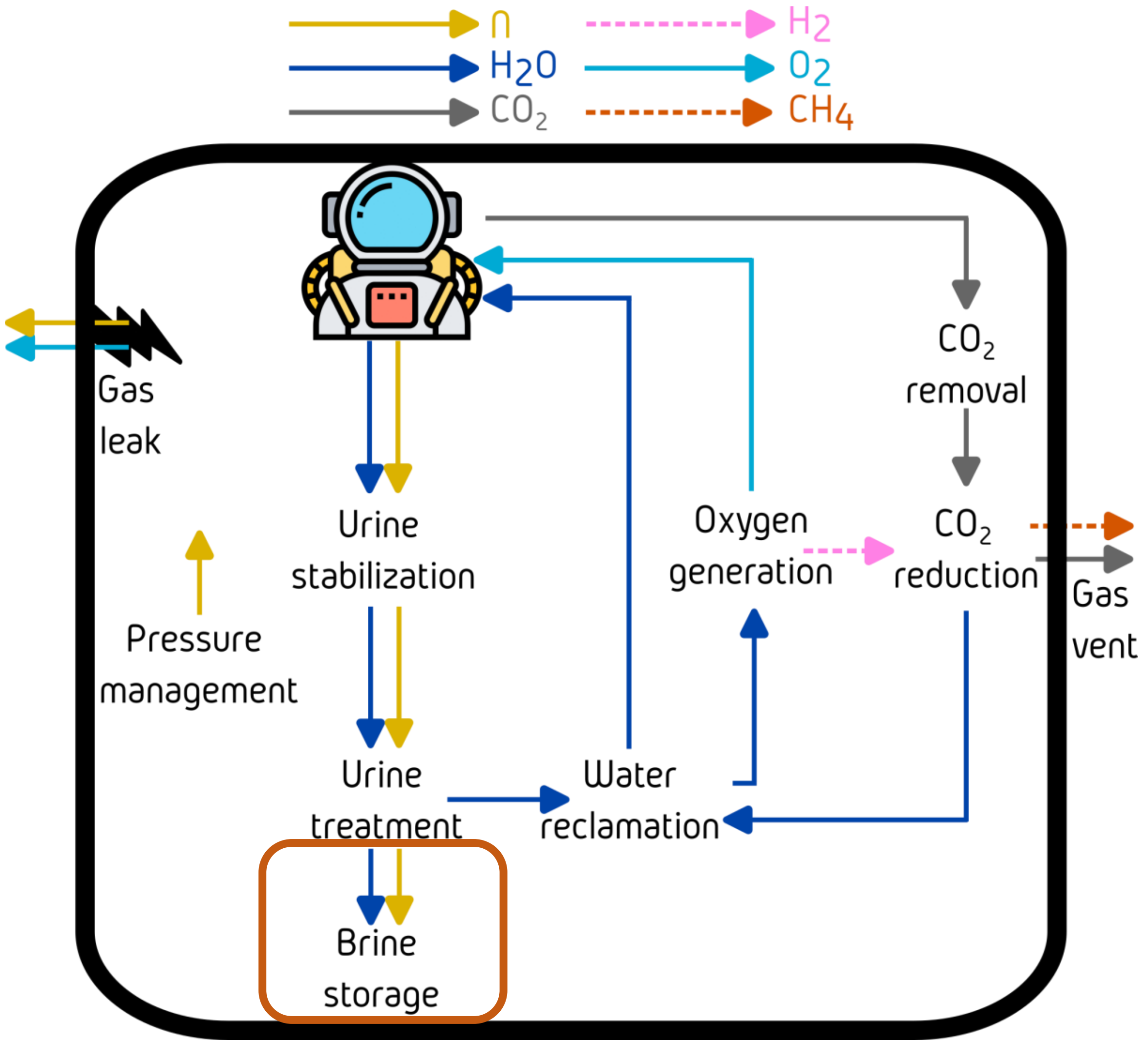
Only 85% of water recovered



State-of-the-art regenerative life support at the ISS

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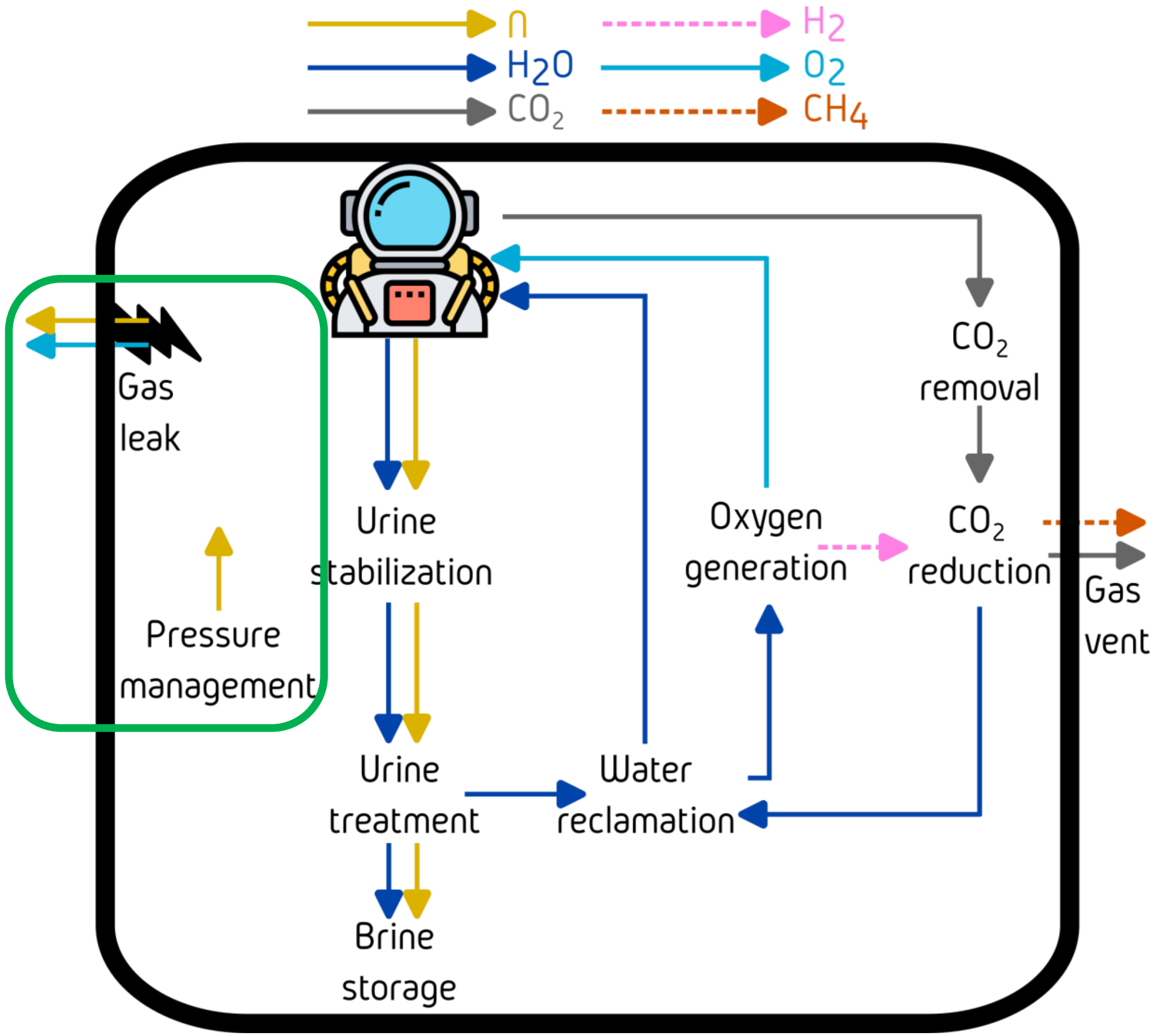
Only 85% of water recovered

