National Aeronautics and Space Administration

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In-Situ Resource Utilization (ISRU) Liquefaction Overview

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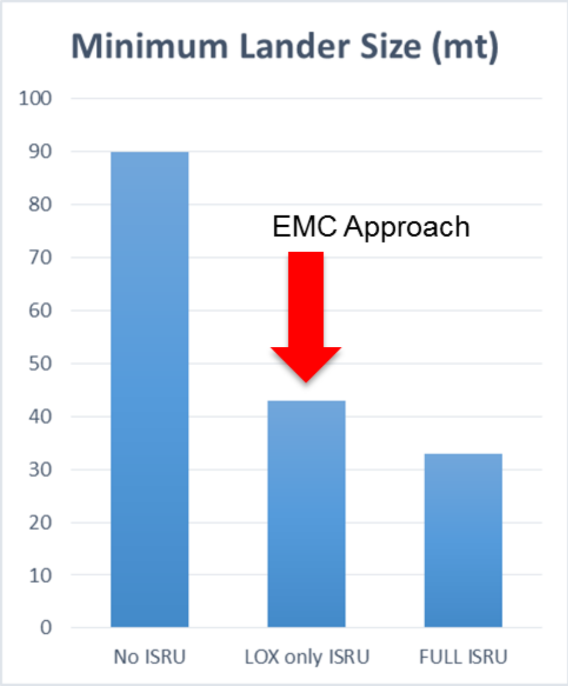
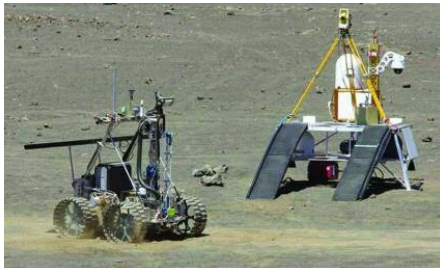
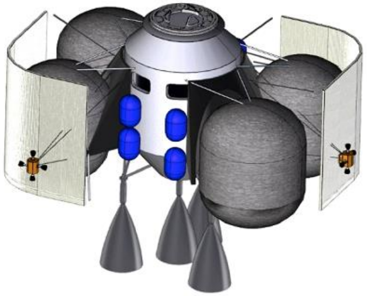
Liquefaction Overview

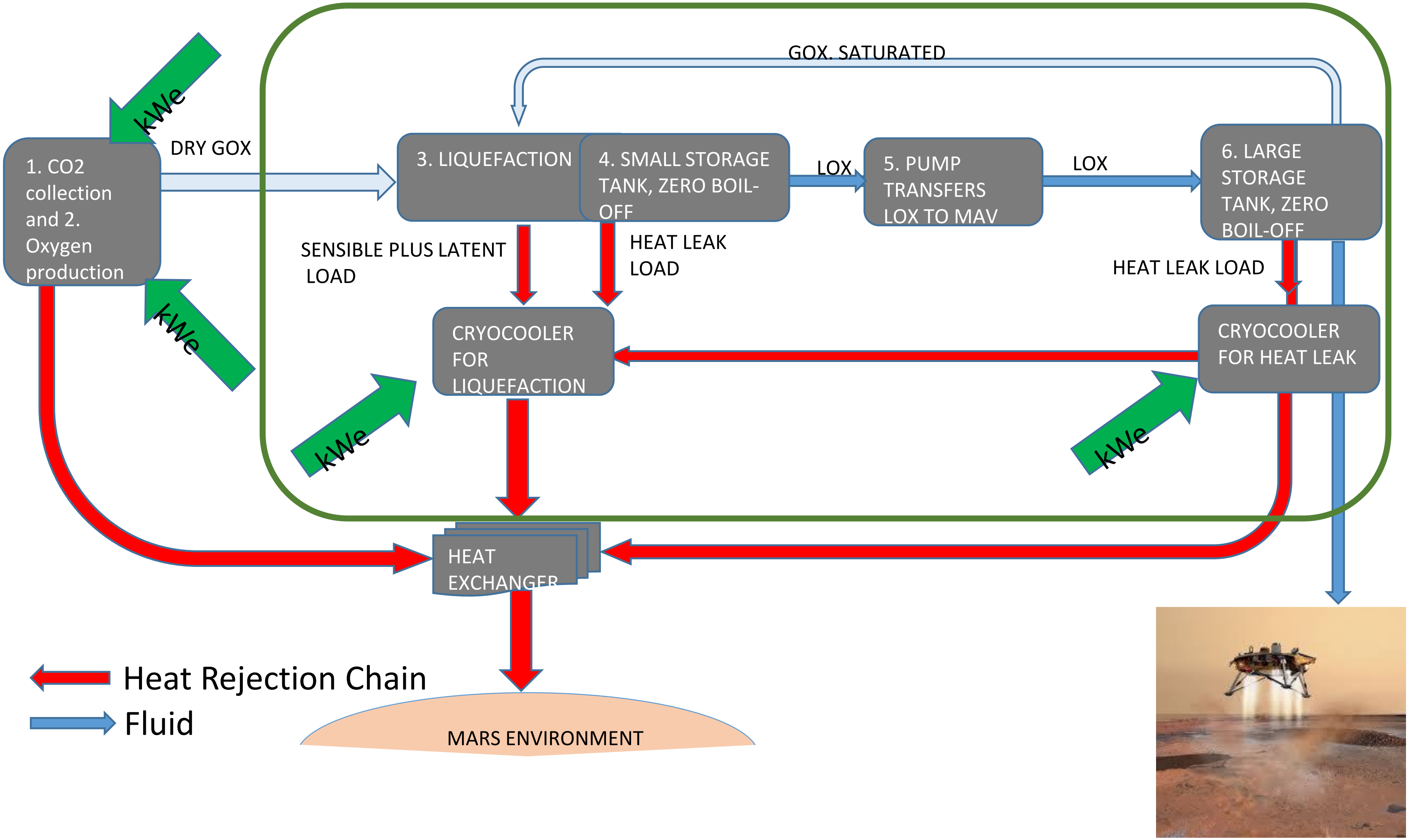
- **Purpose**: Cool and liquefy dry oxygen and store for up to 2 years
- Current Plan: Liquid Oxygen ISRU
  - >50% of total mass for lander is liquid oxygen
  - Methane liquefaction similar in scope and size to oxygen
  - Hydrogen liquefaction approximately an order of magnitude more input power
- Two Key Challenges for Cryogenic Operations:
  - Liquefaction Operations
    - Where, how to liquefy; minimize mass/volume
  - High Performing Insulation Systems in a soft vacuum







