MELiSSA

Technical Note

UNIVERSITEIT GENT

FACULTEIT WETENSCHAPPEN

Memorandum of Understanding 19071/05/NL/CP

MELiSSA FOOD CHARACTERIZATION: PHASE 1

TECHNICAL NOTE: 98.3.23

CHAMBER HARDWARE SPECIFICATION REVIEW

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reference/*réference*	Contract number 22070/08/NL/JC
issue/*édition*	1
revision/*révision*	1
date of issue/*date d'édition*	January 28, 2010
status/*état*	Final
Document type/*type de document*	Technical Note
Distribution/*distribution*	FC1 consortium, ESA/ESTEC

CONFIDENTIAL DOCUMENT

APPROVAL

Title *titre*	Chamber Hardware Specification Review	issue 1 *issue*	revision 1 *revision*

author *auteur*		date January 28, 2010 *date*

Reviewed by (UGent) approved by (UGent)	Martin Weihreter, Laury Chaerle	date *date*

CHANGE LOG

reason for change / *raison du changement*	Issue/ *issue*	Revision/ *revision*	Date/*date*

CHANGE RECORD

Issue: 1 Revision: 1

reason for change/ *raison du changement*	page(s)/*page(s)*	paragraph(s)/ *paragraph(s)*

LIST OF ABBREVIATIONS

ALS	advanced life support
BLS	biological life support
CESRF	Controlled Environment Systems Research Facility
ESA	European Space Agency
HPC	Higher Plant Chamber
MELiSSA	Micro Ecological Life Support System Alternative
NCER	net carbon exchange rate
PCU	Plant Characterization Unit
UAB	Universitat Autònoma de Barcelona
Ugent-HSB	Ghent University, Hormone Signaling and Bio-imaging
UoGuelph	University of Guelph
Unapoli	University of Napoli
Ubern	University of Bern
UCL	Catholic University of Louvain

GLOSSARY

Gully:	also known as trough or gutter. Inclined channel used in hydroponic systems to hold the roots, and where the nutrient solution flows through.

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1 Introduction

The intent of this document is to provide a review of currently available hardware in view of the design of a Plant Characterization Unit (PCU) prototype.

Traditional plant canopy growth analysis involves the destructive sampling of individual plants taken from a full canopy at successive intervals, from which dry weight data is obtained. Biomass accumulation profiles derived from dry weight data are then fitted to models having a defined functional form. Generally, these models have a sole predictor, which is some estimate of plant age (days after planting) or have a number of predictors associated with integrated environment variables (integrated photon flux, degree-days etc.). While these models are predictive in nature, the analyst is required to choose among particular parametric forms which may result in over or under-fitting and poor model performance. This can result in a high degree of collinearity among predictors, especially if a high order polynomial of a single predictor variable is used to model a complex growth profile (e.g. a polynomial in time).
To broaden the range of validity and to avoid the problems of collinearity (at least to some extent) physiological models are developed. These algorithms do not rely on empirical functions such as the above mentioned polynomial fittings but are based on physiological laws. A simple example of bacterial growth would be the Michaelis Menten Kinetic. For plants these models can reach high orders of complexity and require extensive datasets for validation. The advantage however is the fact that dependencies on certain parameters (e.g. temperature, RH or light intensity) can be implemented into one model.
One main goal of the PCU is to develop such a model valid for the different MELiSSA crops. Therefore a broad range of measurements is needed for each crop.
Sampling from a full canopy induces thinning responses in the remaining plants that can obscure growth profiles. Non-destructive techniques have been developed which allow for growth estimation from measures of whole plant or full canopy photosynthetic activity (Dutton et al., 1988). Because these methods are non-intrusive, they are believed to give better results in growth and eco-physiological modelling studies.

Non-destructive growth analysis techniques use Net Carbon Exchange Rate (NCER) as a predictor of plant growth and response to environment conditions (Dutton et al., 1988). NCER is the amount of carbon gained by the plant as a result of net fixation during photosynthesis. If NCER is an instantaneous measure, then plant biomass is simply the signed integral of NCER over a given time period divided by the proportion of carbon in plant biomass.

The challenge in using NCER is in the development of chambers which have the capability to measure NCER with sufficient resolution and accuracy. Single leaf cuvettes have been developed and are routinely used for monitoring leaf photosynthesis. Such cuvettes operate on either a differential or compensating principle in which NCER is estimated from differences in carbon dioxide concentration between inlet and outlet air streams (in the case of differential systems) or from the amount of carbon injected into the cuvette in order to keep carbon dioxide concentrations static (in the case of a compensating system).

2 Existing Plant Growth Systems for ALS

There are few plant growth chambers specifically designed for the study of closed loop advanced life support. Certainly none are made commercially as end users requiring this type of system are few in number. All known systems that have been used in ALS research have been either modified versions of conventional plant growth chambers or custom systems requiring advanced design and engineering.

2.1 Higher Plant Chamber – UAB

The HPC at UAB was completed in 2009. Currently a single prototype, it was designed to integrate along with two more identical units into the UAB MELiSSA pilot plant. It is constructed of primarily 316 stainless steel, tempered safety glass, polypropylene, Teflon, and Viton thermoplastics. The small size of the pilot plant resulted in a unique solution to provide a total of 15 square metres of growing area. Rather than a traditional walk in growth room configuration, the prototype HPC contains a 1 x 5 m long growing area with air-lock access on both ends. This allows for staggered harvesting while maintaining integrity of the MELiSSA loop. Seedlings are introduced on one end, and plants ready for harvest are removed from the other as part of a staggered planting interval. Seedling introduction and mature crop harvest can be performed with minimal aerial contamination of the main growing volume.

Illustration 1: Higher plant chamber at UAB

Dimensions

- Volume = 7.35 m^3 (6 m x 1.11 m x 1.26 m) [8.61 m^3 with airlocks]
- Plant Growing Area = 5 m^2 (1 m x 5 m)

Construction Materials used

- Stainless Steel 316 (walls, floor, valves, plumbing)
- Glass (roof)
- Teflon (tubing, gas expansion bladders)
- Polypropylene (tubing, valves)
- Heresite (oxidation barrier on fans, heat exchangers, motor parts)

- Viton (O-rings, solenoid seats, gaskets)

Analysers

- California Analytical Instruments CO_2/O_2 Analyser (model 600)

Lighting

- 6x600 Watt High Pressure Sodium + 3x400 Watt Metal Halide
- Light level: ~800 µmol m^{-2} $second^{-1}$ PAR at mid canopy

Hydroponic System Sensors

- Electrical Conductivity
- pH
- Temperature
- Main tank and stock tank float level sensors
- Nutrient flow

Chamber Sensors

- Air Humidity sensors (3)
- Air Temperature sensors (3)
- LiCor Quantum Sensors (3)

Environment Control

- Temperature (15 to 30 C) ± 0.2 C
- CO_2 Concentration (ambient to 6000 ppm) ± 10 ppm
- O_2 Concentration (ambient)
- Relative Humidity (50% to 95%) ± 5%

2.2 Hypobaric Chambers – UoG

The Controlled Environment Systems Research Facility at the University of Guelph represents an extensive collection of variable pressure plant growth chambers devoted to the study of biological systems including plants and microbes, in life support roles for space exploration. To simplify engineering requirements for plant growth structures on the Moon or Mars, lower pressures are desirable to reduce mass and decrease atmospheric leakage. Few facilities exist that can provide low pressure plant growth capabilities coupled with complete control over temperature, vapor pressure deficit, gas composition, nutrient delivery, and pressure. The Controlled Environment Systems Research Facility maintains five canopy-scale hypobaric plant growth chambers, with a growing surface of 1.5 m^2 per chamber, whose capabilities are ideally suited for low pressure advanced life support research.

Illustration 2: Hypobaric plant growth chamber at UoGuelph

Individual Chamber Dimensions

- Volume = 4.5 m^3 (1.0 m x 1.8 m x 2.5 m)
- Plant Growing Area = 1.5 m^2 (1 m x 1.5 m)

Construction Materials used

- Stainless Steel 316 (walls, floor, valves, plumbing)
- Glass (roof)
- Teflon (tubing)
- Polypropylene (tubing, valves)
- Heresite (oxidation barrier on fans, heat exchangers, motor parts)
- Viton (O-rings, solenoid seats)

Analysers

- California Analytical Instruments CO_2/O_2 Analysers (5 x model 200)
- Varian Saturn GC/MS
- Gas Chromatograph (SRI 8610C) for ethylene analysis
- Dionex DX500 HPLC Ion Chromatograph (off-line nutrient analysis)

Lighting

- 6x1000 Watt HPS or 6x1000 Watt MH (convertible)
- Light level: 1200 µmol m^{-2} $second^{-1}$ PAR at mid canopy

Hydroponic System Sensors

- Electrical Conductivity (two per chamber)
- pH (manual control)

Chamber Sensors

- Air Humidity sensors (two per chamber)
- Air Temperature sensors (two per chamber)
- Root Zone Temperature sensors (two per chamber)
- LiCor Quantum Sensor (two per chamber)

Environment Control

- Temperature (10 to 30 C) ± 0.2 C
- CO_2 Concentration (0 to 6000 ppm) +/- 10 ppm
- O_2 Concentration (0 – 100%) +/- 1%
- Relative Humidity (50% to 95%) ± 5%

2.3 SEC2 – UoG

The SEC2 walk-in plant growth chambers (aka 'blueboxes') are capable of a high degree of closure and are dedicated specifically to canopy-scale lighting studies, trace hydrocarbon analyses, nutrient recycling studies, and control/manipulation of abiotic growth factors in sealed environment plant production. These sophisticated chambers represent the current technical venue for large scale plant studies related to space life sciences at the University of Guelph.

