ISRU Technology Development for Extraction of Water from the Mars Surface

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NASA ISRU project

Scope: Develop and demonstrate, in ground demonstrations, the component, subsystem, and system technology to enable production of mission consumables from regolith and atmospheric resources at a variety of destinations

- Initial focus
  - Critical technology gap closure
  - Component development in relevant environment (TRL 5)
- Interim goals
  - ISRU subsystems tests in relevant environment (Subsystem TRL 6)
- End goals
  - End-to-end ISRU system tests in relevant environment (System TRL 6)
  - Integrated ISRU-Exploration elements demonstration in relevant environment

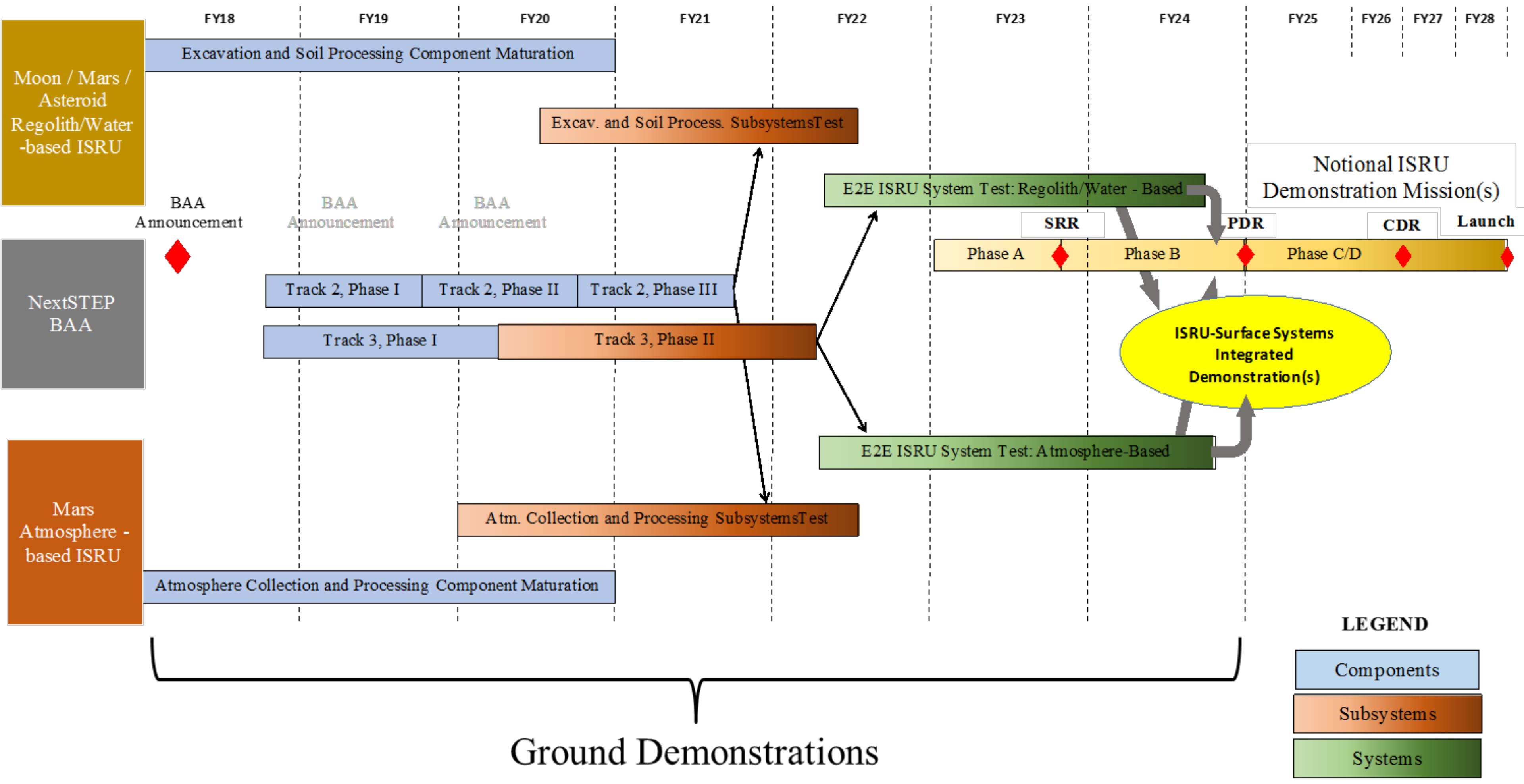
Overall Project Goals

System-level TRL 6 to support future flight demonstration missions

Provide Exploration Architecture Teams with validated, high-fidelity answers for mass, power, and volume of ISRU Systems

NASA ISRU project

All dates are subject to evolving agency policy and funding priorities



HEOMD Advanced Exploration Systems
ISRU Program Exec – N. Suzuki

In-Situ Resource Utilization Project
Project Manager – D. Linne

- 2.0 Systems Engineering & Integration
  - 2.1 Requirements / Arch Definition
  - 2.2 System Modeling & Analysis
  - 2.3 System Level Integration
  - 2.4 ISRU-Surface Systems Integration
- 4.0 Component & Subsystem Technology Development
  - 4.1 Atm Carbon Dioxide Collection Subsystem
  - 4.2 Oxygen Production Subsystem
  - 4.3 Methane Production Subsystem
  - 4.4 Water Electrolysis Subsystem
  - 4.5 Mobility Subsystem
  - 4.6 Prospecting Subsystem
  - 4.7 Excavation Subsystem
  - 4.8 Soil Processing Subsystem
  - 4.9 Product Storage and Distribution Subsystem
- 5.0 System Validation & Test
  - 5.1 Environmental Test Infrastructure