Production – Liquefaction – Storage



Current Work at NASA

- CryoFill Team
  - Cross-Center team
  - Members from JSC, ARC, Glenn, Marshall

- Conducted trade studies on liquefaction operations and insulation systems in 2016 and 2017

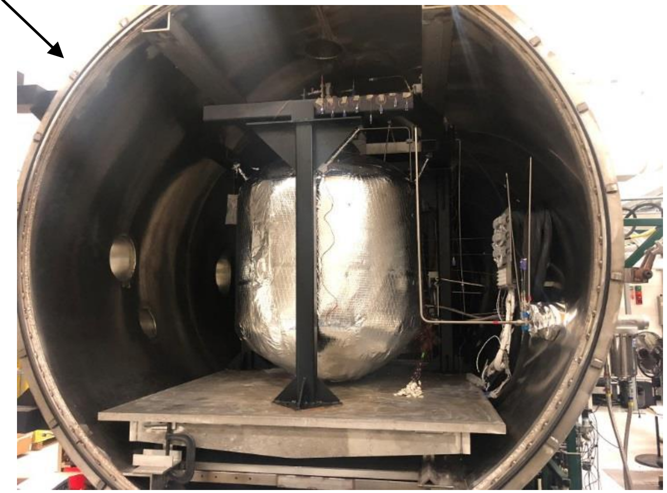
- Working on demonstrating these technologies and anchoring thermal models to demonstration data

  1) Brassboard testing with existing hardware and liquid nitrogen

  2) Prototype testing with new hardware and liquid oxygen

  3) Insulation Development (MarVACS RFI)

  4) Modeling Development



Test hardware installed in ESTF vacuum chamber at MSFC

Liquefaction Options

1) How to Liquefy?

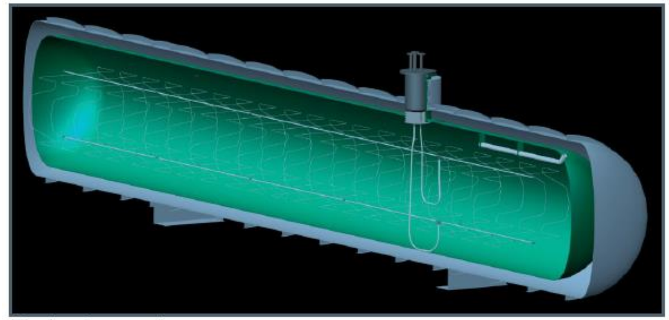
- <u>Tube on tank/broad area cooling</u>
- Tube in tank
- Linde Cycle (open cycle)
- Cold head in tank
- In-line Heat Exchanger

2) Where to Liquefy?

