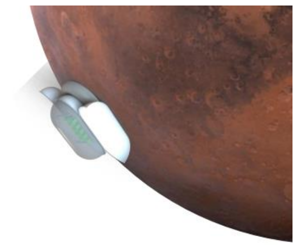

MarsOASIS

Mars Operational Agricultural System for In-Situ Specialization

X-Hab Academic Innovation Challenge 2014-2015

University of Colorado at Boulder

System Reference Manual

Rev A, June 11, 2015

National Space Grant Foundation

NASA

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I. PROJECT CHARTER: X-HAB 2014/2015

Project Name:		eXploration Habitat (X-Hab)
Project Sponsors:		NASA and U.S. Space Grant
Project Manager: Asa Darnell		**Customer:** NASA/Space Grant
Other Stakeholders:		**Stakeholder Responsibilities:**
	Joe Tanner	Advisor
	Jordan Holquist	PhD Student Advisor
	Heather Hava	PhD Student Advisor/Plant biology expert
	Daniel Zukowski	Student Advisor
	Christine Fanchiang	PhD Student Advisor
	Lizzie Lombardi	Staff Advisor/Plant biology expert
	Dr. Bill Liggett	Advisor
	Asa Darnell	Project Manager and Plant Care and Nutrient Delivery subsystem team member
	Christine Chamberlain	Systems Engineer and Plant Care and Nutrient Delivery subsystem team member
	Kier Fortier	Atmosphere subsystem team lead and Structures subsystem team member
	Alex Wassenberg	Atmosphere subsystem team member and Structures subsystem team member
	Henna Jethani	Electrical/Software subsystem team lead and Atmosphere subsystem team member
	Brennan Borlaug	Electrical/Software subsystem team member
	Aastha Srivastava	Electrical/Software subsystem team member
	Anurag Azad	Electrical/Software subsystem team member
	Sai Sindhuja Thirumala	Electrical/Software subsystem team member
	Abhimanyu Ambastha	Electrical/Software subsystem team member
	Chaitanya Soma	Electrical/Software subsystem team member
	Divya Sridhar	Electrical/Software subsystem team member
	John Marino	Electrical/Software subsystem team member and Plant Care and Nutrient Delivery subsystem team member
	Daniel Case	Chief Financial Officer and Plant Care and Nutrient Delivery subsystem team lead
	Paul Guerrie	Structures subsystem team lead
Business Objectives:		Support future research grants and proposals
Project Scope/Objectives:		
To enable a permanent human presence beyond Earth, a regenerative means of food production must be made available for long duration crewed space missions. The scope of X-Hab is to generate a conceptual design and develop a reduced-scale prototype for a pre-deployable Martian plant production system while identifying key science questions and related engineering challenges.		

Primary Objectives:

1. Develop a conceptual design for a system capable of growing food-producing plants in an unmanned, self-controlled environment on the Martian surface.
2. Design, fabricate, and test a reduced-scale prototype to demonstrate system functionality.
3. Identify key science questions and engineering challenges related to plant growth on the Martian surface.

Secondary Objectives:

4. Demonstrate, with a prototype, the system's capability to support research-grade plant science studies in a closed environment.
5. Develop a design that is capable of supporting a variety of food-producing plants.

Deliverables:

1. Develop a conceptual design of a plant-production system that functions on the surface of Mars.
2. Develop and test a reduced-scale prototype of the conceptual design.
3. Publish a list of scientific questions and engineering challenges related to plant growth on the Martian surface.

Ground Rules:

1. Plants grown shall be food-producing.
2. System shall be capable of being operated and maintained in extreme environments (i.e. Martian surface).
3. System shall have a small stowage volume and mass.
4. System shall be deployable upon delivery (i.e. operable upon delivery).
5. System shall be pre-deployable (i.e. arrive prior to human arrival).
6. System shall use pre-planted media or growing system.
7. System shall have a priming volume of water and required gases.
8. System should have a closed water loop.
9. System should be able to harvest and store O2 generated from plants.
10. System prototype shall be built and tested prior to May 2, 2015.

Assumptions and Constraints:

1. The system design will not include the method of delivery (i.e. deployment) to the Martian surface.

Rationale: Given schedule constraints, delivery system planning has been determined to be outside of this project's scope.

2. The system should operate independently of other spacecraft or systems.

Rationale: Without knowledge of the delivery system to the Martian system, we should not assume availability of power or other spacecraft subsystems to support the system.

3. The system will be launched and delivered to the Martian surface using existing or planned transportation vehicles.

Source: X-Hab 2014 Proposal

4. The payload volume shall not exceed 20" x 17" x 30".

5. The system will be designed to grow Outredgeous lettuce.

Rationale: Leafy lettuce requires minimal to no maintenance and has high nutritional content per volume. Outredgeous lettuce has a short growth cycle allowing prototype demonstration within schedule constraints, and allows "cut and come" harvesting. Also, this lettuce has been previously grown in space, providing baseline data for comparison.

6. The system's design will support plant growth from germination to, but not through, harvest.

Rationale: Given schedule constraints, harvest and re-planting have been determined to be beyond this project's scope. It is assumed that a human crew will arrive after system deployment to harvest manually.

Project Completion Date: 05/15/2015	**Budget:** $
Important Deadlines (Tentative, *Not Actuals*): 1. Systems Design Review (CU) – Sept 23, 2014 2. Systems Design Review (NASA) – Sept 30, 2014 3. Preliminary Design Review (CU) – Oct 28, 2014 4. Preliminary Design Review (NASA) – Nov 12, 2014 5. Critical Design Review (CU) – Dec 11, 2014 6. Critical Design Review (NASA) – Jan 14, 2015 7. Progress Checkpoint Review – Mar 11, 2015 8. Class Completion – May 2, 2015	**Resources:** ▪ Bioastronautics Lab ▪ LifeLAB AETHER Atmosphere Rig ▪ LifeLAB RALPHEE/JANA Thermal Vacuum Chambers ▪ Heritage hardware and software ▪ Infinite Harvest consulting

Communication Plan:

1. Weekly Meetings from 3-5 pm Tues/Thurs
2. Weekly subsystem meetings as required
3. Internal communication via email and phone contact, 24 hour mandatory response
4. Document sharing and storage via Google Drive accessible to all team members

Project Sponsor Signatures:

Signature on File w/ Faculty Advisor

Joe Tanner

Project Manager Signature:

Signature on File w/ Faculty Advisor

Asa Darnel

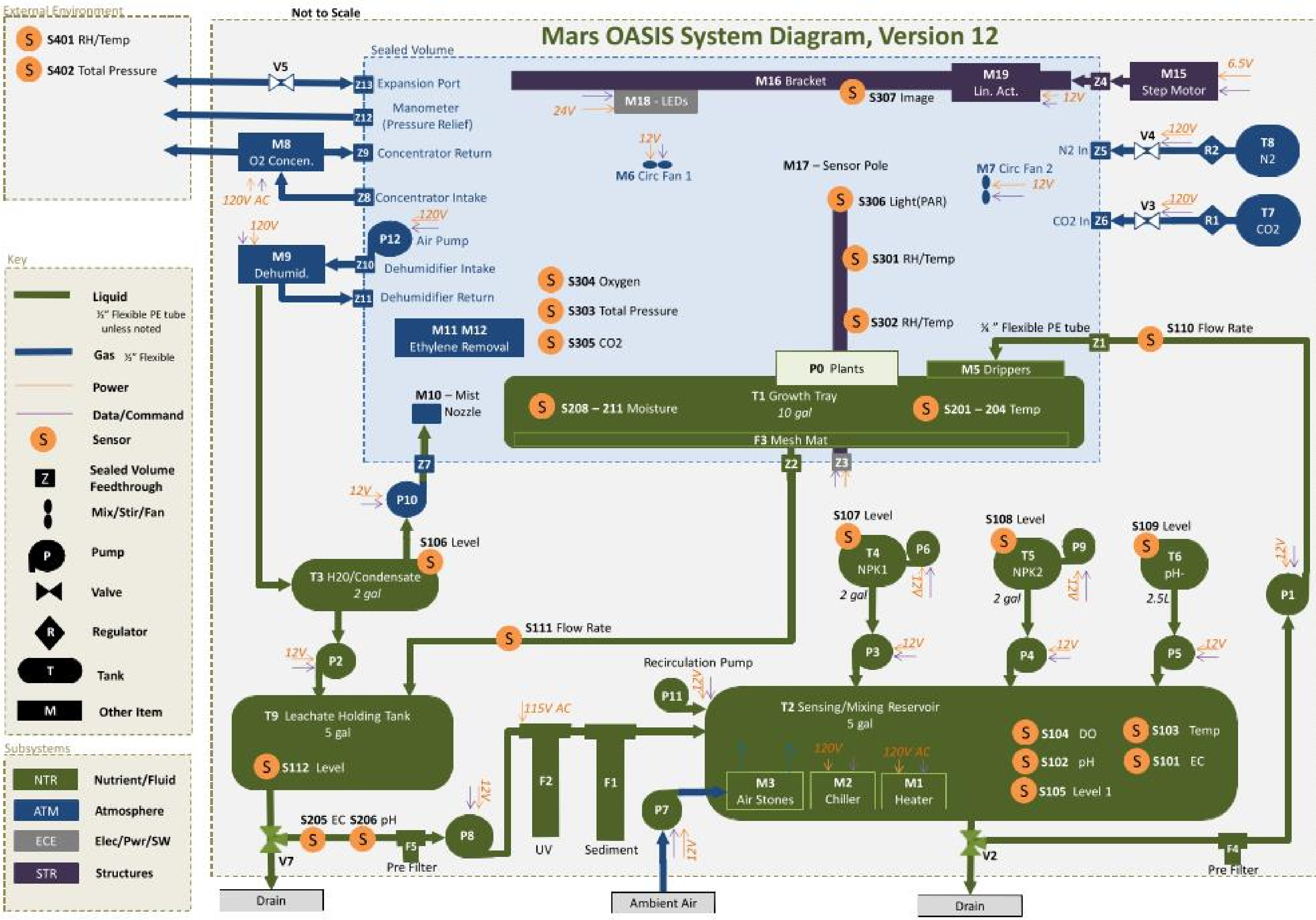
II. PROJECT AND SYSTEM OVERVIEW

The 2015 paper submitted for the International Conference on Environmental Systems (ICES) provides an in-depth review of both the MarsOASIS concept and prototype designs. Paper publication is pending review and final edits, and is attached to this manual (Appendix A).

ñMarsOASIS: A Predeployable Miniature Martian Greenhouse for Crop Production Research,ò*45th International Conference on Environmental Systems,* 12-16 July 2015.

Abstract:
In order to enable long term habitation on planetary surfaces, a means of sustainable food production must be developed. Addressing this need for surface habitats on Mars, the MarsOASIS team has developed a concept for a Martian surface greenhouse for unmanned crop production research as a proof of concept for larger scale food production facilities for manned surface missions. Utilizing in-situ resources such as the Martian atmosphere, sunlight, and UV-C radiation, the greenhouse aims to provide a sustainable method of long-term food production requiring minimal consumable resources. The MarsOASIS system is capable of growing a full life cycle of Outredgeous lettuce with its autonomous control system designed for a unmanned environment, only requiring teleoperation in extreme circumstances. A reduced-scope prototype of MarsOASIS is being developed to test technologies such as a natural/artificial hybrid lighting system, a closed water recycling system, remote teleoperation, and fully autonomous monitoring and control of the greenhouse. The prototype is currently in the final stages of design, with a full demonstration of plant life cycle testing set to occur in summer 2015. Results from this prototype demonstration will help quantify the feasibility of the innovative approaches seen in the MarsOASIS design.

III. SYSTEM PLUMBING AND INTERFACE DIAGRAM



IV. SYSTEM OPERATION

A. Structures

The purpose of the structures subsystem is to support and integrate other subsystems into a single, functional mechanical design. Additionally, the structures subsystem provides a mobile bracket which supports a camera and LED lighting system.

The structural design is composed entirely of 80/20 and encloses all other subsystems with room for plumbing and wiring. An acrylic dome, purchased from Replex Plastics, is used as the upper boundary of the growth volume. The growth volume is sealed from the rest of the system, and feed throughs are used to provide external subsystem components access to the sealed growth volume for plumbing and electronics purposes. The LED and camera-mounted bracket spans the entire growth bed and provides lighting and imaging capabilities at all angles by rotating 180° over the growth bed. Originally, the bracket was designed to be servo driven with two static cameras mounted to it; however, for higher fidelity, the design was updated so that a single camera moves along the length of the bracket (20ò) in addition to the 180° rotation provided by the bracket. The servo was swapped for a motor that will provide torque through a gear assembly.

Component Operation: The toggle clamps surrounding the surface structure can be opened and closed to install or remove the dome. There are four aluminum plates that should be placed on top of the flange prior to closing the toggle clamps, to ensure a tighter seal in the growth volume. The bracket may be rotated by operating the servo motor driver through the Beaglebone interface.

Performance Specifications: The structure sits on eight casters, each capable of supporting 125lbs. The system can therefore be rolled through a 6 foot doorway with ease. The stepper motor has 1200 oz-in of torque and a step angle accuracy of ±5% (Full Step, No Load). It can withstand a maximum radial force of 49.5 lbs (0.79òfrom flange) and a maximum axial force of 13.5 lbs.

Safety or Handling Precautions: The acrylic dome must be handled with care to avoid cracking. The bracket should not be rotated past 90 degrees in its current configuration until it can be made more rigid.

B. Supplemental Lighting

Component Operation: The white supplemental LEDs are mounted to the underside of the camera bracket, therefore allowing LED light to reach all sides of the growing bed via the 180° rotation of the camera bracket. The Outdoor UltraBrightÊ (IP65) Architectural Series Bright White LED Strip Lights, are from Flexfire. They come in a 16 foot reel, are ½òwide, are weatherproof, and can be cut in 2òlong segments. Approximately 6 strips have been mounted on the underside of the bracket, totaling approximately 15 feet. The strips are wired together as one in daisy-chain fashion. To plug them in they require one 24V power source and one ground. The lights can be operated at full constant power, or can be dimmed through pulse width modulation. Currently a single PWM driver is mounted on an aluminum plate that is mounted on the system electronics shelf. This driver is connected to the LED power input. The driver has not yet been connected or controlled from the Beagle bone, but can be operated manually with a signal generator. To do this, connect a signal generator to the green control signal wire from the driver. The lights can then be dimmed by controlling the signal pulse width.

Performance Specifications: The 16 foot reel of Flexfire UltraBright Architectural Series weatherproof LEDs contain 700 individual LED chips, providing a total of 8,510 Lumens (519 lumens per foot), and requiring 84 Watts power at a maximum of 3.5 amps. The color temperature if 6000-6500k, and the beam angle covers 120 degrees. The LEDŝ should be kept at temperatures less than 86 °. Initial calculations show that the lumens provided by 15 feet of UltraBright bracket mounted LEDs will be sufficient to provide the maximum required output (for Outredgeous Lettuce) is 150-450 *u*mol/m^2s PAR. However, further characterization of the PAR output, as installed is needed.

Safety or Handling Precautions: The individual 6 strips are attached by Flexfire connectors that are quite fragile. They have been temporarily glued to ensure they remain fixed. When operated at full capacity, the LEDs will be *quite* bright. Though they are not advertised as hazardous, caution should be taken nonetheless not to stare directly at them.

Other safety precautions from the manufacturer include:
- *Do not mechanically press the strip and its components*
- *Ensure correct polarity when connecting power*

Maintenance Instructions: The strips are rated for 50,000 hours of use before they will dim to 70% of its original brightness. It is possible that the strips may need to be wiped down during maintenance periods, due to the condensation that will likely collect on their surface.

C. Atmospheric Management

Oxygen Removal

Component Operation: The Invacare Oxygen Concentrator is powered with 120VAC. The wires have been stripped, leaving copper wires exposed, and can be attached to the 120VAC power supply and relay. The oxygen concentrator can be turned on via a switch on the front of the unit. The flow rate is controlled via a flowmeter dial on the front of the unit.

Performance Specifications: Concentrator can exhaust oxygen between 0.5 - 5 L/min, at a concentration of 93%. Nearly pure nitrogen is exhausted back into the sealed growth volume.

Safety or Handling Precautions: Concentrator exhausts back into the growth volume. Ensure that the manometer is calibrated such that growth chamber is not over pressurized. Also, there is an exposed compressor fan that spins when the unit is turned on. Avoid contact with the fan blades.

Maintenance Instructions: Concentrator has an operating life of 5 years. The compressor does not have a life expectancy. It is recommended that the oxygen concentrator oxygen output percentage is measured every year in order to monitor saturation of the molecular sieve beds.

Potential Failure Modes and Troubleshooting Tips: If concentrator fails to remove oxygen, or removes oxygen at a concentration much lower than 93%, the molecular sieve beds could be saturated and need replacing. If expected flow rates are not achievable, compressor could need inspection and maintenance.

CO2/ N2 provision

Component Operation: Regulators should remain closed when the gas provision is not needed. Open the regulator (black knob) to allow gas to flow. Solenoids are actuated via 120VAC and do not require pressure assist to open.

Performance Specifications: Regulator should be set to lowest setting, giving an output pressure of 0-50 psi. Output will be >99% CO_2/ N_2.

Safety or Handling Precautions: Exercise caution when working with 120VAC components. Polarity is not a factor for the hot wires of the power lines.

Maintenance Instructions: View regulator pressure gauge in order to monitor N_2 and CO_2 levels. N_2 should be near 1600 psi when full and CO_2 should be near 700 psi when full. Refill as needed for testing purposes.

Potential Failure Modes and Troubleshooting Tips: If solenoids do not actuate, check power connection. If gas is not released from tanks, check tank levels and make sure regulators are open. Ensure that all tubing connections have tight hose clamps securely installed.

Air Circulation

Component Operation: Cooler Guy Blade Master 92 computer fans are powered with 12VDC.

Performance Specifications: Fans operate at a flow rate of 800 - 2800 RPM/ 15.7 - 54.8 CFM.

Safety or Handling Precautions: Ensure that DC (12VDC) voltage is being supplied instead of 120VAC. Check direction of fans (arrows on the side of the housing indicate flow direction).

Maintenance Instructions: Fans have long life time. Clean any dust as needed.

Potential Failure Modes and Troubleshooting Tips: If fans do not operate, make sure connections are all correct. Hermetically seal electronics.

Humidity Control

Component Operation: Pump P10 for fogging nozzle is powered via 12VDC. Dehumidifier is powered via 9VDC (supplied with included converter). Both components have power switches located on the side of their housings.

Performance Specifications: Pump P10 has an output pressure of ~40 psi and a flow rate of 9 mL/s through the fogging nozzle. Water can condense from the dehumidifier at a rate of 250 mL/day.

Safety or Handling Precautions: Ensure that 9VDC (not 120VAC) is supplied to dehumidifier. Handle condensate output line from dehumidifier with care; connection is fragile and should be kept in a vertical position so that condensation does not built up on the inner surface of the tube.

Maintenance Instructions: Operating lifetimes not specified. Fogging nozzle should not have a lifetime. Clean out pre-filter for P10 regularly to ensure particulates do not enter pump lines.

Potential Failure Modes and Troubleshooting Tips: If water does not exit the dehumidifier, make sure the connection between the unit and the condensate tank is secure. Regularly check the pre-filter before P10 for particulate build up. If fogging nozzle is dripping, check hose clamps and connection to nozzle.

Trace Contaminant Control

Component Operation: BluApple sorbers do not require power.

Performance Specifications: N/A

Safety or Handling Precautions: Avoid inhalation, ingestion, and contact with sodium permanganate within BluApples.

Maintenance Instructions: Sodium permanganate packets should be replaced every three months.

Potential Failure Modes and Troubleshooting Tips: If vegetation within system appears to be ripening prematurely, sodium permanganate packets may be saturated and need to be replaced.

D. Nutrient and Water Delivery

General Operation: Liquid conditioning begins in the ómixing tankô(T1) where nutrients are added (from T4 and T5 via P3 and P4) to the water. The water is enriched with dissolved oxygen by an air stone bubbling unit (P7) and further conditioned to the optimal pH value (from T6 via P5). The conditioned water is then pumped (P1) to the growth bed (T1) containing the plants (P0) and soilless substrate via pressure compensated drippers (M5). Most of the water is drained (gravity) into a collection tank labeled óleachateô(T9). Some of the water is taken up by the plant and either remains there or is released into the atmosphere during evapotranspiration, at which point the atmospheric system condenses it into liquid form, deposits it (gravity) into the condensate tank (T3), and finally into (P2) the the leachate tank (T9). From the leachate tank (T9), the liquid is sent through (P8) a 1 micron filtration unit (F1), followed by a UV filter (F2) which acts as a biocide against microbial contaminants. Finally, the filtered liquid is recycled back into the mixing tank to begin the process again. A full cycle occurs on the order of once or twice per day, depending on the maturity of the plant and environmental conditions.

Main Pumps and Pre-Filters: The main pumps (P1, P8, and P2) are 12VDC 1GPM 40PSI and pump about 45ml/sec. Simply connect a power supply and flip switch to turn on. It is imperative that debris of any kind does not enter into the pump. To prevent this, a strainer-style prefilter is included in-line prior to each pump. To clean: unscrew the clear plastic cover to release the strainer, wash it, and replace the cover. Do not take apart the pumps. The screws are tightened to a specific (but undocumented) torque which affects the operation of the pump. These pumps will run dry and they are self-priming.

Dosing Pumps: The dosing pumps (P3, P4, P5) are 12VDC peristaltic pumps and pump about 1ml/sec. Once a voltage is applied, the pump runs, there is no on/off switch. These pumps will run dry and are self-priming.

Recirculating Pumps: The recirculating pumps (P11, P6, P9) are 12VDC and pump about 25ml/sec. Once a voltage is applied, the pump runs, there is no on/off switch. These pumps will not run dry and not are self-priming.

Air Pump: The 12VDC air pump (P7) is used to oxygenate water in the main tank (T1) and provide agitation of the liquid. It pulls in ambient air and outputs it to two air lines which should be fitted with air stones (M3) to provide small bubbles. Once a voltage is applied to the pump, air begins to flow. There is no on/off switch.

Heater, Chiller, UV: The heater (M1), Chiller (M2), and UV filter (F2) are 120V AC power. The heater and chiller are installed in the main tank with a screw-operated feedthrough such that only the heating element is submerged and the wiring remains outside the tank. Use caution with the heater especially, the wiring is exposed and should never be plugged in unless the wiring is sealed. Once power is given, the devices turn on. There is no on/off switch.

Main Sediment Filter: The main sediment filter (F1) is simply a blue housing which unscrews to reveal a replaceable filter cylinder. Make sure the unit is sealed tightly before flowing water through or it will leak.

Drain Valves: The system has two drain valves (V2, V7) and an open hole in the bottom of the growth bed (Z2). The valves have 3 settings: on/off/drain. In the on position, water will be routed through the system; in the drain position, water will spill out (use a bucket); in the off position, water will not pass through the valve. V7 drains the leachate tank. V2 drains the main tank. Z2 empties into the leachate tank.

Drippers: When water is pumped from the main tank (T2) into the growth tray (T1) via P1, it passes through a ring of tubing studded with pressure compensated drippers (M5), this ensures even flow and uniform saturation of the growth medium. The pump will rapidly turn itself on and off to compensate for the pressure limit, this is normal.

Mesh Mat and Drain Cover: The mesh mat (F3) sits at the bottom of the growth bed and prevents sediment from entering the lines through the drain. The drain is covered by a stainless steel strainer which itself is covered by a smaller mesh. Both should be cleaned after each usage. The drain cover is non-removable (affixed with epoxy).

Growth Media: The primary growth medium substrate (~70%) is made from coco coir (CocoLoco brand). This retains water in the root zone and buffers against quick or dramatic changes in liquid composition and temperate. Small rocks (Turface brand) are mixed with the substrate (~20%) to ensure drainage and water flow. The top layer of the mixture (~10%) is seed starting mix that facilitates successful germination.

E. Data Processing for Sensors

Making Python Files on Beaglebone Black microcontrollers:

Accessing Python Files on Beaglebone Black microcontrollers:

Sensor Functions Index:

File Name: ec_cal_0.py
Function: ec_caldry()
Description: Used to clear the calibration and perform dry calibration of the Electrical Conductivity Probe.

File Name: ec_cal_1.py
Function: ec_callow()
Description: Used to get calibration information and perform low point calibration of the Electrical Conductivity Probe

File Name: ec_cal_2.py
Function: ec_calhigh()
Description: Used to get calibration information and perform high point calibration of the Electrical Conductivity Probe

File Name: ec_read_func.py
Function: ec_read(slave_add)
Description: Used to read electrical conductivity value of the solution using the EC probe.

File Name: ph_cal.py
Function: ph_cal()
Description: Used to get the calibration information and perform low point,high point and mid point calibration of the pH probe.

File Name: ph_read_func.py
Function: ph_read(slave_add)
Description: Used to read pH value of the solution using the pH probe.

File Name: do_cal.py
Function: do_cal()
Description: Used to get the calibration information and perform single point calibration of the Dissolved Oxygen probe.

File Name: do_read_func.py
Function: do_read(slave_add))
Description: Used to read DO value of the solution using the DO probe.

File Name: CO2.py
Function: CO2()
Description: Used to read the percentage of CO2 present in the greenhouse.

File Name: O2.py
Function: O2_sensor(PORT_ID)
Description: Used to read the percentage of O2 present in the greenhouse.

File Name: flow_meter.py
Function: flow_meter()
Description: Used to read the value of Turboflow of the water flow.

File Name: moisture.py
Function: moisture_read(ADC_CHANNEL)
Description: Used to read the value of volumetric weight content of soil.

File Name: par.py
Function: par()
Description: Used to read the value of Photosynthetic Photon Flux Density present in the greenhouse.

File Name: liquid_level.py
Function: liquid_level()
Description: Used to read the liquid level

File Name: Stepper.py
Function: Init()
Description: Used to initialise the direction,step and limit for the stepper motor.