  - 5.2 Simulants Development
  - 5.3 Regolith/Water-Based System
  - 5.4 Mars Atm-Based System
  - 5.5 ISRU-Surface Systems Integrated Demonstrations

ISRU Project working requirements

- ISRU products: Propellant for Mars Ascent Vehicle defined in the Evolvable Mars Campaign
  - 6976 kg Methane, 22728 kg Oxygen
- Production time: 434 days @ 24 hr/day operations
  - Based on 26 month launch window. ISRU fuel produced prior to next mission landed.
  - Margin included for: setup, dust storm, failure, reserves
- Fault Tolerance: 3 modules operating at 50%
- Environmental Conditions:
  - For hydrated minerals: Jezero Crater
  - For Ice: Viking 2
- Production rate:
  - 1.5 kg/hr water → 0.67 kg/hr CH_4 and 2.68 kg/hr O_2

Soil Processing Element: Overview

- Goals:
  - Develop technologies to extract water from planetary regolith considering production rate vs:
    - Energy/Power consumption (efficiency, yield, heat recuperation options)
    - Mass and sizing: modularity, batch sizes, soil feed options ,etc
    - Ruggedness in terms of soil, environmental, and operational parameters; seals and component wear; etc
    - Removal of product and disposal of spent material
- Approach
  - With multiple architectures still on the table, several technology options are being advanced. Several options at a higher TRL will keep the project flexible to options such as:
    - Mobile vs Fixed soil processing
    - Resource target and Landing site
    - Power source & location
    - Raw material delivery (e.g. excavator type)
  - Note that the technologies covered here are the in-house efforts only.
  - Goal is to advance toward a down-select in 2020 for the integrated subsystem test. Down-select based on project level considerations and results of other element technologies.
  - All technologies include both breadboard testing and model development