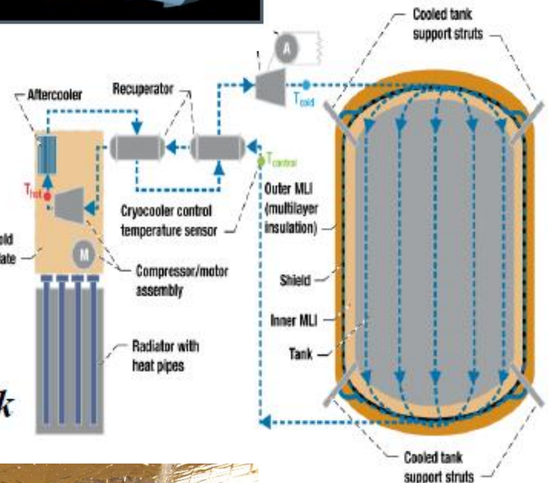
- Liquefy in separate tank
- Liquefy in-line
- <u>Liquefy inside MAV tank</u>

3) Component Development/Selection

- Cryocoolers
- Compressors
- High Efficiency Recuperators



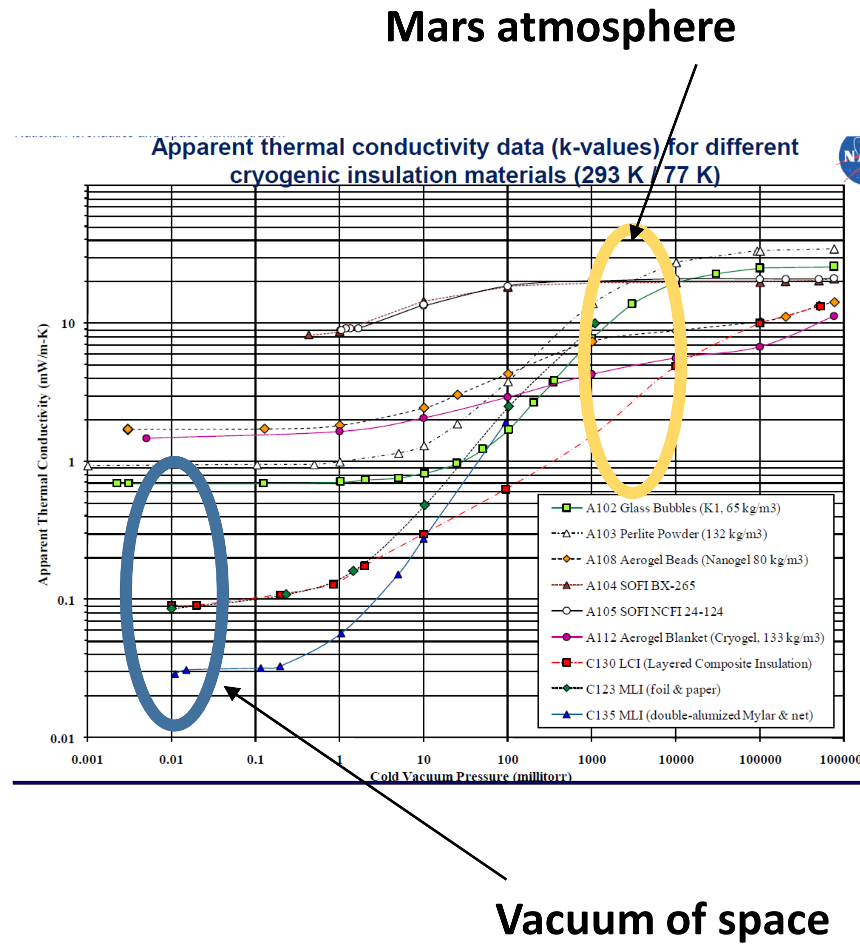
Tube in tank



Tube on tank

Vacuum Options

- Goal: Preserve propellant in tank
- Challenges:
  1) Mars's atmosphere degrades performance of thermal insulation systems
  2) Penetration/Leaks
  3) Operational Failures
- Options
  1) Lightweight vacuum jackets with Multilayer Insulation
  2) Aerogels
     - Best thermal performance in soft vacuum
  3) Spray on Foam Insulation and Multilayer Insulation