Camera Operation:

Connecting the camera to the BeagleBone Black:

1. Power the beaglebone black with the 5V DC power supply (this is important, the beaglebone alone cannot provide the necessary current)
2. Insert the USB camera into the USB port of the board
3. ssh into the board
4. Check to see if the camera is available. Check the contents of the /dev folder, The camera should appear as video0.
5. Run the following camera.py script to capture an image. The script will store the image as ñimage1.jpegò
6. Transfer the image

Code for camera.py:

Carbon Dioxide Sensor Operation:

Connecting the CO2 sensor to the Beaglebone Black:

1. Connect pin P8_24 (TX) to the RX pin on the main terminal UART of the sensor
2. Connect P8_26 (RX) to the TX pin on the main terminal UART of the sensor
3. Provide voltage 5V to the G+ on main terminal
4. Give common ground to both the beaglebone and the sensor
5. Connect the jumper
6. Run the serialc02.py script

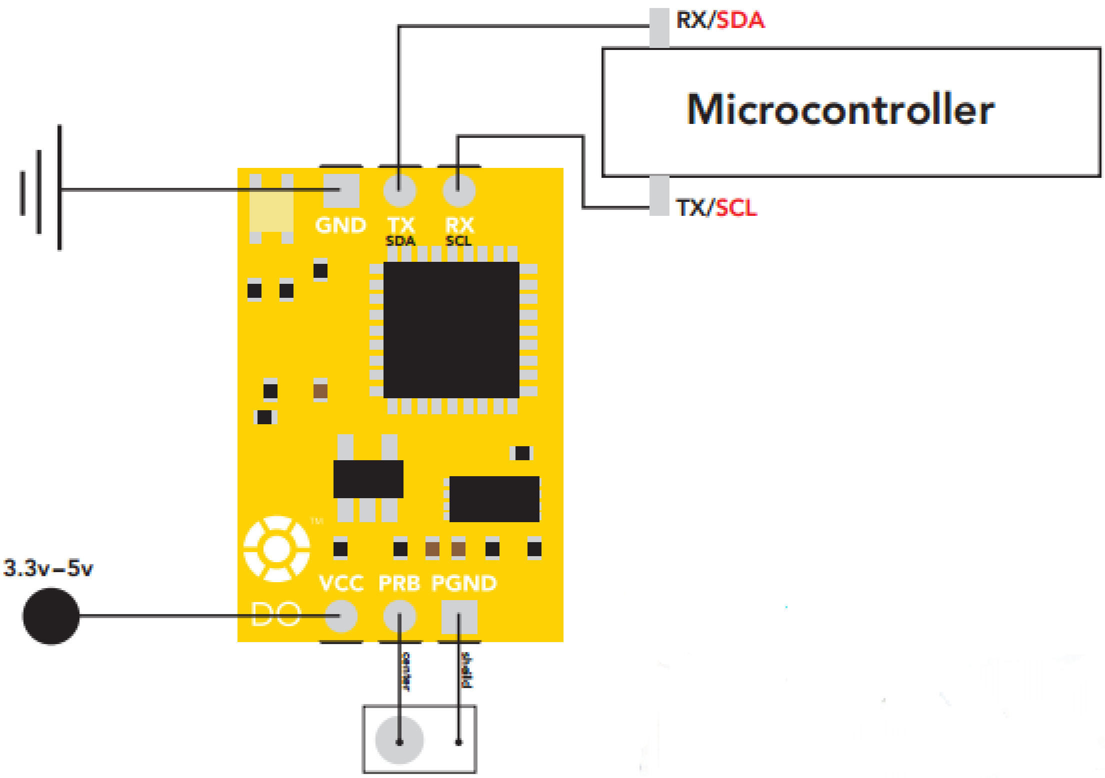
Code for serialc02.py:

Dissolved Oxygen Sensor Operation

Using the Atlas Scientific Dissolved Oxygen sensor with the Beaglebone Black:

1. Operate the DO sensor in I2C mode by shorting the Probe gnd and the Tx pin.It is indicated by a glowing blue led on the circuit.
2. Connect the Tx of the circuit to the SDA of the beagle bone black.Connect the Rx to the SCL.
3. Provide pull up voltage for SDA and SCL of by using resistance of ~4.5k ohms.
4. Provide an operating voltage of 5V to the circuit.Provide a common ground to the circuit and the BBB.
5. Connect the BNC connector which is connected to the EC probe.
6. Run the python script.

Supporting Circuitry:



Code for do_cal.py (calibrating the sensor):

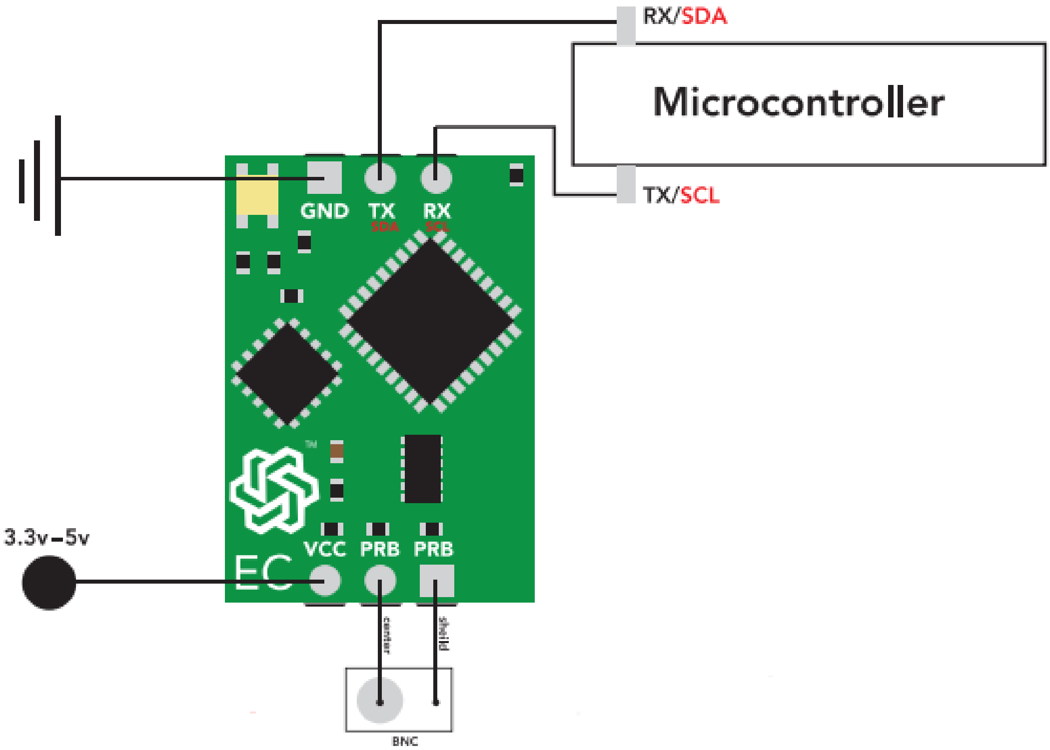
Code for do_read_func.py (reading values):

Electrical Conductivity Sensor Operation

Using the Atlas Scientific Electrical Conductivity sensor with the Beaglebone Black:

1. Operate the EC sensor in I2C mode by shorting the Probe gnd and the Tx pin.It is indicated by a glowing blue led on the circuit.
2. Connect the Tx of the circuit to the SDA of the beagle bone black.Connect the Rx to the SCL.
3. Provide pull up voltage for SDA and SCL of by using resistance of ~4.5k ohms.
4. Provide an operating voltage of 5V to the circuit.Provide a common ground to the circuit and the BBB.
5. Connect the BNC connector which is connected to the EC probe.
6. Run the python script.

Supporting Circuitry:



Code for ec_cal0.py:

Code for ec_read_func.py:

Flow Meter Operation

Code for flow.py:

Liquid Level Sensor Operation

Supporting Circuitry:

Voltage divider: 2x 200kOhm resistors.

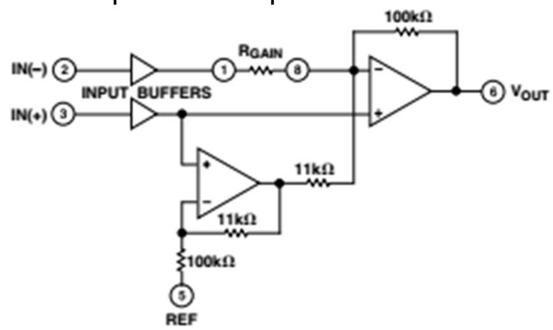
Code for liquid_level.py:

Moisture Sensor Operation

Code for moisture.py

Oxygen Sensor Operation

Supporting Circuitry: The oxygen sensor requires an AMP04 instrumentation amplifier. Itôs a single-supply instrumentation amplifier that operates over a 5V to 15V range.



Code for O2.py

PAR Sensor Operation

MarsOASIS is using the Quantum SQ-200 Apogee Instruments PAR Sensor. The sensor requires and ADC interface with the BeagleBone Black. Radiation that causes photosynthesis is referred to as photosynthetically active radiation (PAR), which is also called photosynthetic photon flux (PPF) that is measured in units of micromoles per square meter per second. The radiation is found in the range of 400 to 700nm.

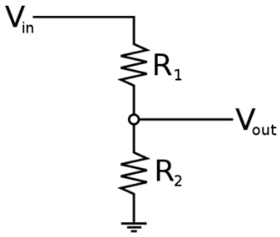
Interface: ADC
Power Supply: 5-24VDC
Current Consumption: 300microAmps
Connections:

- Green Wire: Positive (signal from the sensor)
- White Wire: Input Power
- Clear: Ground (for sensor signal and input power)

Formula:
*Calibration Factor (0.5 micro-mol $m^{-2}s^{-1}$ per mV)*Sensor Output Signal (mV) = PPF (micro-mol $m^{-2}s^{-1}$)*
0.5 * 4000 = 2000

Full sunlight will return a PPF measurement of 2000 micro-mol $m^{-2}s^{-1}$, which should return an output signal of 4000 mV for an a sensor input voltage supply of 0 to 5V.

Support Circuitry:
The sensor needs a voltage divider.



The output current needs to be less than 300microAmps and the input voltage will be 5V so I = Vin/(R1 + R2). Setting I=300microA and Vin to 5V, we get R1 + R2 = 17kOhms. Rounding up to 20kOhms and knowing that the BeagleBone can only take ADC signals of 1.8V max.

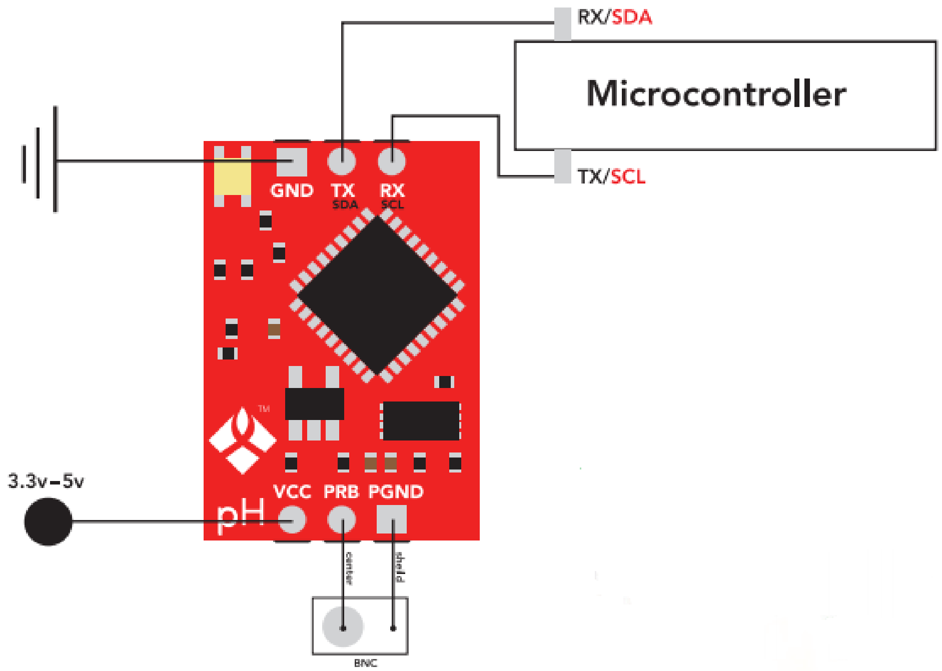
Code for par.py

pH Sensor Operation

Using the pH Atlas Scientific sensor with the Beaglebone Black microcontroller:

1. Operate the pH sensor in I2C mode by shorting the Probe gnd and the Tx pin.It is indicated by a glowing blue led on the circuit.
2. Connect the Tx of the circuit to the SDA of the beagle bone black.Connect the Rx to the SCL.
3. Provide pull up voltage for SDA and SCL of by using resistance of ~4.5k ohms.
4. Provide an operating voltage of 5V to the circuit.Provide a common ground to the circuit and the BBB.
5. Connect the BNC connector which is connected to the EC probe.
6. Run the python script.

Supporting Circuitry:



Code for PAR Sensor:

F. Control Logic

Operating Instructions:

- Load BB1_control.py to Beaglebone 1 and BB2_control.py to Beaglebone 2.
- Download the zmq module on both the beaglebones.
- Download the Adafruit Beaglebone modules on both Beaglebones.
- Load global_var and mech_ctrl modules on both Beaglebones.
- Load the Sensor modules on both Beaglebones.
- Load the watering, mixing and VPD python modules in Beaglebone 1.
- Load gas composition and lighting pythonmodules in Beaglebone 2.
- Download cv2 module on Beaglebone 1 for camera control.
- Run the python script BB1_control.py on Beaglebone 1.
- Run python script BB1_control.py on Beaglebone 2.
- The control software is now operating.

G. Power and Component Actuation

The power to all mechanical components are controlled using relays. With the exception of stepper motor all mechanical components connect to Sainsmart 8 channel relay board which works on 5V and provides eight SPDT relays on each board. The control signals for the relays are active low and connect to the Beaglebone black GPIO pins using a 5 to 3.3V bi directional level shifter. The "Beaglebone Connections map" Contains detailed description on how and where each component is connected on the relay board and their respective power supplies. The following python code configures the Beaglebone black GPIO pin as an output and toggles a relay. The code below makes an assumption that the pin has been configured as GPIO and no other resources like HDMI interface is accessing it. To run the below code first SSH into the Beaglebone and install the Adafruit BBIO GPIO library and python 2.7.

In the above code the variablesòport_idòand ñSTATUSòwill be set by the user. The port_id relates to the port on the beaglebone to which the relay control signal is connected to and the STATUS is set to ñONòif the user want to run on the relay and set to ñOFFòif the user wants to turn the relay off.

H. Graphical User Interface

The Graphical User Interface (GUI) is the platform which is the link between the system and the user. It gives a visual representation of the events in the system. Through the GUI you can monitor the plant growth via a visual representation of the plant growth parameters and live images of the plant, you can control the plant growth by feeding a change in optimal sensor range, sampling rate, etc. It also enables the ability to remotely initiate or pause the plant growth cycle. Some basic instructions for loading and accessing server and website files are included below. For more detail, see the attached *Continuity Documents.*

Linux is the recommended platform for web development. The languages used for developing the front end are HTML, CSS, Javascript and jQuery. We chose a template and worked of it.

All files related to the MarOASIS GUI can be found in the XHab 2014/2015 folder, under 03_Electrical/Software➔GUI.

Knowing Javascript and jQuery is really important. The following is a list of must watch tutorials:

http://www.lynda.com/JavaScript-tutorials/JavaScript-Essential-Training/81266-2.html?srchtrk=index:1%0Alinktypeid:2%0Aq:javascript%0Apage:1%0As:relevance%0Asa:true%0Aproducttypeid:2

http://www.lynda.com/search?q=jquery&f=level%3a1%5eBeginner

Also basic knowledge of Responsive Web Design, AJAX using jQuery and JSON using Javascript of jQuery is a must.

Software:

1. Nginx- For setting up a localhost -http://wiki.nginx.org/Install
2. Mozilla Firefox- https://www.mozilla.org/en-US/firefox/developer/
3. Firebug (Works only for Firefox)- For debugging- http://getfirebug.com/

Setup (For Linux):

1) Nginx

Follow the instructions on http://wiki.nginx.org/Install

Using the following commands to start, stop, restart and check status

- ñsudo service nginx startò -- Start Nginx
- ñsudo service nginx stopò -- Stop Nginx
- ñsudo service nginx statusò -- Check Nginx status
- ñsudo service nginx restartò -- Restart Nginx

2) Host File Change

1. Change directory to ñ/etcò ------ ñcd /etcò
2. Open the ñhosts òfile ------ ñvim hostsò
3. Insert the following(hit óiôto insert) ------ ñ127.0.0.1 local.autoponics.comò
4. Save it ------ ñESC : wqò

4) "ESC :wq" to save the file

-- Your folder for storing all your files
-- Default file

Now when you enter local.autoponics.com the browser pulls up the index.html file which resides at /home/anurag/xhab

Now for example if you enter local.autoponics.com/xyz/abc.html then it pulls up the abc.html file from /home/anurag/xhab**/xyz** folder.

I. Simulated Lighting

Component Operation: The external Martian light is simulated using a customizable spectrum light fixture designed, built and provided by AcroOptics. This lighting system has not yet been used for the MarsOASIS system, and thus these instructions come straight from the AcroOptics materials found at the end of this section. The lighting system can be controlled/operated/setup through two interfaces: a computer GUI or a small LCD screen on the unit with buttons for navigation and to change settings. The MarsOASIS team has verified the functionality of the unit through the LCD screen.

The AcroOptics team has customized the CRAVE24 system firmware to include a timing scheme to incorporate the Martian day length of 24.67 hours rather than the standard 24 hour length. To use this mode, which may not be necessary in all cases, the user must go through the LCD screen on the unit rather than the computer GUI, and it eliminates some of the lighting customization seen in the Earth mode. Below are the steps to set up the unit in Mars ode and begin operation:

1. Set the date/time (this is the Earth date/time).
2. Set "day data" to give you the sun behavior that you want. This data is used for both the "Day" and "Mars" modes. Set the moon data to anything you want, it won't have an effect in Mars mode. Right now this means that you can't set the sunrise time to occur during the last 40 minutes of the (mars) day, hopefully that won't be an issue.
3. Setup the LCD to show "Mars Time", this will let you know the current Mars day number and time (0:00 - 24:40).
4. Set the operation mode to "Mars".

Once in Mars mode, the spectrum can be customized using percentages on the LCD screen on the unit. To get an idea of the spectrum you are creating, please use the Output Spectrum Calculator provided by AcroOptics, available in the X-Hab 2014-2015 folder, under 12_Design Documents➔AcroOptics.

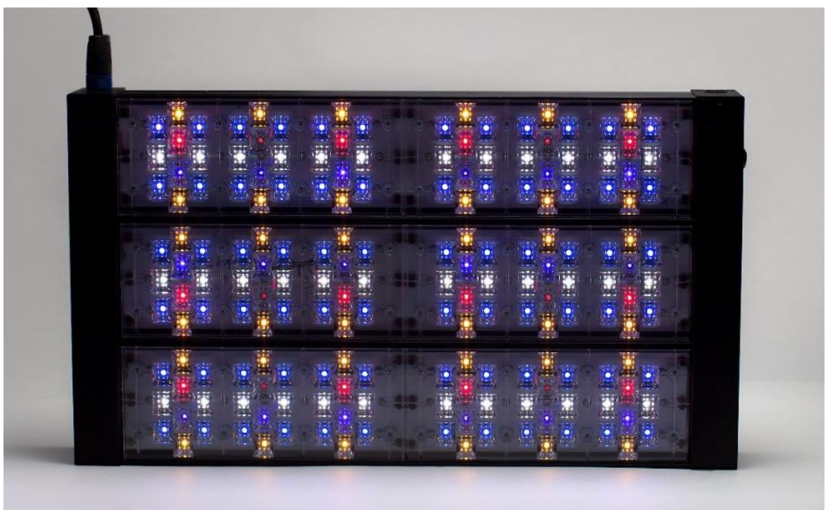
Performance Specifications: The following performance specifications (provided courtesy of *AcroOptics*) outline all capabilities of the CRAVE24 system in the standard "Earth Mode." However, for the Martian mode, customization must be done through the built in LCD screen which does not allow use of variance of spectrum/intensity over the course of the test length, as the days are all of equal length and intensity. It may be desirable to use the system in Earth mode instead of Mars mode to gain customization but it will then be limited to 24 hours.

Safety Concerns: Since the CRAVE24 unit is Commercial Off-The-Shelf (COTS), nearly all safety issues and concerns have been addressed by AcroOptics, however there are a few things remaining to think about. The unit has built in temperature management with controlled fans and temperature sensors that shut the unit down if high temperatures are reached. Even with this feature, it is advantageous to operate the CRAVE24 unit in an environment where it can be surrounded by air to prevent high temperatures and potential damage to MarsOASIS and AcroOptics hardware. The second concern is the mass of the system. With the weight coming in near 35lbs, it is imperative to hang the lighting system in a safe manner with a large factor of safety so the unit is not dislodged and dropped where it could cause human injury and hardware damage to a very expensive system.

CRAVE 24

The CRAVE 24 is a programmable, full-spectrum horticultural light for standard 5' x 5' grow spaces. Designed to optimize biomass and flowering, the fixture generates light peaks that correspond to the wavelength ranges for photosynthesis. Additionally, significant broad-spectrum coverage benefits both plant appearance and many other light-sensitive biological processes.

The accompanying software allows for custom grow cycles up to 500 days, with variable light output by day. It also makes configuring multiple fixtures to run identical or varying programs simple and fast. The fixture has two fully-tunable program cycles, which can be used either to mimic the sun and moon, or overlapped to shift the spectral power distribution over the course of the day.



It can be configured to operate in several different modes according to the user's desires, and to imitate the light characteristics required for the maintenance and propagation of all photosynthetic organisms.

The fixture requires far less energy and emits significantly less heat than metal halide or high-pressure sodium fixtures with the same output, reducing HVAC expenses and ensuring long fixture life.

Functional Highlights:

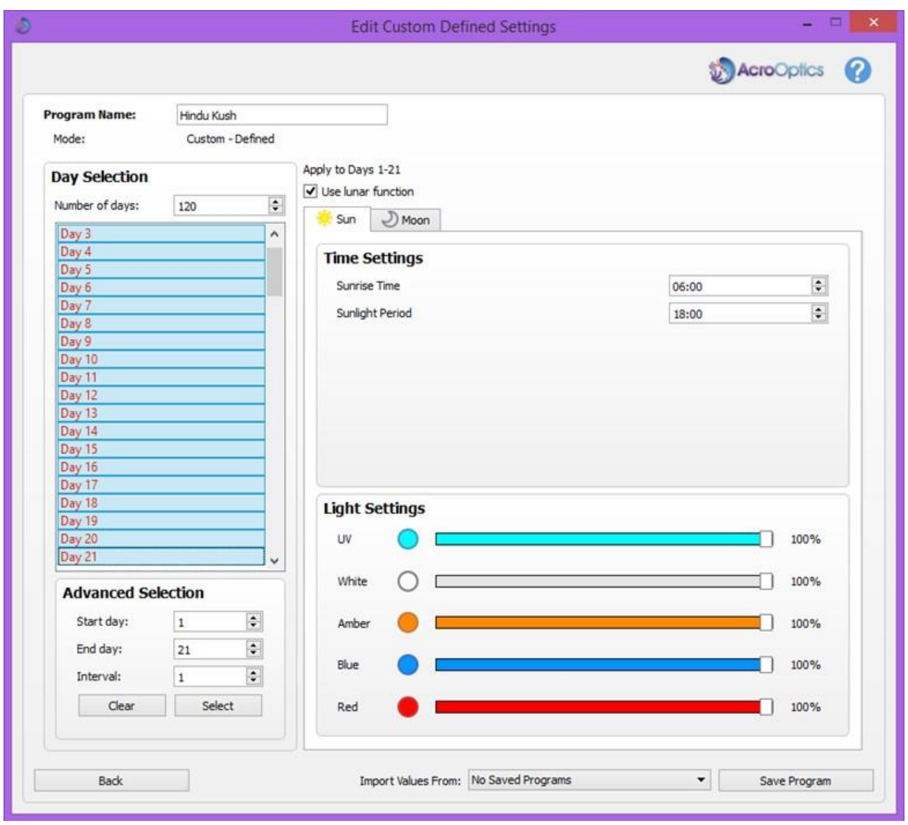
- **Fully Controllable:** The fixture can be programmed using a navigational menu and LCD display directly on the fixture, or via USB using free software downloaded from our website, simplifying the creation of even the most complex light routines. The fixture can also be accessed via optional WiFi feature
- **High-quality Optics:** TIR lens optics blend and focus the light where it is needed, minimizing spill-over/glare.
- **Very Large Array Design:** Ensures a uniform light distribution over the entire grow area – no hotspots or dead zones.

- **Flexibility:** Daisy-chaining the fixtures allows a grow space of any size or shape to be optimally illuminated: the programmability means plants don't need to be moved around for different stages of the grow cycle.
- **Durability:** the fixture housing is powder-coated steel and anodized aluminum, ensuring a long usable life with minimal maintenance. High quality components and exceptional design means your fixture will last for many years.
- **Longevity:** the design and power draw of the fixture means the light output will be within 90% of the first day it was turned on after 50,000 hours of use.
- **Low Lifetime Cost:** no bulbs to replace, up to 75% less electrical usage, 80% less heat output, and up to 50% less water consumed compared with HID means a lower lifetime cost.
- **Room to Grow:** updateable firmware ensures your fixtures can keep up with the latest software improvements.

The CRAVE fixture – Advanced Lighting for Advanced Thinkers.