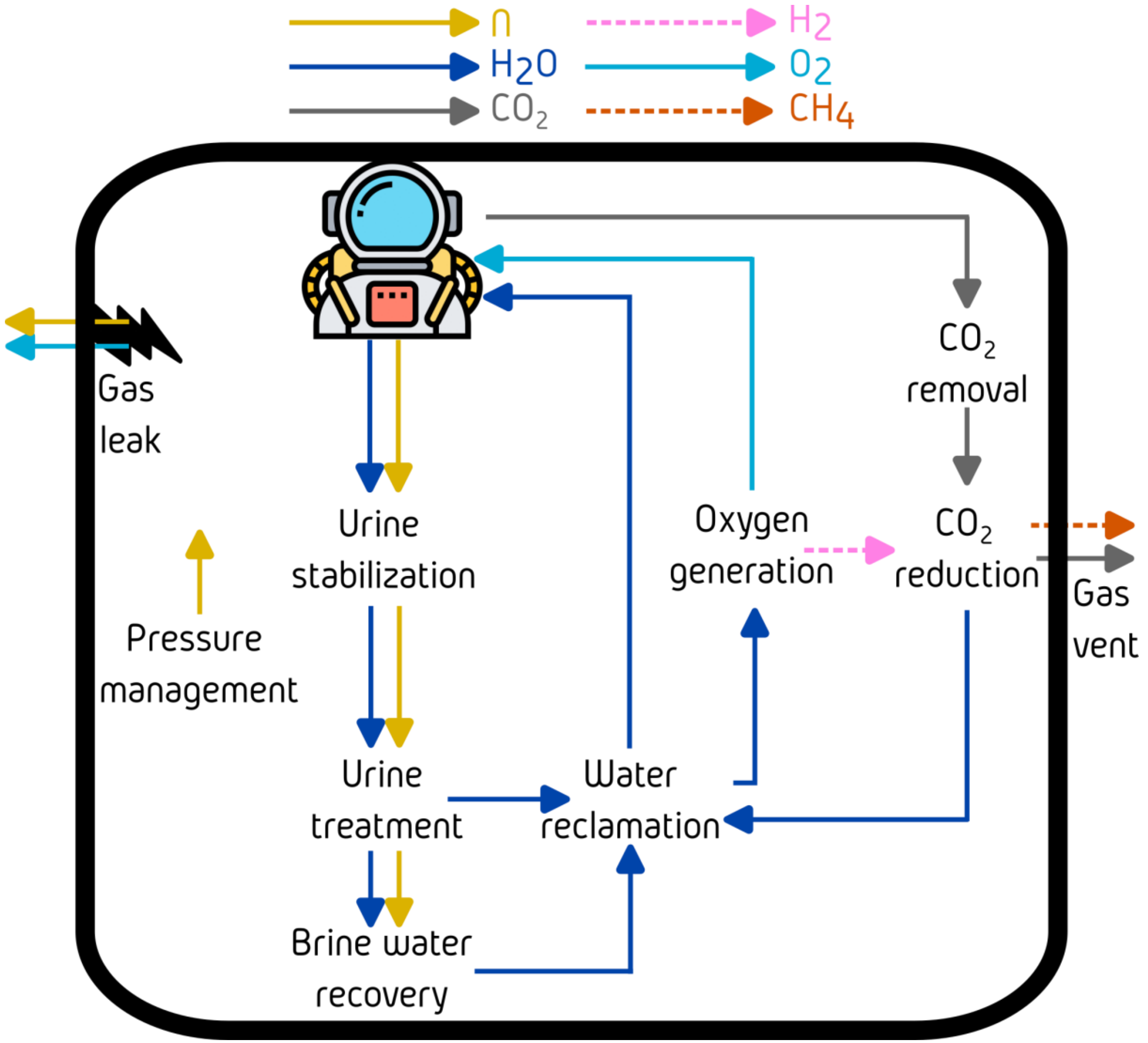
No N_2 gas regeneration
→ 133 kg N_2 to ISS per year[1]
→ **32 kg needed for trip to Mars**



(1) Schaezler, R.N. and Cook, A.J., 2015, July. Report on ISS O2 Production, Gas Supply and Partial Pressure Management. In *International Conference on Environmental Systems* (No. JSC-CN-33571).

Bleeding-edge solutions for water recovery

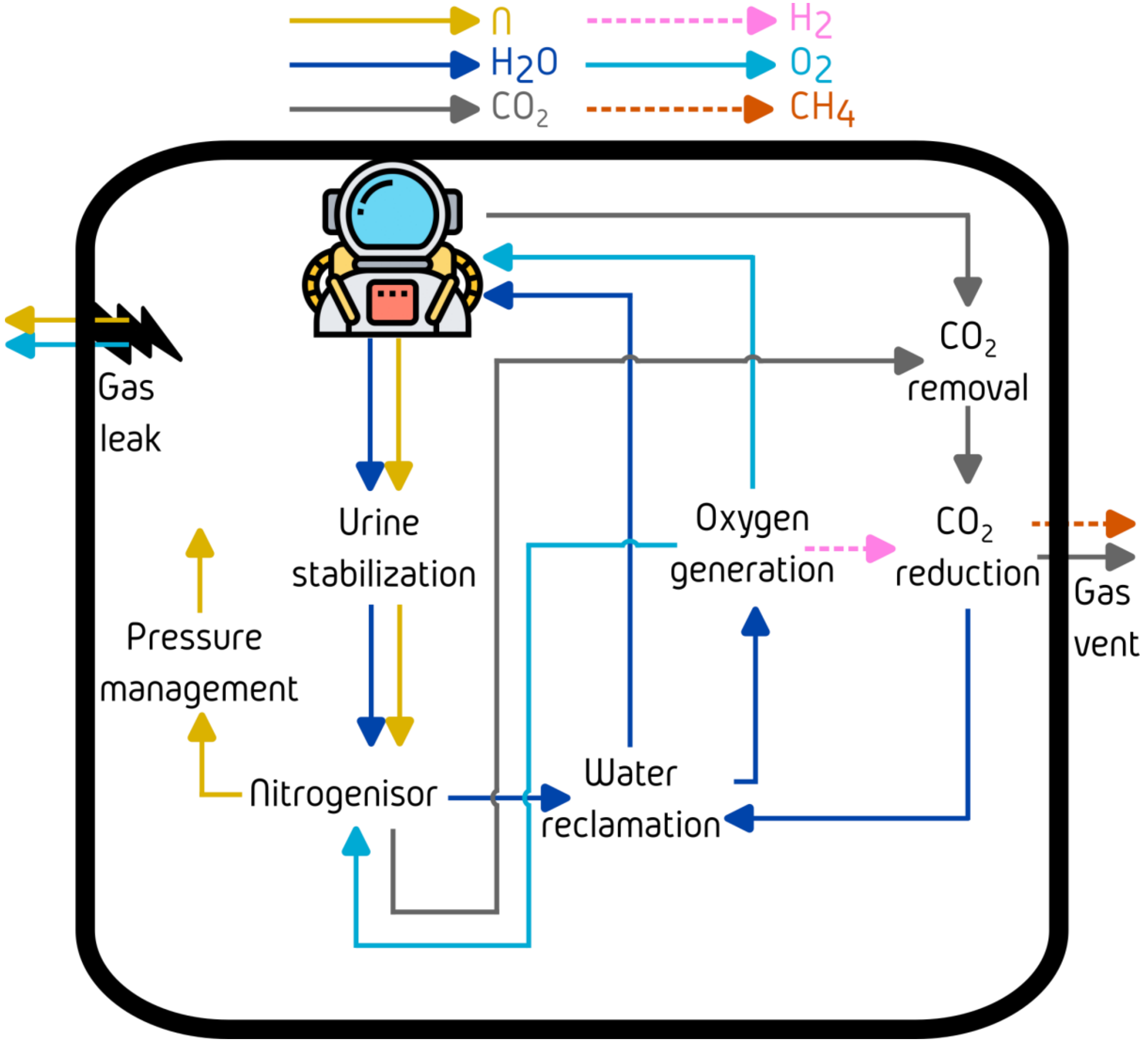
- Crewed Mars transit mission requires **98% water recovery**
- Current high TRL proposal involves recovering water from urine brine
  → 80% efficient