Illustration 3: UoGuelph SEC2 plant growth chambers

Dimensions

- Volume = 29 m^3 (430 ft^3) (4.5 m x 2.8 m x 2.3 m)
- Plant Growing Area = 5 m^2 (54 ft^2) (2 m x 2.5 m)

Construction Materials used

- Stainless Steel 316 (walls, floor, valves, plumbing)
- Glass (roof)
- Teflon (tubing, gas expansion bladders)
- Polypropylene (tubing, valves)
- Heresite (oxidation barrier on fans, heat exchangers, motor parts)
- Viton (O-rings, solenoid seats)
- Silicone sealant (DOW-Corning RTV 732) and silicone grease

Analysers

- LiCor LI6262 Gas Analyser for CO_2/H_2O vapor
- California Analytical Instruments Oxygen Analyser (model 100P)
- Gas Chromatograph/Mass Spectrometer (HP-5890/HP-5971)
- Gas Chromatograph (SRI 8610C) for ethylene analysis
- Dionex DX500 HPLC Ion Chromatograph (off-line nutrient analysis)

Lighting

- 9x600 Watt HPS + 6x400 Watt MH
- Light level: 500 to 800 µmol m-2 second-1 PAR at bench height

Hydroponic System Sensors

- Electrical Conductivity (two per chamber)
- pH (two per chamber)

Chamber Sensors

- Air Humidity sensors (two per chamber)
- Air Temperature sensors (two per chamber)
- Root Zone Temperature sensors (four per chamber)
- LiCor Quantum Sensor (one per chamber)

Environment Control

- Temperature (10 to 40 C) +/- 0.2 C
- CO_2 Concentration (ambient to 3000 ppm) ± 10 ppm
- O_2 Concentration (ambient)
- Relative Humidity (50% to 95%) ± 5%

2.4 Commercial Vendors

There are a number of commercial suppliers of controlled environment chambers including Binder (Germany), BioChambers (Winnipeg, Manitoba, Canada), Conviron (Winnipeg, Manitoba, Canada), Powers Scientific (Pipersville, Pennsylvania, USA), Qubit Systems (Kingston, Ontario, Canada), Sanyo (San Diego, California, USA), Sheldon Manufacturing (Cornelius, Oregon, USA), Weiss-Gallenkamp (Leicestershire, UK), Z-Sciences Corporation (Westmount, Quebec, Canada), however none offer the combination of degree of closure, inert construction materials, integrated nutrient delivery systems and production area required for ALS research.

3 Specific Biological Requirements

Some parameters will require modification based on growing area/volume and pressure requirements.

Parameter	**Requirement**
Illumination day	> 600 umols PAR (Photosynthetically Active Radiation) at trough height averaged throughout the chamber
Illumination night	0 to 20 micromoles PAR (minimum light intensity that will not induce a physiological response)
Temperature (air)	15C - 30C +/- 0.5C
Air velocity	0.1 – 1.0 m/s within crop - continuous variable speed required heat mitigation may require higher velocities and is an acceptable deviation from the listed requirement
Water supply	0.1 – 1.0 L/min – continuous/timed variable flow required
Nutrient supply	pH and EC control
Pressure	Ambient with passive compensation
Gas environment	CO2 0 – 5000 ppm (controlled to setpoint +/- 10 ppm) O2 0-40% (settable upper limit control) Ethylene 10 - 1000 ppb (with mechanism for removal)
Humidity[1]	40 – 95% (controlled to setpoint +/- 5%)
Leakage	<5% per day as measured by loss of CO_2 over a 24h period

[1] Humidity control will be compromised at the extreme temperature setpoints

4 Cultivation Surface Size

The required amount of growing area per PCU is a critical design parameter and must be determined early in the design process. Actual calculations will be obtained from food characterization studies yet to be completed, The first obtained data from Food Characterization 1 will indicate the needs for crop harvest quantity (nutritional analysis, processing), crop cultivar selection and modeling data gathering. However, in order to maintain commonality between ESA partners, the existing Higher Plant Chamber production dimension of 5 m^2 should be maintained if feasible.

Whereas 5 m^2 is a manageable size, a single chamber with this production area does not meet the statistical requirements of scientific research. To achieve statistical reliability while maintaining continuity with current plant growth systems, It is proposed that the initial PCU growing area will total 5 m^2, but be comprised of 3 identical chambers, each with a growing area of 1.67 m^2. Maintaining equivalent production area with that of the UAB HPC would ensure reliable comparative studies between partners, while the provision of three separate chambers will provide the temporal and statistical flexibility required to maximize ALS science output.

As a growing area of ~ 1.6 m^2 is a manageable size for an individual chamber, increases in cultivation surface area can be achieved through construction of additional chambers. The proposed control system should accommodate any number of individual chambers, all of which share a common control/data logging computer (each chamber is however autonomous in operation should the control computer be unavailable), as well as common nutrient and chilled/hot water systems.

5 Crop Types

The PCU design should be adaptable either directly or through simple modification to accommodate the majority of candidate food crops. Food crops of particular current interest to ALS include: wheat, onion, lettuce, kale, potato, tomato, rice, soybean, spinach, beet, radish, and lettuce.

6 Environmental Requirements

The prototype should withstand/operate as required within the typical laboratory thermal and humidity environments. Extremes in temperature or humidity may affect thermal or operational control. Similarly, the facility HVAC system should be able to accommodate the PCU thermal load.

7 Design Requirements from Modeling

Results from chamber modeling will need to be considered in the final configuration of the PCU.

8 Design Requirements from Crop Evaluation

Results from wheat, potato, and soybean cultivar trials will need to be considered in the final configuration of the PCU.

9 Design Requirements from Food Processing

Results from the study of food processing requirements will need to be considered in the final configuration of the PCU.

10 Subsystems

The chamber design is assessed based on the operational contributions of five critical subsystems.

10.1 Chamber Shell

The chamber shell is the integral component that houses the lighting, irrigation, air handling, and control subsystems. It includes the plant growth compartment, lamp loft, electrical enclosures and conduits, access ports, air handling blowers and heat exchangers, as well as transport and leveling systems.

10.2 Lighting

Plant growth chambers are able to provide ideal conditions for plant growth and development. Temperature, humidity, and gas composition can be controlled to a high degree of accuracy and precision, thus providing the conditions for optimal growth. However, the single most critical limiting factor to optimal growth in all plant chambers is the delivery of optimal (quality and quantity) irradiation. As light is the most important factor to growth, and the most energy intensive subsystem in the chamber, selection of an ideally suited irradiation source is of great importance.

10.3 Irrigation

The irrigation subsystem is composed of all the sensors, actuators, tubing, troughs, and storage tanks that are required to deliver an adequate supply of temperature controlled water and nutrients to the crop.

10.4 Air handling

The air handling subsystem consists primarily of the sensors, actuators, ductwork, and heat exchangers required to maintain adequate temperature and humidity control within the PCU. It also includes the sensors and actuators for air composition control (CO_2, O_2, ethylene).

10.5 Control

The control subsystem integrates the lighting, irrigation, and air handling subsystems. As one of the critical components in the overall system, care must be exercised in the selection of a vendor. A system with a long track record in environment control (specifically plant production environment control) and value-added service should be considered. Given the critical nature of this component, post installation support and service should be given significant weight in the selection process. Furthermore, given the nature of ALS research, the vendor should also be flexible in terms of software modifications and updates.

It is the long term intention of the food characterization project to provide for interconnections among ongoing research activities at various locations (eg. Guelph, Gent, Napoli, Bern). The control system should provide the capability for efficient data communications and remote control of geographically separate chamber systems. This will facilitate concurrent replication of experimental activities and foster personnel exchanges and training opportunities.

11 Chamber Shell Subsystem Requirements

The primary design criteria for the chamber shell revolve around component material selection. All internal surfaces should be made of inert materials to minimize potential off gassing of VOCs that could influence plant productivity. Suitable materials include 316 passivated stainless steel, polypropylene, Teflon, glass, and Viton. As much as possible, the chamber should be insulated with up to 2” of extruded polystyrene to mitigate thermal fluctuations induced by the external environment. The building (dedicated room) HVAC should minimize the external influences, while mitigating lamp system heat load.

Air handling system layout providing optimal growth conditions should be chosen based on previous experience and simulations, and matched with operational (access) requirements.

12 Lighting Subsystem Requirements

There are two basic requirements for lighting in the PCU: a suitable spectrum of sufficient intensity for plant growth and development and energy efficiency. In addition a layout assuring maximal intensity and homogeneity is required. Importantly heat load on the plant growth compartment should be minimized when possible. There are numerous commercial lamp systems available, however only the ones of potential use in the PCU are noted.

High Pressure Sodium (HPS) Lamps

The high-pressure sodium lamp has a transparent discharge tube filled with a gas and sodium mixture (the conductor.) An electric current vaporizes the conductor causing it to glow, which results in the emission of light and heat. The ballast (a current regulating device) is required to limit and stabilize the current passing through the lamp, greatly reducing the loss of energy in the form of heat. The ballast also prevents overdriving of the lamp, resulting in longer lamp life.