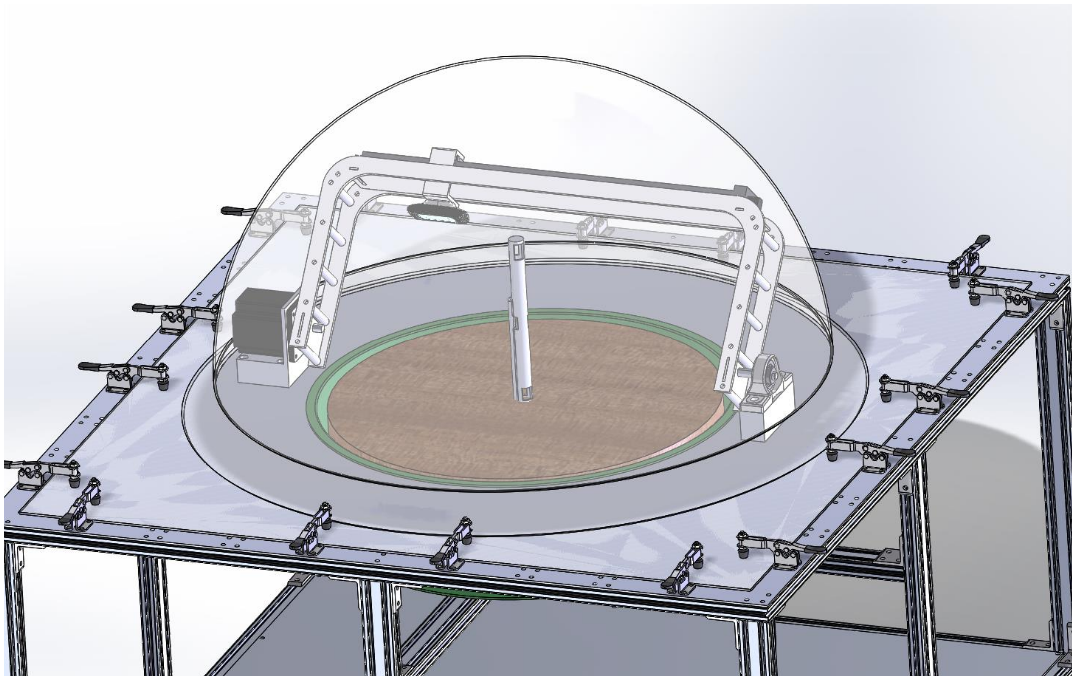
User Interface

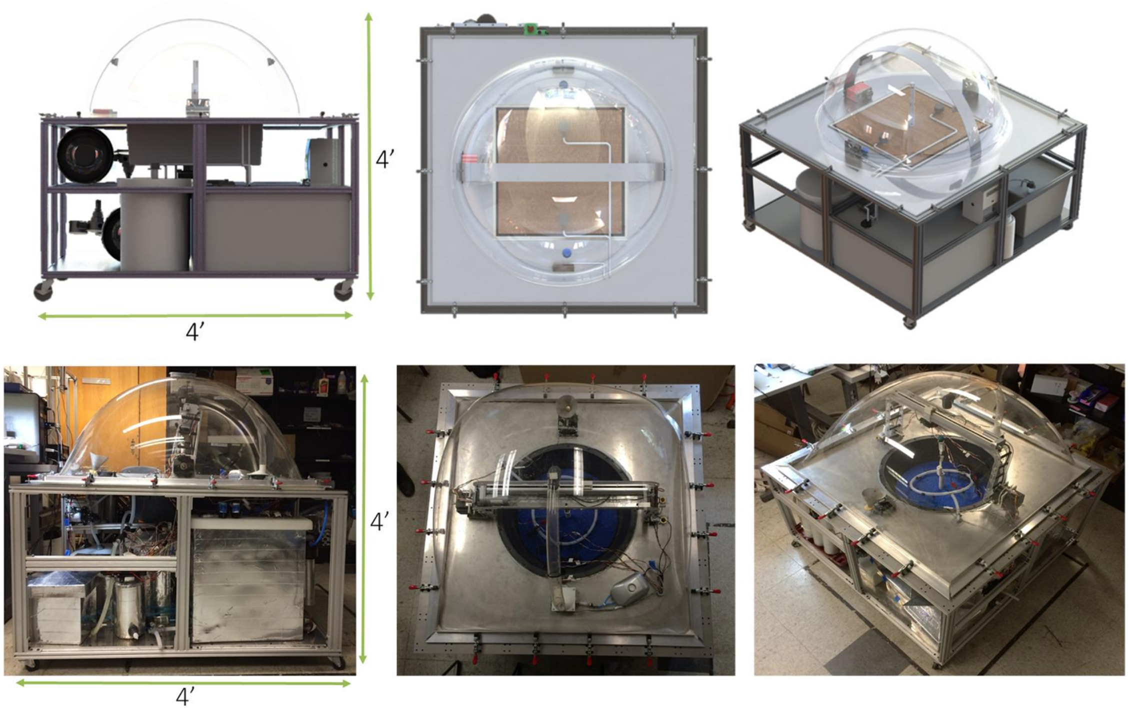
Settings can be made for individual days, multiple days simultaneously, or on a recurrent basis (e.g. every 30 days). Sun and Moon can be used to mimic solar/lunar cycles for a specific geographic region, or used to shift the color output over the course of a single day by overlapping the photoperiods. Solar/lunar schedules can be downloaded from our website by selecting the desired location from a globe.)



V. MECHANICAL DRAWINGS

CAD models and drawings for the MarsOASIS concept and prototype can be found in the X-Hab 2014-2015 Folder under 01_Sturcture➔CAD. The full prototype assembly file is located in: *01_Sturcture➔CAD➔Prototype CAD➔Prototype CAD➔Assem.SLDASM*





VI. MECHANICAL FEED-THROUGHS

Sys ID	System	Function	Line OD	Notes	Part Description	Hole Dia. (Inches)	Link
Z1	NTR	Liquid - Conditioned water into growth area	0.593	*From main sensing reservior to growth bed*	Liquid Tight Straight Cord Grip 1/2 Trade Size, for 0.5"-0.6" Cord Diameter	1.1	http://www.mcmaster.com/#8302k15/=vzsers
Z2	NTR	Liquid - Plant leachate out of growth tray	1/2" NPT	*From growth bed to leachate tank (Bottom of growth bed)*	Supplied by NTR team		
Z3	STR	Hole for Sensor Pole		*(Bottom of growth bed)*			
Z4	EESW	Electronics feed through for motors and remaining instruments					
Z5	ATM	Air line for N2 - shared with CO2 line via wye barbed fitting	1/4" NPT	*Place near CO2 line, both of which should be near (underneath) a circulation fan*	Liquid Tight Straight Cord Grip 1/2 Trade Size, for 0.38"-0.5" Cord Diameter	0.82	http://www.mcmaster.com/#standard-cord-grips/=vzse9e
Z5	ATM	Air line for CO2 - shared with N2 line via wye barbed fitting	1/4" NPT	*Place near N2 line, both of which should be near (underneath) a circulation fan*	Liquid Tight Straight Cord Grip 1/2 Trade Size, for 0.38"-0.5" Cord Diameter	0.82	http://www.mcmaster.com/#standard-cord-grips/=vzse9e
Z7	ATM	Water line for humidification	1/4" NPT	*From water supply -> humidifier pump -> misting nozzle*	Liquid Tight Straight Cord Grip 1/2 Trade Size, for 0.38"-0.5" Cord Diameter	0.82	http://www.mcmaster.com/#standard-cord-grips/=vzse9e
Z8	ATM	Air line - oxygen concentrator intake	1/2" NPT	*To fittings on oxygen concentrator*	Liquid Tight Straight Cord Grip 3/4 Trade Size, for 0.63"-0.75" Cord Diameter		http://www.mcmaster.com/#8302k19/=vzsg6q

Z9	ATM	Air line - oxygen concentrator return	1/4" NPT	*Returns Nitrogen to chamber from oxygen concentrator*	Liquid Tight Straight Cord Grip 1/2 Trade Size, for 0.38"-0.5" Cord Diameter		http://www.mcmaster.com/#8302k19/=vzsg6q
Z10	ATM	Air line - dehumidifer intake	1/4" NPT	*Air from growth volume to dehumidifier*	Liquid Tight Straight Cord Grip 1/2 Trade Size, for 0.38"-0.5" Cord Diameter	0.82	http://www.mcmaster.com/#standard-cord-grips/=vzse9e
Z11	ATM	Dehumidifier Return	1/4" NPT	*From lab air to growth volume *relief valve*	Liquid Tight Straight Cord Grip 1/2 Trade Size, for 0.38"-0.5" Cord Diameter	1.125	http://www.mcmaster.com/#8682t24/=vzrf84
Z12	ATM	Manometer	1/2" NPT	*From growth volume to lab air *relief valve*	Through-Wall Fitting Polypropylene, NPT Female on Both Ends, 3/4 Pipe Size	1.6	http://www.mcmaster.com/#36895k142/=vzshtz
Z13	ATM	Port of Jordan - Expansion port	1/2" NPT	*Expansion Port for Future Use*	Miniature Through-Wall Fitting High-Pressure Brass, 1/2 Pipe Size	1.125	

VII. COMPONENT LIST

The table in **Appendix B** contains detailed information on all components in the MarsOASIS prototype. Specification or data sheets are attached *electronically* to this manual as a zipped file called *MarsOASIS Refernce Manual - Appendix C Spec Sheets.zip*.

VIII. ELECTRICAL INTERFACE DOCUMENTS

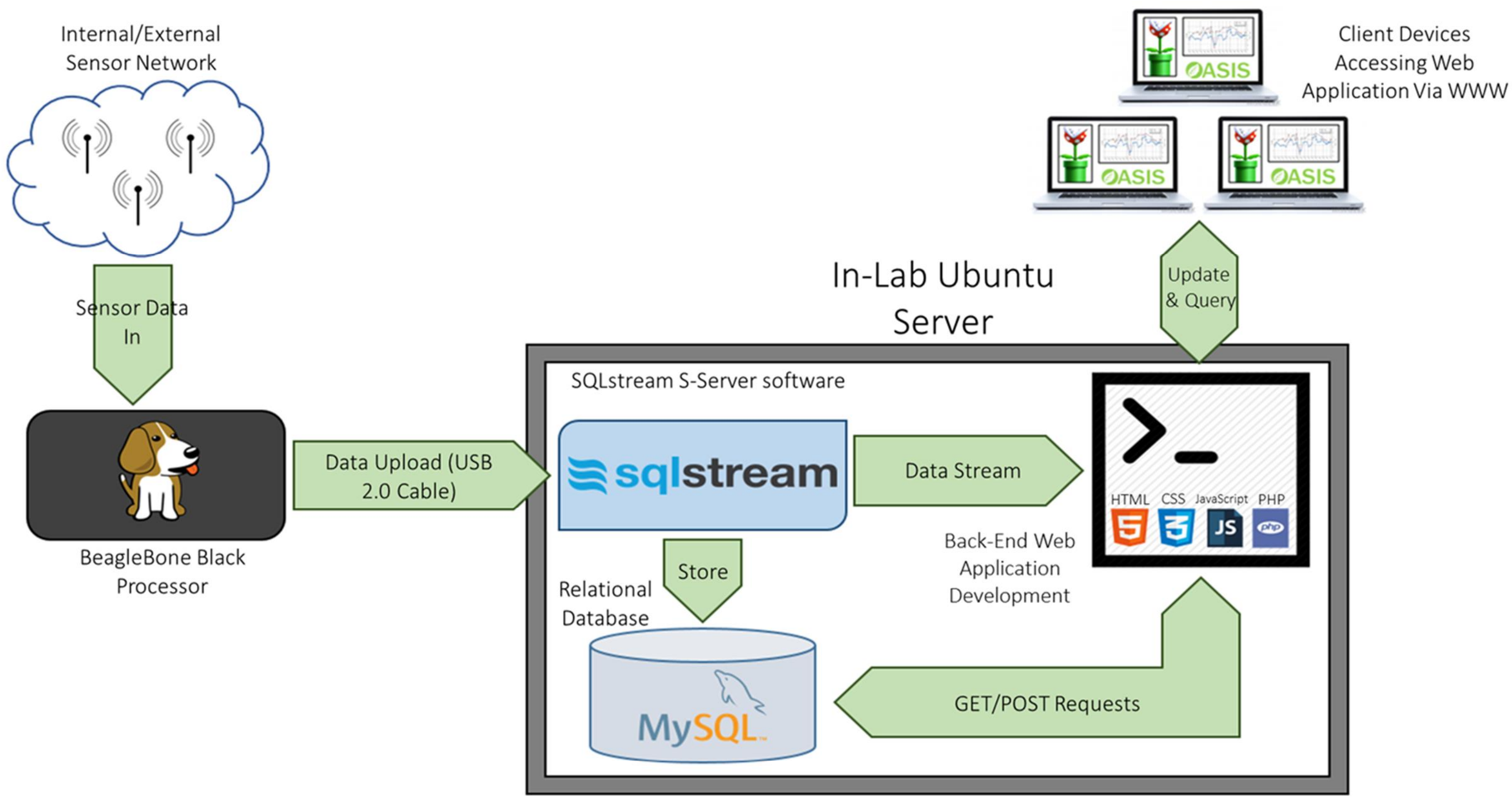
A. Sensor Inventory

Sensor	Qty	Function	Make and Model	Power (V)	Current (Amps)	Output	Units	Range	Accuracy
EC	2	Electrical Conductivity (Measuring Nutrient Deficit) in Growth Medium & Reservoir	Atlas Scientific, EC-EZO	3.0-5.5 (DC)	0.05	0-5 (RS232)	µS-cm-1	0.55-500,000	+/- 2
pH	2	pH in Growth Medium & Reservoir	Atlas Scientific, pH-EZO	3.0-5.5 (DC)	0.0183	UART or 0-Vcc	pH	.001 to 14.000	+/- 0.02
Temperature	5	Liquid Temperature in Reservoir (1) & Growth Medium (4)	Dallas Semiconductor, DS18B20	3.0-5.5 (DC)	0.0015	12-bit	deg C	-55-125	+/-0.5
Moisture	4	Volumetric Water Content in Growth Medium	Vegtronix, VH-400	3.5-20 (DC)	0.007	0 - 3V	%	0-50	2% @ 25°C
DO Probe	1	Dissolved Oxygen in Mixing Reservoir	Atlas Scientific, DO Probe w/ EZO DO Circuit	3.0-5.5 (DC)	0.0183	UART or 0-Vcc	mg/L	0.01-35.99	+/-0.2
Liquid Level	6	Liquid Level in Mixing, Nutrient, pH, Leachate, & Condensate Tanks	Milone Technologies, PN-12110215TC-8	3.3 (DC) 10V Max	depends on pull up resistors	1500Ω-300Ω	Inches	0-8	+/- 10%
Flow Meter	2	Water Flow Rate Into & Out of Growth Bed	Atlas Scientific, Turbo Flow Flow Meter w/ FLO-30 Circuit	3-24 (DC) 2.5-5 (DC, Circuit)	unknown	0-345 Hz (probe) 0-VCC (circuit)	lpm	0.8-7.6	367 uL (probe pulse)
RH/Temp (Air)	3	Internal (2) & External (1) Relative Humidity & Air Temperature	Dallas Semiconductor, AM2302/DHT22	3..3-5.5 (DC)	0.0015	16 bit	% deg C	0-100 -40-80	+/- 2% +/-0.5
Total Pressure	2	Internal (1) & External (1)Total Atmospheric Pressure	Bosch, BMP180	1.8-3.6 (DC)	<0.001	19 bit	hPA	300 - 1100	+/- 0.12
Oxygen	1	Internal O_2 Concentration	MaxTec, R125P01-002	passive (amplifier circuit)	0	10.0 to 15.5 mV	%	0-100	+/- 1%
CO_2	1	Internal CO_2 Concentration	CO2meter.com, SE-0018 K30 STA	4.5-14V (DC)	0.040	0-4V (or 1-5V)	ppm	0-5000	+/- 30 +/- 3%
Light (PAR)	1	Internal Photosynthetically Active Radiation, 410 nm-655 nm, 180° FOV	Apogee Instruments, SQ-215	5-24V (DC)	300 uA (nominal)	0-5V	µmol m-2 s-1	0 - 2500	+/- 1%
Camera	1	Plant Health Imagery	Logitech C920	5 (DC)	1.5A	n/a	RGB	1 to 255	n/a

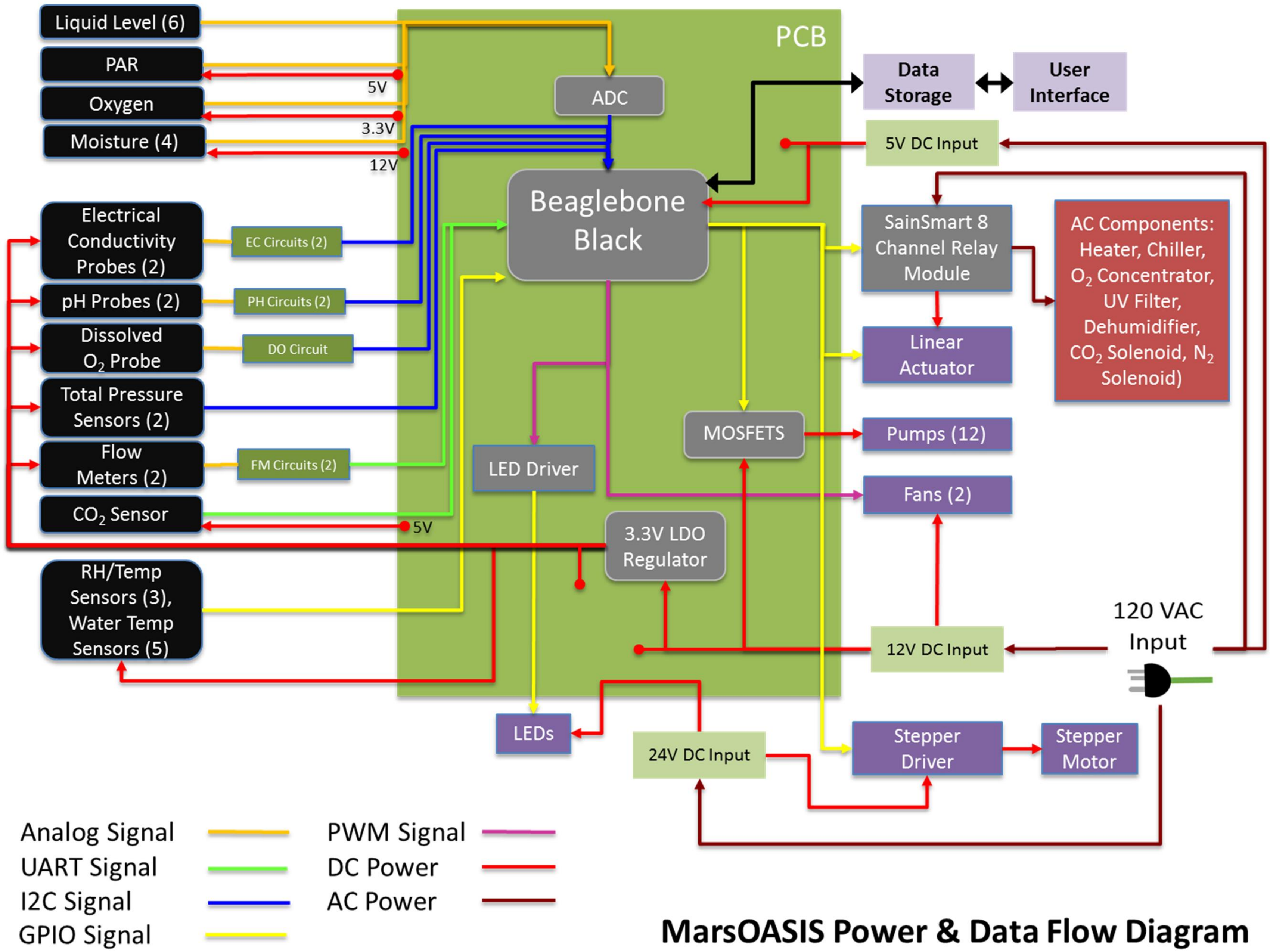
B. Actuator Inventory

Component	SysID	Relay Channel	Power (W)	Voltage	Current (Amps)	Control Hardware
Main Pump	P1	R1_C1	30	12V DC	2.5	SainSmart 8 Channel DC 5V Relay
Water Heater	M1	R1_C2	750	120V AC	6.3	
Water Chiller	M2	R1_C3	50	120V AC	5	
Condensate Pump	P2	R1_C4	30	12V DC	2.5	
Nutrient 1 Dosing	P3	R1_C5	0.96	12V DC	0.08	
Nutrient 2 Dosing	P4	R1_C6	0.96	12V DC	0.08	
pH Dosing	P5	R1_C7	0.96	12V DC	0.08	
Filter Pump	P8	R1_C8	30	12V DC	2.5	
Humidifier Pump	P10	R2_C1	30	12V DC	2.5	
Dehumidifier	M9	R2_C2	22.5	120V AC	2.5	
Air Pump, Dehumidifier	P12	R2_C3	2	120V AC	0.017	
Nutrient 1 Circulation	P6	R2_C4	3.6	12V DC	0.3	
O2 Concentrator	M8	R2_C5	390	120V AC	4.3	
N2 Solenoid	V4	R2_C6	9VA	120V AC	unknown	
Main Tank Circulation	P11	R2_C7	3.6	12V DC	0.3	
Air Bubbler	P7	R2_C8	5.52	12V DC	0.46	
UV Filter	F1	R3_C1	10	120V AC	unknown	
Fan 1	M6	R3_C2	3.12	12V DC	0.26	
Fan 2	M7	R3_C3	3.12	12V DC	0.26	
CO2 Solenoid	V3	R3_C4	9VA	120V AC	unknown	
Nutrient 2 Circulation	P9	R3_C5	3.6	12V DC	0.3	
Linear Actuator	LA1 LA2	R3_C6 R3_C7	3	12V DC	0.25	L293D Motor Driver ï Solarbotics (Qty 2)
Stepper (ST) Motor	ST	R3_C8	16.25	6.5	2.5	KL-5056 20-50VDC 5.6A Bipolar Stepper Motor Driver
LEDs (16 foott reel)	M18	N/A	84	24V DC	3.5	PWM Driver

C. Power and Data Distribution



MarsOASIS User Interface Diagram



MarsOASIS Power & Data Flow Diagram

D. PCB Interface Definition

Component	Pin Number	Pin Label	Signal	Description	Connection Component	Connection Pin	Address	Part Number	Location	Connecto	J Connector Pin	General Signal (Data/Logic	Analog
BBB1	1	P8_1	DGND		PCB	DGND							
BBB1	2	P8_2	DGND		PCB	DGND							
BBB1	3	P8_3	GPIO	Temp sensors com	TEMP1	2				J2	17		
BBB1	4	P8_4	GPIO	Temp sensors com	TEMP2	4				J3	5		
BBB1	5	P8_5	GPIO	Temp sensors com	TEMP3	4				J3	7		
BBB1	6	P8_6	GPIO	Temp sensors com	TEMP4	4				J3	8		
BBB1	7	P8_7	GPIO	Temp sensors com	TEMP5	4				J3	10		
BBB1	8	P8_8	GPIO	Temp sensors com	RH/TEMP1	2				J3	11		
BBB1	9	P8_9	GPIO	Temp sensors com	RH/TEMP2	2				J3	13		
BBB1	10	P8_10	GPIO	Temp sensors com	RH/TEMP3	2				J3	14		
BBB1	11	P8_11	GPIO	Res. Heater Enable	U26, Open Collector	2							
BBB1	12	P8_12	GPIO	Res. Chiller Enable	U26, Open Collector	4							
BBB1	13	P8_13	PWM	LED 3.3V PWM goe	U24, AND Gate	2							
BBB1	14	P8_14	GPIO	Ox. Con. Enable sig	U26, Open Collector	8							
BBB1	15	P8_15	GPIO	According to the H-	U5, Half Bridge and U6, Logic Inverter	2,2							
BBB1	16	P8_16	GPIO	To enable the linear	U26, Open Collector	17							
BBB1	17	P8_17	GPIO	Power is supplied to	U7, Low Side Power Switch	1							
BBB1	18	P8_18	GPIO	Power is supplied to	U8, Low Side Power Switch	1							
BBB1	19	P8_19	PWM										
BBB1	20	P8_20	GPIO	Power is supplied to	U9, Low Side Power Switch	1							
BBB1	21	P8_21	GPIO	Power is supplied to	U10, Low Side Power Switch	1							
BBB1	22	P8_22	GPIO	Power is supplied to	U11, Low Side Power Switch	1							
BBB1	23	P8_23	GPIO	Power is supplied to	U12, Low Side Power Switch	1							
BBB1	24	P8_24	GPIO	Power is supplied to	U13, Low Side Power Switch	1							
BBB1	25	P8_25	GPIO	Power is supplied to	U14, Low Side Power Switch	1							
BBB1	26	P8_26	GPIO	Power is supplied to	U15, Low Side Power Switch	1							
BBB1	27	P8_27	GPIO	Power is supplied to	U16, Low Side Power Switch	1							
BBB1	28	P8_28	GPIO	Power is supplied to	U17, Low Side Power Switch	1							
BBB1	29	P8_29	GPIO	This line enables th	U26, Open Collector	6							
BBB1	30	P8_30	GPIO	Solenoid1 Enable si	U26, Open Collector	11							
BBB1	31	P8_31	GPIO	Solenoid2 Enable si	U26, Open Collector	13							
BBB1	32	P8_32	GPIO	UVFilter Enable sig	U26, Open Collector	15							
BBB1	33	P8_33	GPIO	Computer Ready G	U24, AND Gate and U27, Logic Inverter	All 'A' lines, 2							
BBB1	34	P8_34	GPIO	Stepper Motor Direc	U25, Logic Translator	4							
BBB1	35	P8_35	GPIO	Stepper Motor Enab	U25, Logic Translator	3							
BBB1	36	P8_36	PWM	Stepper Motor Cloc	U25, Logic Translator	2							
BBB1	37	P8_37	UART5_TXD+	Carbon Dioxide1 U	CD1_TX	2				J3	3		
BBB1	38	P8_38	UART5_RXD+	Carbon Dioxide1 U	CD1_RX	3				J3	4		
BBB1	39	P8_39	GPIO										
BBB1	40	P8_40	GPIO										
BBB1	41	P8_41	GPIO										
BBB1	42	P8_42	GPIO										
BBB1	43	P8_43	GPIO										
BBB1	44	P8_44	GPIO										
BBB1	45	P8_45	PWM	PWM line for fan sp	Vent. Fan 1					J7	4		
BBB1	46	P8_46	PWM	PWM line for fan sp	Vent. Fan 2					J7	8		
BBB1	47	P9_1	DGND										
BBB1	48	P9_2	DGND										
BBB1	49	P9_3	VDD_3V3										
BBB1	50	P9_4	VDD_3V3										
BBB1	51	P9_5	VDD_5V										
BBB1	52	P9_6	VDD_5V										
BBB1	53	P9_7	SYS_5V										
BBB1	54	P9_8	SYS_5V										
BBB1	55	P9_9	PWR_BUT										
BBB1	56	P9_10	SYS_RESETN										