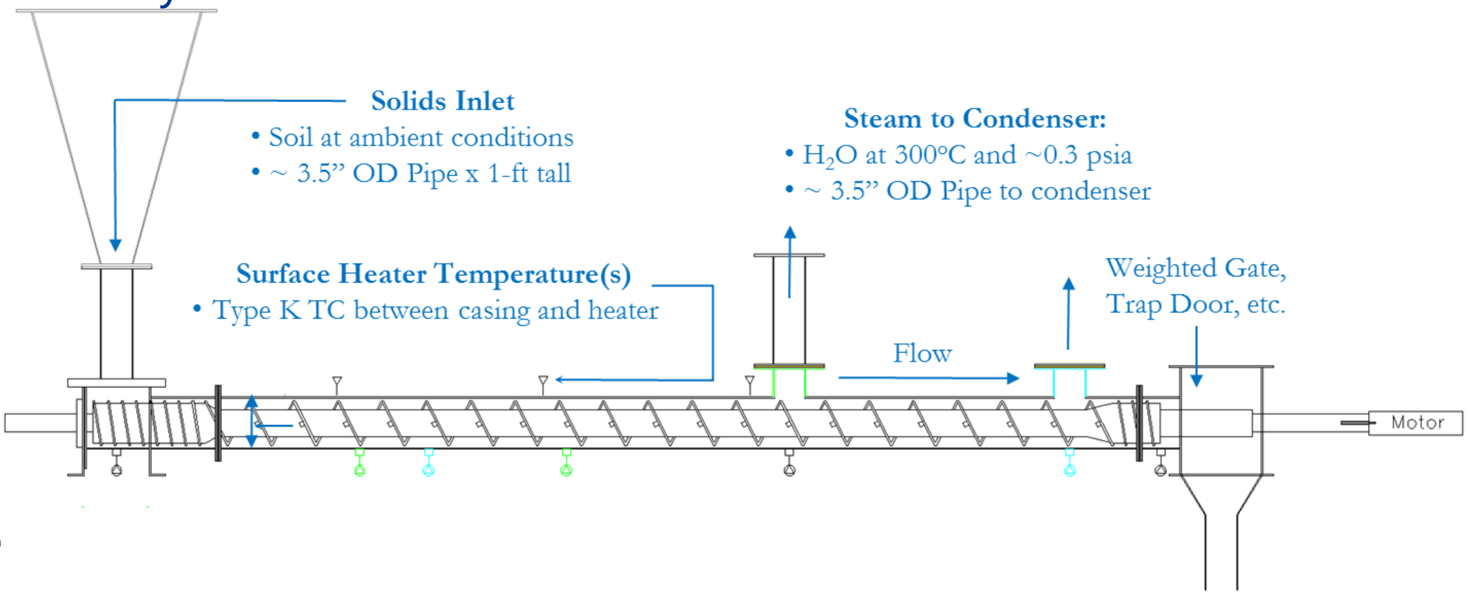
Soil Processing Element Technologies

- Hydrated mineral resources
  - **Auger Dryer:** Granular material is continuously conveyed through a closed, heated auger assembly. The varying pitch of the auger flutes, along with a regolith head in the hopper, seal the system so that the evolved water vapor is pressure fed to the condenser.
  - **Microwave:** Granular material is fed into a resonant cavity where the water is released via microwave radiation. A porous regolith vessel will used to facilitate water release and collection such that a continuous feed of regolith can be processed.
  - **Open air:** A bucket wheel is used to retrieve granular material from a hopper, or from the surface itself, and dump it onto a inclined heated tray. Atmospheric gas is blown over the tray (duct not shown) to sweep water vapor into the condenser. Vibration conveys material down the heated tray.
- Subsurface Ice
  - **Rodriquez Well (“Rodwell”):** This terrestrial concept is currently in use at Antarctic field stations. The ice sheet is accessed via a borehole and a heat probe is used to melt and maintain a liquid ‘well’ within the ice. Water is pumped out of the well for use.