Insulation Trade Results

Relative Scoring Results	Insulation System Mass	Active System Power	Insulation System Cost	Insulation System Manufacturability	Insulation System Operational Flexibility	Insulation System Reliability	% of total points scored
Quest LRMLI	0.0976319	0.0573333	0.0002327	0.0005248	0.0582015	0.0025097	22
Improved 2016 MLI/VJ	0.0131803	0.0811321	0.0002433	0.0054227	0.0753195	0.0221692	20
MLAI	0.0392968	0.0035157	0.0026652	0.0264139	0.0188299	0.1087544	20
VJ + MLAI	0.0012204	0.0573333	0.0002327	0.0054227	0.0582015	0.0644161	19
SOFI/MLI	0.0515008	0.0035157	0.0037017	0.0306121	0.0017118	0.1087544	20

From the results above, there was no clear "winner" or even separation between the options.

However, there was one clear issue:

- Systems with good mass/power have a low reliability.
- Systems with high reliability have high mass/power.

Thus the conclusion the team is currently drawing is that in order to lower the mass of the insulations system significantly (~500 kg + multiple cryocoolers), there needs to be some development and investment in the Quest and MarVACS options to drive up the reliability and team understanding of these options.

Thermal Concerns

1) Transients in Mars/Moon Environment (daily, seasonal)

2) Stratification within the tank

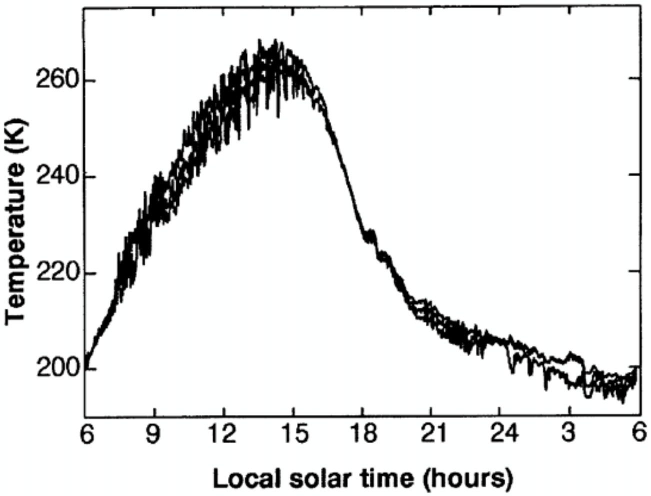
3) 2 phase heat transfer

4) Co-Storage of Oxygen and Methane
   - *Store at same or different temperatures?*

5) Liquefaction rate at high fill percentage

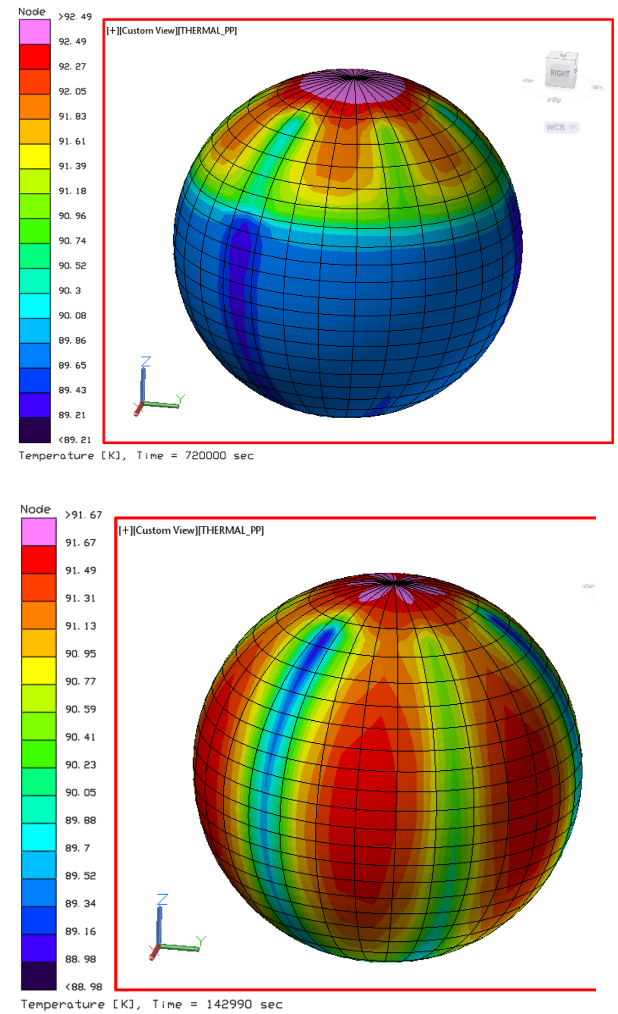
6) CFD Boundary Assumptions

7) Purity/Contamination
   - *Effects on liquefaction process (preventing condensation)*
   - *Solids at the bottom of the tank?*