Component	Pin Number	Pin Label	Signal	Description	Connection Component	Connection Pin	Address	Part Number	Location	Connecto	J Connector Pin	General Signal (Data/Logic	Analog
BBB1	57	P9_11	UART4_RXD	UART Recive Line	FM2_RX	3				J2	8		
BBB1	58	P9_12	GPIO										
BBB1	59	P9_13	UART4_TXD	UART Transmit line	FM2_TX	2				J2	7		
BBB1	60	P9_14	PWM										
BBB1	61	P9_15	GPIO										
BBB1	62	P9_16	PWM										
BBB1	63	P9_17	I2C1_SCL		EC1,PH1,EC2,PH2,DO1,TP1,ADC1,ADC2 (_RX/SCL)	3,3,3,3,3,4,19,19	1,2,3,4,5,119,34,33						
BBB1	64	P9_18	I2C1_SDA		EC1,PH1,EC2,PH2,DO1,TP1,ADC1,ADC2 (_TX/SCL)	2,2,2,2,4,5,18,18	1,2,3,4,5,119,34,33						
BBB1	65	P9_19	GPIO	This is the middle of	LS3	1				J3	18		
BBB1	66	P9_20	GPIO	This is the middle of	LS4	1				J3	19		
BBB1	67	P9_21	I2C2_SCL		TP2	4	119						
BBB1	68	P9_22	I2C2_SDA		TP2	5	119						
BBB1	69	P9_23	GPIO										
BBB1	70	P9_24	UART1_TXD	UART Transmit line	FM1_TX	2				J2	5		
BBB1	71	P9_25	GPIO										
BBB1	72	P9_26	UART1_RXD	UART Recive Line	FM1_RX	3				J2	6		
BBB1	73	P9_27	GPIO										
BBB1	74	P9_28	PWM										
BBB1	75	P9_29	PWM										
BBB1	76	P9_30	PWM										
BBB1	77	P9_31	GPIO										
BBB1	78	P9_32	VDD_ADC										
BBB1	79	P9_33	AIN4										
BBB1	80	P9_34	GNDA_ADC										
BBB1	81	P9_35	AIN6										
BBB1	82	P9_36	AIN5										
BBB1	83	P9_37	AIN2										
BBB1	84	P9_38	AIN3										
BBB1	85	P9_39	AIN0										
BBB1	86	P9_40	AIN1										
BBB1	87	P9_41	GPIO										
BBB1	88	P9_42	PWM										
BBB1	89	P9_43	DGND										
BBB1	90	P9_44	DGND										
BBB1	91	P9_45	DGND										
BBB1	92	P9_46	DGND										
EC1	1	GND	DGND		PCB	DGND	1	SEN-12908	Liquid Tanks & Plumbing	J2	21	1	
EC1	2	TX/SDA	I2C		BBB1	64				J2	1	1	
EC1	3	RX/SCL	I2C		BBB1	63				J2	2	1	
EC1	4	VCC	3.3V-5V		PCB	3.3V				J2	20	1	
EC1	5	PRB	N/A	This is a probe line f	External BNC								
EC1	6	PRB	N/A	This is a probe line f	External BNC								
PH1	1	GND	DGND		PCB	DGND	2	SEN-10972	Liquid Tanks & Plumbing	J2	23	1	
PH1	2	TX/SDA	I2C		BBB1	64				J2	3	1	
PH1	3	RX/SCL	I2C		BBB1	63				J2	4	1	
PH1	4	VCC	3.3V-5.5V		PCB	3.3V				J2	22	1	
PH1	5	PRB	N/A	This is a probe line f	External cable								
PH1	6	PGND	N/A	This is a probe line f	External cable								
TEMP1	1	GND	DGND		PCB	DGND		SEN-11050	Liquid Tanks & Plumbing	J2	37	1	
TEMP1	2	DQ	Digital In/Out		BBB1	3				J2	17	1	
TEMP1	3	Vdd	3V-5V		PCB	3.3V				J2	36	1	
DO1	1	GND	DGND		PCB	DGND	5	EZO-DO	Liquid Tanks & Plumbing	J2	35	1	1
DO1	2	VCC	3.3V-5V		PCB	3.3V				J2	34	1	
DO1	3	RX/SCL	I2C		BBB1					J2	16	1	
DO1	4	TX/SDA	I2C		BBB1					J2	15	1	
DO1	5	PRB	N/A	This is a probe line f	External cable								

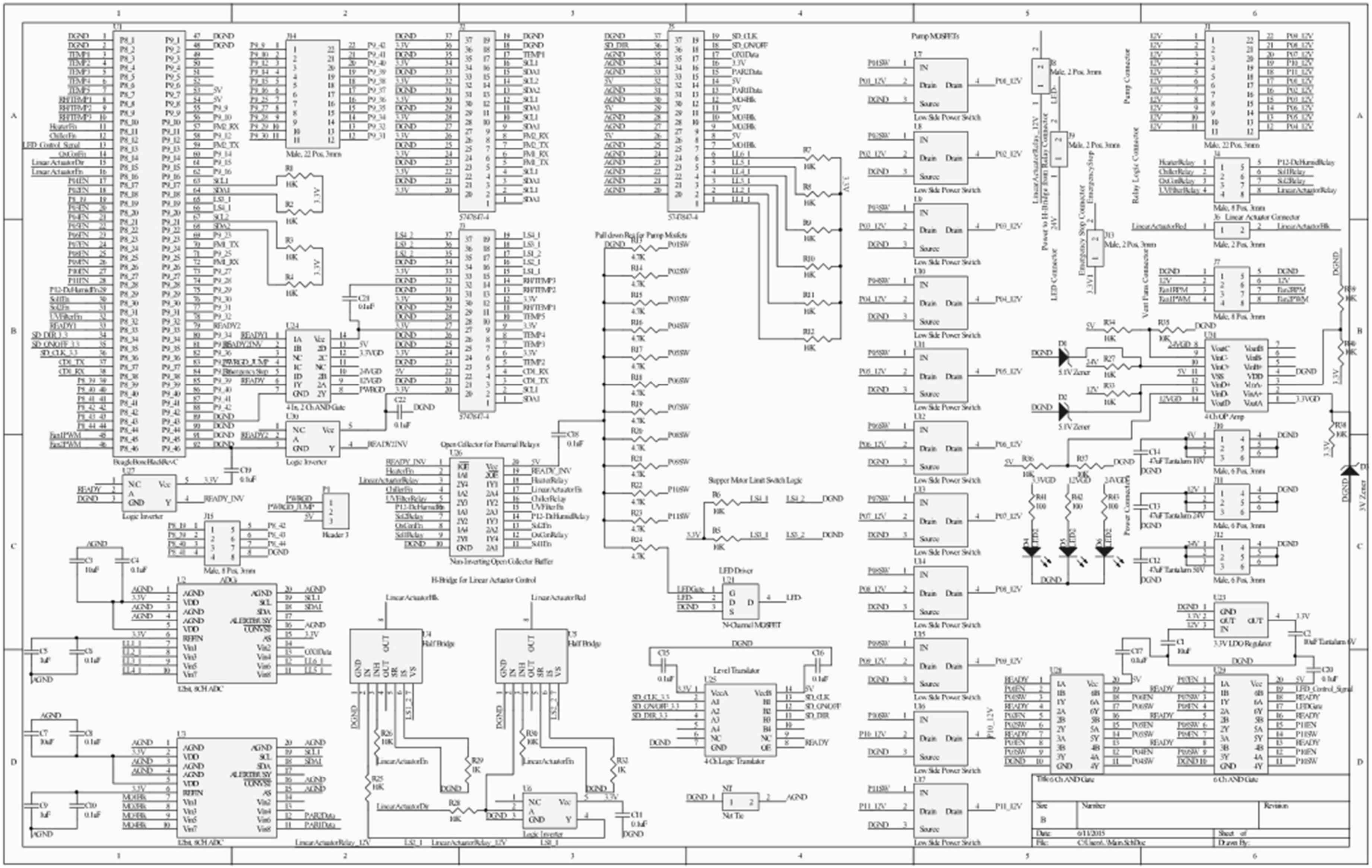
Component	Pin Number	Pin Label	Signal	Description	Connection Component	Connection Pin	Address	Part Number	Location	Connecto	J Connector Pin	General Signal (Data/Logic	Analog
DO1	6	PGND	N/A	This is a probe line f	External cable								
LL1	1	Rref	N/A		NC	NC		PN-1211021	Liquid Tanks & Plumbing				1
LL1	2	Rsense	Analog		ADC1	7				J5	1		1
LL1	3	Rsense	AGND		PCB	AGND				J5	20		
LL1	4	Rref	N/A		NC	NC							
LL2	1	Rref	N/A		NC	NC		PN-1211021	Liquid Tanks & Plumbing				1
LL2	2	Rsense	Analog		ADC1	8				J5	2		1
LL2	3	Rsense	AGND		PCB	AGND				J5	21		
LL2	4	Rref	N/A		NC	NC							
LL3	1	Rref	N/A		NC	NC		PN-1211021	Liquid Tanks & Plumbing				1
LL3	2	Rsense	Analog		ADC1	9				J5	3		1
LL3	3	Rsense	AGND		PCB	AGND				J5	22		
LL3	4	Rref	N/A		NC	NC							
LL4	1	Rref	N/A		NC	NC		PN-1211021	Liquid Tanks & Plumbing				1
LL4	2	Rsense	Analog		ADC1	10				J5	4		1
LL4	3	Rsense	AGND		PCB	AGND				J5	23		
LL4	4	Rref	N/A		NC	NC							
LL5	1	Rref	N/A		NC	NC		PN-1211021	Liquid Tanks & Plumbing				1
LL5	2	Rsense	Analog		ADC1	11				J5	5		1
LL5	3	Rsense	AGND		PCB	AGND				J5	24		
LL5	4	Rref	N/A		NC	NC							
LL6	1	Rref	N/A		NC	NC		PN-1211021	Liquid Tanks & Plumbing				1
LL6	2	Rsense	Analog		ADC1	12				J5	6		1
LL6	3	Rsense	AGND		PCB	AGND				J5	25		
LL6	4	Rref	N/A		NC	NC							
FM1	1	GND	DGND		PCB	DGND		SEN-203F	Liquid Tanks & Plumbing	J2	25	1	
FM1	2	TX	UART		BBB1	70				J2	5	1	
FM1	3	RX	UART		BBB1	72				J2	6	1	
FM1	4	VCC	2.5V-5.5V		PCB	3.3V				J2	24	1	
FM1	5	PRB	N/A	This is a probe line f	External cable								
FM1	6	PGND	N/A	This is a probe line f	External cable	DGND							
FM2	1	GND	DGND		PCB	DGND		SEN-203F	Liquid Tanks & Plumbing	J2	27	1	
FM2	2	TX	UART		BBB1	59				J2	7	1	
FM2	3	RX	UART		BBB1	57				J2	8	1	
FM2	4	VCC	2.5V-5.5V		PCB, PRB	3.3V				J2	26	1	
FM2	5	PRB	N/A		External cable (PRB)								
FM2	6	GND	DGND		PRB	DGND							
TEMP2	1	NC	N/A					SEN-11050	Growth Medium				
TEMP2	2	NC	N/A										
TEMP2	3	VDD	3V-5.5V		PCB	3.3V				J3	24	1	
TEMP2	4	DQ	Digital In/Out		BBB1	4				J3	5	1	
TEMP2	5	GND	DGND		PCB	DGND				J3	25	1	
TEMP2	6	NC	N/A										
TEMP2	7	NC	N/A										
TEMP2	8	NC	N/A										
TEMP3	1	NC	N/A					SEN-11050	Growth Medium				
TEMP3	2	NC	N/A										
TEMP3	3	VDD	3V-5.5V		PCB	3.3V				J3	6	1	
TEMP3	4	DQ	Digital In/Out		BBB1	5				J3	7	1	
TEMP3	5	GND	DGND		PCB	DGND				J3	26	1	
TEMP3	6	NC	N/A										
TEMP3	7	NC	N/A										
TEMP3	8	NC	N/A										
TEMP4	1	NC	N/A					SEN-11050	Growth Medium				
TEMP4	2	NC	N/A										
TEMP4	3	VDD	3V-5.5V		PCB	3.3V				J3	27	1	

Component	Pin Number	Pin Label	Signal	Description	Connection Component	Connection Pin	Address	Part Number	Location	Connecto	J Connector Pin	General Signal (Data/Logic	Analog
TEMP4	4	DQ	Digital In/Out		BBB1	6				J3	8	1	
TEMP4	5	GND	DGND		PCB	DGND				J3	28	1	
TEMP4	6	NC	N/A										
TEMP4	7	NC	N/A										
TEMP4	8	NC	N/A										
TEMP5	1	NC	N/A					SEN-11050	Growth Medium				
TEMP5	2	NC	N/A										
TEMP5	3	VDD	3V-5.5V		PCB	3.3V				J3	9	1	
TEMP5	4	DQ	Digital In/Out		BBB1	7				J3	10	1	
TEMP5	5	GND	DGND		PCB	DGND				J3	29	1	
TEMP5	6	NC	N/A										
TEMP5	7	NC	N/A										
TEMP5	8	NC	N/A										
EC2	1	GND	DGND		PCB	DGND	3	SEN-12908	Growth Medium	J2	29	1	
EC2	2	TX/SDA	I2C		BBB1	64				J2	9	1	
EC2	3	RX/SCL	I2C		BBB1	63				J2	10	1	
EC2	4	VCC	3.3V-5V		PCB	3.3V				J2	28	1	
EC2	5	PRB	N/A		External cable								
EC2	6	PRB	N/A		External cable								
PH2	1	GND	DGND		PCB	DGND	4	SEN-10972	Growth Medium	J2	31	1	
PH2	2	TX/SDA	I2C		BBB1	64				J2	11	1	
PH2	3	RX/SCL	I2C		BBB1	63				J2	12	1	
PH2	4	VCC	3.3V-5.5V		PCB	3.3V				J2	30	1	
PH2	5	PRB	N/A		External BNC								
PH2	6	PGND	N/A	This is a probe line f	External cable								
MO1	1	BARE	GND		PCB	AGND		VH400-2M	Growth Medium	J5	27		1
MO1	2	RED	3.5V-20V		PCB	12V				J5	26		1
MO1	3	BLACK	Analog		ADC2	7				J5	7		1
MO2	1	BARE	GND		PCB	AGND		VH400-2M	Growth Medium	J5	28		1
MO2	2	RED	3.5V-20V		PCB	12V				J5	8		1
MO2	3	BLACK	Analog		ADC2	8				J5	9		1
MO3	1	BARE	GND		PCB	AGND		VH400-2M	Growth Medium	J5	30		1
MO3	2	RED	3.5V-20V		PCB	12V				J5	29		1
MO3	3	BLACK	Analog		ADC2	9				J5	10		1
MO4	1	BARE	GND		PCB	AGND		VH400-2M	Grwoth Medium	J5	31		1
MO4	2	RED	3.5V-20V		PCB	12V				J5	11		1
MO4	3	BLACK	Analog		ADC2	10				J5	12		1
RH/TEMP1	1	VDD	3.3V-5.5V		PCB	3.3V		393	Internal	J3	30	1	
RH/TEMP1	2	DQ	Digital In/Out		BBB1	8				J3	11	1	
RH/TEMP1	3	GND	DGND		PCB	DGND				J3	31	1	
RH/TEMP2	1	VDD	3.3V-5.5V		PCB	3.3V		393	Internal	J3	12	1	
RH/TEMP2	2	DQ	Digital In/Out		BBB1	9				J3	13	1	
RH/TEMP2	3	GND	DGND		PCB	DGND				J3	32	1	
TP1	1	VIN	3V-5V		PCB	3.3V	119	BMP180	Internal	J3	20	1	
TP1	2	Vo	3V@100mA		NC	NC							
TP1	3	GND	DGND		PCB	DGND				J3	21	1	
TP1	4	RX/SCL	I2C		BBB1	63				J3	2	1	
TP1	5	TX/SDA	I2C		BBB1	64				J3	1	1	
OX1	1		Analog		ADC1	13		R125P01-002	Internal	J5	17		1
OX1		GND								J5	16		
OX1						3.3V				J5	35		
CD1	1	GND	DGND		PCB	DGND		SE-0018 K30	Internal	J3	23	1	
CD1	2	TX	UART		BBB1	37				J3	3	1	
CD1	3	RX	UART		BBB1	38				J3	4	1	
CD1	4	G0	5V-9V		PCB	5V				J3	22	1	
PAR1	1	GREEN	Analog		ADC2	11		SQ-215	Internal	J5	13		1

Component	Pin Number	Pin Label	Signal	Description	Connection Component	Connection Pin	Address	Part Number	Location	Connecto	J Connector Pin	General Signal (Data/Logic	Analog
PAR1	2	WHITE	5V-24V		PCB	5V				J5	32		1
PAR1	3	CLEAR	GND		PCB	AGND				J5	33		1
PAR2	1	GREEN	Analog		ADC2	12		SQ-215	External	J5	15		1
PAR2	2	WHITE	5V-24V		PCB	5V				J5	14		1
PAR2	3	CLEAR	GND		PCB	AGND				J5	34		1
RH/TEMP3	1	VDD	3.3V-5.5V		PCB	3.3V		393	External	J3	33	1	
RH/TEMP3	2	DQ	Digital In/Out		BBB1	10				J3	14	1	
RH/TEMP3	3	GND	DGND		PCB	DGND				J3	34	1	
TP2	1	VIN	3V-5V		PCB	3.3V	119	BMP180	External	J2	32	1	
TP2	2	Vo	3V@100mA		NC	NC							
TP2	3	GND	DGND		PCB	DGND				J2	33	1	
TP2	4	SCL	I2C		BBB1	67				J2	14	1	
TP2	5	SDA	I2C		BBB1	68				J2	13	1	
LED Driver	1	G	PWM	This is the GATE lin	U24	3		785-1146-5-ND					
LED Driver	2	D	LED-	This will be connect	LED	2				J9	2		
LED Driver	3	S	DGND	To protect the board	PCB	DGND							
LED Driver	4	D	LED-	This will be connect	LED	2				J9	2		
Camera	USB				BBB1	USB							
Res. Heater Relay Signal					U26, Open Collector	18				J4	1		
Res. Chiller Relay Signal					U26, Open Collector	16				J4	2		
Vent. Fan 1	1	GND	GND		PCB	DGND				J7	1		
Vent. Fan 1	2	V+	12V		PCB	12V				J7	2		
Vent. Fan 1	3	RPM			NC	NC				J7	3		
Vent. Fan 1	4	PWM	PWM		BBB1	45				J7	4		
Vent Fan 2	1	GND	GND		PCB	DGND				J7	5		
Vent Fan 2	2	V+	12V		PCB	12V				J7	6		
Vent Fan 2	3	RPM			NC	NC				J7	7		
Vent Fan 2	4	PWM	PWM		BBB1	46				J7	8		
Ox Concentrator Relay Signal					U26, Open Collector	12				J4	3		
Dehumidifier/P12 Relay Signal					U26, Open Collector	14				J4	5		
Step Driver		ON/OFF+	5V Logic		U25, Logic Translator	12				J5	18		
Step Driver		ON/OFF-	GND		PCB	DGND				J5	37		
Step Driver		CLK+	5V Logic		U25, Logic Translator	13				J5	19		
Step Driver		CLK-	GND		PCB	DGND				J2	18		
Step Driver		DIR+	5V Logic		U25, Logic Translator	11				J5	36		
Step Driver		DIR-	GND		PCB	DGND				J2	19		
Limit Switch 1	1			Linear actuator limit	12V Signal from the Linear Actuator Relay					J3	15		
Limit Switch 1	2			Linear actuator limit	U4, Half Bridge	7				J3	16		
Limit Switch 2	1			Linear actuator limit	12V Signal from the Linear Actuator Relay					J3	17		
Limit Switch 2	2			Linear actuator limit	U5, Half Bridge	7				J3	35		
Limit Switch 3	1			Stepper motor limit	BBB1	65				J3	18		
Limit Switch 3	2			Stepper motor limit	PCB	DGND				J3	36		
Limit Switch 4	1			Stepper motor limit	BBB1	66				J3	19		
Limit Switch 4	2			Stepper motor limit	PCB	DGND				J3	37		
Linear Actuator	1	Red	24V	The H-Bridge config	U4, Half Bridge	8				J6	1		
Linear Actuator	2	Black	24V	The H-Bridge config	U5, Half Bridge	8				J6	2		
P01	1		12V		U7, Low Sid Power Switch	2,4				J1	1		
P01	2		DGND		PCB	DGND							
P02	1		12V		U8, Low Sid Power Switch	2,4				J1	2		
P02	2		DGND		PCB	DGND							
P03	1		12V		U9, Low Sid Power Switch	2,4				J1	3		
P03	2		DGND		PCB	DGND							
P04	1		12V		U10, Low Sid Power Switch	2,4				J1	4		
P04	2		DGND		PCB	DGND							
P05	1		12V		U11, Low Sid Power Switch	2,4				J1	5		
P05	2		DGND		PCB	DGND							

Component	Pin Number	Pin Label	Signal	Description	Connection Component	Connection Pin	Address	Part Number	Location	Connecto	J Connector Pin	General Signal (Data/Logic	Analog
P06	1		12V		U12, Low Sid Power Switch	2,4				J1	6		
P06	2		DGND		PCB	DGND							
P07	1		12V		U13, Low Sid Power Switch	2,4				J1	7		
P07	2		DGND		PCB	DGND							
P08	1		12V		U14, Low Sid Power Switch	2,4				J1	8		
P08	2		DGND		PCB	DGND							
P09	1		12V		U15, Low Sid Power Switch	2,4				J1	9		
P09	2		DGND		PCB	DGND							
P10	1		12V		U16, Low Sid Power Switch	2,4				J1	10		
P10	2		DGND		PCB	DGND							
P11	1		12V		U17, Low Sid Power Switch	28				J1	11		
P11	2		DGND		PCB	DGND							
Solenoid1 Relay Signal					U26, Open Collector	9				J4	6		
Solenoid2 Relay Signal					U26, Open Collector	7				J4	7		
UV Filter Relay Signal					U26, Open Collector	5				J4	4		

E. Electrical Schematics



IX. SYSTEM BUDGETS

A. Gas Budget

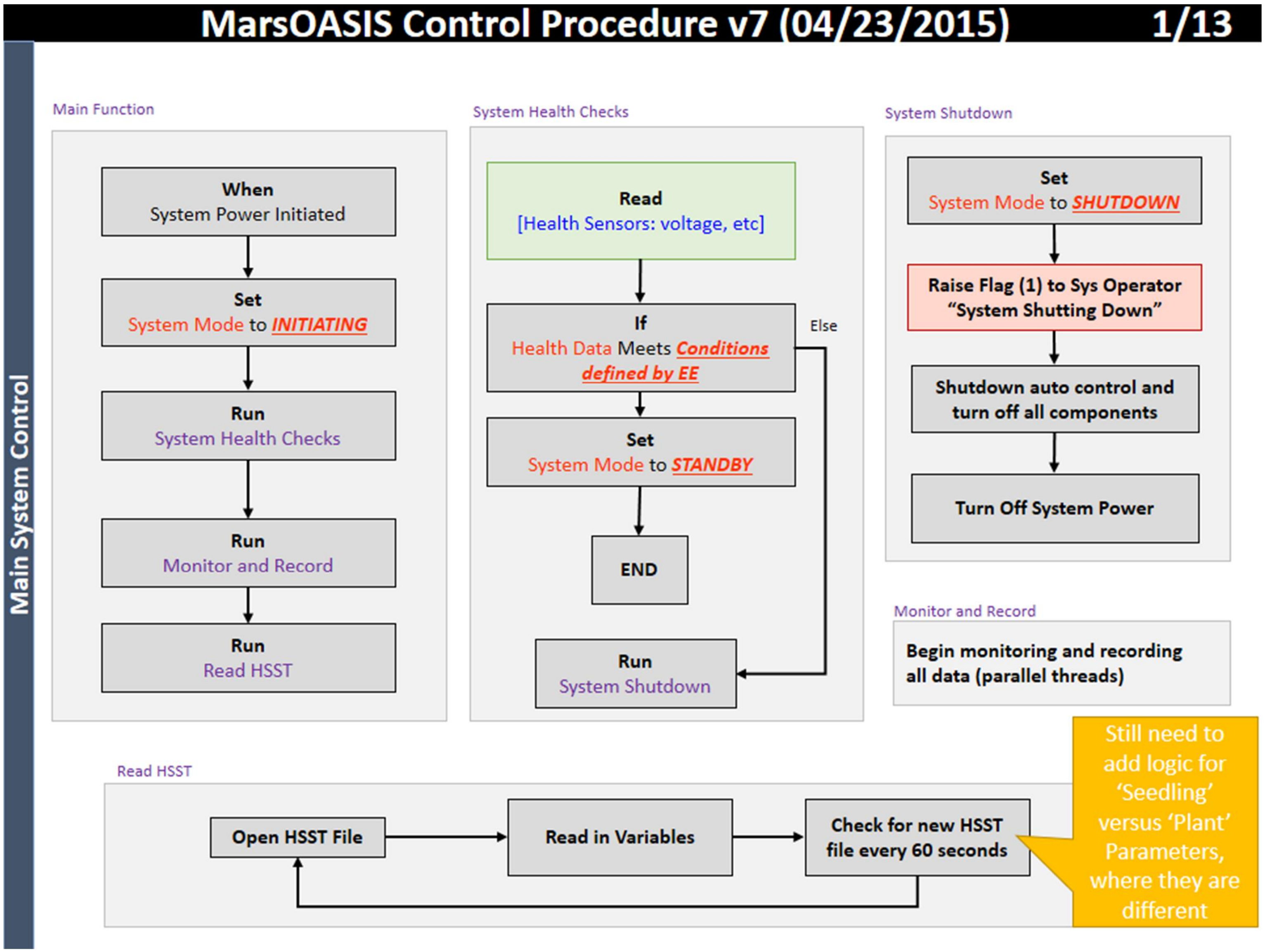
Constituent	Concentration (%)	Tank Pressure-Full (psi)	Tank Volume (L)
N2	>99	1600	1.89
CO2	>99	700	1.89
O2	93	n/a	n/a