Auger Dryer

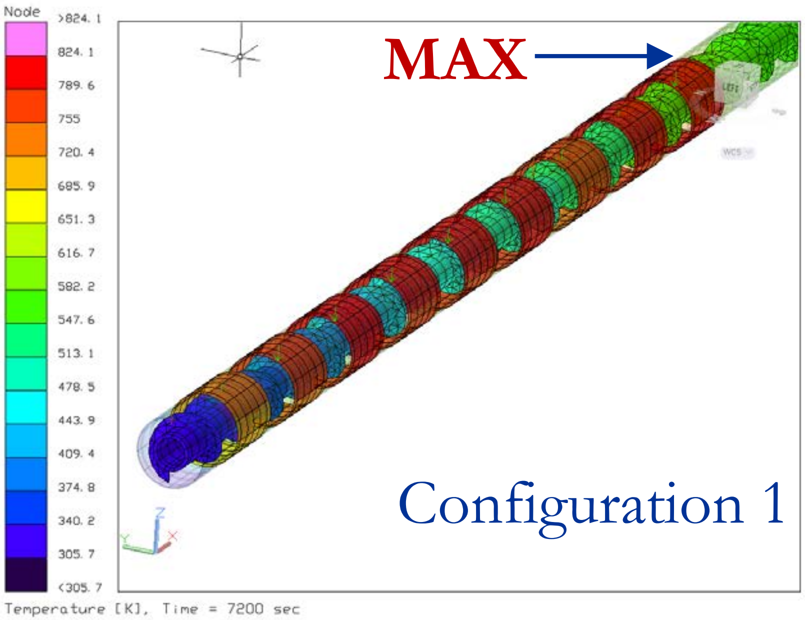
- Background:
  - Based on terrestrial design for granular material dryers in pharmaceutical, agriculture, food industries, etc
  - Concept baselined in the 2016 EMC campaign ISRU system model study. Terrestrial system equations were modified and incorporated into model for scaling.
- Year 1 goals
  - Design, build, and test a breadboard system for Mars application (simulants, pressures) based scaling parameters in model
  - Examine con-ops and performance that will feed into subsequent design iterations.
  - Validate model performance parameters and empirical assumptions; improve auger model for application into ISRU system model

Plug seal example by Conveyor Engineering & Manufacturing



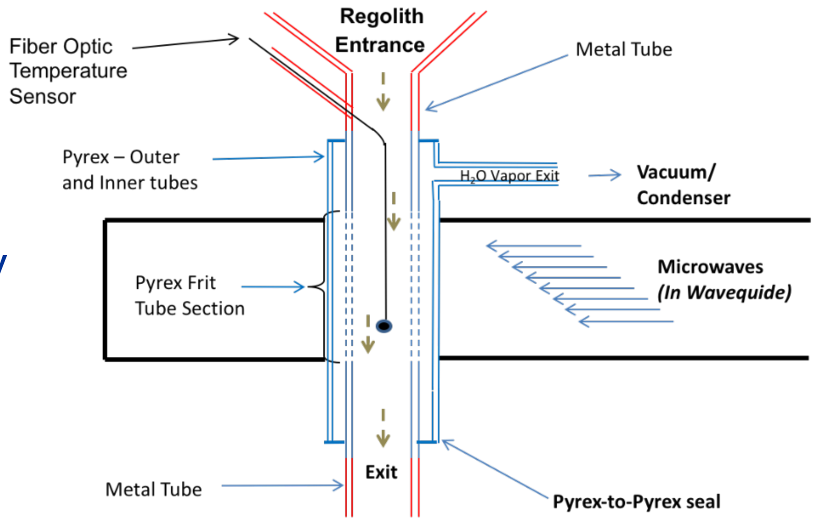
Auger Dryer

- Status
  - Breadboard has been designed and fabrication complete. Test setup in progress
    - Phase 1 is with a plastic casing for material flow observations
    - Phase 2 will be a metal casing with heater and water condenser for water evolution studies including, energy efficiency, yield (residence time, temperature, etc)
      - Designed to allow for full or partial production flow rates: zoned heaters and fluid ports
  - Soil hopper with soil column for pressure seal will be tested at various operational pressures