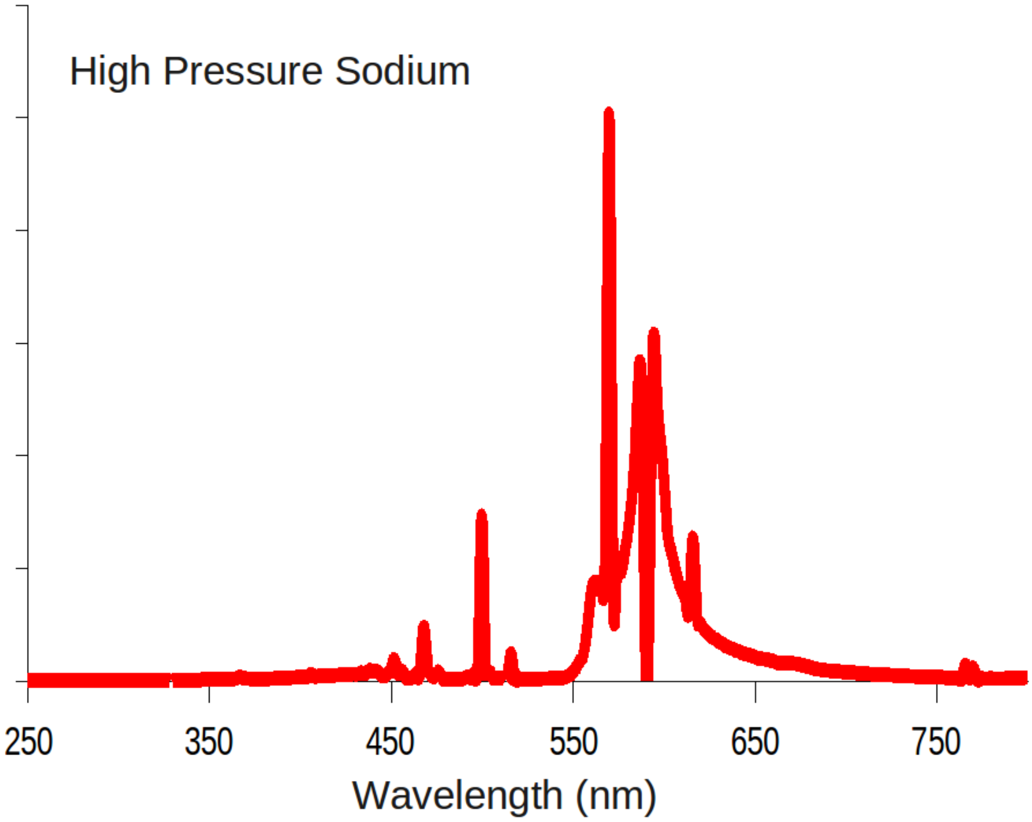


Illustration 4: Spectra of a high pressure sodium lamp

HPS is the most energy efficient lamp for greenhouse lighting. About 30% of the electric energy input is converted into PAR, compared to 6.7% for incandescent lamps. Only 14% of the light energy is in the waveband between 400 and 565 nm, with the majority (PAR) occurring between 565 and 700 nm (Illustration 4), providing maximum plant growth. The remaining energy is converted to infrared energy.

The useful life of HPS lamps is twice that for Metal Halide (MH). Furthermore, the light output during the lamp life typically will drop less than 10%, ensuring homogeneous lighting conditions across temporally dissociated studies.

Metal Halide (MH) Lamps

Metal Halide lamps produce a whitish light that closely resembles the spectrum of daylight. A MH lamp has a transparent discharge tube filled with a mixture of inert gas (typically argon), metal halide salts (mixture determines spectrum) and mercury (the conductor.) An electric current vaporizes the conductor causing it to glow, which results in the emission of light and heat.

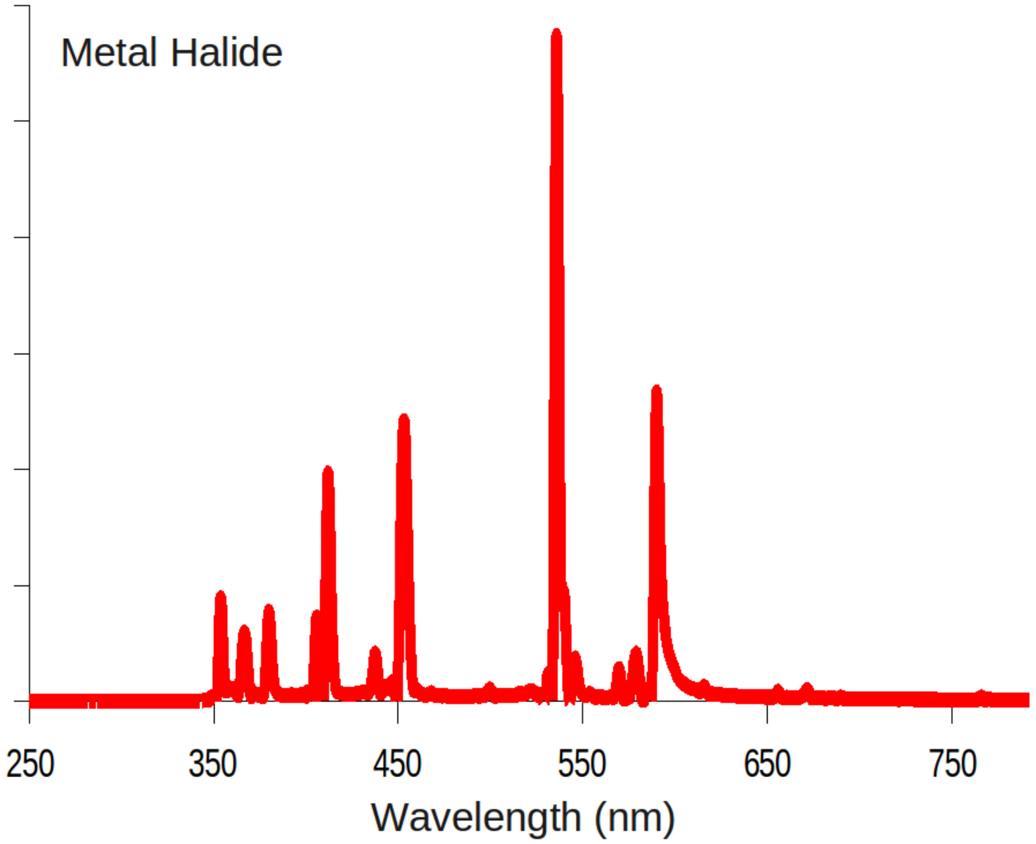


Illustration 5: Spectrum of a metal halide lamp

About 55% of the light energy of a MH lamp falls in the waveband of 400 - 565nm. The highest radiant energy peaks fall in green and orange wavebands. MH lamps have a wider spectrum than mercury or sodium lamps, because they contain metal salts of the group 17 (formerly VII and VIIA) elements fluorine, chlorine, bromine and iodine. They are less energy efficient and have a shorter life-span than HPS. However, compared to lighting with fluorescent tubes, fewer fixtures are required making MH lamps more cost-effective.

MH lamps serve a distinct purpose in the scheme of supplemental greenhouse lighting. They can be combined to work in tandem with other light sources, such as HPS lamps, for particular applications such as growth rooms without sunlight where a complete light spectrum is required for balanced plant growth.

Light Emitting Diodes

LEDs are based on the semiconductor diode and produce a form of electroluminescence when suitable power is applied. They have a number of advantages over traditional irradiation sources including lower energy consumption (due to the restricted wavelength output – LED power supplies will be no more energy efficient than those of HPS and MH), longer lifetime, improved robustness, smaller size and faster switching. However, they are relatively expensive and require more precise current and careful heat management. For plant growth, a combination of red (620-645nm) and blue (453-466nm) lamps in various ratios are generally used.

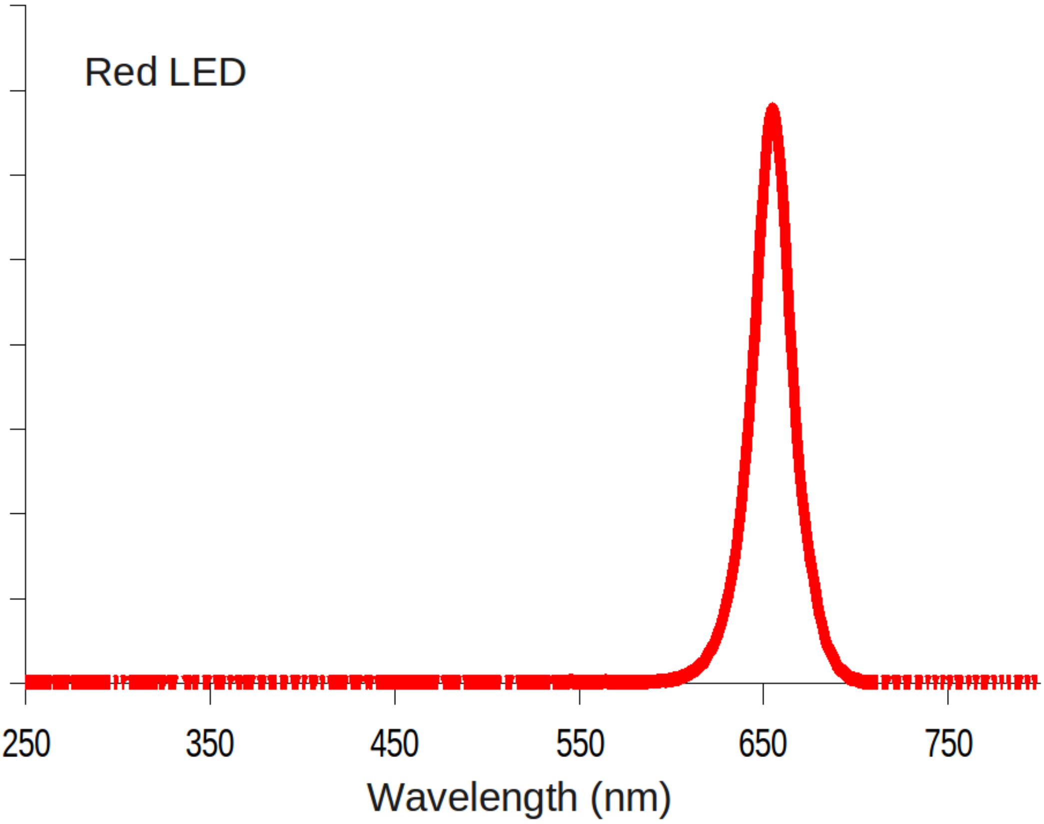


Illustration 6: Spectrum of a red light emitting diode

While modern advances in Light Emitting Diode (LED) technology have rendered the diodes themselves more efficient, when one considers the reduced delivery capacity compared to HPS or MH lamps, it is recommended that more conventional lamp types (MH, HPS) be considered. As LED technologies advance, this option may be revisited in the future.