B. Liquid Budget

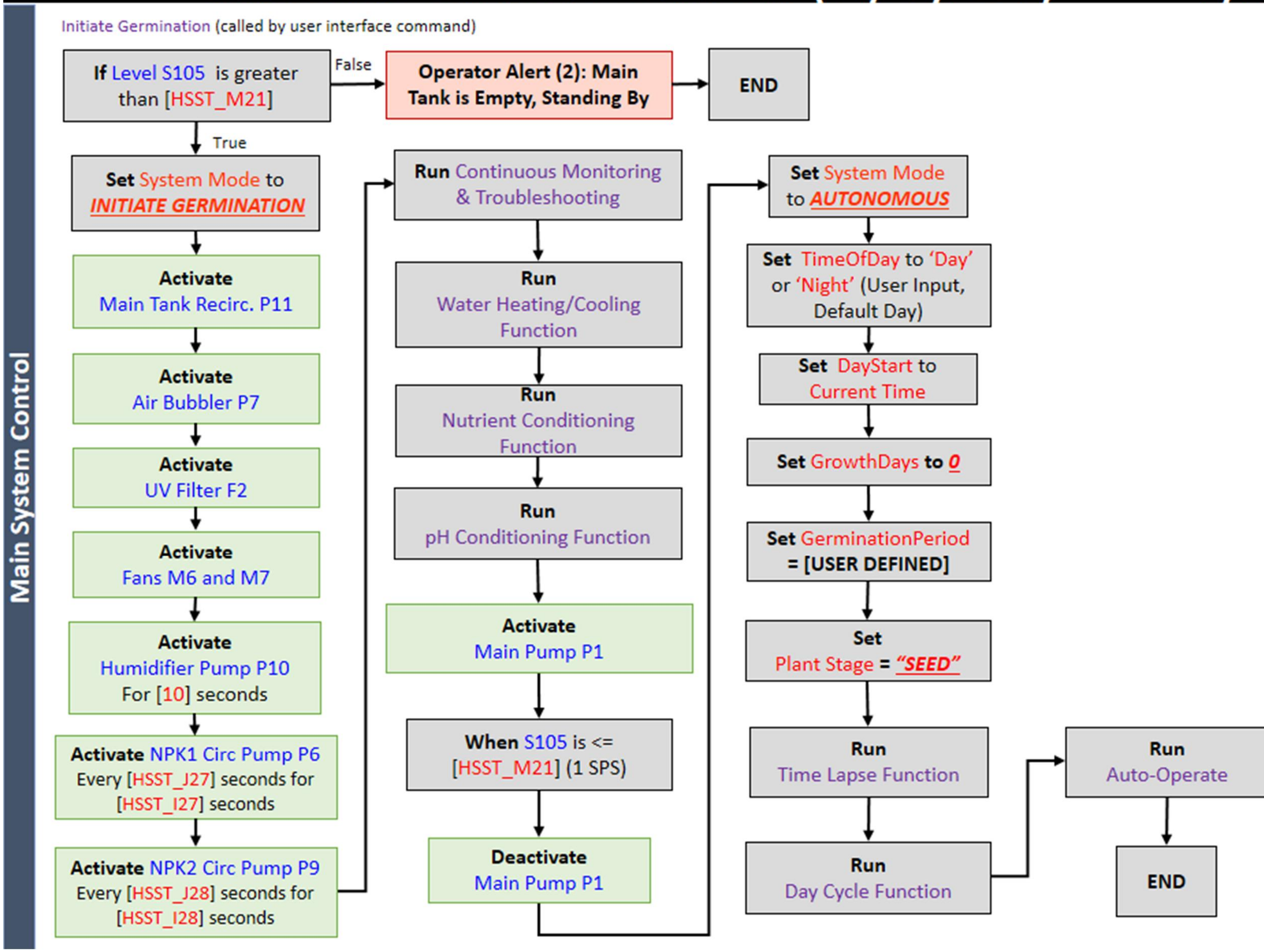
Liquid Budget				
Item	**Rationale/Source**	**Units**	**Amount**	**Gallons**
Water Volume				
Growth Tray				
Volume	pi*r2*h	cubic ft	1.3	
x Saturation Percent	78% of the volume will be water	%	0.8	
x Conversion Factor (liters)		-	28.3	
Growth Tray		**liters**	**28.9**	**7.6**
Plant Needs				
Plant Daily Water Needs	Ray Wheeler paper via Gioia Massa	ml/m2/day	4000.0	
x Growth Area	pi*r2	m2	0.3	
x Growth Cycle	45 day cycle	days	45.0	
x Conversion Factor	Convert to Liters	-	0.0	
Without Recycling		liters	**52.5**	**13.9**
x Recycling Factor	90% of water will be recycled	-	0.1	
Plant Needs with Recycling		**liters**	**5.3**	**1.4**
Tank Buffers	Tanks canđ be dry1			
Main Tank	Depends on shape of tank	liters	1	
+ Leachate Tank	Depends on shape of tank	liters	1	

Tank Buffers		**liters**	**2.0**	**0.5**
Grand Total Water		liters	**36.1**	**9.5**
Tank Size	Round to nearest standard gallon size	liters	**37.9**	**10.0**
Nutrient Volume				
Nutrient Volume				
Liters of Water2	Assume filtering strips all nutrients	liters	81.4	21.5
Concentration (stored)	Recommended by GM	-	4.0	1.1
Nutrient Volume	C1V1 = C2V2	liters	**11.6**	**3.1**
Tank Size (2x)	Two tanks for two part solution	liters	**7.6**	**2.0**
Notes				
1) Sensors, heater, cooler, pump require that tanks not be empty				
2) Need to condition all ~52 liters that the plant processes over the life cycle plus the full saturation of the				
growth medium (~29 liters).				

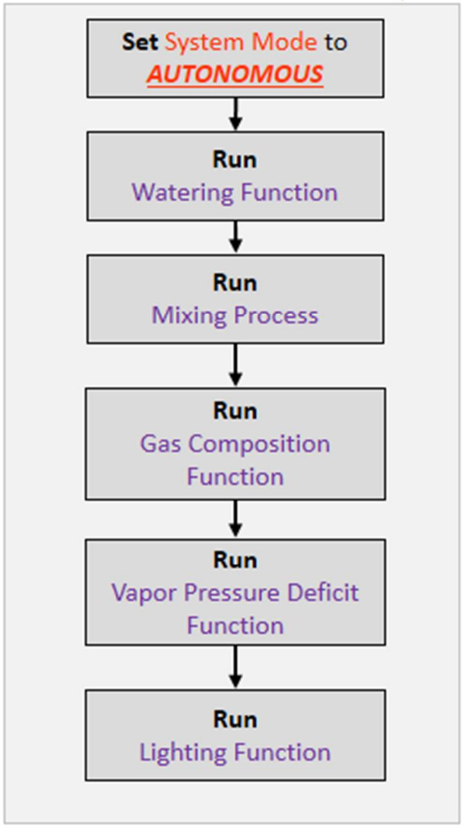
X. CONTROL LOGIC FLOW DIAGRAM



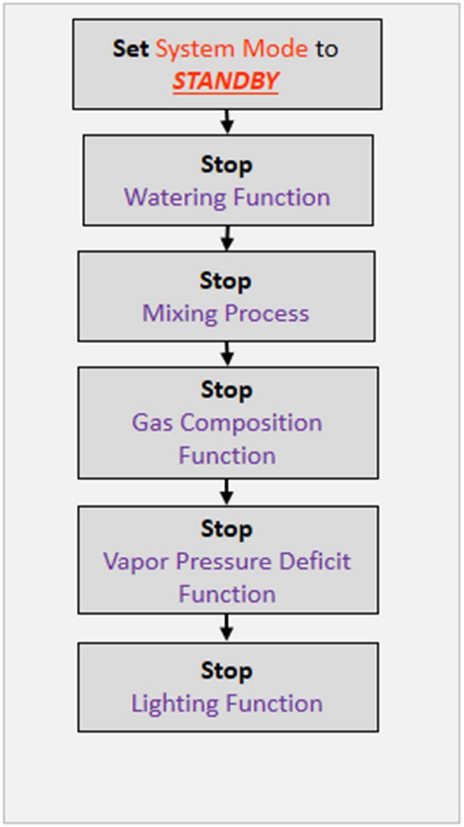
MarsOASIS Control Procedure v7 (04/23/2015)



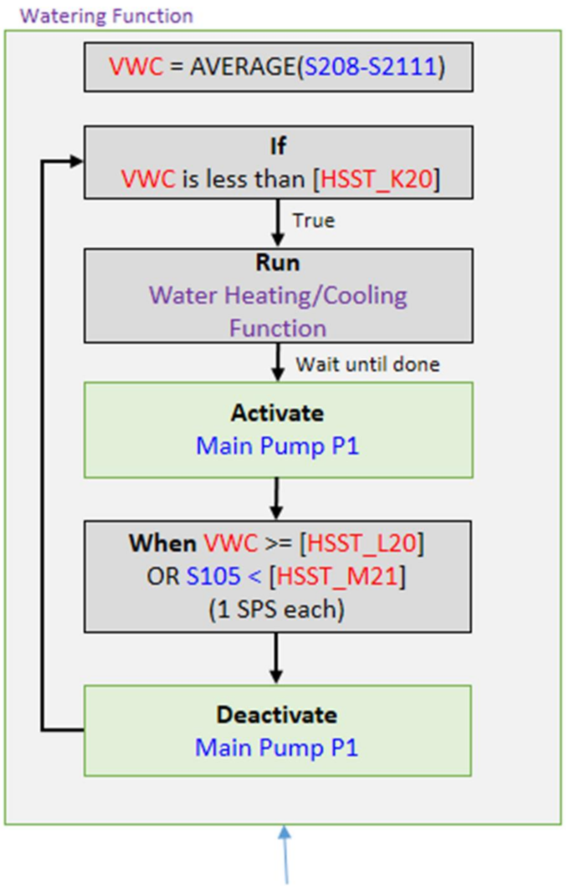
Auto-Operate (called by user interface 'Resume' button or Germination Initiation Function)

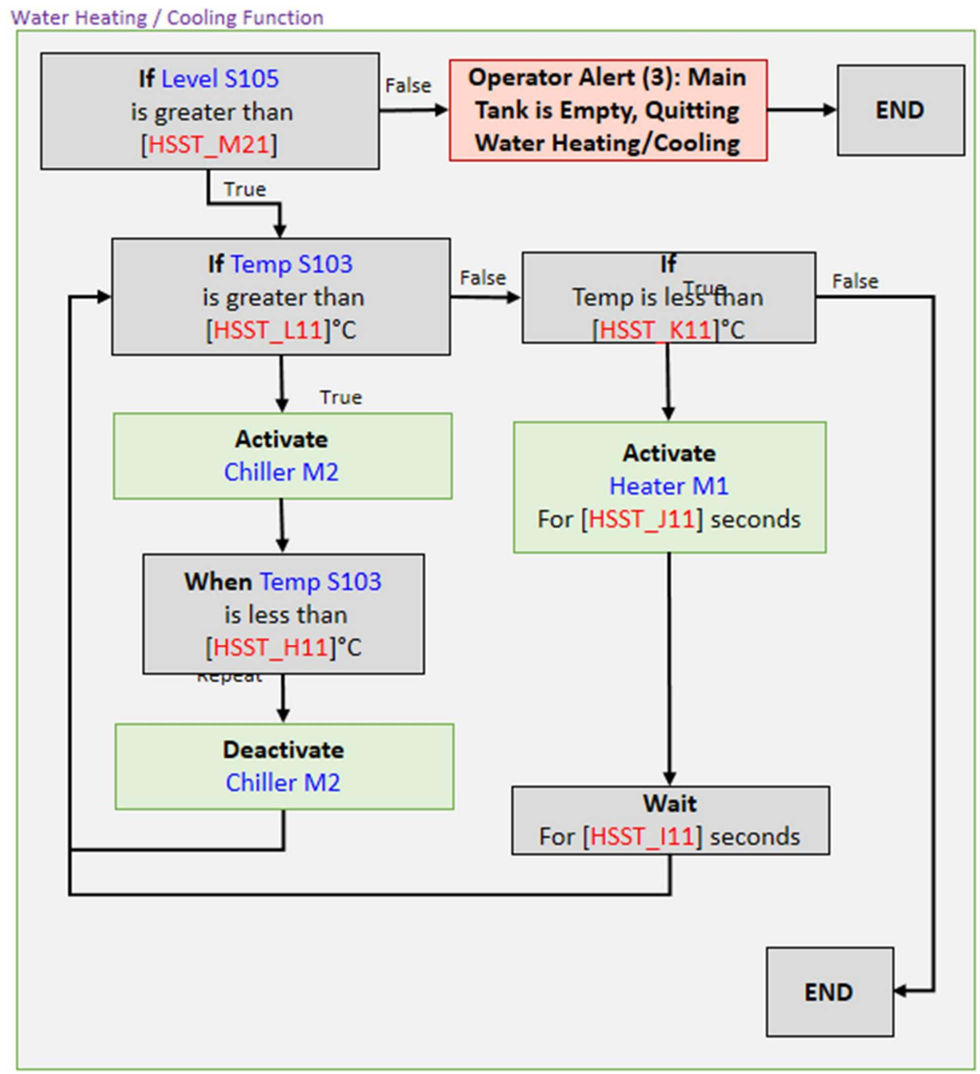


Tele-Operate (only called by user interface command)



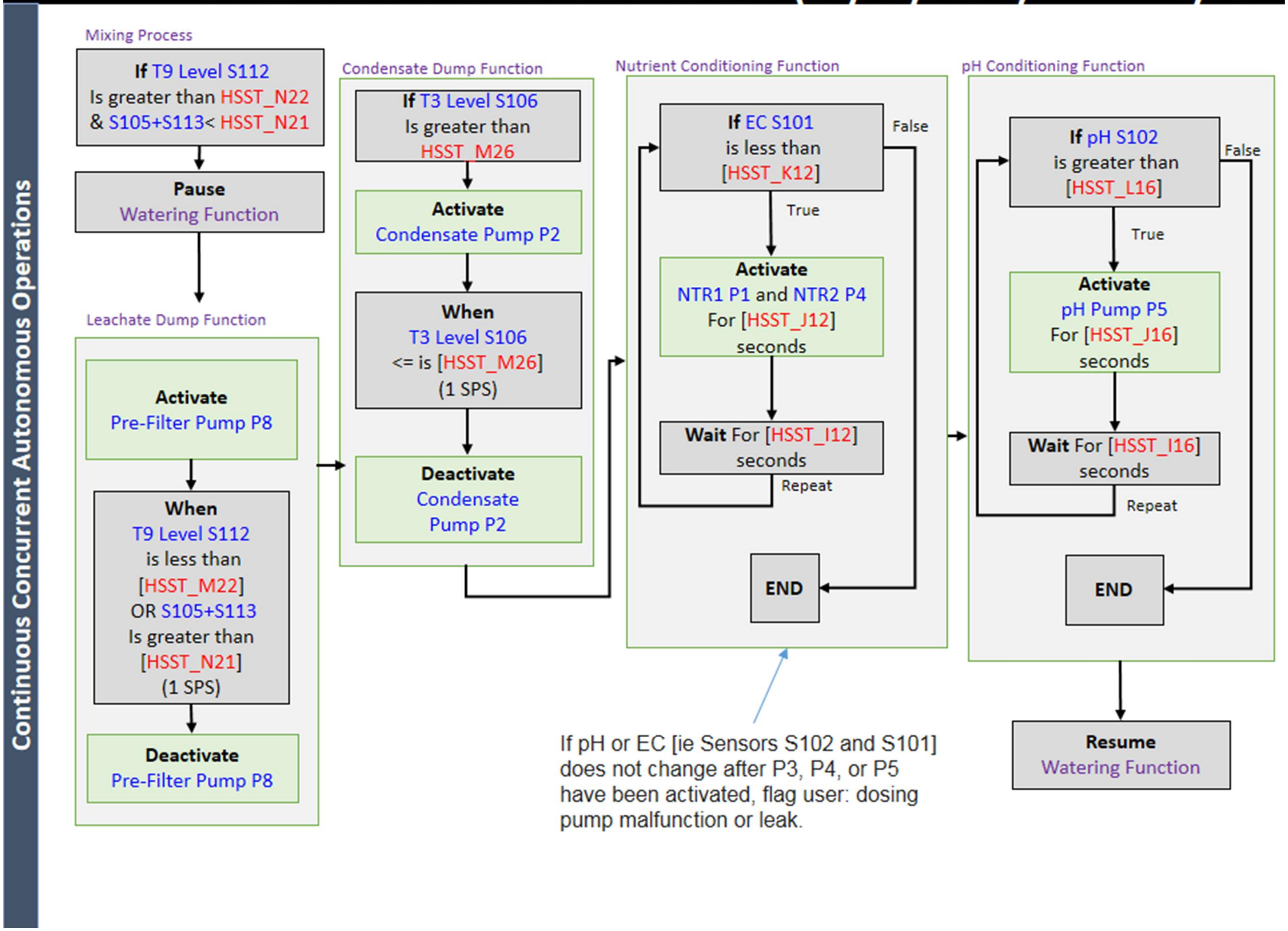
Continuous Concurrent Autonomous Operations



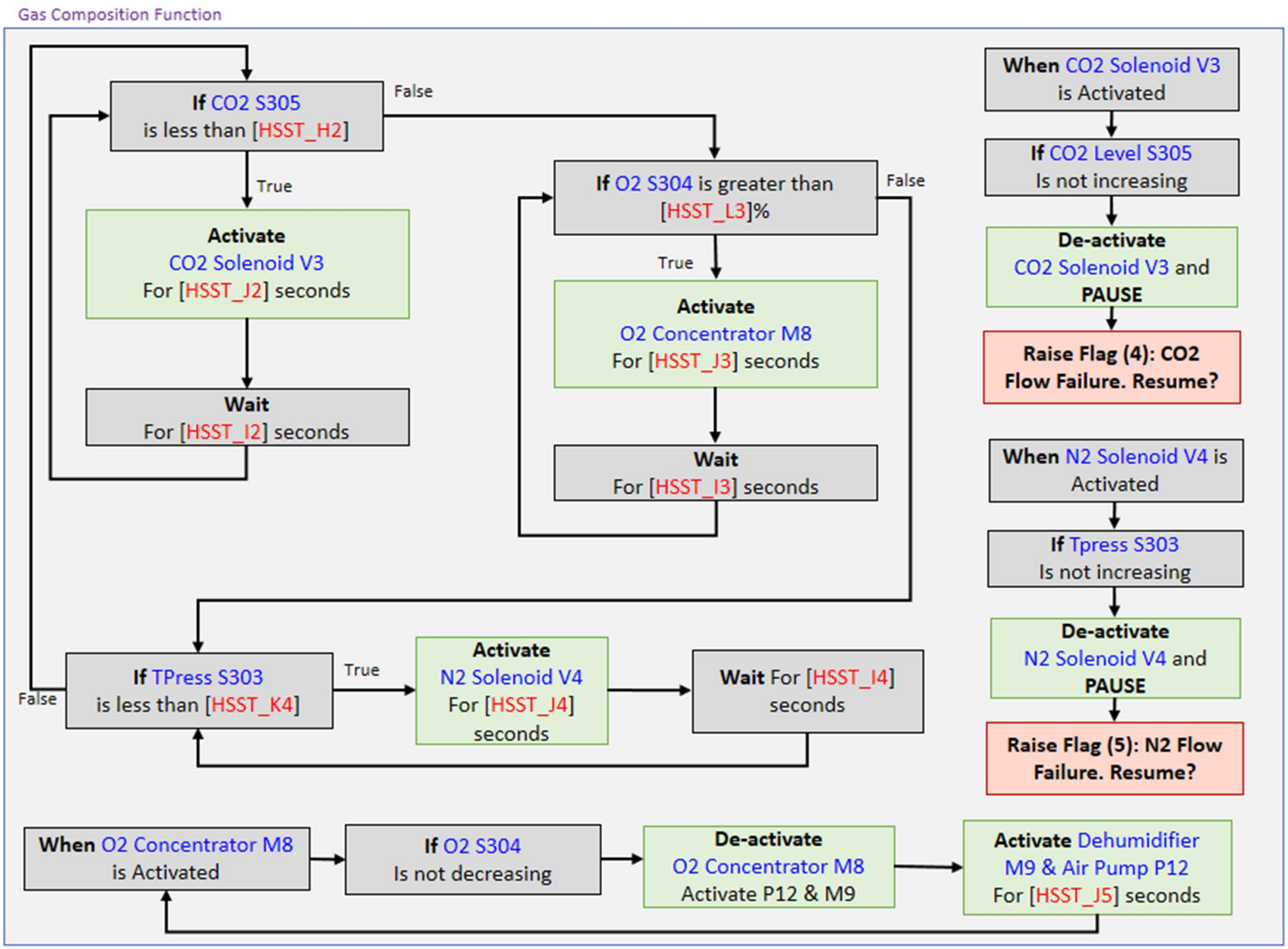


If Moisture Content [ie Sensors S208-S211] do not change after P1 has been activated, flag user: watering command malfunction. If Flow Sensor S110 indicates flow, the issue is with the drop ring (M5), if not, the issue is with the pump (P1).

MarsOASIS Control Procedure v7 (04/23/2015)

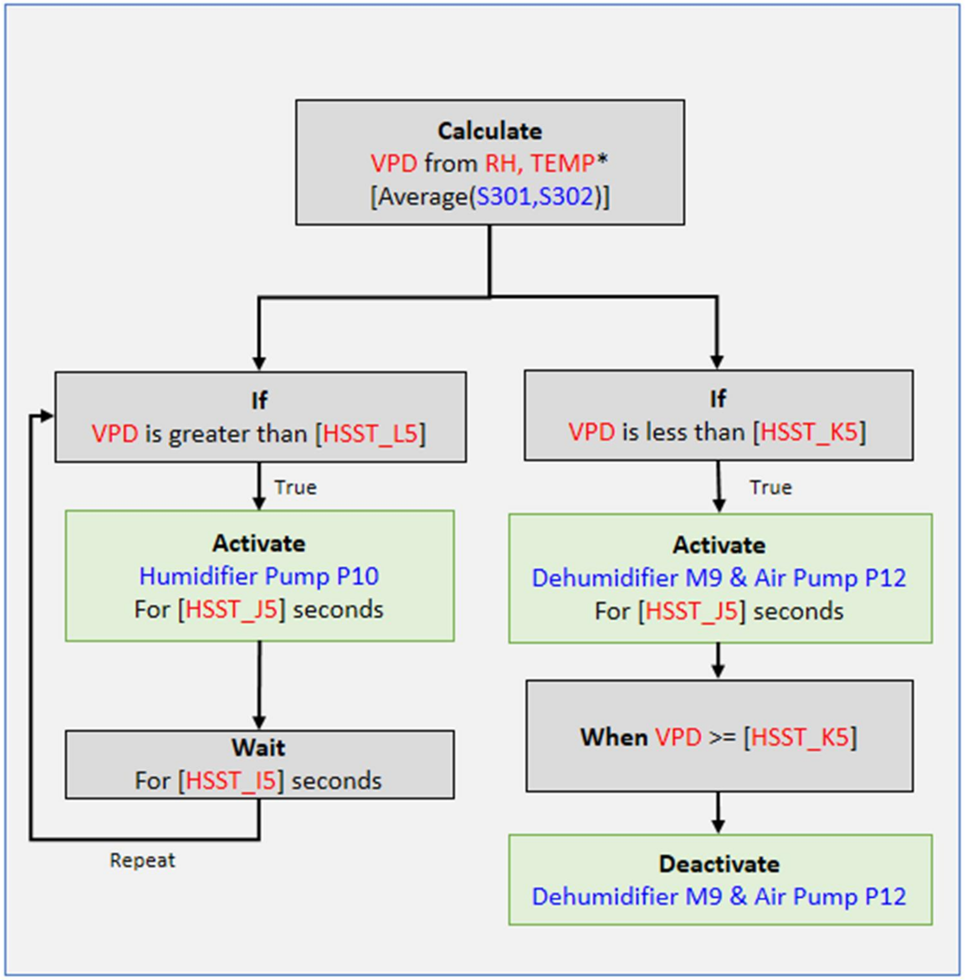


Continuous Concurrent Autonomous Operations



Continuous Concurrent Autonomous Operations

Vapor Pressure Deficit Function



After running P10, if RH does not increase after 60 seconds, send error message: Humidification Failure