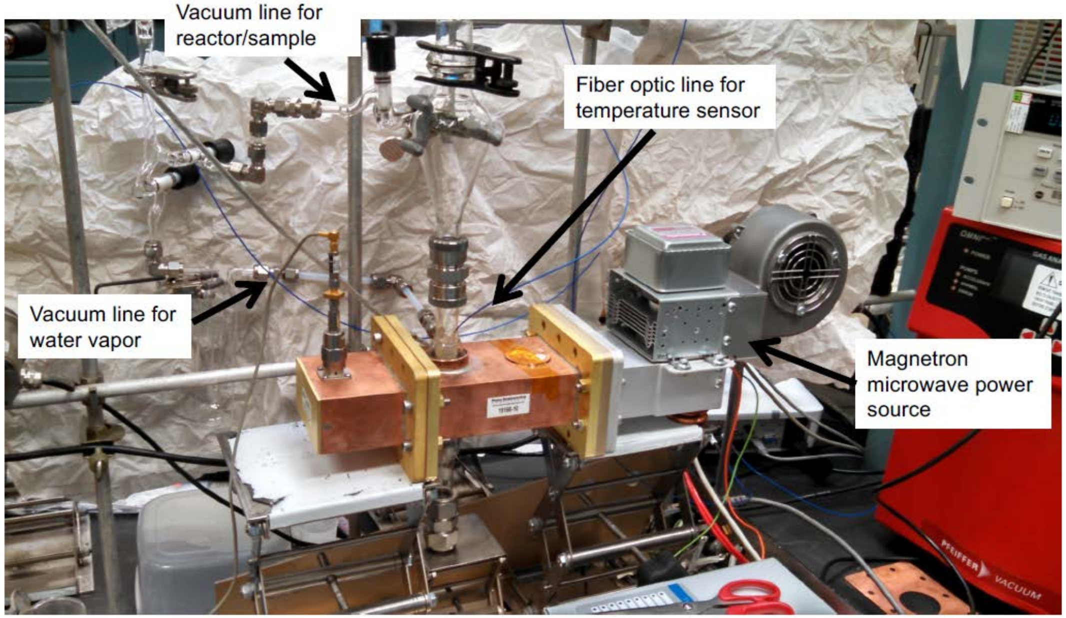
Microwave

- Background:
  - Earlier efforts using microwave heating of lunar simulants for reactor and construction purposes
  - Internal R&D funds in 2017 to look at Mars application using various hydrated minerals was the direct predecessor to this work
- Year 1 Goals:
  - Advance breadboard to accommodate hydrated regolith simulants and continuous throughput
  - Examine power efficiencies
    - Reflected power & soil temperatures
    - Solid state amplifier versus magnetron with adjustable cavity: resonant frequency optimization
  - Evaluate porous tube properties
    - Pore size vs efficiency in soil flow and water removal
  - Design of continuous soil feed system
    - Estimate soil flow rate versus applied power