Radio frequency Lamps

In a radio frequency lamp, a 2.4 GHz microwave energy source is focused on a small transparent glass ampoule containing a noble gas at low pressure. Microgramme quantities of selected metal halide salts are also present in the ampule and are critical to producing the desired spectrum. The microwave beam is focused through a waveguide containing the ampoule. An electric field forms which ionizes the noble gas molecules, forming a plasma within the glass ampoule. The plasma then vaporizes the metal halide salts present and the plasma and metal halide salts emit light. This technique provides the ability to produce a broad spectral emission using simple chemical compounds.

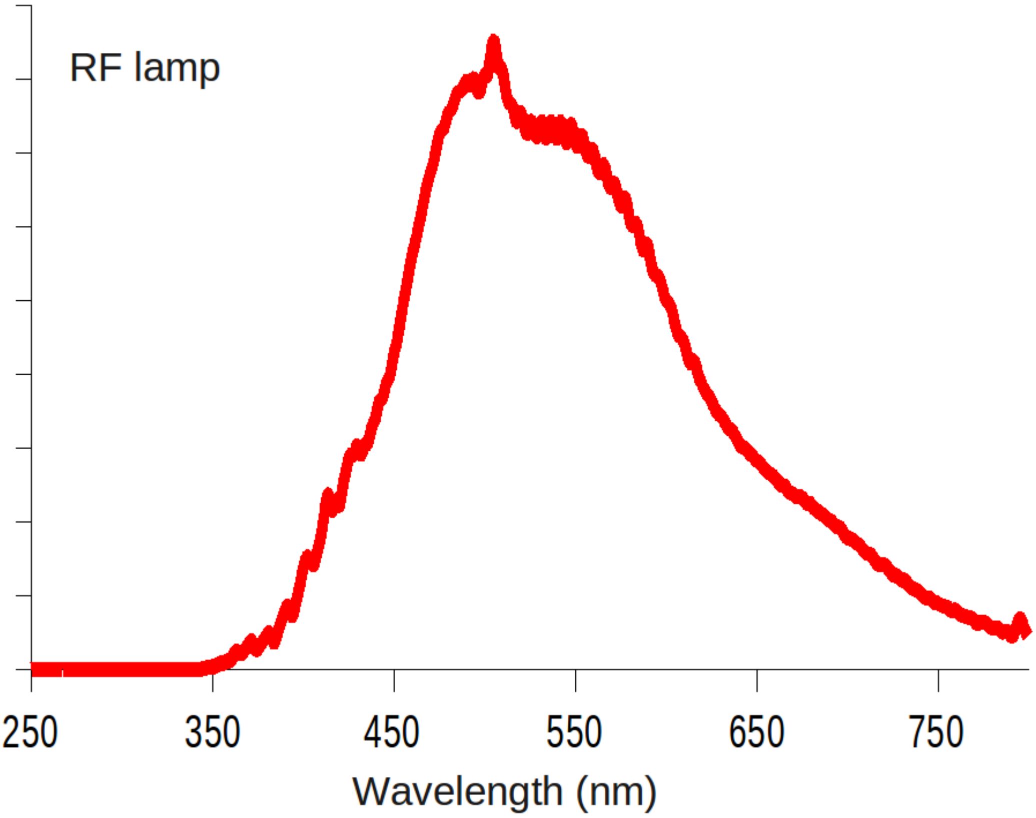


Illustration 7: Spectrum of a radio frequency lamp

Recommended System: HPS and MH

It is recommend that a user configurable combination of HPS and MH lamps targeting a lighting intensity of 600 µmol m^{-2} s^{-1} PAR or better at bench level. Switchable ballasts are available which can operate either HPS or MH lamps. This would allow the most versatility in lighting spectra with reasonable power input requirements. A remote ballast lighting system may accommodate up to 4 bulbs with reflectors (eg. Hortilux Maxima Reflector) per m^2. For a 1.67 m^2 growing area, 6 x 1000 Watt HPS/MH switchable lamps are recommended. As homogeneity is a problem when HPS and MH are combined in a 6 lamp configuration, it is recommended that only HPS or MH be used at any one time.

Lamp cooling can be achieved through active circulation of room air across the lamps (through the lamp loft) using a series of box fans, however this method requires that building temperature control that is able to handle the excess heat load.

For future consideration, the RF lamp should be fully investigated for reliability in these systems. Past UoGuelph research has shown these lamps to be exceptional for plant growth due to their low energy consumption and superior spectrum. Reliability concerns at the time prevented continued use.

13 Irrigation Subsystem Requirements

The irrigation system should be of a recirculating closed NFT design as this is the most common system in ALS research. Depending on research requirements, the irrigation system should be adaptable to other types of irrigation (ie. drip or deep water culture)A general list of components includes:

- universal trough covers that can support a wide variety of crops
- nutrient solution tank volume of ~200L
- gravity feed of stock two part nutrient (with ability to expand to multiple component injection), as well as acid and base
- common stock solution containment separate from chamber shell
- nutrient solution level monitoring of 'too high' and 'too low'
- nutrient solution temperature measurements
- nutrient solution temperature control

- control over pH and EC with redundancy
- stainless steel impeller pump with inlet screen
- bypass circulation system to maintain solution homogeneity and adequate solution aeration
- DO monitoring, TBC
- subsampling valve from main bypass line for manual solution sampling during sealed crop growth trials
- nutrient solution flow sensor
- primary construction materials of polypropylene, 316 stainless steel, Teflon, and Viton
- IR video camera with IR lighting for root/tuber visualization within the growing trough

14 Air Handling Subsystem Requirements

Air should be recirculated throughout the chamber at a rate that allows proper cooling. Generally, the air velocity is determined by the heat load from the lighting system. This velocity will exceed the minimal requirements for air movement within a developing plant canopy (leaf boundary layer minimization is a target for more efficient gas exchange).

Primary Requirements

- two variable speed blowers with integral motor for redundancy in case of failure. Two fans at reduced speed will decrease motor and bearing maintenance requirements.
- hot and cold water heat exchangers
- air velocity sensor
- two T/RH sensors
- tipping bucket for condensate (evapotranspiration) measurement
- three-way valves for heating/cooling loop
- heat exchanger recirculation pumps for improved system response
- CO_2/O_2 analyzer
- O_2 mitigation (Oxygen concentrator to remove excess)

Once final sizing and general chamber configuration has been confirmed, modeling of the air handling system will be required in order to optimize air distribution and heat exchanger properties.

15 Control Subsystem Requirements

The key component in interoperability between chambers and global partners lies in the control system.

Primary Requirements

- Distributed control – autonomous operation of each chamber with a centralized computer control server and data acquisition and recording
- Individual chamber controllers with 48 hour internal data backup/restore in the event the controller is disconnected.
- Software that provides seamless global access to chamber data and control systems
- Concurrent secure access to all partner systems
- Individual accounts with access tracking and secure access
- Data recording with up to 1 second resolution if required
- Data graphing and simple data retrieval
- Data export to text file with user selectable parameters and time interval
- User modifiable control algorithms
- Expandable – additional growth chambers can be added without additional programming requirement
- integrated control of environment, irrigation, and nutrient management
- Integrated sensor/actuator failure alarm system with user notification system (autodialer, email, or other alternative)
- Manually operable control relays

16 General Hardware Requirements

Sensors			
	Subsystem	Output requirements	Possible Suppliers

Flow	Nutrient Delivery	frequency	Cole Parmer
Tipping bucket	Nutrient Delivery	Dry contact	LaCross
PAR	Lighting	0 – 10 mV	LICOR
CO_2/O_2	Air Handling	4 – 20 mA	CAI
Temperature (2)	Nutrient Delivery	Thermister	Argus
Temperature (2)	Lighting	Thermister	Argus
T/RH (2)	Air handling	4 – 20 mA	Vaisala
pH (2)	Nutrient Delivery	4 – 20 mA	Hanna
EC (2)	Nutrient Delivery	4 – 20 mA	Hanna
Air flow sensor	Air handling	4 – 20 mA	Geneq
Actuators			
	Subsystem	Type / input	Possible Suppliers
Nutrient pump	Nutrient Delivery	Variable / 90 VDC	Interpump
Lamps	Lighting	HPS-MH / 6 x 1000 Watt	Hortilux
Blower motor	Air handling	Variable frequency drive	TBD
Blower	Air Handling	Integrated with motor	Delhi
Loft fans	Lighting	24 VDC	TDB
Proportional valves	Air handling	24VAC / 4-20 mA or 0-10V	
Valves (solenoid)	Nutrient Delivery Air Handling	SS-Viton / 24 VAC SS–Viton / 24 VAC	Asco Asco
Power			
Regulated power supply	ALL	TDB	TDB
transformer (24VAC)	ALL	24 VAC	TBD
transformer (24VDC)	ALL	24 VDC	TBD
Connections			
Connectors – electrical	ALL	TDB	TBD
Wire		TDB	TDB
Connectors – plumbing	Nutrient Delivery Air Handling	SS and PP SS and PP	TBD TBD

Additional desirable hardware unrelated to chamber operation include:

- pan/tilt/zoom/slide visible spectrum camera
- NIR camera for root/tuber monitoring
- leaf area meter
- GC or photoacoustic system (ethylene detection)
- Ion chromatograph (nutrient analysis)

17 Operational Requirements

17.1 Seeding and germination

There are no external requirements for germination and establishment of seedlings. All aspects of crop production can take place within the chamber. In general operation mode, the candidate crop is overseeded and thinned to the correct density after a specified (crop specific) period of time. This procedure eliminates the requirement for external growing facilities and provides important data on crop germination and establishment.