*VPD from RH, TEMP

$T = T(^\circ C) + 273.15$

$A = -1.044 \times 10^{4}$

$B = -1.129 \times 10^{1}$

$C = -2.702 \times 10^{-2}$

$D = 1.289 \times 10^{-5}$

$E = -2.478 \times 10^{-9}$

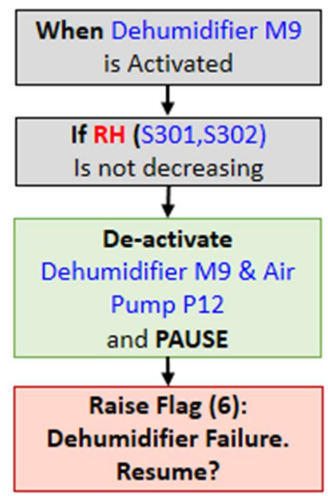
$F = 6.456$

$vp_{sat} = e^{(A/T + B + CT + DT^2 + ET^3 + F \ln T)}$

$vp_{air} = vp_{sat} \times RH \div 100$

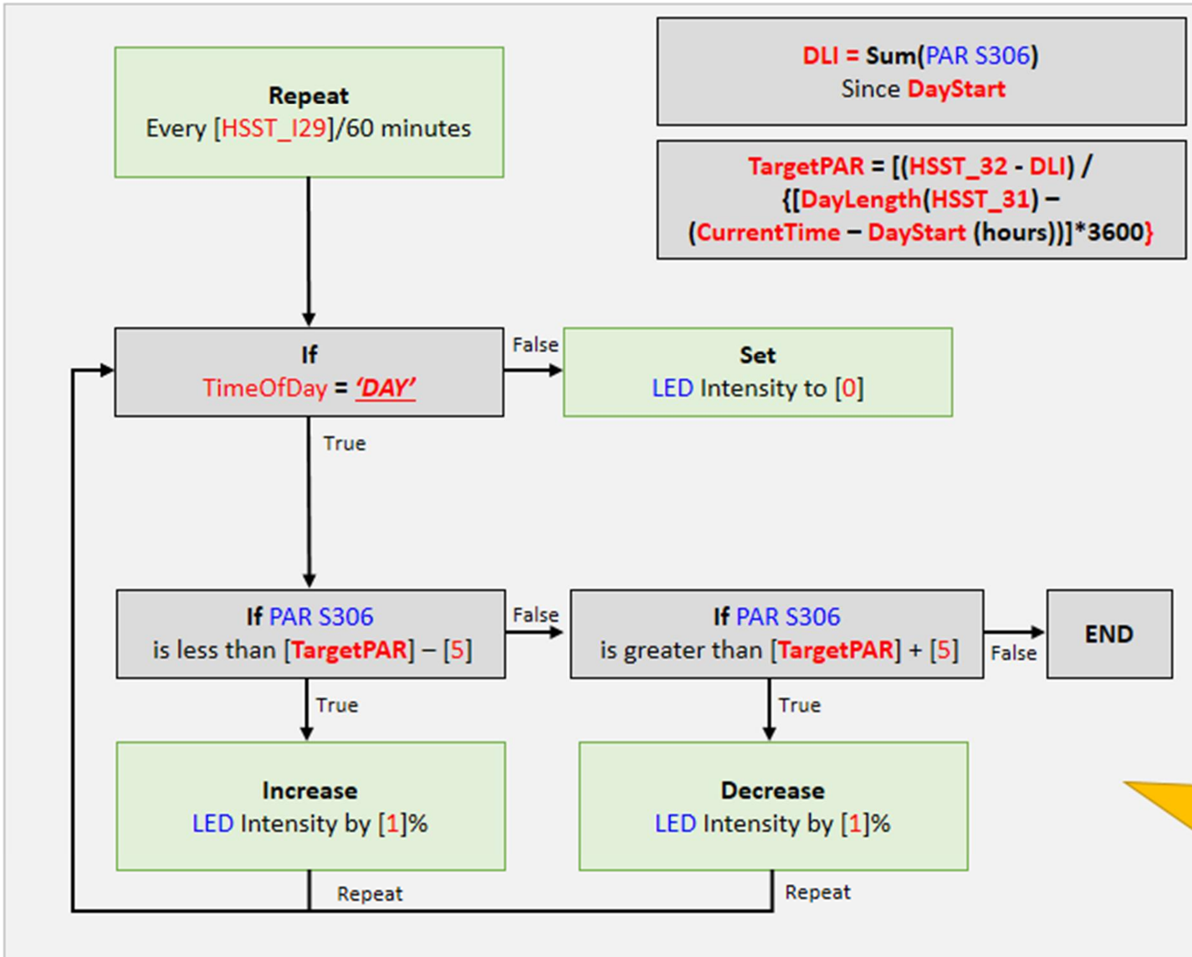
$VPD = vp_{sat} - vp_{air}$

http://ohioline.osu.edu/aex-fact/0804.html



Continuous Concurrent Autonomous Operations

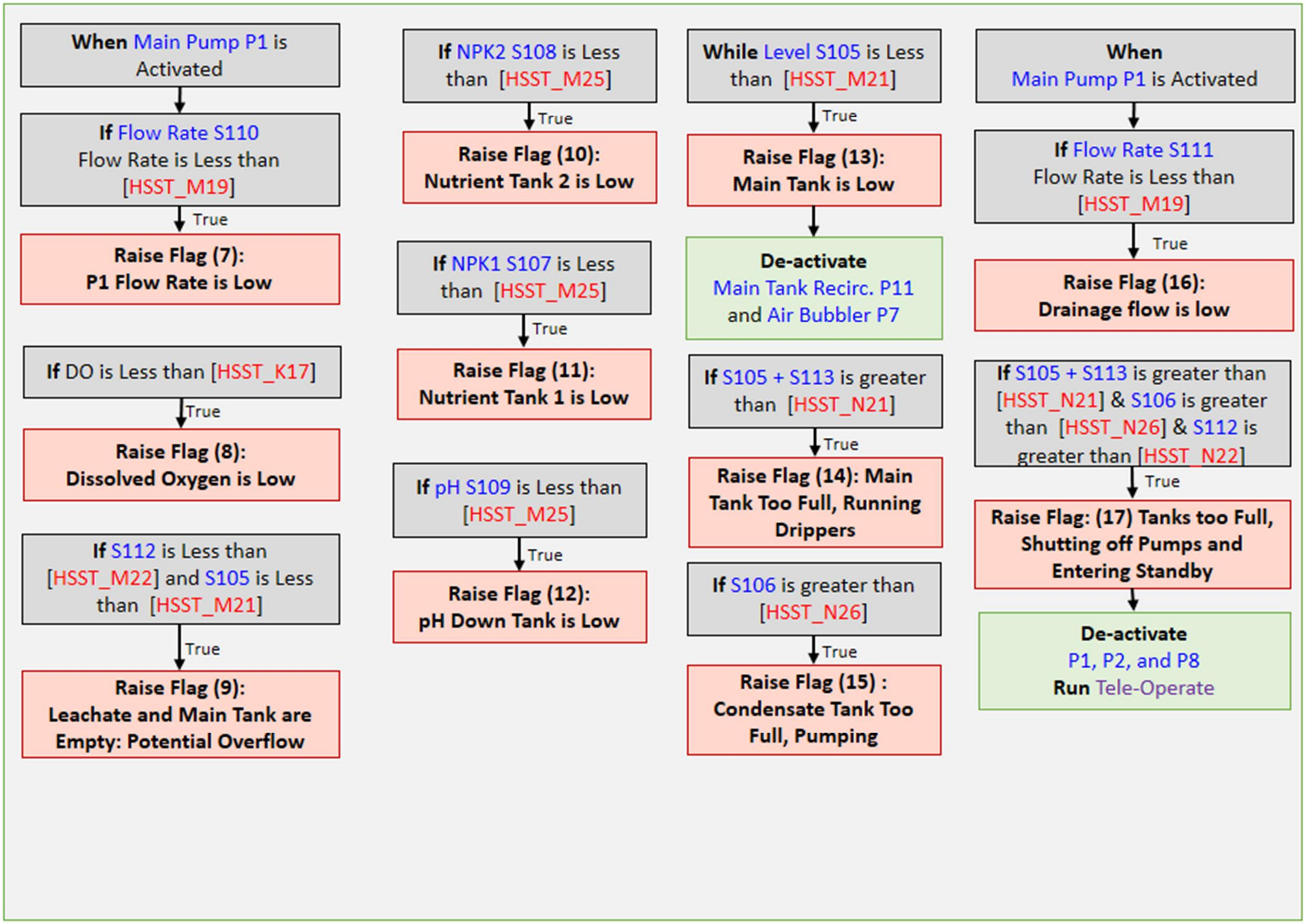
Lighting Function



Still need to add logic for bracket control when LEDs are on

Continuous Concurrent Autonomous Operations

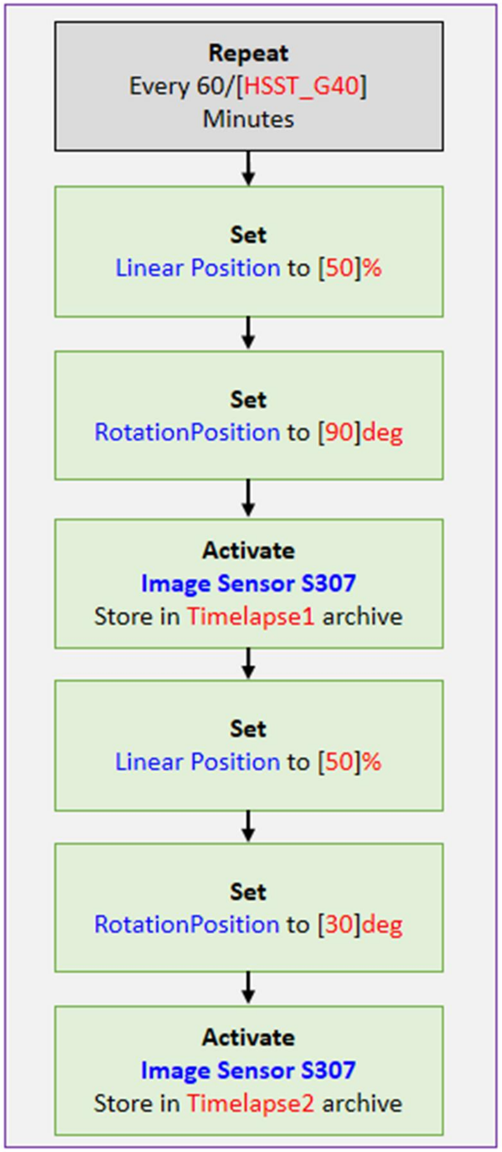
Continuous Monitoring and Troubleshooting



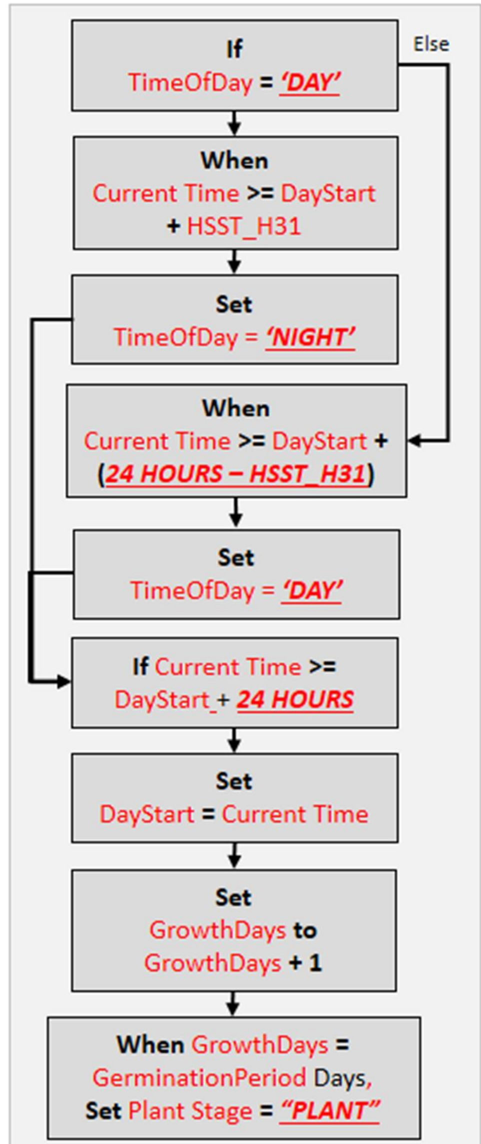
MarsOASIS Control Procedure v7 (04/23/2015)

Recurring Daily Operations

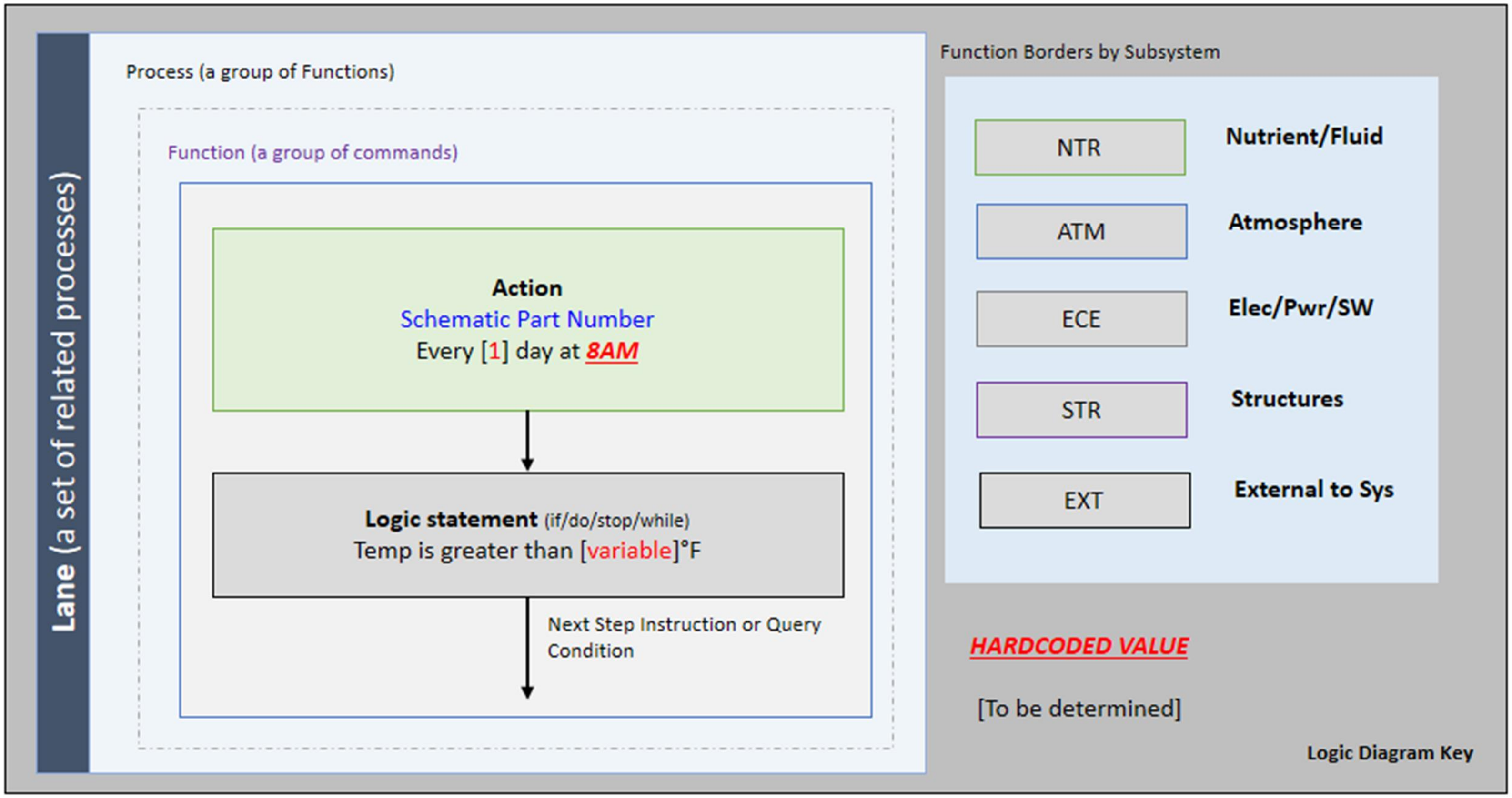
Timelapse Function



Day Cycle Function



Legend


Lane (a set of related processes)
Process (a group of Functions)
Function (a group of commands)
Action
Schematic Part Number
Every [1] day at 8AM
Logic statement (if/do/stop/while)
Temp is greater than [variable]°F
Next Step Instruction or Query Condition
Function Borders by Subsystem
NTR
Nutrient/Fluid
ATM
Atmosphere
ECE
Elec/Pwr/SW
STR
Structures
EXT
External to Sys
HARDCODED VALUE
[To be determined]
Logic Diagram Key

User Flag IDs

Flag ID	Alert Text
1	System Shutting Down
2	Main Tank is Empty, Standing By
3	Main Tank is Empty, Quitting Water Heating/Cooling
4	CO2 Flow Failure. Resume?
5	N2 Flow Failure. Resume?
6	Dehumidifier Failure. Resume?
7	P1 Flow Rate is Low
8	Dissolved Oxygen is Low
9	Leachate and Main Tank are Empty: Potential Overflow
10	Nutrient Tank 2 is Low
11	Nutrient Tank 1 is Low
12	pH Down Tank is Low
13	Main Tank is Low
14	Main Tank Too Full, Running Drippers
15	Condensate Tank Too Full, Pumping
16	Drainage flow is low
17	Tanks too Full, Shutting off Pumps and Entering Standby

XI. SYSTEM REQUIREMENTS

A. Definitions, Ground Rules, and Assumptions

Mission Statement:
Design a concept for a pre-deployable Martian greenhouse and develop a reduced-scope prototype to identify key science questions and engineering challenges.

Rationale:
In order to enable permanent human presence beyond Earth, a regenerative means of producing food must be available for long duration crewed space missions. A prototype greenhouse system will also serve as a platform for research-grade crop production studies in controlled environments.

Objectives:

1. Martian Greenhouse Concept

- What does a system need to successfully grow food-producing plants on Mars?
- What are the engineering challenges associated with doing so?

2. Reduced-Scope Prototype

- Provide proof-of-concept for the overall conceptual system design.
- Demonstrate innovative approaches to a subset of engineering challenges.

PROJECT DEFINITIONS AND ACRONYMS	
Controlled Environment	Environment in which the parameters relative to the subject plant are monitored and controlled within set ranges.
Deployable Upon Landing	'Operable' upon landing.
HSST	Habitat Sensing Specification Table (contains specific environmental control requirements for the subject plant)
Materially Closed Environment	Environment in which mass is conserved within the bounds of the environment, and pathways with the outside are eliminated.
MCLSS	Martian Crop Life Support System
OASIS	Operational Agricultural System for In-Situ Specialization
Payload	Payload to be delivered to the Martian surface that includes the plant seeds, consumables, supporting structure, and all supporting systems for plant germination, growth, and maintenance prior to harvest.
Pre-Deployable	Delivered to the Martian surface prior to crewed missions, and is operational without human presence.
Subject Plant	Plant chosen for growth in the prototype greenhouse and for the mission conceptual design baseline.

GROUND RULES ***<u>Source</u>: G1-G9: X-Hab Challenge 2015 Solicitation, Desirable Features***	
G1.	Plants grown will be food producing.
G2.	MCLSS will be capable of being operated and maintained in extreme environments.
G3.	MCLSS will have a small payload volume and mass.
G4.	MCLSS will be deployable upon landing. (i.e., óperableôupon landing)
G5.	MCLSS will be pre-deployable (i.e., áarrives and operates prior to astronauts arrivingô).
G6.	MCLSS will use pre-planted media or growing system.
G7.	MCLSS will have a priming volume of water and required gases.
G8.	MCLSS will have a closed water loop.
G9.	MCLSS will be able to harvest and store O2 generated from plants.
ASSUMPTIONS	
A1.	The MCLSS will not incorporate means of delivery (or deployment) to the Martian surface. *Rationale: Given schedule constraints, delivery systems have been determined to be outside of this project's scope.*
A2.	Subject plant seeds survive transport to the Martian surface.
A3.	The MCLSS will be self-powered, independent of spacecraft or lander systems. *Rationale: Without knowledge of the delivery system to the Martian system, we should not assume availability of power to support the greenhouse.*
A6.	Subject plant will be Outredgeous lettuce *Rationale: fast growing, baseline data, low maintenance, continuous harvest, nutritional content*
A7.	The MCLSS need only support plant cycle phases from germination up until (not through) harvest. *Rationale: Given schedule constraints, harvest and re-planting have been determined to be beyond this project's scope.*
A8.	MCLSS will rely on telemetry system of orbiters (and/or lander) to communicate with Earth ground station.
SYSTEM LEVEL REQUIREMENTS	
SYS1.1	Plant growth area will be 1 m^2
SYS1.2	MCLSS atmosphere will be 0.61 m tall.
SYS2.1	System shall provide remote control capability for initiating germination.
SYS2.2	System will provide nutrients for seed germination per the HSST.
SYS2.3	System will provide light necessary for seed germination per the HSST.
SYS2.4	System will provide moisture necessary for seed germination per the HSST.
SYS2.5	System will provide environment necessary for seed germination per the HSST.

SYS2.6	System will provide power necessary to support seed germination .
SYS3.1	System will provide nutrients necessary for seedling growth per the HSST.
SYS3.2	System will provide light necessary for seedling growth per the HSST.
SYS3.3	System will provide water necessary for seedling growth per the HSST.
SYS3.4	System will provide environment necessary for seedling growth per the HSST.
SYS3.5	System will provide power needed for seedling growth.
SYS4.1	System shall protect the plant subject from harm due to environmental hazards.
SYS4.2	System shall provide control of environmental parameters and consumables.
SYS4.3	System shall ensure harvest ready plants are edible.
SYS4.4	System will provide power needed for health maintenance.
SYS4.5	System shall protect the sub-systems from harm due to environmental hazards.

B. Concept to Prototype Change Summary

Operating Environment	Concept (Mars)	Prototype (Lab, No Additional Env. Testing)
Gravity	3.7 m/s^2 (~2/5 Earth Gravity)	9.8 m/s^2
Atmospheric Pressure (Outside/Inside /Δ)	0.6 /35 /34.4 kPa	101 /101/0 kPa
External Atmospheric Composition	95.3% CO_2, 2.7% N_2, 1.6% Ar, 0.13 O_2 , 0.08% CO	78% N_2, 21% O_2, trace amounts of H_2O, Ar, CO_2, etc)
Temperature Range Outside	-75ºC to -2ºC (-103 to 28 ºF), Equatorial, Gale Crator	18-14 ºC (65-75ºF), Laboratory
Magnetic Field	No global magnetic field	Global Magnetic Field
Light	590W/m2 maximum, 24.67 hours per day	590W/m2 maximum, 24.67 hours per day (Simulated with lamps)
Wind Speed	10 m/s average (~30 m/s maximum)	0 m/s
Environmental Hazards	Dust, Solar radiation, micro-meterites	None
Requirement	**Concept Approach**	**Prototype Approach**
CO_2 Provision (ATM 2.2	Filtrete filter and fan to a compressor and storage tank	CO2 cylinders will provide needed CO2 via solenoid actuators.
Oxygen Removal (ATM3.2)	Pressure Swing Adsorbtion; Zeolites for N2 adsorbtion and recovery	Nitrogen depleted atmosphere will be vented to lab
Excess Oxygen Storage (ATM3.3)	*Oxygen will be stored after passing through the PSA adsorption columns.*	Atmospheric management system will measure atmospheric O2 vented from the system.
N_2 Provision (ATM4)	Volume of nitrogen will be launched from Earth in payload.	Nitrogen will be delivered from tanks in the lab via solenoid actuators
Relative Humidity Adjustment (ATM6.2)	Intake fans bring in wet air over the cooling loops to condense water. The water is sent to the water management system.	COTS dehumidifier, misting system; water is sent to water management system.
Data Handling (CC1.1, CC3)	RAD6000	Beaglebone Black
Plant Image Spatial Coverage (CC4.1.2)	Camera slides along moveable bracket, giving coverage close to 360 degrees circumferentially.	Two cameras mounted 45 degrees from horizontal plane on curved bracket.
Data Telemetry (CC5 and COM1.1)	Data compressed prior to transmission and uplinked to Mars orbiters.	Compressed data packets from microprocessor will be transmitted to online server
Lighting Provision (LT1,LT2)	Natural/artificial hybrid light system with LEDs mounted on strip on moveable bracket	Simulated in-situ light and artificial LEDs mounted on strip on moveable bracket.
Dissolved Oxygen Injection (NTR5.2)	Pure O2 from storage tanks will be bubbled through main reservoir	Air from external atmosphere MCLSS will be bubbled through main reservoir
Power Provision (PWR1-12)	Flexible photovoltaics on inside of clamshell lid w/ solid-	AC wall outlet and power processing unit for

	state lithium ion battery storage; power processing unit for distribution	distribution.
Growing Area (STR1)	Pill shaped structure will contain a 1 m^2 growth area	3 ft diameter skylight dome will contain a 2' x 2' plant growth area for the prototype.
Growing Height (STR2)	Upper shell will have average height of 0.61m	COTS skylight dome will provide minimum of 12" from plant base to ceiling with a maximum height of 20"
Structure Fits Through Door (STR3)	N/A	Structure is 4ô wide on castors and can fit through 6 foot doorway.
Outgassing Protection (STR4.1)	MPPS structure exposed to vacuum shall be made of materials with TML and CVCM according to NASA outgassing standards.	Not Applicable to Prototype
MPPS structrue shall attenuate UV-C wavelengths (<280nm) by at least 95% during a growth cycle (STR5)	PEEK and polycarbonate attenuate UVC wavelengths by >99%	Not Applicable to Prototype
Passive Thermal Control (STR7)	Large thermal mass (> 200,000 J/K); polycarbonate upper shell allows visible and IR radiation to pass through; clamshell lid insulates at night; PEEK for lower shell has low thermal conductivity; aerogel and multilayer insulation; cushion for additional thermal protection	Not Required in Laboratory Environment: No clamshell lid, thermal insulation or cushion included
Natural Light Transmission (STR8)	Polycarbonate upper-shell w/ Clamshell Lid with actuation for open/close	Transparent dome will allow natural light transmission
Moveable w/ <50 lb Force	Not Applicable	MCLSS prototype will be on castors
Atmospheric Heat Input (TC1, TC2.2)	System will use aerogel insulation and a heater to maintain desirable temperature levels.	Not applicable to prototype
Atmospheric Heat Removal (TC2.3)	Clam shell will remain open if system overheats, heat exchanger	Misting will occur to decrease atmospheric temperature
Air Flow Measurement (TC3.1)	Anemometers uniformly spaced throughout growing area	Not Applicable to Prototype (due to cost)
Water Supply Pathogen Removal (WTR3.4)	System will expose reservoir water to in-situ UV-C light	UV-C lamp before reservoir and after pre-filter
Water Flow Rate Monitoring (WTR3.5.1)	Flow meter at growth tray outlet	Estimated from pump status and tank water level

C. Mars OASIS Requirements with Conceptual and Prototype Design Approaches

L2.1 ATMOSPHERE				
ReqID	**Requirement**	**Concept Approach**	**Prototype Req.**	**Prototype Approach**
ATM1	Atmospheric management system will provide priming volume of gases necessary for seed germination per the HSST.	Volume of gases necessary for germination will be launched from Earth in payload.	Same	CO2 cylinder will provide needed CO2 via solenoid actuators (T7 to R1 to V3 to V6); N2 cylinder will provide makeup gas.
ATM1.1	Atmospheric management system should have mechanism to release priming volume when and as directed by Command and Control System.	Valves will release priming volume	Same	Same
ATM2	Atmospheric Management system shall maintain controlled atmospheric CO2 concentration per HSST.	System will use in-situ CO2 to replenish CO2 concentration.	Same	See 2.1-2.3
ATM2.1	Atmospheric Management system shall measure atmospheric CO2 concentration levels per HSST.	CO2 sensors will measure CO2 concentration.	Same	Same
ATM2.2	Atmospheric Management system shall deliver CO2 when and as directed by Command and Control System.	Filtrete filter and fan to a compressor and storage tank	Same	CO2 cylinders will provide needed CO2 via solenoid actuators (T7 to R1 to V3 to V6, air pushed by M7 circulation fan)
ATM2.3	Atmospheric Management system should passively maintain stable target CO2 concentration.	Structure will be sealed. See requirement STR3	Same	Same
ATM3	System shall maintain controlled atmospheric O2 concentration per HSST.	Oxygen will be scrubbed and stored via pressure swing adsorption.	Same	See 3.1-3.3
ATM3.1	Atmospheric Management system shall measure atmospheric O2 concentration levels per HSST.	O2 sensors will measure O2 concentration.	Same	Sensor 304 measures oxygen
ATM3.2	Atmospheric Management system shall remove O2 when and as directed by Command and Control System.	Pressure Swing Adsorbtion; Zeolites for N2 adsorbtion and recovery	Same	Oxygen will be removed by oxygen concentrator, going through intake Z12 or Z8, through valve V8, into M8 (concentrator)
ATM3.3	Atmospheric Management system should safely harvest and store excess atmospheric O2.	Oxygen will be stored after passing through the PSA adsorption columns.	Atmospheric management system will measure atmospheric O2 vented from the system.	oxygen concentration coming from O2 concentrator will be characterized in system testing, and the the O2 vented will be estimated from the time during which the oxygen concentrator is acctivated.
ATM3.3.1	System should maintain O2 levels below 30%	Oxygen will be removed and stored	Same	See 3.2
ATM3.4	Atmospheric Management system should passively maintain stable target O2 concentration.	Structure will be sealed. See requirement STR3	Same	Same