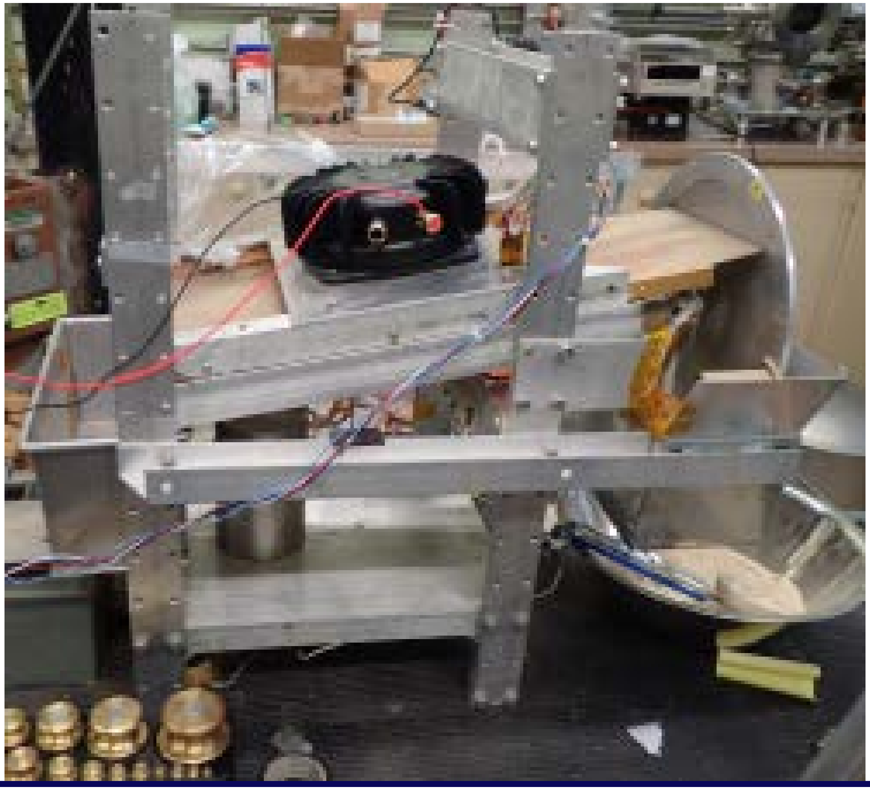
Microwave

- Status
  - Testing in progress with porous tube at vacuum conditions
    - Preliminary results with 5um pore tube are promising
    - Thermal Model validation of soil temperatures shows good agreement
  - Fabrication complete of adjustable magnetron cavity
  - Examination of dielectric constant of Mars soil simulants: Range for operations
  - Fiberoptic thermometer in cavity for temperature measurement of soil
  - Soil feed system and condenser are being developed



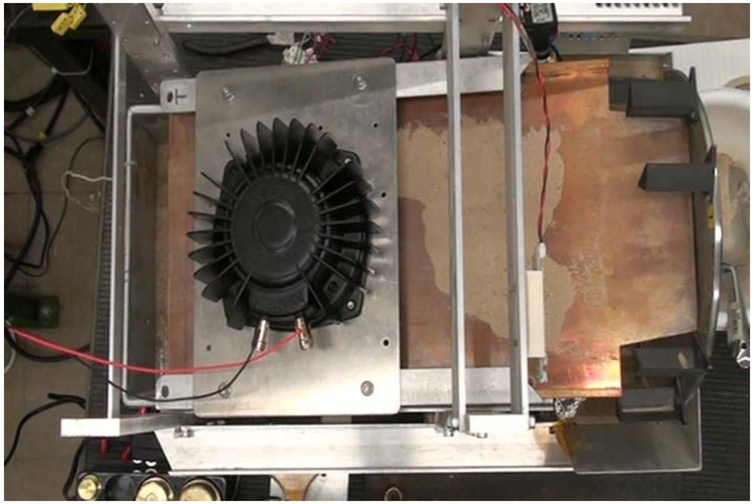
Open Air Processor

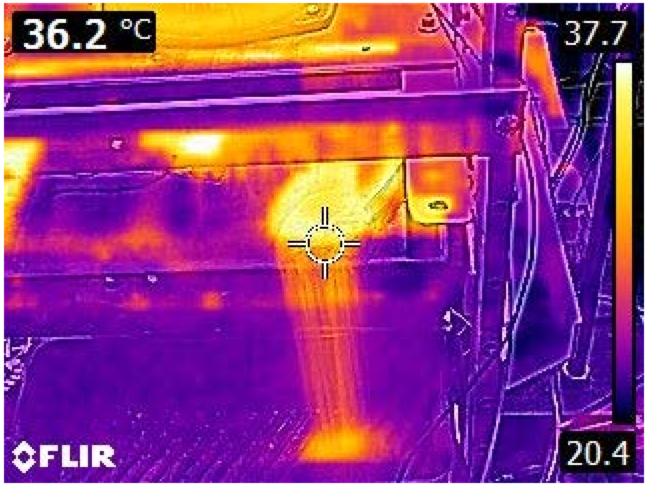
- Background
  - Internal R&D award in 2016 to examine proof of concepts
    - Roto-tiller concept in 2016, Bucket wheel concept in 2017
    - All proof-of-concept hardware tested at Mars environmental conditions (pressure, gas, simulant)
  - Concepts to avoid need for high temperature, dust tolerant seals
- Year 1 Goals
  - Using hardware developed in 2017, run parametric studies to develop and validate a model
  - Use model for scaling and improvements for hardware redesign to meet full production rate and improve yield efficiency