17.2 In-situ crop management

As a sealed environment, little, if any, in-situ management is required. In most cases of ALS crop characterization, after the initial crop thinning, the chamber would remain closed until the time of harvest. If experimental protocols require intermittent sub-sampling of crop tissue, the system can be opened briefly with minimal disruption to gas exchange data and analysis.

17.3 Harvest

With a removable tray system, the crop can be removed to an area specifically designed to allow efficient and effective further processing.

17.4 Cleaning

Routine cleaning should be performed between crop cycles to minimize contamination by plant pathogens, fungi, algae or other microorganisms. Generally, interior surfaces can be cleaned with a dilute alcohol solution while hydroponic wetted surfaces are cleaned by recirculating an aqueous ozone solution of approximately 2 – 4 milligrams per litre throughout the system.

17.5 Maintenance access

To simplify routine and non-routine maintenance, all areas of the chamber should be within reach through either sealed doors or removable access panels.

18 Other Design Considerations

In addition to the structural and control requirements of the chamber noted above, the following considerations should also be made.

18.1 Aesthetics

The chamber should have an exterior colour of ESA blue or similar. All internal parts should be constructed of inert materials. Appropriate electrical and plumbing tracking should be used where needed.

18.2 Transportation and Assembly

No single dimension of the chamber and components should exceed that of a double wide standard size door frame. In order to pass through typical door height restrictions, the lamp canopy should be removable. Elevator dimensions or window size and corridor width will be evaluated for each potential location.

18.3 Labour Requirement

The current chamber design relies on labour for plant cultural management, planting and harvesting. No mechanised systems are proposed, as the scale does not justify the expense and complexity associated with these systems.

18.4 Future Cropping Systems

The chamber design should accommodate additional cropping systems such as Deep Water or Aeroponics with minimal difficulty.

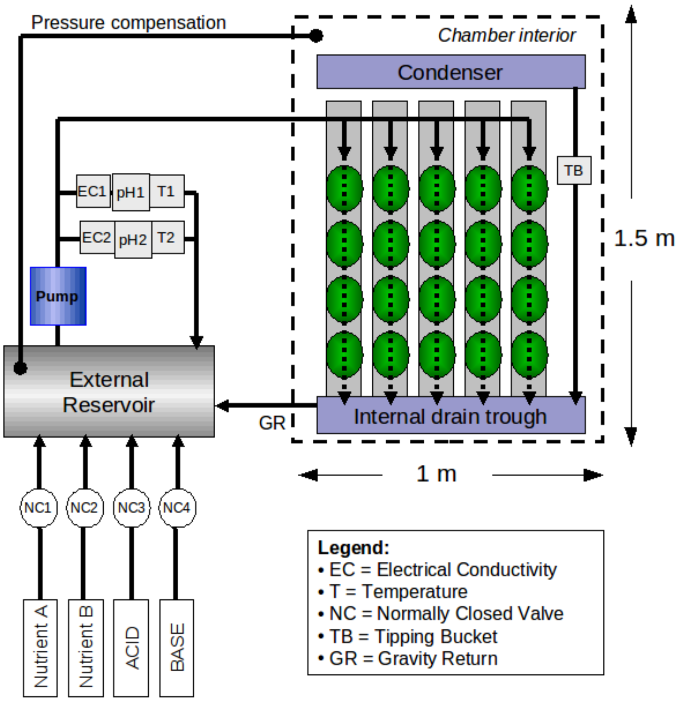
19 Facility Requirements

The laboratory space and utility requirements devoted to the PCU is of great importance. The total footprint of the chambers and ancillary equipment is appropriately 10 m^2, with a height requirement of 4 m (to allow opening of the lamp loft and access). Utility requirements include the following key services:

- Electrical power: TBD
- Deionized and tap water lines
- Building HVAC
- Recirculating chilled water supply @ 6 C
- Recirculating hot water supply – user selectable between 40 and 80 C
- Compressed $CO_{2,}$ supply with >99.9% purity

20 Preliminary concept

The current concept consists of three individual units each with a growing area of 1.67 square meters and a common, user expandable control system (Appendix 1). It incorporates a single upward swinging access door on each chamber, intended to provide efficient harvest and intermittent access.



- NFT design
- 200 litre temperature controlled external polypropylene reservoir
- Circulation pump
- Gravity return of water
- Electrical conductivity (2)
- pH sensors (2)
- Gravity feed of acid, base, and nutrient solutions

Illustration 8: Schematic representation of the hydroponics system for the initial chamber concept

21 References

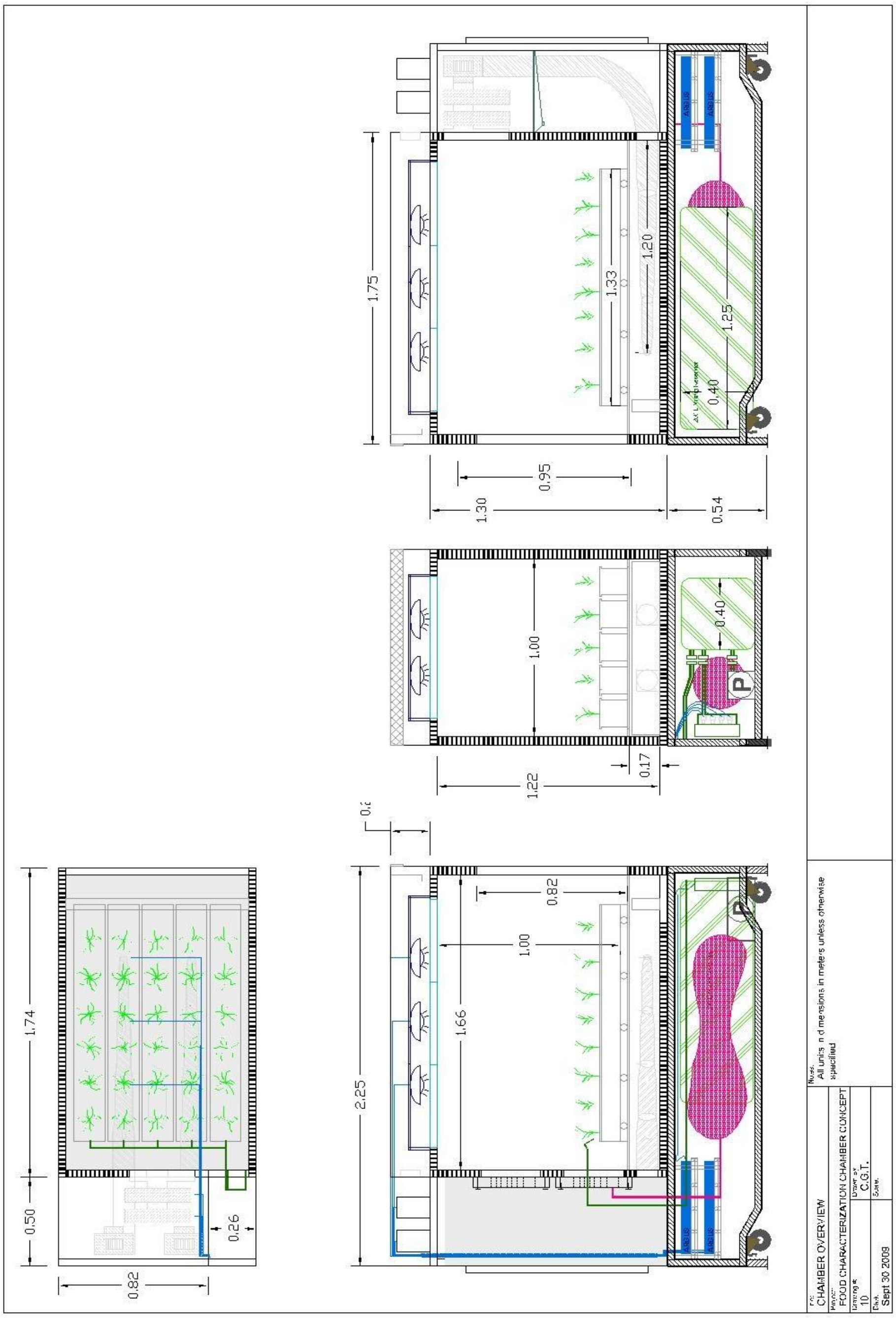
Dutton, RG, J Jiao, MJ Tsujita and B Grodzinski; 1988; Whole Plant CO2 Exchange Measurements for Non-Destructive Estimation of Growth; Plant Physiol.; 86:355-358