Kelsey, L.K., Pasadilla, P., Fisher, J. and Lee, J., 2015, July. Ionomer-membrane Water Processor (IWP) Engineering Development Unit (EDU) Brine Water Recovery Test Results. 45th International Conference on Environmental Systems.

Nitrogenisor concept for pressure management

- Nitrogenisor = membrane aerated biofilm reactor + electrochemical urine stabilization
- Biological conversion of urine to N_2
  - → N_2 can be used for pressure management
  - → No brine formation equals 100% theoretical water recovery



Is the Nitrogenisor concept feasible for a crewed Mars transit mission based on mass and energy considerations?

1. Can Nitrogenisor provide enough N_2 to offset losses and maintain cabin pressure?
2. Is the mass associated with hardware and consumables favorable to state of the art?
3. Is the energy requirement comparable or favorable to state of the art?

Mission scenario methodology

- Urine estimation:
  - Basic metabolic model based on protein intake and N diversion to urine

$$N_U = M_{CM} \cdot f_{PN,i} \cdot f_{N,PN} \cdot f_{i \to U}$$

- NGR mass balance:
  - Based on stoichiometric balances.
- Leakage estimation based on preliminary DST requirements

→ Structural leakage[1] + 1 contingency EVA per month[2]

0.05 kg/d 0.015 kg/d

- Total mission time = 650 days
- # Crew members = 4

(1) Adamek, C., 2019. *Gateway system requirements* (No. JSC-E-DAA-TN71173).
(2) Goodliff, K. E., Stromgren, C., Dickert, Z., Ewert, M. K., Hill, J., & Moore, C. (2017). Logistics Needs for Future Human Exploration Beyond Low Earth Orbit. In *AIAA SPACE and Astronautics Forum and Exposition* (p. 5122).

Can Nitrogenisor provide enough N_2 to offset losses and maintain cabin pressure?

- Stochastic approach was used to implement uncertainty in the scenario analysis
  - 1000 random samples were taken from distributions below

Crew parameters					
Crew member Weight	75	±	10	kg	Urine estimation
Fraction N found in urine	0.85	±	0.05	g N/g N	Urine estimation
Urine volume	1.64	±	0.28	kg	Urine estimation
NGR parameters					
Fraction COD to aerOHO	0.6	±	0.1	(-)	Stochiometric assumptions
AerAOB/NOB activity ratio*	3	±	1	(-)	Stochiometric assumptions
N removal efficiency	77	±	8	%	Stochiometric assumptions
N removal rate	1.09	±	0.14	g N/L/d	Stochiometric assumptions

** lognormal distribution*

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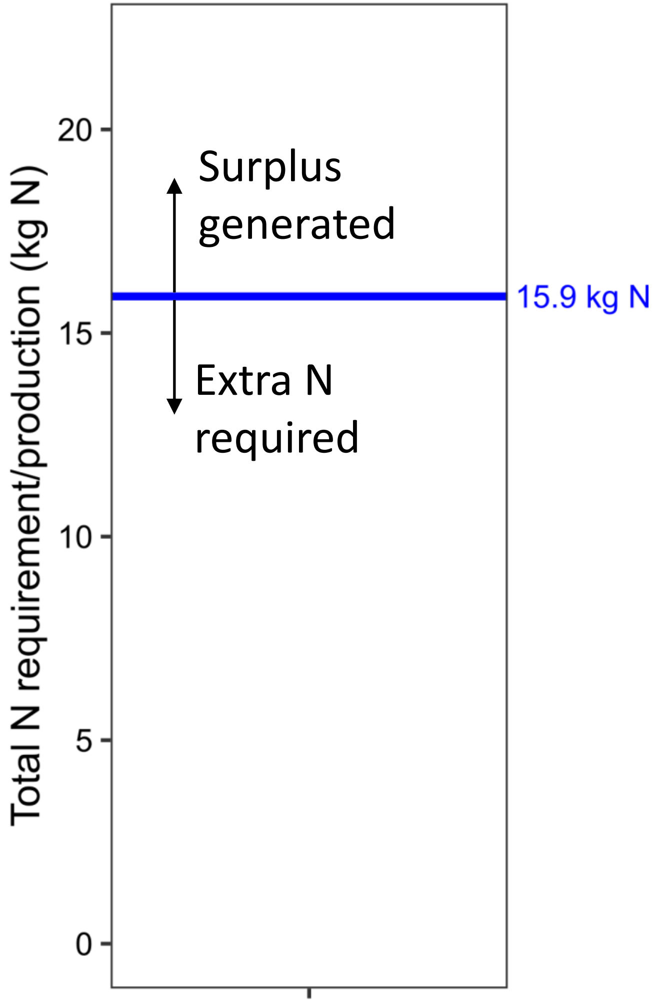

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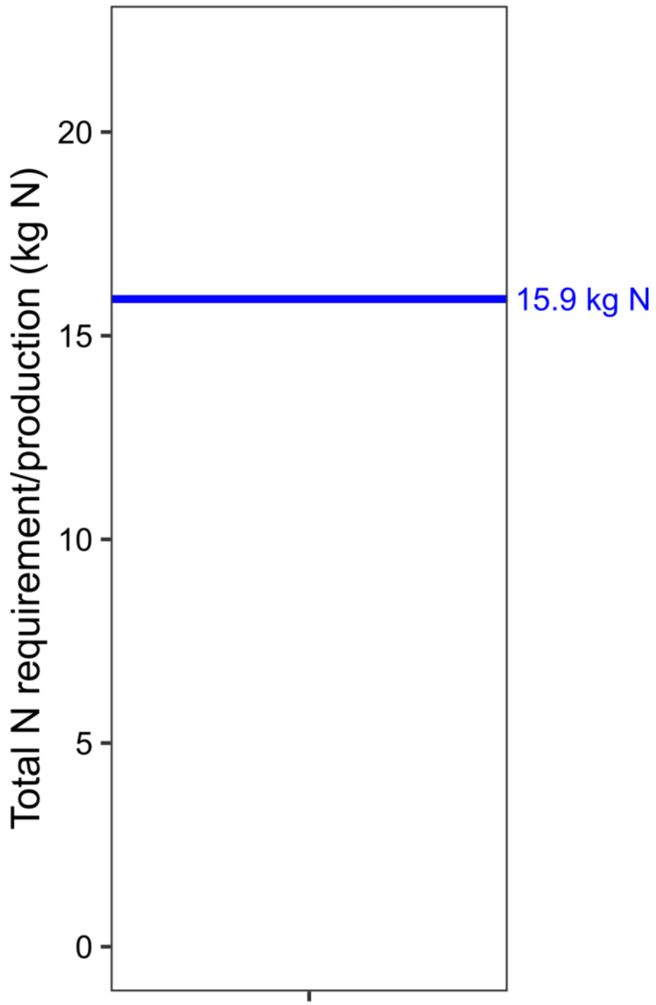