Open Air Processor

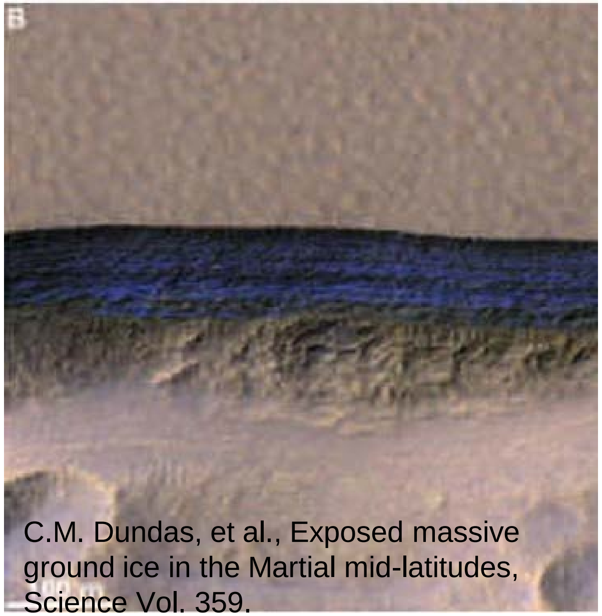
- Status
  - Re-work of the vibration driver for the inclined tray to get repeatable flow results
  - Additional sensors including
    - Accelerometer for flow characterization
    - Improved accuracy load cell, vibration isolated
    - Additional thermocouples for better soil measurement
  - Initial model development completed
  - Room pressure testing for soil flow studies complete; techniques validated
  - Mars environment testing currently underway