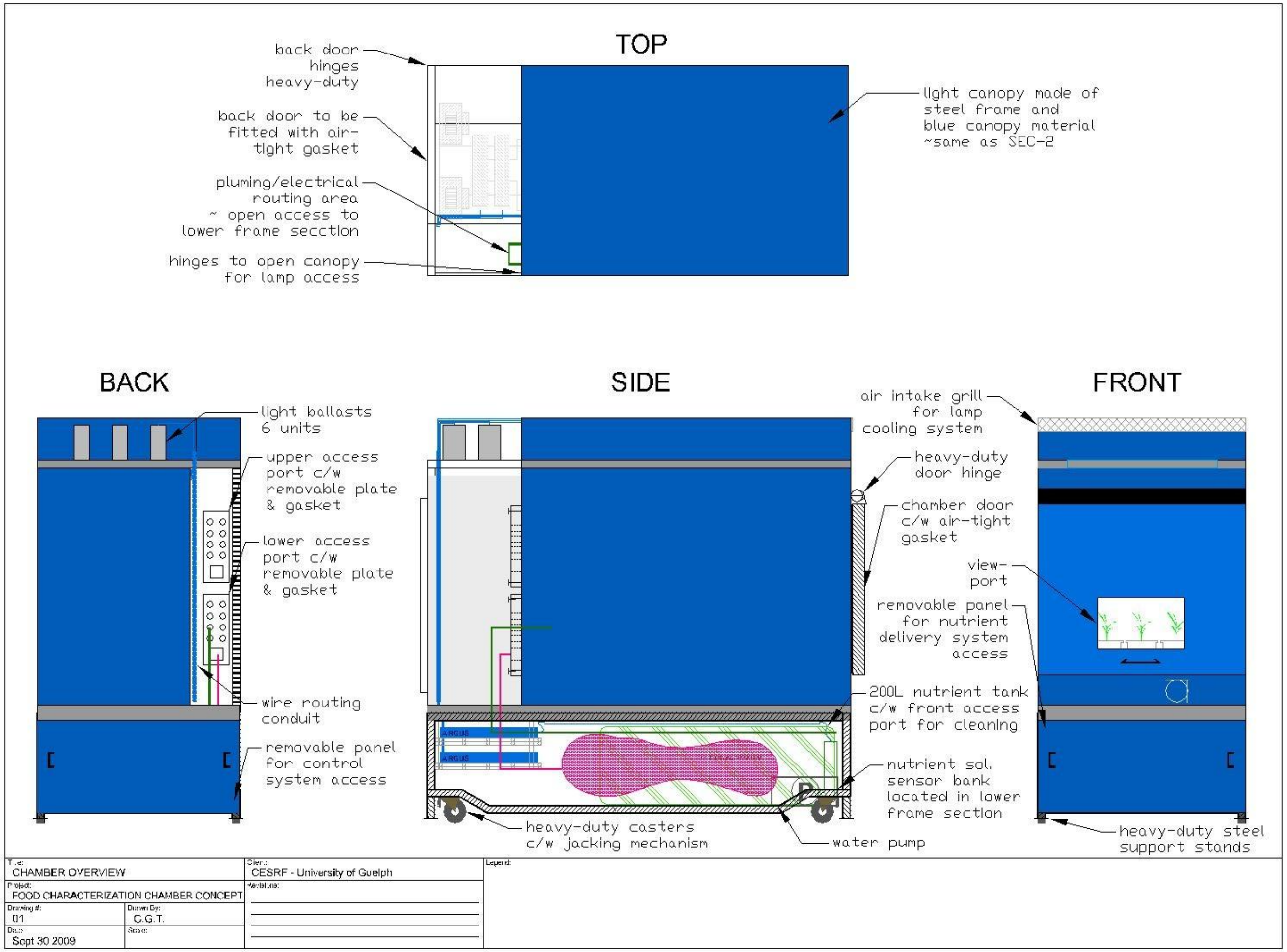
Lange, K.E., A.T. Perka, B.E Duffield, and J.F. Jeng. 2005. Bounding the spacecraft atmosphere design for future exploration missions. NASA CR-2005-213689

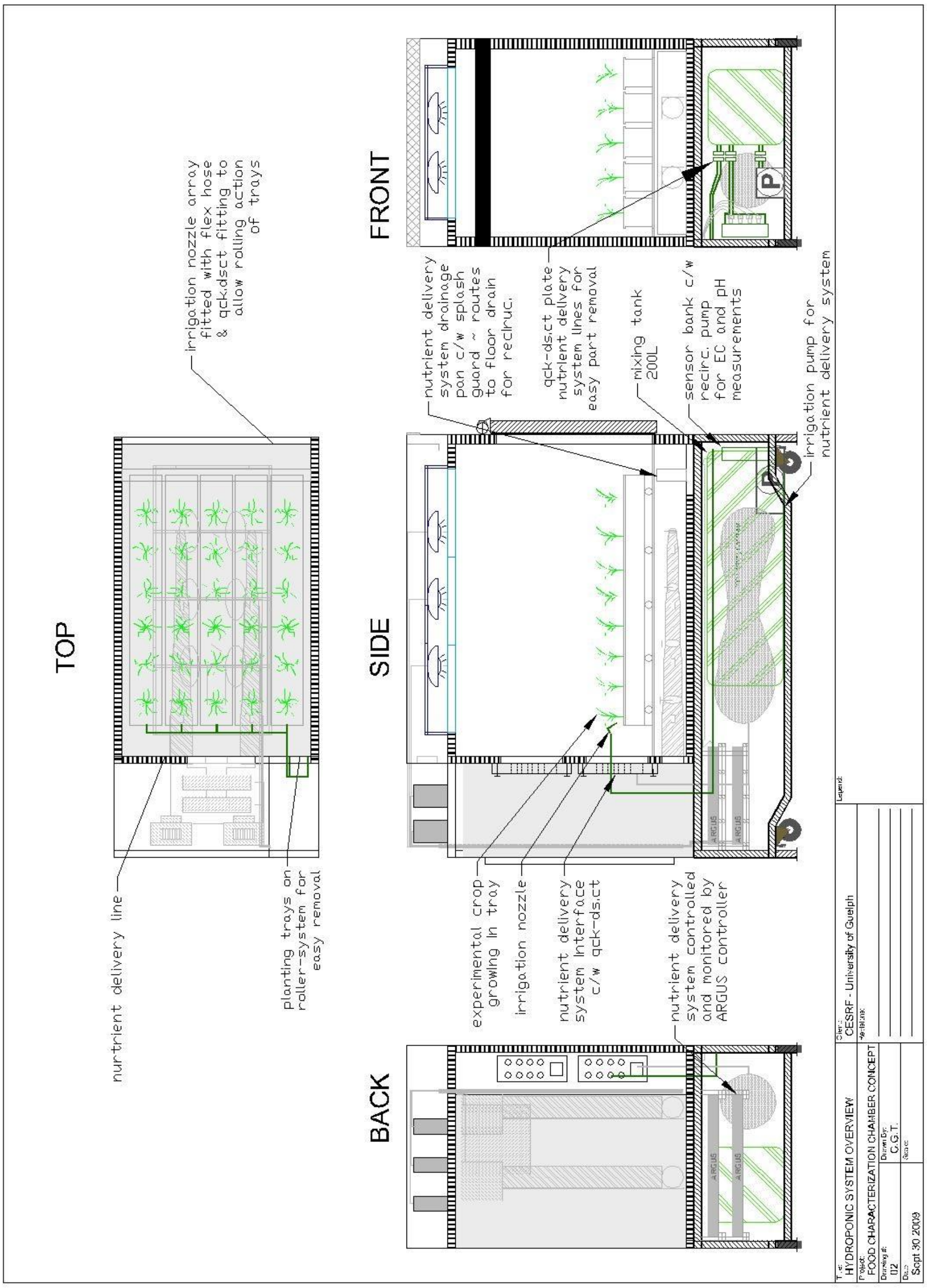
Wheeler, R.M. and C. Martin-Brennan (eds.). 2000. Mars greenhouses: Concept and Challenges. Proceedings from a 1999 Workshop. NASA Tech. Memorandum 208577