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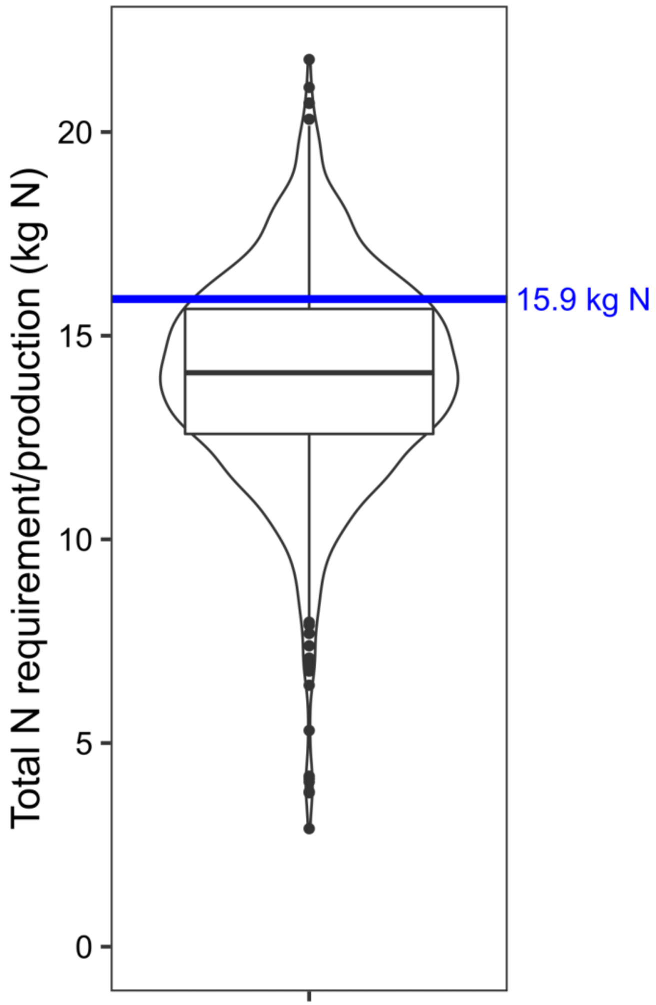
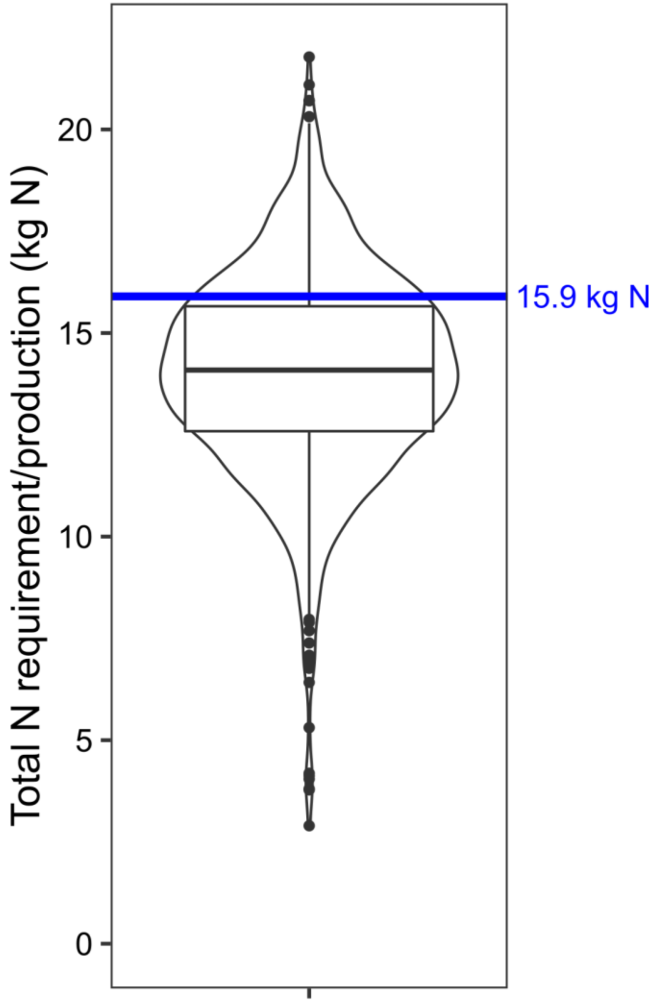


Can Nitrogenisor provide enough N_2 to offset losses and maintain cabin pressure?

- Average N_2-N produced = 14 ± 2.5 kg N_2-N
  - → Average offset of 88 %
- 25% of the runs resulted in enough gas production to offset all losses
- Long ‘tail’ in distribution
  - → Critical parameters?



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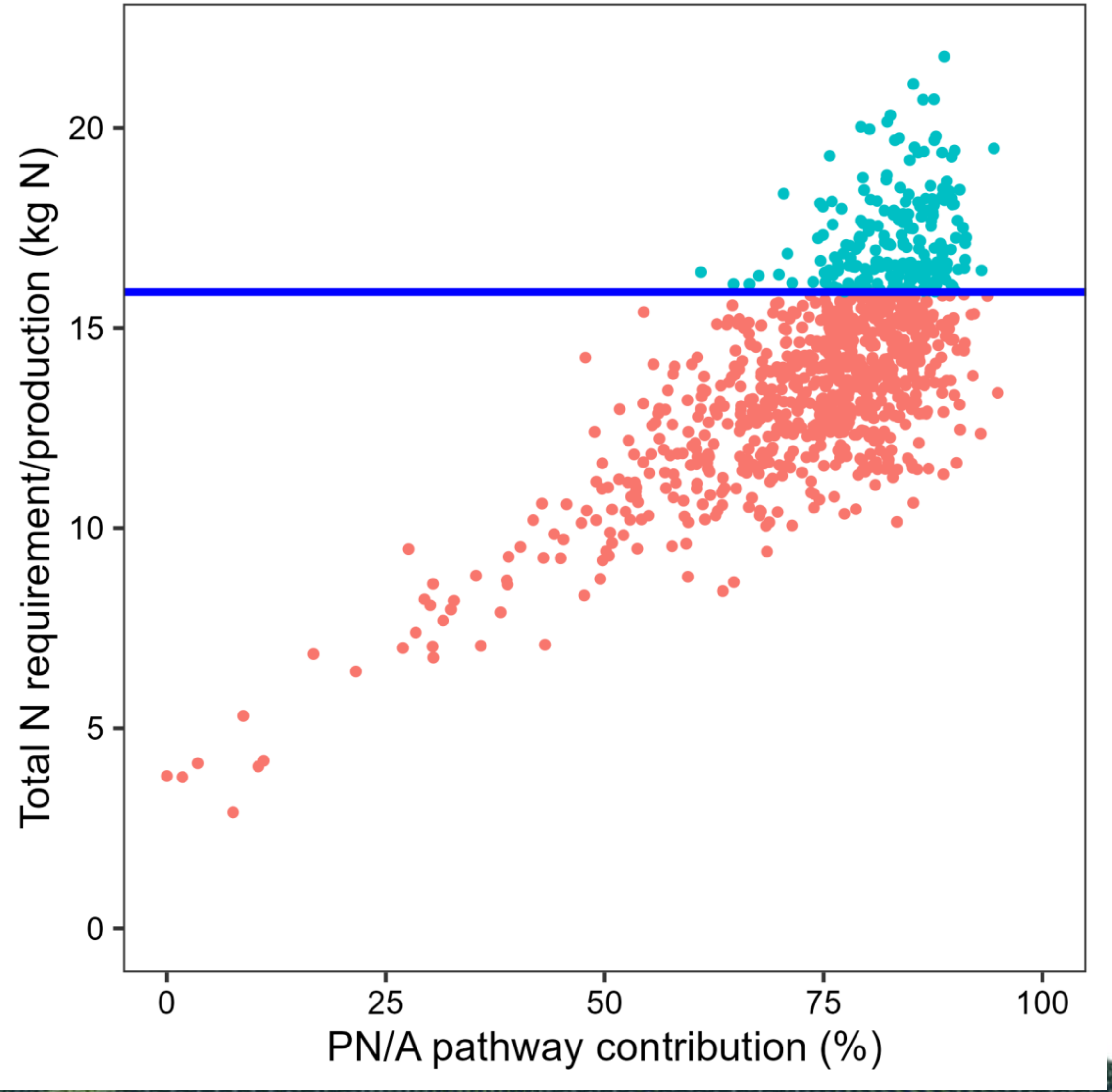