ATM4	Atmospheric Management system shall maintain controlled atmospheric concentration of Nitrogen gas.	Volume of nitrogen will be launched from Earth in payload.	Same	N2 cylinders will provide needed N2 via solenoid actuators (T8 to R2 to V4 to Z6, air pushed by M7 circulation fan)
ATM4.1	Atmospheric Management system shall measure N2 gas concentration levels per HSST.	Total pressure, O2, and CO2 will be measured, and N2 concentration derived.	Same	Same
ATM4.2	Atmospheric Management system shall deliver N2 gas when and as directed by Command and Control System.	Nitrogen will be delivered from tanks in the bioastro lab via solenoid actuators.	Same	Same a ATM4
ATM4.3	Atmospheric Management system should passively maintain stable target concentration of N2 gas.	Structure will be sealed. See requirement STR3	Same	Same
ATM5	Atmospheric Management system shall not allow trace contaminants to exceed tolerable limits per HSST.	Ethylene contaminants will be removed with ethylene sorbers	Same	Same
ATM5.3	Atmospheric Management system shall passively remove Ethylene from the atmosphere.	Zeolite sorber to oxidize ethylene and positive pressure to move air through filter	Same	Same
ATM6	Atmospheric Management system shall maintain controlled atmospheric relative humidity per HSST.	A dehumidifier design has been made that sends refrigerant to the exterior, is cooled, and then sent over cooling loops. Intake fans bring in wet air over the cooling loops to condense water. The water is sent to the nutrient subsystem for storage and treatment.	Same	COTS dehumidifier, combined with mister (from T3 to P10 through Z7 to M10,mist nozzle to humidify; air through Z12 through M9 to T3 to dehumidify)
ATM6.1	Atmospheric Management system shall measure atmospheric relative humidity.	RH/Temperature Sensors	Same	Sensors S301-S302
ATM6.2	Atmospheric Management system shall adjust relative humidity when and as directed by Command and Control System.	Water vapor from main water resevoir and external heat exchanger to condense water vapor	Same	See ATM6
ATM6.3	Atmospheric Management system should passively maintain stable target atmospheric relative humidity.	Structure will be sealed. See requirement STR3	Same	Same
ATM6.4	Atmospheric Management system shall send condensed excess water vapor to nutrient and fluids management system.	Water will be sent with water tubes.	Same	Water vapor to travel from M9 (dehumidifier) to T3 (Condensate Tank)
ATM7	System shall maintain atmospheric pressure per HSST.	CO2, O2, and N2 systems will be controllable to maintain desired pressure; relief valve for overpressure	Same	After achieving desired partial pressure of CO2 and O2, N2 will be added (see ATM4) to achieve desire total pressure. In the event of overpressurization, O2 concentrator can be run, port of Jordan or relieve valve will

				activate.
ATM7.1	System shall measure atmospheric pressure.	Pressure sensors will measure atmospheric pressure.	Same	Sensor S303
ATM7.2	System shall adjust atmospheric pressure when and as directed by Command and Control System	Relief valves, CO2, N2, O2 control	Same	See ATM7
ATM7.3	System shall passively maintain target atmospheric pressure.	Structure will be sealed. See requirement STR3	Same	Structure will be sealed and include emergency relief valves for over or underpressurization.
ATM8	System shall maintain pressure delta no greater than 0.1 psi from ambient laboratory pressure.	N/A to concept	Same	System will employ manometer for 0.1 psi pressure relief
L2.2 COMMAND AND CONTROL				
ReqID	**Requirement**	**Concept Approach**	**Prototype Req.**	**Prototype Approach**
CC1	Command and Control System shall activate MCLSS upon receipt of authorization from Earth ground station.	Via GUI at ground station on Earth	Same	Same
CC1.1	Command and Control System shall deliver system status data defined in the Software Reference to Communications system.	Via data handling on RAD6000.	Same	Data handling on Beaglebone Black.
CC2	Command and Control System shall send actuation command for germination upon receipt of authorization from Earth ground station.	After receipt of command from GUI, Germination Mode will be initiated and actuation signals sent as appropriate.	Same	Same
CC3	Command and Control system shall autonomously control subsystems to adjust growth parameters based on data received from sub-system monitors.	Algorithmic based control through RAD6000; components actuated through relay control	Same	Algorithmic based control through Beaglebone Black, according to Control Logic structure
CC3.1	Command and Control system shall receive growth parameter data from sub-system sensors as defined in MarsOASIS ICD	Sensors will return data to microprocessor	Same	Same
CC3.2	Command and Control system shall process growth condition parameters from sub-system data.	RAD6000 Microprocessor	Same	Beaglebone Black Processor
CC3.3	Command and Control system shall determine actuation requirements based on measured and required growth parameters, as specified in the HSST.	Algorithmic based control through RAD6000.	Same	Algorithmic based control through Beaglebone Black, according to Control Logic structure
CC3.4	Command and Control System shall send actuation signals to subsystems to adjust controlled growth conditions to nominal levels when the measured state is outside of the ideal range for longer than the allowed duration.	Algorithmic based control through RAD6000.	Same	Algorithmic based control through Beaglebone Black, according to Control Logic structure
CC3.5	Command and Control System shall deliver growth parameter data to Communications system as defined in Software Reference.	Data will be compressed and sent via RAD6000.	Same	Data will be compressed and sent via RAD6000

CC4	Command and Control System shall monitor sub-system health, as defined in Software Reference	Combination of sensor readings and algorithms on microprocessor.	Same	Same
CC4.1	Command and Control system shall monitor plant health.	USB/i2c cameras mounted on track on adjustable bracket; JPEG compression; OpenCV image processing	Same	Same
CC4.1.1	At least one image at a fixed position of the full plant shall be delivered to the Communications system at least every 4 hours while the system is operating.	Timer controlled relay will operate cameras. Fixed position to be defined in HSST.	Same	Same
CC4.1.2	The command and control system will deliver a plant image within 45 degrees of a requested circumferential angle to the Communications system when commanded by the Earth ground station operator.	Camera will be able to move along bracket, capable of reaching ~360 degree field of view	Command and control system will deliver plant image within 5 degrees of requested angle.	One camera, mounted on rotating bracket, and moving along bracket with linear actuators, allowing ~360 degree field of view.
CC4.2	Command and Control system shall monitor the external environment per the HSST.	Via sensors listed on sensor map	Same	S401-405
CC4.2.1	Command and Control system shall receive external environment data from system sensors as defined in the HSST.	Sensors will return data to microprocessor.	Same	Same
CC4.2.2	Command and Control System shall deliver external environment data to Communications system.	Via algorithmic control on microprocessor	Same	Same
CC4.3	Command and Control system shall monitor sub-system health indicators as defined in Software Reference..	Combination of sensor readings and control algorithms on microprocessor.	Same	Same
CC4.3.1	Command and Control system shall receive system status data from system sensors as defined in Software Reference.	Data will be stored and delivered. Data processing for analysis will be done on Earth.	Same	Same
CC4.3.2	Command and Control System shall deliver system status data to Communications system.	Data defined in ICD will be stored and delivered to online server.	Same	Same
CC5	Command and Control system shall receive telemetered command signals from Earth based ground station	Data will delivered via online server.	Same	Same
CC6	Command and Control System shall send override actuation signals to power switchable components when instructed by Communications system.	Via algorithmic control on microprocessor	Same	Same
L2.3 COMMUNICATIONS				
ReqID	**Requirement**	**Concept Approach**	**Prototype Req.**	**Prototype Approach**
COM1	Communications system shall record and display all monitored data at an Earth ground station.	Web-based GUI that can be accessed by general public with special login authority for those who need it to see more detailed parametric data and use tele-operated functions.	Same	Same
COM1.1	Communications system shall telemeter all monitored	Data compressed prior to transmission	Communications system	All information will come off in

	data to Martian orbiter(s)	and uplinked to Mars orbiters	shall transmit all monitored data to MCLSS prototype ground station.	compressed data packets from microprocessor and sent to online server.
COM1.2	Communications system shall provide graphical visualization of monitored data on Earth based ground support equipment, as defined in Software Reference.	GUI. Website that can be accessed by general public with special login authority for those who need it to see more detailed parametric data and use tele-operated functions.	Same	Same
COM1.2.1	Communication system will provide alerts when system health is at medium or high risk as defined in the HSST.	via GUI	Same	Same
COM1.3	Communications system shall log monitoring and event data received at the Earth ground station.	See 1.3.1	Same	Same
COM1.3.1	System data file defined in the Software Reference will be recorded and stored at least every 60 minutes while the system is active.	Data storage on cloud and backup on board storage	Same	Same
COM1.3.2	System data file defined in the Software Reference will be recorded and stored when requested by the ground station operator.	See 1.3.1	Same	Same
COM2	Communications system shall provide remote override capability for controlled conditions from ground station.	GUI will send updated HSST values to HSST file on server	Same	Same
COM2.1	Communications system shall include user interface option to simulate a time lag of in the receipt and transmission of all data to and from the MCLSS of a duration input by the user.	N/A	Same	Time lag option on GUI will enforce a defined transmission delay to and from the microprocessor
COM3	Communications system shall deliver system activation signal to Command and Control System when commanded by ground station operator.	GUI will send activation signal from interface to processor	Same	Same
COM4	Communicatinos system shall deliver germination activation signal to Command and Control System when commanded by ground station operator.	GUI will send germination signal from interface to processor	Same	Same
COM5	Communication system shall deliver image acquisition signal to Command and Control System when commanded by ground station that includes the desired circumferential image angle.	GUI will send camera command to processor that includes desired camera angle parameters.	Same	Same
L2.4 LIGHTING				
ReqID	**Requirement**	**Concept Approach**	**Prototype Req.**	**Prototype Approach**
LT1	Lighting system will provide light necessary for seed germination per HSST.	See LT2	Same	Same

LT2	Lighting system shall maintain controlled light levels for seedling growth.	Natural/artificial hybrid light system with red and blue LEDs mounted on strip on moveable bracket	Same	Simulated in-situ light and white LEDs mounted on strip on moveable bracket.
LT2.1	Lighting system shall measure PAR intensity per HSST.	Light (PAR) sensor	Same	S306
LT2.2	Lighting system shall adjust PAR intensity when and as directed by Command and Control System.	Red/Blue LEDs mounted on adjustable bracket, controlled separately. Intensity in blue and red spectrums will be independently controlled by PWM.	Same	Same
LT 2.4	*Light should be uniformly distributed over entire growing area.*	LEDs will be uniformly spaced along bracket. Analysis will be done to evaluate light distribution given curved bracket.	Same	Same
L2.5 NUTRIENT DELIVERY				
ReqID	**Requirement**	**Concept Approach**	**Prototype Req.**	**Prototype Approach**
NTR1	Nutrient delivery system shall provide initial nutrients for germination when actuated.	See NTR1.1-1.2	Same	Same
NTR1.1	Nutrient delivery system shall contain pre-planted media or growing system.	Coconut Coir Growth Medium; Hydroponic system will deliver nutrients in solution when activated.	Same	A mix of Coco Coir and Turface for the main growth medium; on top of which sits a 1-1.5in layer of germination mix
NTR1.2	Seed distribution should maximize growing area per plant.	Diamond planting pattern will be utilized, per SME recommendation	Same	Same
NTR2	Nutrient Delivery system shall maintain controlled NPK concentration levels in growth medium.	See NTR2.1-2.3	Same	Same
NTR2.1	Nutrient Delivery system shall measure NPK concentration levels in growth medium per HSST.	EC sensors located per Sensor Map	Same	S205 (out); S101 (in)
NTR2.2	Nutrient Delivery system shall deliver NPK nutrients to growth medium when and as directed by Command and Control System.	Pre-set amount of pre-mixed single nutrient solution will be sent from nutrient tank to resevoir when actuated, with Nutrient dosing pump	Same	Nutrient solution from T4 and T5 will be fed with dosing pumps P3 and p4 into main tank, until correct EC is reached. Nutrient tanks will be stirred with circulation pump
NTR2.3	Nutrient Delivery system should passively maintain stable target NPK concentration levels in growth medium.	Nutrient rich water will be recycled to minimize addition of nutrient solution	Same	Same
NTR3	Nutrient Delivery system shall maintain controlled pH in growth medium.	See NTR3.1-3.3	Same	pH down solution (T6) will be fed with dosing pumpt P5 into main tank (T2). pH up solution is not required, per advisors
NTR3.1	Nutrient Delivery system shall measure pH of the growth	Single pH sensor	Same	S206 (out) and S102 (in)

	medium per HSST			
NTR3.2	Nutrient Delivery system shall adjust pH of growth medium when and as directed by Control and Communication System	Nitric Acid to lower pH; pH pump	Same	See NTR3 and Control Logic
NTR3.3	Nutrient Delivery system should passively maintain stable target pH in growh medium	Nutrient rich water will be recycled to minimize pH adjustment	Same	Same
NTR4	Nutrient Delivery system shall maintain controlled micronutrient concentrations in growth medium.	See NTR4.1-4.3	Same	Same
NTR4.1	Nutrient Delivery system shall measure micronutrient concentrations in growth medium per HSST.	EC sensors located per Sensor Map will measure total nutrient concentrations	Same	Same
NTR4.2	Nutrient Delivery system shall deliver micronutrients to growth medium when and as directed by Command and Control System.	Pre-set amount of pre-mixed nutrient solution will be sent from nutrient tank to resevoir when actuated	Same	Same
NTR4.3	Nutrient Delivery system should passively maintain stable target micronutrient concentration levels in growth medium.	Nutrient rich water will be recycled to minimize addition of nutrient solution.	Same	Same - Note, for longer growth cycles, iron mangeanate may need to be supplemented due to loss from UVC filtering.
NTR5	Nutrient Delivery system shall maintain controlled dissolved oxygen levels in growth medium.	See NTR 5.1-5.3	Same	Same
NTR5.1	Nutrient Delivery system shall measure dissolved oxygen in growth medium per HSST.	DO Sensor in growth medium and reservoir	Same	DO sensor (S104) in reservoir only to know DO of water coming into growth medium
NTR5.2	Nutrient Delivery system shall inject dissolved oxygen into growth medium when and as directed by Control and Communication System.	Pure O2 from storage tanks will be bubbled through main reservoir	Same	Air from laboratory will be bubbled through main reservoir (P7 to M3)
NTR5.3	Nutrient Delivery system should maintain uniform dissolved oxygen concentrations in growth medium	Water will be continuously circulated, providing additional aeration, at a flow rate specified in the HSST	Same	Water in main tank will be continuously circulated prior to being delivered to growth medium.
NTR6	Nutrient Delivery system shall maintain controlled growth medium temperature.	See NTR 6.1-6.3	Same	Same
NTR6.1	Nutrient Delivery system shall measure growth medium temperature per HSST.	Temperature sensors in growth medium and reservoir	Same	S201-204
NTR6.2	Nutrient Delivery system shall adjust growth medium temperature when and as directed by Control and Communication System.	Growth medium temperature controlled by reservoir temperature, adjusted by a chiller and heating element, prior to watering	Same	M2 (chiller) and M1 (heater) in T2 (main tank)
NTR6.3	Nutrient Delivery system should passively maintain stable target growth medium temperature.	Large thermal mass of system and water volume will provide high heat capacity.	Same	Same

L2.6 POWER				
ReqID	**Requirement**	**Concept Approach**	**Prototype Req.**	**Prototype Approach**
PWR1	Power system will provide power to the Command and Control system during germination.	Flexible photovoltaics w/ solid-state lithium ion battery storage; power processing unit for distribution	Same	AC wall outlet and power processing unit for distribution; See power distribution diagram and power budget.
PWR2	Power system will provide power to the Lighting system during germination.	See PWR1	Same	See PWR1
PWR3	Power system will provide power to the Thermal Control system during germination.	See PWR1	Same	See PWR1
PWR4	Power system will provide power Atmospheric Management system during germination.	See PWR1	Same	See PWR1
PWR5	Power system will provide power Water Management system during germination.	See PWR1	Same	See PWR1
PWR6	Power system will provide power to the Command and Control system during growth phase.	See PWR1	Same	See PWR1
PWR7	Power system will provide power to the Lighting system during growth phase.	See PWR1	Same	See PWR1
PWR8	Power system will provide power to the Thermal Control system during growth phase.	See PWR1	Same	See PWR1
PWR9	Power system will provide power Atmospheric Management system during growth phase.	See PWR1	Same	See PWR1
PWR10	Power system will provide power Water Management system during growth phase.	See PWR1	Same	See PWR1
PWR11	Power system will provide power Nutrient Delivery system during growth phase.	See PWR1	Same	See PWR1
PWR12	Power system will provide power to the Communications system during growth phase.	See PWR1	Same	See PWR1

L2.7 STRUCTURES				
ReqID	**Requirement**	**Concept Approach**	**Prototype Req.**	**Prototype Approach**
STR1	Structure should allow a 1 meter squared growing area for plants	Pill shaped structure will contain a 1 m^2 growth area	Plant growth area will a minimum of 3 square feet.	3 ft diameter skylight dome will contain a 2' diameter circular plant growth area for the prototype.
STR2	Structure should allow a average of 61 cm of height from plant base to ceiling for plant growth.	Upper shell will have average height of 0.61m	Prototype MCLSS should allow an average of 12" of height from plant base to ceiling for plant growth.	COTS skylight dome will provide minimum of 12" from plant base to ceiling with a maximum height of 20"

STR3	Structure should fit through 6 ft doorway	N/A for concept	Same	structure is 4 feet wide and on castors
STR4	Structure will maintain total net system atmospheric pressure leak rate of less 10% over a 28 day life cycle.	Components and vessel will be sealed to achieve desired leak rate	Same	Same
STR4.1	MPPS structure exposed to vacuum shall be made of materials with TML and CVCM according to NASA outgassing standards	Materials chosen for concept meet this requirement	N/A - out of scope	N/A - out of scope
STR5	MPPS structrue shall attenuate UV-C wavelengths (<280nm) by at least 95% during a growth cycle	PEEK and polycarbonate attenuate UVC wavelengths by >99%	N/A - out of scope	N/A - out of scope
STR6	Food grade (safe) materials shall be used for components interacting with plant environment.	All materials considered are non-toxic	Same	Same
STR7	Structure should provide thermal protection to passively maintain stable target atmospheric temperature.	Large thermal mass (> 200,000 J/K); polycarbonate upper shell allows visible and IR radiation to pass through; clamshell lid insulates at night; PEEK for lower shell has low thermal conductivity; aerogel and multilayer insulation; cushion for additional thermal protection	N/A - out of scope	N/A - out of scope
STR8	Structure should allow transmission of natural sunlight into the system atmosphere when directed by the Command and Control System.	Polycarbonate uppershell w/ Clamshell Lid with actuation for open/close;	Structure should allow transmission of natural sunlight into atmosphere.	Transparent dome will allow natural light transmission
STR9	MCLSS shall be internally accessible.	MPPS shall use non-permanant and reuseable fasteners.	Same	Same
STR10	Structure will be sealed to minimize water loss from the system while in operation.	Components and vessel will be sealed to minimize water leakage, and water loss will be monitored and measured during system operation.	Same	Same
STR11	MCLSS shall be able to be moved with less than 50 lbs force.	N/A	Same	MCLSS prototype will be on castors
STR12	Electrical and mechanical components shall be protected from humidity and condensation.	Area under dome (atmosphere) and growth tray will be a sealed volume, protecting other components from humidity. Components in sealed area will be required to operate in the wet environment during one life cycle.	Same	Verify ruggedness of components under dome
STR13	System will include ability to intake and exhaust from/to external environment.	N/A	Same	Prototype will include a manual intake/exhaust port.

L2.8 THERMAL CONTROL

ReqID	Requirement	Concept Approach	Prototype Req.	Prototype Approach

TC1	Thermal Control system will provide temperature necessary for seed germination per the HSST.	System will use MLI and a heater to maintain desirable temperature levels.	Same	Laboratory ambient temperature considered sufficient
TC2	Thermal Control system shall maintain controlled atmospheric temperature.	See TC2.1-2.3	Same	Laboratory ambient temperature considered sufficient for prototype testing
TC2.1	Thermal Control system shall measure atmospheric temperature per the HSST.	Thermistors will measure system temperature.	Same	S301 and S302
TC2.2	Thermal Control system shall provide heat input when and as directed by Command and Control System.	System will use aerogel insulation and a heater to maintain desirable temperature levels.	Removed	N/A - out of scope
TC2.3	Thermal Control system shall remove heat when and as directed by Command and Control System.	Clam shell will remain open if system overheats, heat exchanger	Same	Misting will occur to decrease atmospheric temperature. See ATM6
TC3	Thermal Control system shall provide downward air flow within range specified in HSST	System shall use adjustable speed electronics fans to circulate the air and ensure it is well-mixed.	Same	Electronics fan: need analysis to show air flow will be provided in the required range.
TC3.1	Thermal Control system shall measure air flow per the HSST.	Anemometers uniformly spaced throughout growing area	N/A - out of scope - sensor is too expensive for prototype	N/A - out of scope
TC3.2	Thermal Control system shall adjust air flow when as directed by Command and Control System.	Fan speed will be adjustable and calibrated to desired air flow without plants present	Same	Same
L2.9 WATER MANAGEMENT				
ReqID	**Requirement**	**Concept Approach**	**Prototype Req.**	**Prototype Approach**
WTR1	Water management system will provide priming volume of water necessary for seed germination per HSST.	Priming volume will be stored in resevoir and leachate tank, according to water budget.	Same	Same
WTR1.1	Water management system should have mechanism to release priming volume when and as directed by Command and Control System.	Pump turned on in Germination Mode	Same	Same
WTR2	Water Management system shall maintain controlled moisture levels at plant roots.	See WTR2.1-2.3	Same	Same
WTR2.1	Water Management system shall measure moisture levels at plant roots per HSST.	Ultrasonic Range Finder in an empty column within the growth medium. The water in the column represents Growth Medium saturation level.	Same	S208-211
WTR2.2	Water Management system shall distribute clean water to plant roots when and as directed by Command and Control System.	1/4 tube punctuated by pressure regulated drippers	Same	Same

WTR2.3	Water Management system should passively maintain stable target moisture levels at plant roots.	Wicking system	Same	Same
WTR3	Water Management system shall recycle water	See WTR3.1-3.3	Same	Same
WTR3.1	Reservoir for growth medium water shall store volume specified by water budget.	Separate Water Tank	Same	Same
WTR3.2	Water Management System shall measure liquid level in water reservoir per HSST	Liquid Level Sensor (aquaplumb type)	Same	S105
WTR3.3	Growth medium water will have turbidity < 5 NTUs	Sediment pre-filter (5 micron);	Same	Same
WTR3.4	Water management system will remove pathogens from reservoir.	System will expose reservoir water to in-situ UV-C light	Same	UV-C lamp before reservoir and after pre-filter (P8 to F2 to F1 to T2)
WTR3.5	Water Management System shall distribute clean nutrient laden water to growth medium at a rate greater than maximum expected plant transpiration.	Water will be pumped from from reservoir to growth tray at a rate of 1 GPM	Same	Transpired water will collect in condensate tank which will be conditioned and fed back into growth medium as soon as moisture sensors indicate watering is needed.
WTR3.5.1	Water Management System shall monitor flow rate from growth medium according to HSST.	Flow meter at growth tray inlet & outlet	Same	S111 (from), S110 (to)
WTR3.6	Water Management system shall collect drainage water from growth medium.	Water runoff passes through filter before going back into the mixing tank.	Same	T1 to Z2 to V1 to T9
WTR3.7	Water Management system shall collect condensed water from atmospheric management system.	Atmosphere and Thermal Control will deposit water into an intake pipe after being condensed into liquid.	Same	M9 (dehumidifer) to T3 holding tank to P2 to T9 (leachate tank)
WTR4	Water Management system shall maintain controlled water temperature at plant roots.	See WTR4.1-4.2	Same	Same
WTR4.1	Water Management system shall measure water temperature at plant roots per HSST.	Temperature Sensors within growth medium and temperature sensors in reservoir	Same	S103 in reservoir and S201-204 in growth medium
WTR4.2	Water Management system shall adjust water temperature when and as directed by Command and Control System.	Water chiller and heating element in reservoir will provide temperature control	Same	M2 (chiller), M1 (heater)
WTR5	Water Management system shall store fresh water supply according to water budget in MarsOASIS ICD.	Fresh water tank	Same	Fresh water stored in tank T3
L3 ADDITIONAL SYSTEM SPECIFICATIONS DERIVED FROM OPERATIONAL AND PRODUCTION CONTSTRAINTS				
ReqID	**Requirement**	**Concept Approach**	**Prototype Req.**	**Prototype Approach**
SPEC1	All materials and components within the sealed volume should be able to withstand the expected operating	N/A	Same	All components specifications, where possible, have been

	temperature, pressure, and high humidity conditions			reviewed for compatability with expected operating environment.
SPEC2	Because the MCLSS will be subjected to dissolved salts and distilled water that may be corrosive, internal materials and components in contact with the water loop should be corrosion resistant and made from rustproof materials, such as stainless or epoxy coated steel, or plastic.	N/A	Same	All applicable components have been reviewed for compliance with this requirement.
SPEC3	Electronic components should be able to function under expected vibration levels	N/A	Same	Unverified
SPEC4	The system will be expect to perform for the duration of one operational test (45 day growth cycle).	N/A	Same	All components specificatinos have been reviewed to assure expected life time is greather than 45 days of use.
SPEC5	Water management system will include a drain that can remove all water from the reservoir.	N/A	Same	Requirement met (V2)
SPEC6	Overcurrent Protection: The system will be fuse protected in the event of excessive power draw by the camera linear actuator or bracket stepper motor.	N/A	Same	Feature has been incorporated in power system design.
SPEC7	System software should incorporate a safe shutdown procedure in event of power loss or catastrophic system failure	N/A	Same	Safe shutdown procedure is in development.
SPEC8	Temperature sensors must be shielded from excessive heat (i.e., beyond operating limits) from lamps both internal and external to the system.	N/A	Same	Unverified
SPEC9	Component exposure to the sealed internal atmosphere will be minimized and exposed components will be water resistant or proof.	N/A	Same	Unverified
SPEC10	Materials coming in contact with the plants, atmosphere, or water loop (including caulking compounds and sealants and condenser materials) should also be non-toxic to the subject plants.	N/A	Same	All applicable materials and components have been reviewed and meet this requirement.
SPEC11	All pipework and fittings for the hydroponic and water management system should be made of plastic and stainless steel or plastic-bodied pumps of self-priming type should be used.	N/A	Same	Requirement met.
SPEC12	Plant bed material should be rust and corrosion proof	N/A	Same	LDPE flexible plastic
SPEC13	Plant bed must tolerate structural load from plants, growth medium and water	N/A	Same	Low Density Polyethelyne (LDPE) tub will be supported by 80/20 aluminum bars.