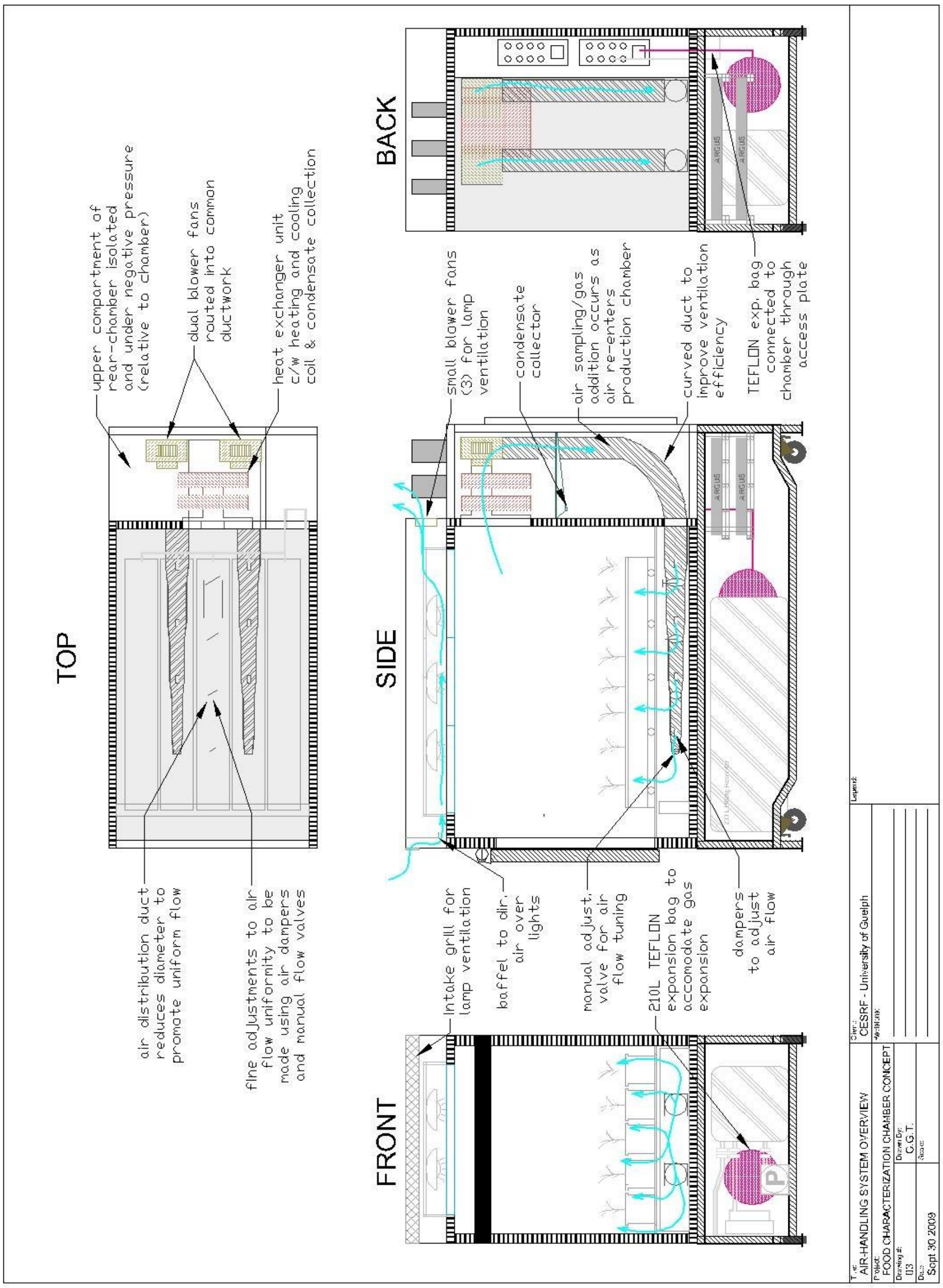
22 Appendix 1

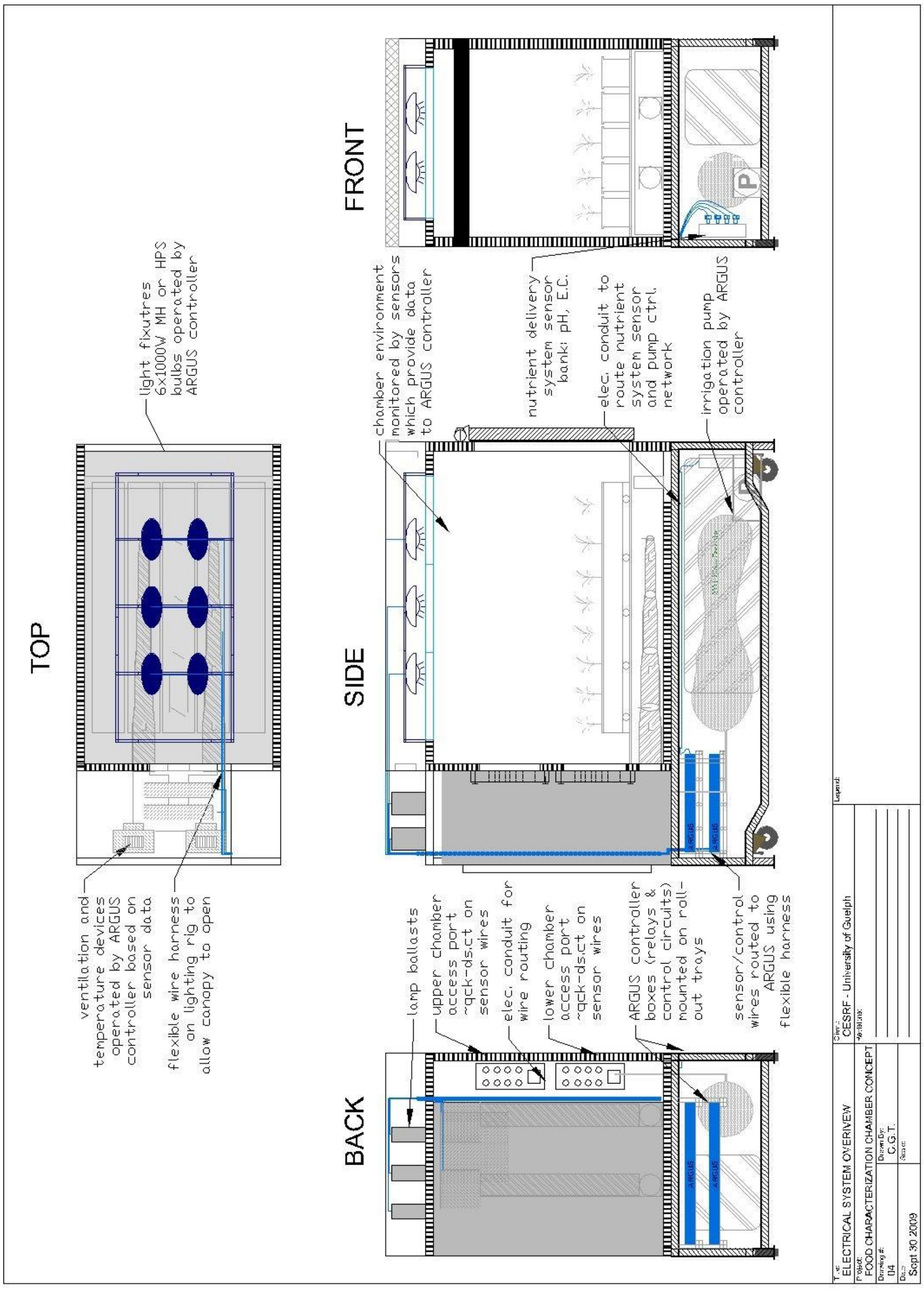
Prototype design concept

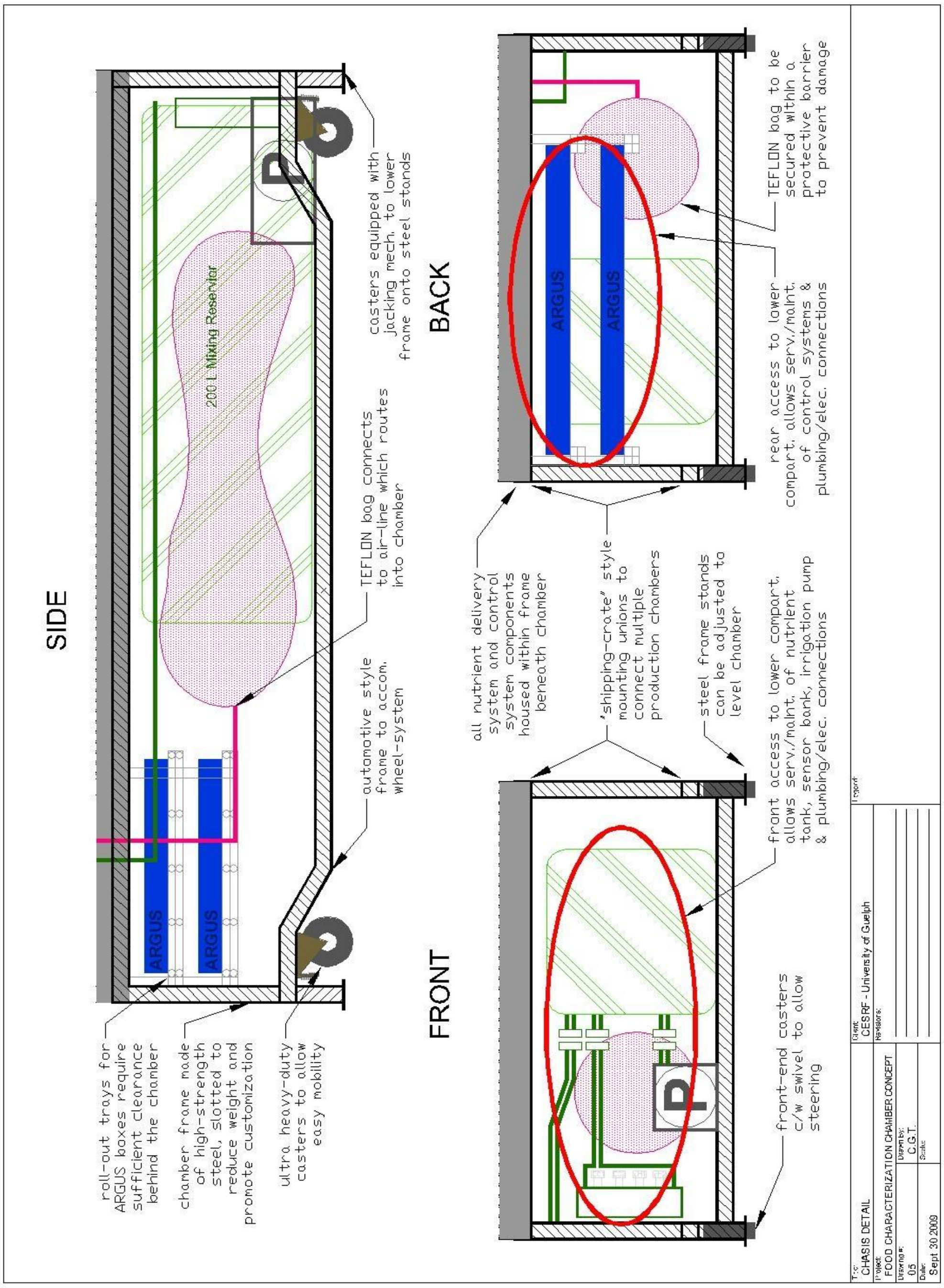

1.75
1.33
1.20
1.25
0.40
0.95
1.30
0.54
1.00
0.40
P
1.22
0.17
0.82
1.00
1.66
2.25
1.74
0.50
0.26
0.82
All units and mensions in meters unless otherwise specified
CHAMBER OVERVIEW
FOOD CHARACTERIZATION CHAMBER CONCEPT
10
C.G.T.
Sept 30 2009