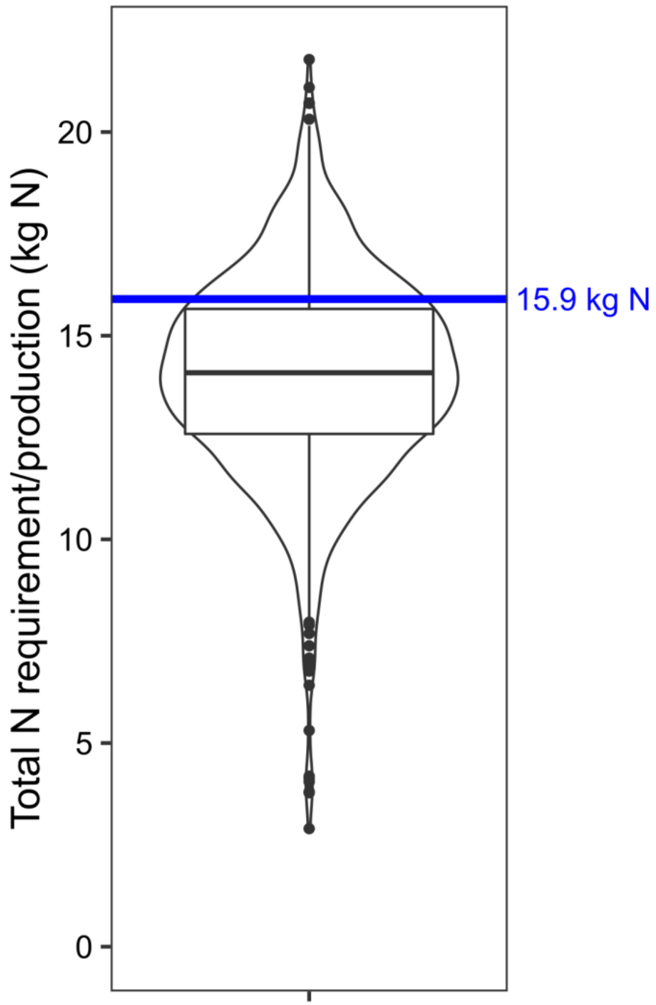

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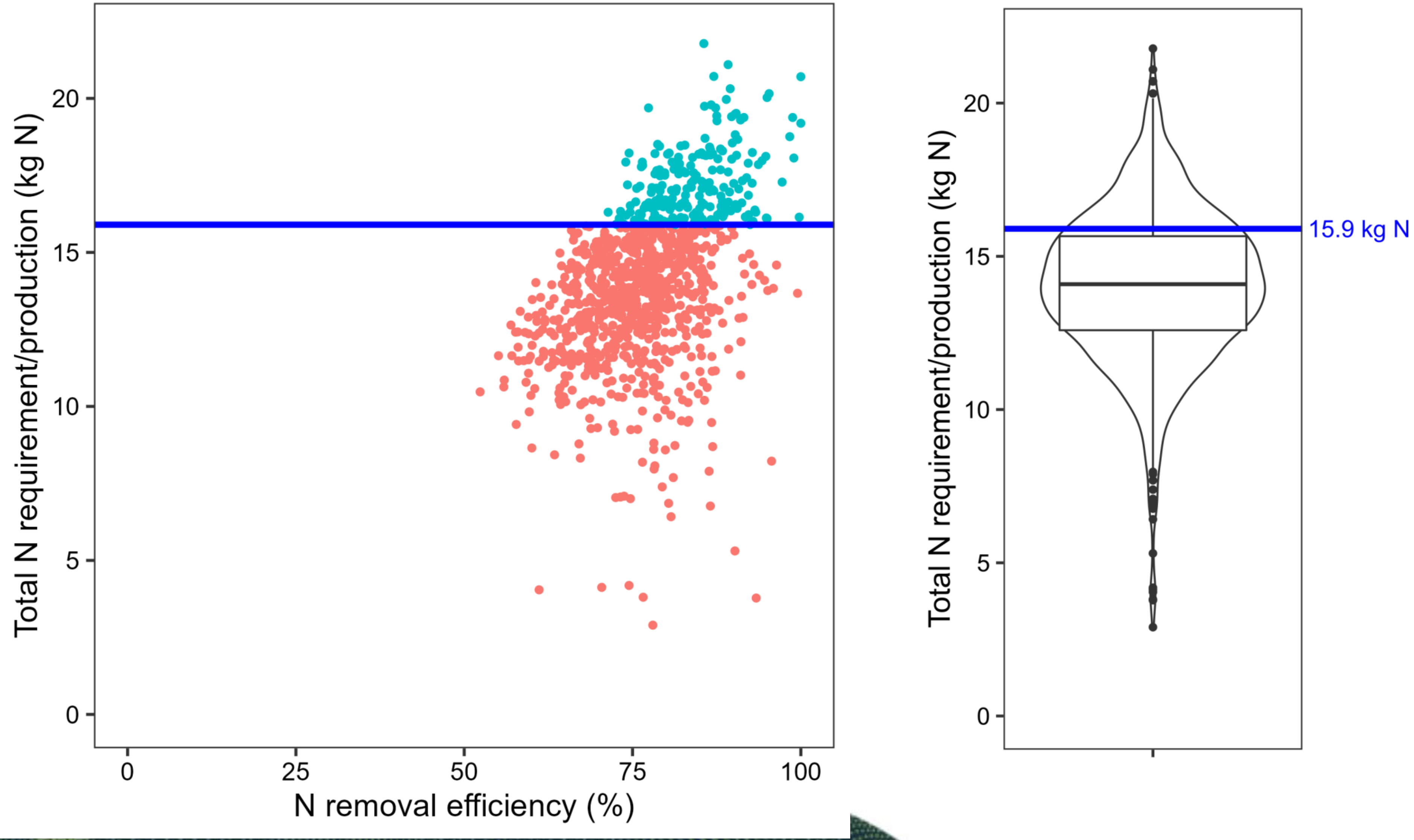
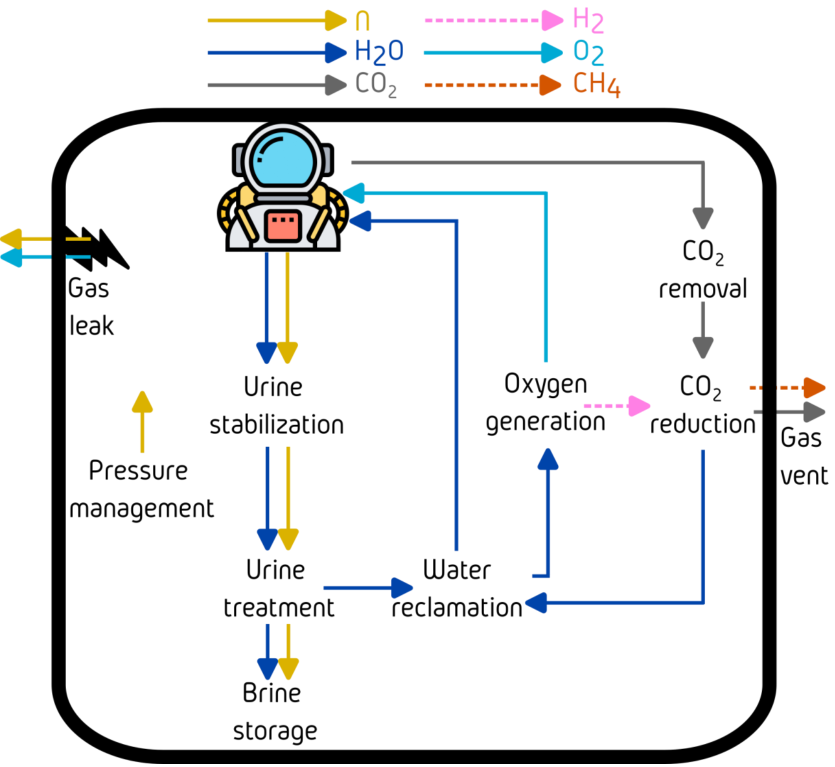