Current Work – Modeling

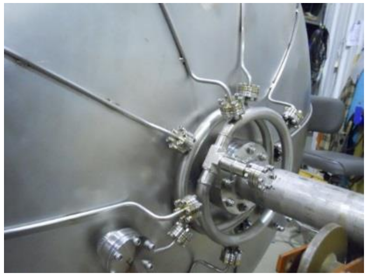
- Developed transient thermal model of MAV sized tank in Thermal Desktop to enable team to understand system performance
  - TD model does not currently model stratification in the ullage layer
- Incorporated 90 W cryocooler into model
- Ran initial CFD to understand internal liquefaction heat transfer coefficients better
- Developed thermal model of zero boil-off tank to predict brassboard system performance and anchor future test data to model



Tank Wall Temperature at different fill levels

Link to paper: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170009150.pdf

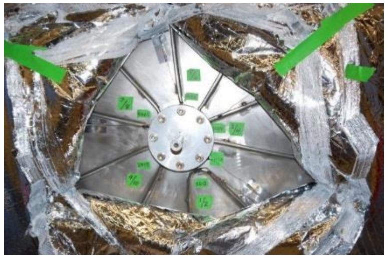
Current Work – Modeling



Top of ZBO tank

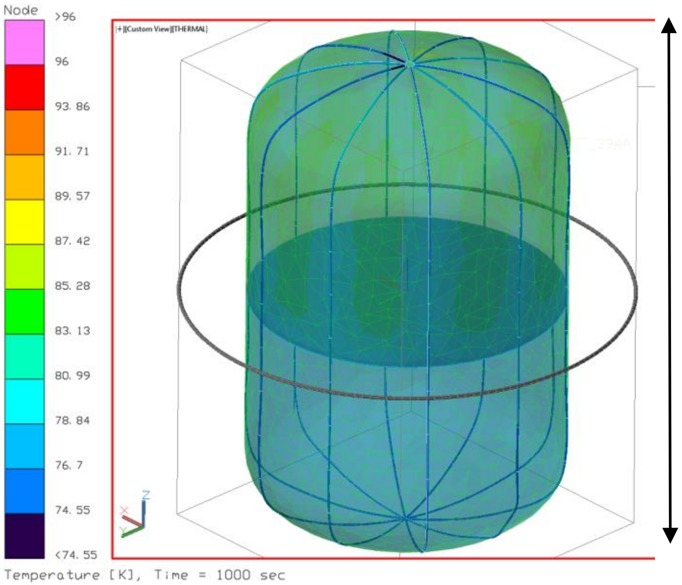
- Brassboard modeling in progress
  - Tests will look at liquefaction at different fill levels, constant vs. non constant liquefaction, and different cryocooler settings

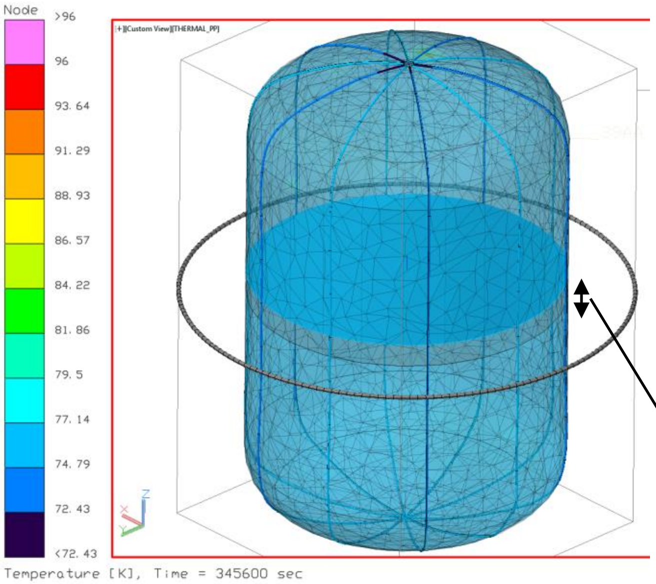
- Model built in Thermal Desktop, uses compartments



Bottom of ZBO tank

Initial fill level: 50%





(4 days)

Liquid Level Increase

Plans Going Forward