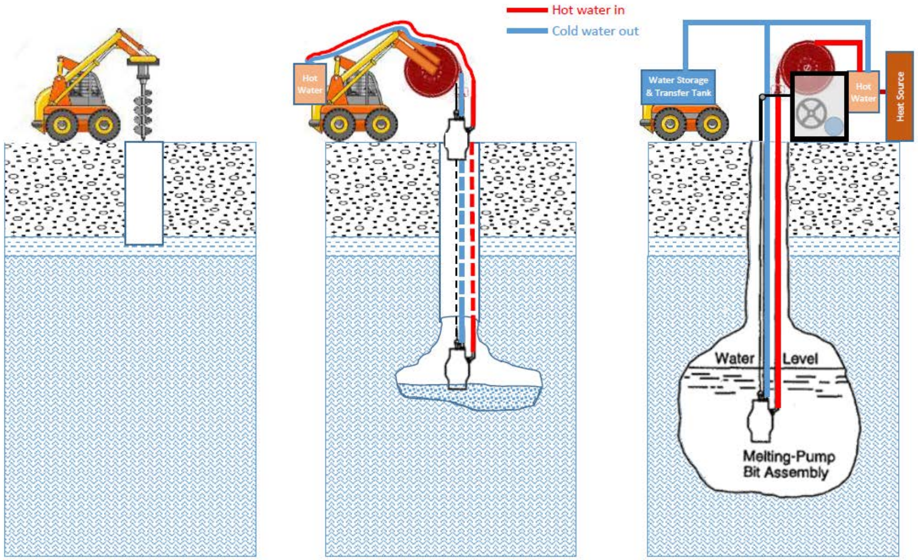


Rodwell

- Background:
  - Rodwells are in use terrestrially (Antarctic field stations) for water generation from subsurface ice sheets.
    - Subsurface Glaciers have been identified on Mars, as shallow as 1m deep (Dundas, 2018)
  - CRREL (Cold Regions Research and Engineering Laboratory) has generated a numeric model for Rodwell design. This model has been leveraged to develop a ISRU Mars Rodwell system to:
    - Estimate mass & power for Mars relevant hardware
    - Examine Concept of Operations of Rodwell for various operating conditions (production rates, location, etc)
    - Initial trade study results to be published at AIAA Space 2018.



C.M. Dundas, et al., Exposed massive ground ice in the Martial mid-latitudes, Science Vol. 359.



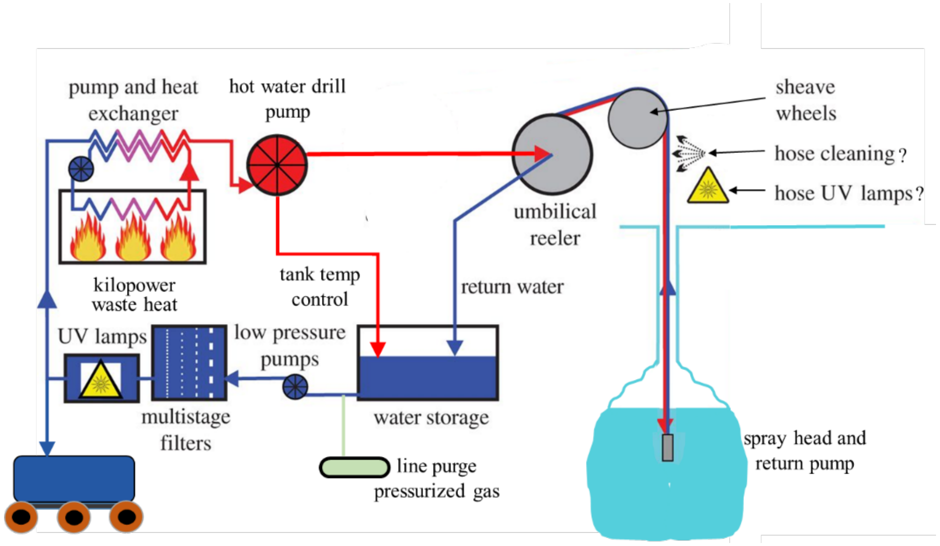
Phase 1: Drill through overburden into top of ice.

Phase 2: Melt into ice. Begin forming water pool.

Phase 3: Steady state operation.

Rodwell

- Year 1 Goals:
  - Modify existing Rodwell model developed by CRREL to accommodate Mars environmental conditions
  - Examine impact of Mars environment on Rodwell efficacy and con-ops
    - Mars environmental conditions including: thermal parameters, pressure effects (sublimation), etc
    - Mars surface conditions including: impurities in ice, depth to ice, overburden composition, etc
  - Experimentally measure need parameters in a thermal vacuum environment for model application
- Status:
  - Agreement in place with CRREL to help modify existing model
  - Experimental study in formulation to obtain parameters needed for Mars adaptation of model
    - Thermal properties, sublimation/phase conditions, etc
    - Currently identifying which are driving parameters for the model



Summary

- Technology development is underway for several ISRU water extraction hardware concepts for Mars application.
  - Hydrated minerals (Auger dryer, Microwave, Open Air)
  - Subsurface Ice (Rodwell)
- Models are developed with experimental and breadboard efforts for use in larger ISRU system models
- Each effort consists of a 3 year development plan, with the goal of integrating into a larger subsystem test in 2020.
  - Concurrent technology advance allows for flexibility in system design; depending on architecture decisions and progress of associated subsystems