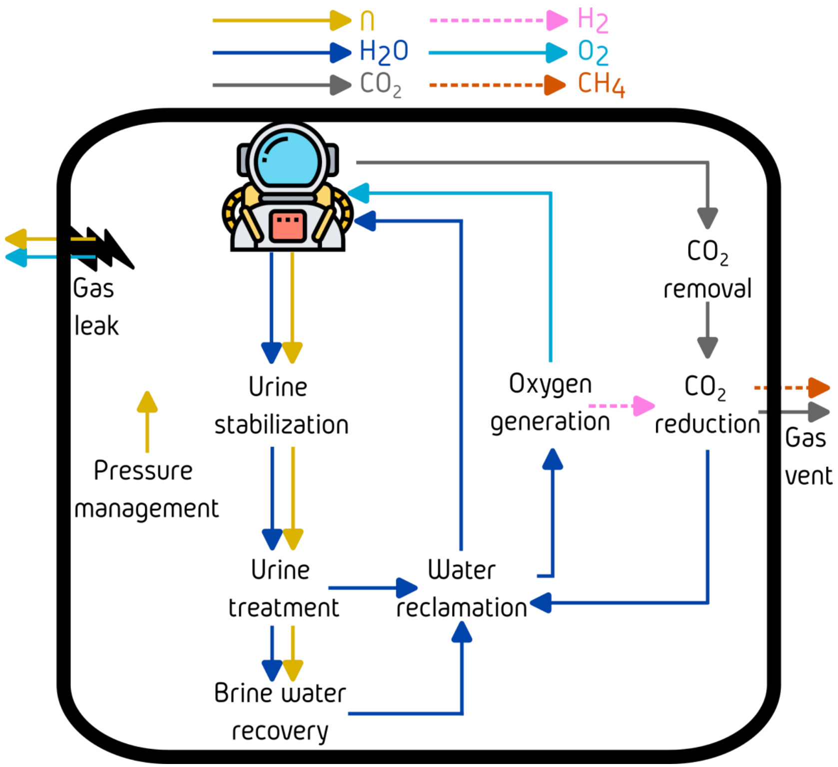
Can Nitrogenisor provide enough N_2 to offset losses and maintain cabin pressure?

1. Nitrogenisor can offset on average 88% of the N losses
2. In 25% of the scenarios, enough N_2 gas was produced to offset all N losses
3. High N removal efficiency and PN/A pathway crucial for high offset

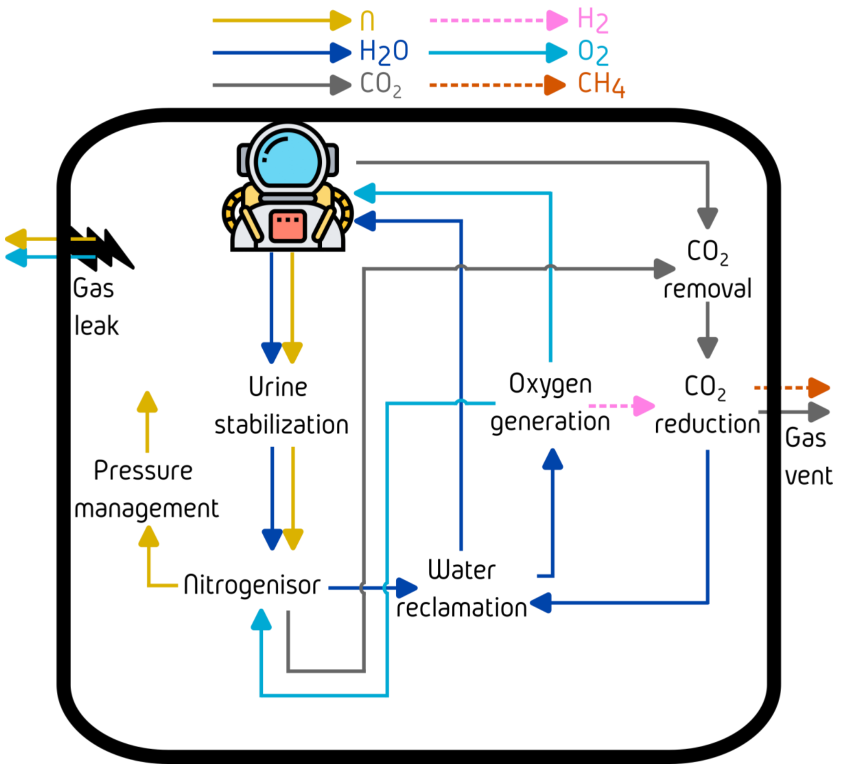
Is the mass associated with hardware and consumables favorable to state of the art?