SPEC14	water budget and control logic must allow for sufficient water depth in tanks containing submersible sensors.	N/A	Same	Water budget includes water buffer for submerging components as needed.
SPEC15	Desired resolution and range of each sensor should be above the expected noise floor of the integrated sensor.	N/A	Same	Sensors have been reviewed and meet this requirement
SPEC16	Components in the water recycling loop should be chosen to maintain water seal (i.e., no leaks) at the expected flow rates and pressures.	N/A	Same	Requirement met.
SPEC17	All pipe fittings should have barb fitting connection type.	N/A	Same	Requirement met
SPEC18	System should be grounded, in order to avoid electrical damage in the case of an electrical short	N/A	Same	Requirement met
SPEC19	Water heating element must be submerged when operated.	N/A	Same	Requirement will be met, and controlled in control logic,
SPEC20	Oxygen outlet will be protected from sparks or other heat sources.	N/A	Same	Requirement met.

D. Habitat Sensing Specification Table (HSST)

ReqID	Category	Parameter	Units	Measurement Range (Units)	Measurement Resolution (Units)	Min Sample Rate (N/hr)	Set Point (Units)	Settling Time (seconds)	Actuation Time (seconds)	Ideal Min, Plant	Ideal Max, Plant	Tolerable Min, Plant	Tolerable Max, Plant	Ideal Min, Germ	Ideal Max, Germ	Tolerable Min, Germ	Tolerable Max, Germ	Lower Value Limit	Upper Value Limit	Comments	Sources
1.1	Internal Atmosphere	CO_2 Partial Pressure (Daytime Only)	ppm	0-2000	100	60	1500	5	0.5	1000	2000	100	500000	1000	2000	100	500000	0	2000	>50% creates risk of settline out (GCH); <100 ppm, CO_2 exchange rate approaches zero; must be pressure/temp compensated - set ponit based on std pressure/temp	comments from Ray Wheeler
1.2	Internal Atmosphere	O_2 Partial Pressure	%	0-100	1	60	17.5	5	1	12	21	10	25	12	21	10	25	*0*	*100*	*25 kPa is 30% concentration, set point is earth concentration, given 84 kPa total pressure*	comments from Ray Wheeler
1.3	Internal Atmosphere	Total Pressure	hPA	300 - 1100hPa	100	60	840	5	0.5	800	840	750	847	800	840	750	847	0	1500	1/4 atm (plants can survive) to 1atm (Earth at Sea Level); Add N_2 to raise, vent to lower; system limited to ambien plus 0.1 PSI before manometer overflows	Dr. Ray Wheeler talk 9/29/2014
1.4	Internal Atmosphere	Vapor Pressure Deficit	kPa	n/a	n/a	360	0.5	5	1	0.5	1.2	0.4	1.4	0.5	1.2	0.4	1.4	0	5	Calculated from temp and RH (http://ohioline.osu.edu/aex-fact/0804.html)	Wikipedia (http://en.wikipedia.org/wiki/Vapour_Pressure_Deficit)
1.5	Internal Atmosphere	Relative Humidity	%	5 - 99	1	360	65	5	1	50	70	30	90	50	70	30	90	0	100	Controlled to reach desired VPD	http://www.cornellcea.com/attachments/Cornell%

																					20CEA%20Lettuce%20 Handbook%20.pdf
1.6	Internal Atmosphere	Temperature (Day)	deg C	−40 to 80	0.2	360	n/a	n/a	n/a	23	27	21	29	20	25	18	27	n/a	n/a		
1.7	Internal Atmosphere	Temperature (Night)	deg C	−40 to 80	0.2	360	n/a	n/a	n/a	18	22	15	24	18	22	15	24	n/a	n/a	Within maxmum Earth temps; should be measured near plant canopy; cool temps could be used to slow growth	http://www.weekendgardener.net/vegetables/lettuce.htm and comments from Ray Wheeler; Set point of 23 NASA/TM–2003-211184.
1.8	Internal Atmosphere	Air flow	m/s	n/a	n/a	n/a	n/a	n/a	n/a	0.15	0.5	0.1	0.8	0.15	0.5	0.1	0.8	n/a	n/a	Downward air flow required, not measured but regulated fan power controls air flow	http://www.controlledenvironments.org/Growth_Chamber_Handbook/Ch14.pdf, page 194
2.1	Nutrient & Water Delivery	Soil/Medium Temperature	deg C	0 - 100	1	60	18	n/a	n/a	15	20	10	22	15	20	4.4	27	0	50	http://www.weekendgardener.net/vegetables/lettuce.htm	http://www.johnnyseeds.com/p-6609-outredgeous-romaine-lettuce.aspx
2.2	Nutrient & Water Delivery	Water Temperature	deg C	0 - 100	1	60	23	10	10	22	24	21	25	18	21	16	23	0	50	Water boils at 100C at 1atm and ~67C at 1/4atm (sensor); cooler temp also prevents fungal growth	http://www.howardresh.com/Hydroponic-Lettuce-Production1.html says 18-21 C. Use 23 as a 'set point' NASA/TM–2003-211184; cornell lettuce handbook says 24-26
2.3	Nutrient & Water Delivery	Electrical Conductivity (EC)	µS-cm-1	3 - 3000	1	60		10	1	1150	1250	800	2000	1150	1250	800	2000	0	5000	1150-1250 above source water (plant). 3 -3000 is distilled water to a margin above lettuce maximum	http://www.cornellcea.com/attachments/Cornell%20CEA%20Lettuce%20Handbook%20.pdf http://www.homehydrosystems.com/ph_tds_ppm/ph_vegetables_page.html; http://www.fao.org/docrep/005/y4263e/y4263e0e.htm (90% yield for upper limit)
2.3.1	Nutrient & Water Delivery	Nitrogen (N)	ppm	n/a	n/a	n/a	n/a	n/a			100-200		n/a		100-200	n/a	n/a	n/a	n/a	Nitrate + Ammonium	http://www.howardresh.com/Hydroponic-Lettuce-Production1.html; UoA Lettuce Intensive Course
2.3.2	Nutrient & Water Delivery	Phosphorus (P)	ppm	n/a	n/a	n/a	n/a	n/a			15-90		n/a		15-90	n/a	n/a	n/a	n/a		http://www.howardresh.com/Hydroponic-Lettuce-Production1.html; UoA Lettuce Intensive

																					Course
2.3.3	Nutrient & Water Delivery	Potassium (K)	ppm	n/a	n/a	n/a	n/a	n/a			80-350		n/a		80-350	n/a	n/a	n/a	n/a		http://www.howardresh.com/Hydroponic-Lettuce-Production1.html; UoA Lettuce Intensive Course
2.4	Nutrient & Water Delivery	pH	pH	2 - 12	0.2	60	6	10	0.5	5.5	6	5	6.5	5.5	6	n/a	n/a	0	15		http://www.cornellcea.com/attachments/Cornell%20CEA%20Lettuce%20Handbook%20.pdf. Ray et Al give 5 - 6.5 as ideal.
2.5	Nutrient & Water Delivery	Dissolved O2	mg/L	0 - 15	0.1	60	8	300		7	n/a	2.1	n/a	7	n/a	n/a	n/a	n/a	n/a	DO is temperature dependent: (see chart) max solubility is 15; 100% sat for givent temp is ideal; Should not fall below 2.1mg/L (Plant)	http://www.cornellcea.com/attachments/Cornell%20CEA%20Lettuce%20Handbook%20.pdf
2.6	Nutrient & Water Delivery	Resevoir Turbidity	NTU	n/a	n/a	n/a	n/a	n/a			<5		n/a		<5	n/a	n/a	n/a	n/a	Turbidity will not be monitored	
2.7	Nutrient & Water Delivery	Flow rate	gpm	0.2-2	0.05	360	1	10		0.58	0.34	0.23	0.47	0.58	0.34	0.23	0.47	n/a	n/a	Plant Growth Chamber Handbook, page 127; to maintain DO uniformity and flow through UV filter (page 129) - will not be monitored directly	
2.8	Nutrient & Water Delivery	Growth Medium Volumetric Water Content	%	0-50	1	60	50	0		25	50	10	100					0	100		
	Nutrient & Water Delivery	Main Tank Level	Inches	0-16	0.5	3600	n/a	0	n/a	n/a	n/a	2.5	13	n/a	n/a	n/a	n/a	0	20		
2.10	Nutrient & Water Delivery	Leachate Tank Level	Inches	0-8	0.5	3600	n/a	0	n/a	n/a	n/a	2.5	6	n/a	n/a	n/a	n/a	0	10		
2.11	Nutrient & Water Delivery	NTR Tank 1 Level	Inches	0-8	0.5	3600	n/a	0	n/a	n/a	n/a	2.5	6	n/a	n/a	n/a	n/a	0	10		
2.12	Nutrient & Water Delivery	NTR Tank 2 Level	Inches	0-8	0.5	3600	n/a	0	n/a	n/a	n/a	2.5	6	n/a	n/a	n/a	n/a	0	10		
2.13	Nutrient & Water Delivery	pH Tank Level	Inches	0-8	0.5	3600	n/a	0	n/a	n/a	n/a	2.5	6	n/a	n/a	n/a	n/a	0	10		
2.14	Nutrient & Water Delivery	Condensate Tank Level	Inches	0-8	0.5	3600	n/a	0	n/a	n/a	n/a	2.5	6	n/a	n/a	n/a	n/a	0	10		
2.15	Nutrient & Water Delivery	Nutrient 1 Mixing	L/min	unknown	unknown	n/a	n/a	60	10	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a		
2.16	Nutrient & Water Delivery	Nutrient 2 Mixing	L/min	unknown	unknown	n/a	n/a	60	10	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a		
3.1	Internal Atmosphere	Light intensity (PAR)	μmol m-2 s-1	0 - 2000	2	60	262	3600	0	200	250	150	450	200	250	150	450	0	500	Tolerable range taken from Growth Chamber Handbook	http://www.cornellcea.com/attachments/Cornell%

																					20CEA%20Lettuce%20 Handbook%20.pdf http://www.usa.lighting.philips.com/pwc_li/main/shared/assets/downloads/pdf/horticulture/leaflets/general-booklet-philips-led-lighting-in-horticulture-USA.pdf
3.2	Internal Atmosphere	Supplemental Light Spect.	nm	400 - 800	5	n/a	n/a	n/a		400	700	300	800	400	700	300	800	n/a	n/a	Centered on Red and Blue light, or white light is OK too. Not directly measured	http://www.cornellcea.com/attachments/Cornell%20CEA%20Lettuce%20Handbook%20.pdf
3.3	Internal Atmosphere	Light cycle	hours on	0 - 24	2.7e-4	n/a	18	n/a		18	24	14	24	24	24	Day 0: 24		0	24	1 sec = 2.7e-4 hrs	http://www.cornellcea.com/attachments/Cornell%20CEA%20Lettuce%20Handbook%20.pdf and comments from Ray W.
3.4	Internal Atmosphere	Daily light integral	mol m-2 d	n/a	1	n/a	17	n/a		15	20	13	23	22	24	20	24	0	50	Calculated as PAR (µmol.m-2.s-1) x 0.0864	
4.1	External Atmosphere	'Air' Termperature	C	-153 to 20	1	60	n/a	n/a			n/a		n/a		n/a		n/a	0	50	Martian coldest temp in winter to highest temp in summer	http://quest.nasa.gov/aero/planetary/mars.html
4.2	External Atmosphere	'Air' Pressure'	kPa	0.375 to 1.125	0.1	60	n/a	n/a			n/a		n/a		n/a		n/a	n/a	n/a	Mars avg pressure 7.5milibars +- 50% variation	http://quest.nasa.gov/aero/planetary/mars.html
4.3	External Atmosphere	Solar Irradiance	µmol m-2 s-1	0 - 2000	2	60	n/a	n/a			n/a		n/a		n/a		n/a	n/a	n/a	Darkness to noontime high	http://quest.nasa.gov/aero/planetary/mars.html
4.4	External Atmosphere	Humidity	%	0 - 100	1	60	n/a	n/a			n/a		n/a		n/a		n/a	n/a	n/a	Max nightime martian humidity is 100%	http://quest.nasa.gov/aero/planetary/mars.html
4.5	External Atmosphere	O2 Partial Pressure	kPa	0-35.0	0.1	60	n/a	n/a			n/a		n/a		n/a		n/a	n/a	n/a		
4.6	External Atmosphere	CO2 Partial Pressure	kPa	0-2.0	0.001	60	n/a	n/a			n/a		n/a		n/a		n/a	n/a	n/a		
5.1	Internal Atmosphere	Ethelyne et al.	ppb	n/a	n/a	n/a	n/a	n/a			<25		n/a		<25		n/a	n/a	n/a	will not be measured directly	Dr. Ray Wheeler talk 9/29/2014
5.2	Internal Atmosphere	Plant Image	RGB	1 to 255	>1000x1000	1	n/a	n/a			n/a		n/a		n/a		n/a	n/a	n/a		

XII. Change Log

Date	Requestor	System	Feature	Change Description	Requirements Affected	Other Impacts	Systems Affected	Reason for Change
11/19/2014	Paul	Structure	Camera bracket for prototype	We would now like to have two cameras fixed to the bracket instead of one camera that can move.	CC4.1.2	May not have desired coverage of plant growth area with 2 cameras.	CC	Reduced growth area requires a curved bracket. Mounting moveable camera along curved bracket will be too complex for the scope of the prototype.
11/24/2014	Kier	ATM	Heater	Atmospheric heater is to be removed from prototype design because testing environment will be stable and within desired temperature range of plant.	TC2.2		WTR	
2/6/2015	Chris	CC	Requirement Update	CC4.1.1 - qualified that time lapsed images sent to CC will be taken at a fixed position	CC4.1.1	None	CC, COM	Clarify requirement
2/6/2015	Chris	COM	Requirement Addition	Added requirement COM2.1 to include user defined time lag option on GUI.	COM2		COM	
2/13/2015	Chris	STR	Requirement Addition	Added STR13: System will include ability to intake and exhaust from/to external environment.	ATM2 (CO2 control), ATM3 (O2 Control), ATM4 (N2 control), ATM7 (total pressure control)	May reduce ability to autonomously control atmopshere, and increase water loss from system over growth cycle.	WTR and ATMO	Requested by project stakeholders
2/13/2015	Chris	STR	Requirement update	Growth area required changed to minimum of 3 square feet, to match prototype growth bed chosen.	STR1.1	None	None	Protototype scope
2/14/2015	Chris	CC	System Diagram Update	Removed sensors S406 and S406, measuring O2 concentrator exhaust composition.	ATM3.3	None	ATM	Unnecessary complexity; requirement can be met through estimation and testing.
2/14/2015	Chris	ATM	Requirement Addition	System shall maintain pressure delta no greater than 10 psi from ambient laboratory pressure.	ATM8	If relief valves activate, will lose control of gas composition in sealed section.	STR, ATM	Recommended by project stakeholders for laboratory safety.
2/14/2015	Chris	LT	Requirement correction	Lighting system will measure PAR intensity (changed from light intensity and spectrum)	LT2.1	None	LT, NTR	Measuring spectrum is out of scope for this project and measurng intensity is sufficient.
2/14/2015	Chris	LT	Requirement correction	Lighting system will adjust light intensity only (not spectrum)	LT2.2	None	LT, NTR	we opted to removed the Red/blue LEDs, since spectrum control was deemed out of scope for the prototype, per advisor recommendation.
2/15/2015	John	NTR	Component Change	Growth Medium Mix changed from pure Coco Coir to a mixture of Coco Coir and Turface beneath a 1inch layer of Germination Mix		None	NTR	Coco Coir alone does not have optimal water retention and drain properties. The seeds will not germinate in a coarse soilles mix: a purpose-made germination mix will

								increse the chances of a sucessful germination.
2/15/2015	John	NTR	Schematic/Component Change	Condensate tank will drain into Leachate Tank instead of Main Tank.		Control Logic, Order of Operations	NTR, STR	1) In the previous setup, the condensate loop would never have been filtered 2) Running somewhat 'clean' water through the filtration loop after the leachate has gone through will limitedly 'clean' the pipes and sensors.
3/9/2015	Kier	ATM	Schematic/Component Change	Air pump will feed air into dehumidifer. Air pump is located INSIDE growth volume, going through a feed through into the dehumidifier				1) air flow through dehumidifier was not sufficient to achieve condensation
3/9/2015	Kier	ATM	Schematic/Component Change	3-way solenoid no longer used, separating feedthroughs for oxygen concentrator intake and dehumidifier return				
3/11/2015	Kier	ATM	Schematic/Component Change	Changed relief valve to a manometer for internal pressure relief				
3/11/2015	John	NTR	Schematic/Component Change	Added level sensor to main tank				Main Tank too tall for one sensor.
3/14/2015	John	NTR	Schematic/Component Change	Added Pre-Filters (F4, F5)before P1 and P8			NTR	Debris (esp from fabrication) can break pump, prefilters will catch large sediment
5/22/2015	Paul	EE Sensors	Requirement Removal and System Diagram Change	Remove external CO2, O2, and PAR sensors from requirements and design.	HSST 4.5 and 4.6, CC3.1	Minimal - components are not critical for system operation or control; they provide additional data to the user about the external environment for troubleshooting/research purposes		Reduce system complexity for unnecessary sensors; Also there are only 6 UART connecttions available on the BeagleBone and the CO2 sensor requires an additional UART connection
6/11/2015	Chris	EE Sensors	Sensor removal	Remove LL sensor 7, and replace LL6 with a longer tape sensor	HSST 2.9	none		Liquid level sensor cannot be submerged, so we cannot use the stacked design as planned

XIII. Risk Assessment

MarsOASIS RISK ASSESSMENT, REV -							
Risk Description	**Subsystem Affected**	**Risk Statement**	**Handling Action**	**L**	**C**	**RAC**	**Comments**
Dust Abrasion of CO2 Gas Intake Compressor	ATM	Given that in-situ CO2 will be extracted from the Martian atmosphere into the MCLSS, there is the potential that compressor system will be abraded by dust, reducing performance or causing system failure.	Mitigate: Filtrete filter	2	5	10	This is an engineering challenge to be addressed in the final paper.
Early Seed Germination	ATM, WTR	Given that seeds will be transported within the MCLSS from Earth to Mars and the MCLSS will be on the Martian surface for some period of time prior to germination initiation there is the potential for germination to begin prematurely.	Mitigate: Control conditions	1	5	5	This is an engineering challenge to be addressed in the final paper, defining recommended environmental controls to prevent gemination.
Sensor Failure	CC	Given that measured environmental parameter data is required for autonomous control of those parameters, there is the potential for sensor failure to result in crop degradation or loss of crop.	Mitigate: Redundant sensors	1	5	5	
Sensor Calibration	CC	Given that MCLSS sensors will be calibrated prior to launching and deploying on Mars, there is the potential that they will lose calibration after transit to the Martian surface.	Research	1	5	5	This is an engineering challenge to be researched in the final project paper. The sensors with risk of calibration loss will be identified, and possible mitigations proposed.
Wilting	COM	Given that telemetry communication between the MCLSS and the Earth ground station may be limited to a short period within a days time, there is the potential that plant wilting or other emergency conditions may occur compromising the crop before the ground operator can detect or react to the situation.	Mitigate: The system will process digital images of plants to determine whether wilting is occurring, convert to emergency mode, and send emergency signal to Earth ground station through deep space network if possible.	2	5	10	This is an engineering challenge to be researched in the final project paper. Though the inabiity to react immediately to degraded enviornmental parameters presents a threat to the crop, reliability telemetered communication with Mars is currently unavailable technology. One could make the assumption that multiple orbiters could be available to increase communication capability.
Condensation on Electrical	CC/COM	Given that water vapor in the atmosphere may condense onto exposed electrical	Mitigate: Component exposure to the atmosphere will be minimized	2	5	10	

Components		components there is the potential for electrical component short circuit, resulting in electrical system degradation or failure.	and exposed components will be water resistant or proof.				
Algae Buildup on Dome	LT	Given that MCLSS atmospheric conditions are conducive to algal growth, there is the potential for algae to grow and accumulate on the transparent dome or articial lighting system, reducing or blocking light transmission from the sun or articial lighting system.	Research	2	3	6	This is an engineering challenge to be researched in the final project paper. In a longer growth cyle, algal buildup on the dome may be more likely. Algacidal materials might be explored to treat dome.
Light Degradation Due to Dust Accumulation or Abrasian	LT	Given that dust storms can occur over large distance for days or weeks at a time on Mars, accumulating on the dome or causing abrasion, there is the potential for sun transmission to be reduced below tolerable levels for plant growth or survival.	Mitigate: The clamshell lid will close during periods of high winds and/or low light and artificial light take over during dust storms.	1	5	5	This is an engineering challenge to be researched in the final project paper. Stored power is expected to last through the average length dust storm, but may not be able to provide enough power for artificial lighting throughout a longer 1-2 month long storm. Exected probability crop loss due to loss of light from a dust storm after exhausting back up power will be analyzed for the final paper.
UV-C Nutrient Depletion	NTR	Given that UV-C radiation is used as a biocide for pathogen control in the root zone, there is the potential for iron chlorosis due to the destruction of iron chelate.	Mitigate	2	4	8	Addition of iron to the nutrient solution.
Off-balance or Depleted NPK Due to Differential Uptake	NTR	Given that plants may take up N, P, or K at varying rates, there is the potential that N, P, or K levels may become off balance or depleted.	Accept: EC measurements will detect overall reductio in NPK concentration and system will add pre-mixed nutrients. Risk of severe imbalance is considered low.	2	5	10	
Failure of Lid Closure Due to Dust Infiltration	STR	Given that there the clamshell lid will be open during the day to collect light, there is the potential that dust can infiltrate the hinge, leading to mechanical failure of the lid to close and potential crop failure due to low nightime temperatures.	Mitigate: Clamshell lid design will incorporate components that will be protected from dust penetration, such as hermetic joints.	1	5	5	
Micrometeroid Impact	STR	Given that the Martian atmosphere is 1% as dense as Earth's there is the potential for micrometerites to impact and penetrate	Accept:	1	5	5	The likelihood of penetration due to micrometeorite impact is considered low and a minimal risk.

		the structure, resulting in loss of internal pressure.					
Radiation Exposure	STR	Given that there is increased particulate radiation (solar and galactic) on the Martian surface compared with that on Earth, there is potential for plant damage due to radiation exposure.	Accept	1	3	3	Expected ionizing radiation exposure over 100 day mission is ~20 REM, well under expected plant tolerance of ~1000 REM
Salt Buildup in Condensor or Plumbing	NTR, WTR, TC	Given that salt deposits (from dissolved solids in the nutrient solution) could build up in the water vapor condensor, water pumps, growth medium or plumbng to the water resevoir, there is the potential that the condensor or plumbing could clog and degrade flow rates through the system.	Research - run test prior to system activation to determine need for inline reverse osmosis filter	2	5	10	Discuss as an engineering challenge. A system running for a longer or multiple life cycles will need to be flushed with fresh water requiring additional mass for the water and an additional fresh water tank.
Internal Fluid Leak	WTR	Given that fluid will be traveling through the water management system under pressure, there is the pontential that water could leak from the water management system resulting in loss of total water available for plant uptake and potential damage to other systen components.	Mitigate: Components will be chosen and tested to withstand expected water pressures and minimize likelihood of leaks.	1	5	5	
Fungal Infections at Plant Roots (Root Rot)	WTR	Given that nutrient enriched water will be recycled and recirculated through the water resevoir, ther is the potential for fungal spores to grow and infect plant roots, resulting in degraded plant growth or crop failure	Mitigate: keep root medium aerated and water circulating; filtration will be used to remove or kill spores or other pathogens	1	5	5	
Water Overheating	WTR	Given that electrical components will present a heat load into the system, there is the potential for water to become too warm for healthy plant growth.	Accept: The risk of water overheating is considered to be low, given the hight heat capacity of the water and that the atmospheric temperatre will be controlled.	1	5	5	
Pump or Valve Failure	WTR	Given that components with mechanisms or moving parts are at a higher risk of failure in the extreme temperatures and pressures and reduce gravity of the Martian environment, there is the potential	Accept	2	5	10	

		for pump or valve failure to occur resulting in loss of water at the plant roots					
Bitflip	CC/COM	Given increased radiation exposure in the Martian atmosphere and the inability to reproduce the flight environment in ground testing, there is the potential for software malfunction due to bitflip.	Accept	1	5	5	
Radiation Damage to Electrical Components	CC/COM	Given the increased radiation levels in the Martian environment, there is the potential for degraded electrical component performance.	Research	2	5	10	
Thermal and Humidity Control Under Extreme Temperature Variations	TC	Given the extreme temperature variation of the Martian atmosphere there is the potential for extreme temperature swings to occur outside of the ability of the MCLSS to control.	Research	2	5	10	
Power Generation Degradation Due to Dust Accumulation	PWR	Given that dust storms can occur over large distance for days or weeks at a time on Mars, there is the potential for solar panel power generation to be degraded.	Mitigate: The clamshell lid will close during periods of high winds and/or low light.	2	5	10	This is an engineering challenge to be researched in the final project paper.
Tip Burn Due to Lighting Heat Load	LT	Given that artificial lighting will be used in close proximity to plant leaves, there is the potential that heat from artificial lights may burn lettuce leaves.	Research: Expected temperature from LEDs will be investigated and a requirement added to bound light distance from plants.	2	5	10	
Structure Tipping	STR	Given potential for high winds on the Martian surface there is the potential for the structure to tip over.	Accept: Risk considered minimal given system weight	2	5	10	
Water Loss in O2 Removal	WTR	Given that air will be directly vented to the laboratory to remove oxygen, water vapor will also be lost.	Accept: Margin in water budget is sufficient.				