VCD



BPA



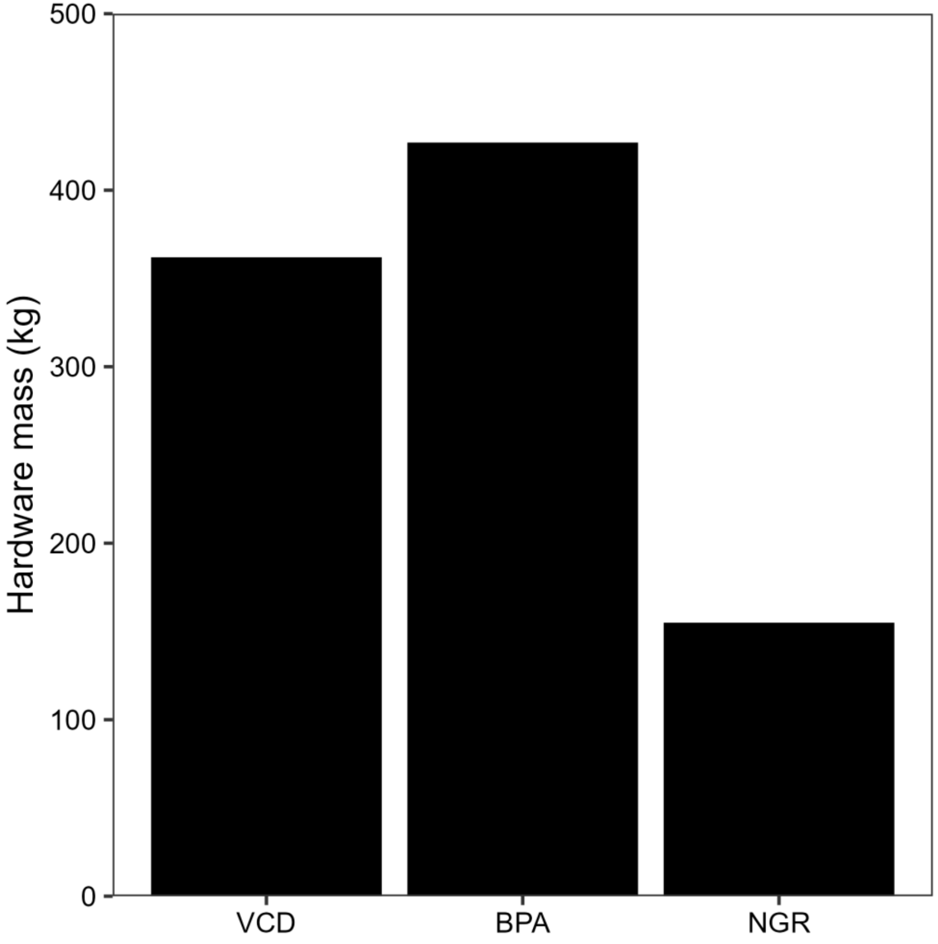
NGR

Can Nitrogenisor provide enough N_2 to offset losses and maintain cabin pressure?

- VCD and BPA hardware numbers sourced from literature
- Nitrogenisor numbers based on required volume to treat N load

→Nitrogenisor hardware mass is significantly lower (57%)

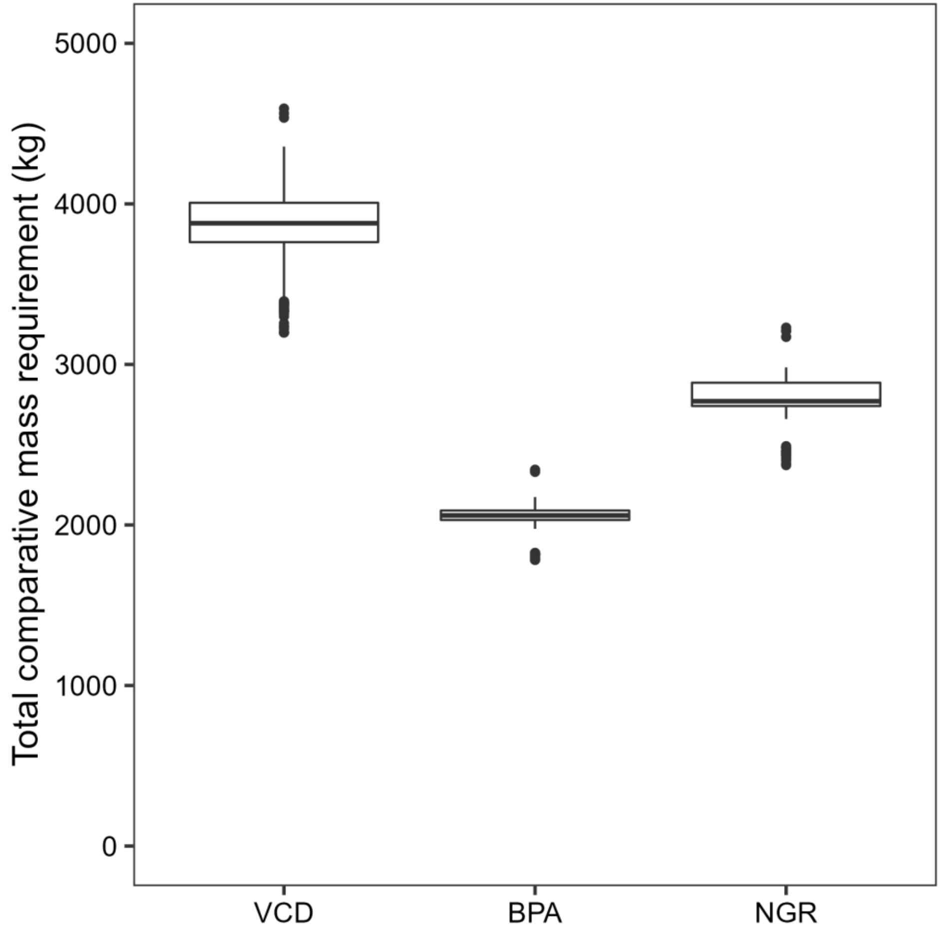
Hardware mass



Can Nitrogenisor provide enough N_2 to offset losses and maintain cabin pressure?

- Total comparative mass of Nitrogenisor is lower than VCD scenario
- BPA wins the mass competition

Total mass



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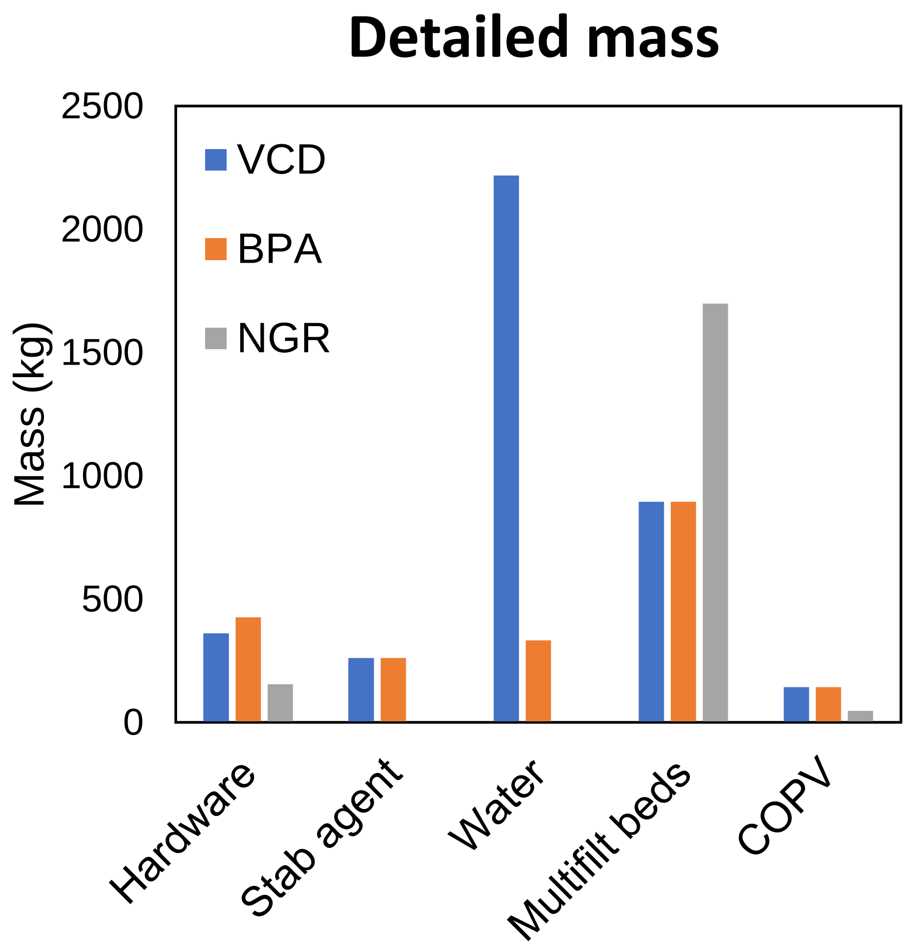
- Total comparative mass of Nitrogenisor is lower than VCD scenario
- BPA wins the mass competition

  → Mainly because of lower consumable need in the water reclamation step



Is the mass associated hardware and consumables comparable or favorable to state of the art?

1. Nitrogenisor Hardware mass is 57 % lower than state of the art
2. Brine water recuperation wins in terms of total mass because of lower salinity
3. Integrated solution for salt loading to water reclamation step is required

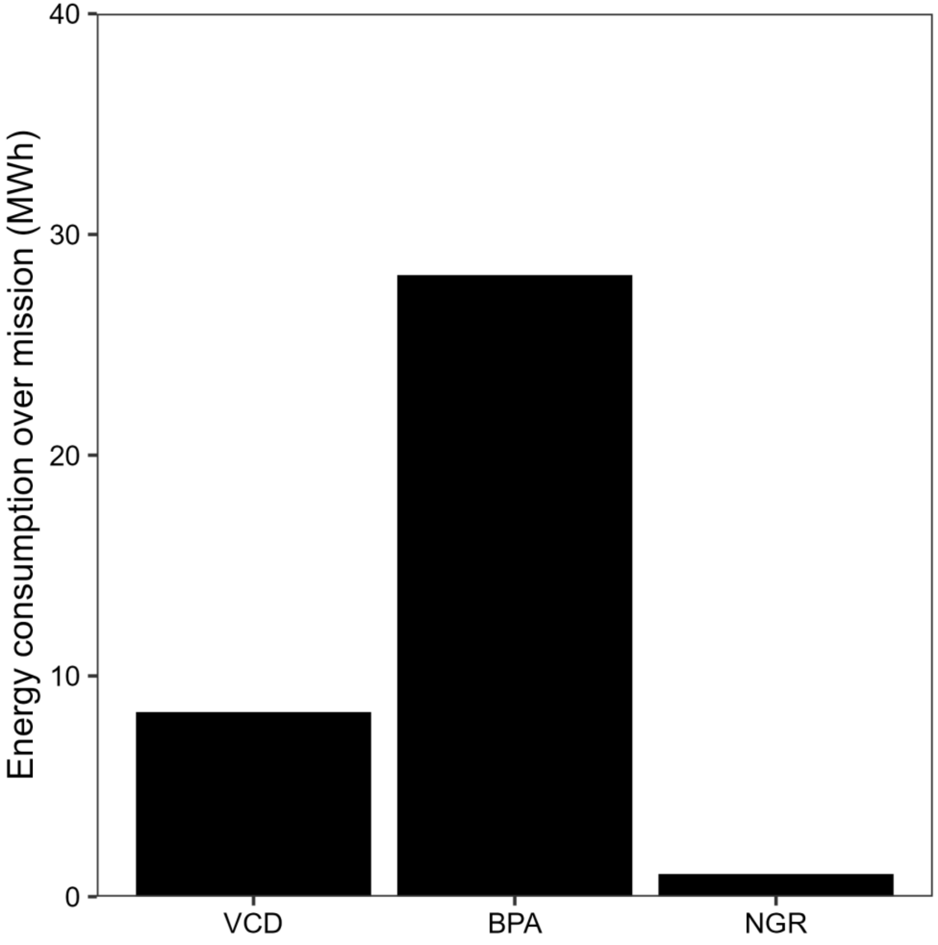
Can Nitrogenisor provide enough N_2 to offset losses and maintain cabin pressure?

- VCD and BPA numbers sourced from literature
- Nitrogenisor based pumping, stabilization, oxygen supply and CO_2 removal

→ Nitrogenisor requires significantly less energy!

→ 97% of nitrogenisors energy budget is to produce O_2 and treat CO_2

Energy required to treat urine



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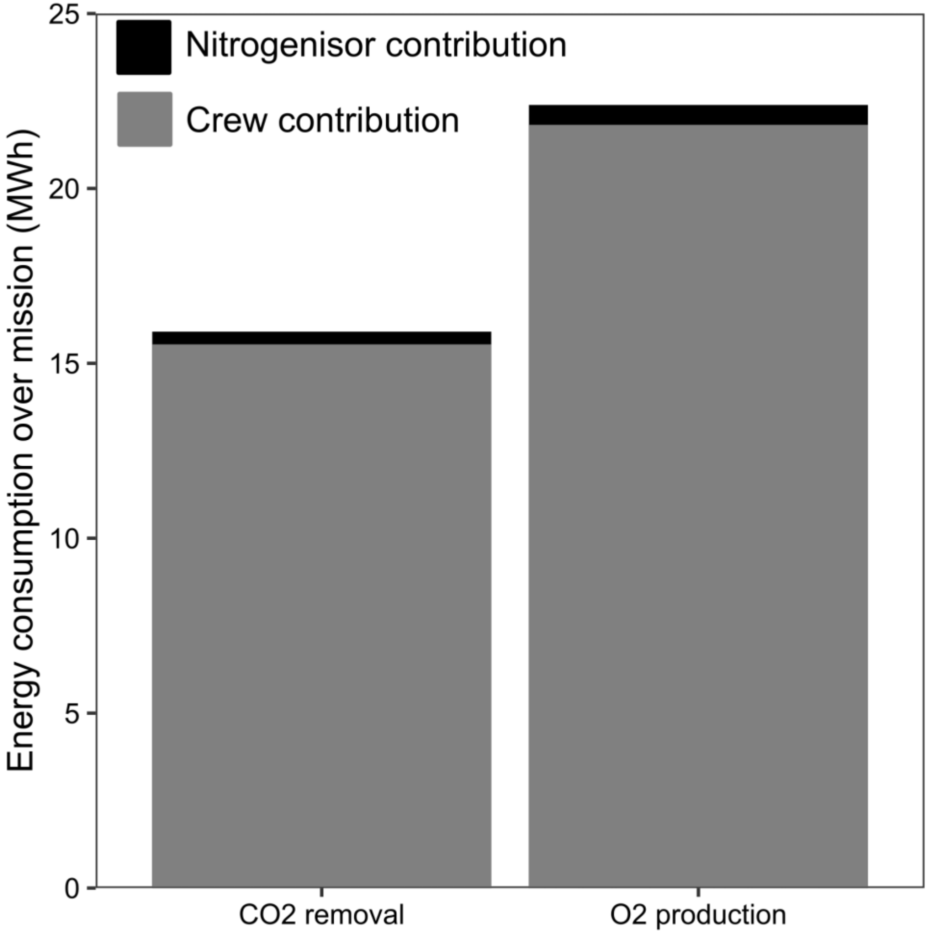

Is the energy requirement comparable or favorable to state of the art?

1. Nitrogenisor uses considerably less energy compared to state of the art to treat urine
2. Almost all energy associated with treating urine using nitrogenisor is O_2 production and CO_2 removal
3. While significant for Nitrogenisor, added O_2 production and CO_2 removal is insignificant for total energy budget

In conclusion…

Is the Nitrogenisor concept feasible for a crewed Mars transit mission based on mass and energy considerations?

1. Can Nitrogenisor provide enough N_2 to offset losses and maintain cabin pressure?
   → **Nitrogenisor can offset on average 88% of the N losses**
2. Is the mass associated with hardware and consumables favorable to state of the art?
   → **Nitrogenisor Hardware mass is 57 % lower than state of the art, though beaten by brine water recovery**
1. Is the energy requirement comparable or favorable to state of the art?
   → **Nitrogenisor uses considerably less energy compared to state of the art to treat urine**

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