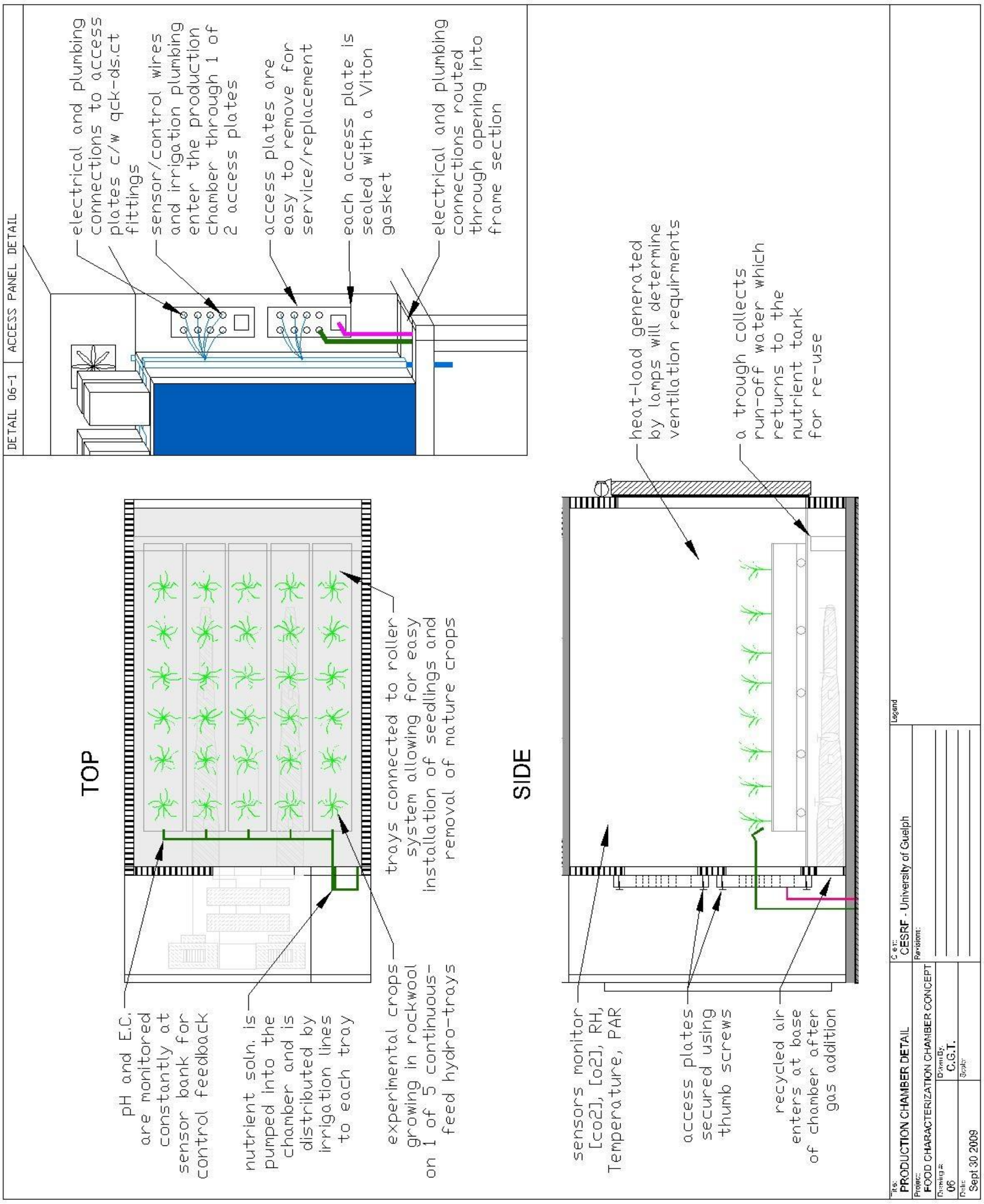

TOP
back door hinges heavy-duty
back door to be fitted with air-tight gasket
pluming/electrical routing area ~ open access to lower frame secction
hinges to open canopy for lamp access
light canopy made of steel frame and blue canopy material ~same as SEC-2
BACK
SIDE
FRONT
light ballasts 6 units
upper access port c/w removable plate & gasket
lower access port c/w removable plate & gasket
wire routing conduit
removable panel for control system access
heavy-duty casters c/w jacking mechanism
water pump
air intake grill for lamp cooling system
heavy-duty door hinge
chamber door c/w air-tight gasket
view-port
removable panel for nutrient delivery system access
200L nutrient tank c/w front access port for cleaning
nutrient sol. sensor bank located in lower frame section
heavy-duty steel support stands
Title:
CHAMBER OVERVIEW
Client:
CESRF - University of Guelph
Project:
FOOD CHARACTERIZATION CHAMBER CONCEPT
Revisions:
Drawing #:
01
Drawn By:
C.G.T.
Date:
Sept 30 2009
Scale:
Legend:

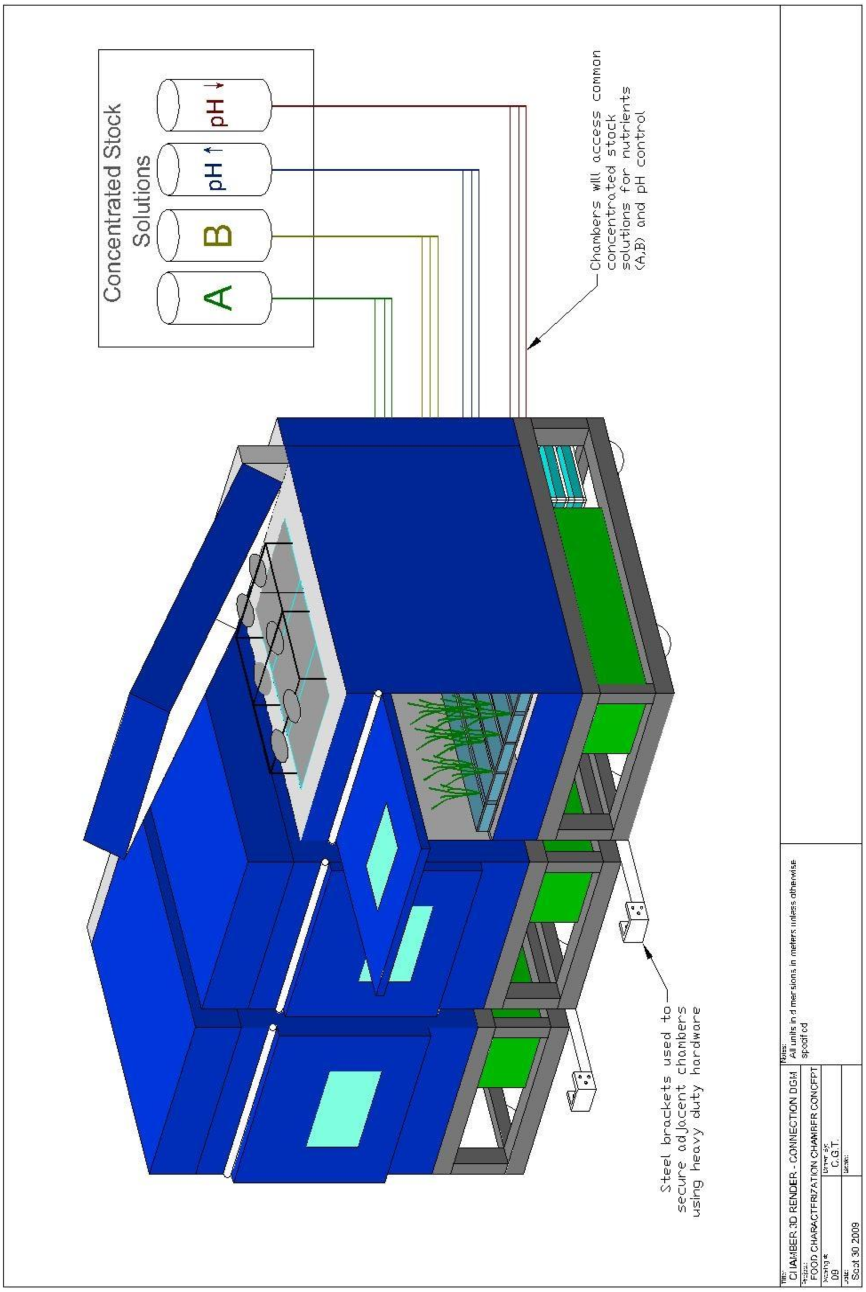

TOP
SIDE
FRONT
BACK
irrigation nozzle array fitted with flex hose & qck.dsct fitting to allow rolling action of trays
nutrient delivery system drainage pan c/w splash guard ~ routes to floor drain for recirc.
qck-ds.ct plate nutrient delivery system lines for easy part removal
mixing tank 200L
sensor bank c/w recirc. pump for EC and pH measurements
irrigation pump for nutrient delivery system
nurtrient delivery line
planting trays on roller-system for easy removal
experimental crop growing in tray
irrigation nozzle
nutrient delivery system interface c/w qck-ds.ct
nutrient delivery system controlled and monitored by ARGUS controller
P
ARGUS
Legend:
HYDROPONIC SYSTEM OVERVIEW
FOOD CHARACTERIZATION CHAMBER CONCEPT
CESRF - University of Guelph
112
C.G.T.
Sept 30 2009

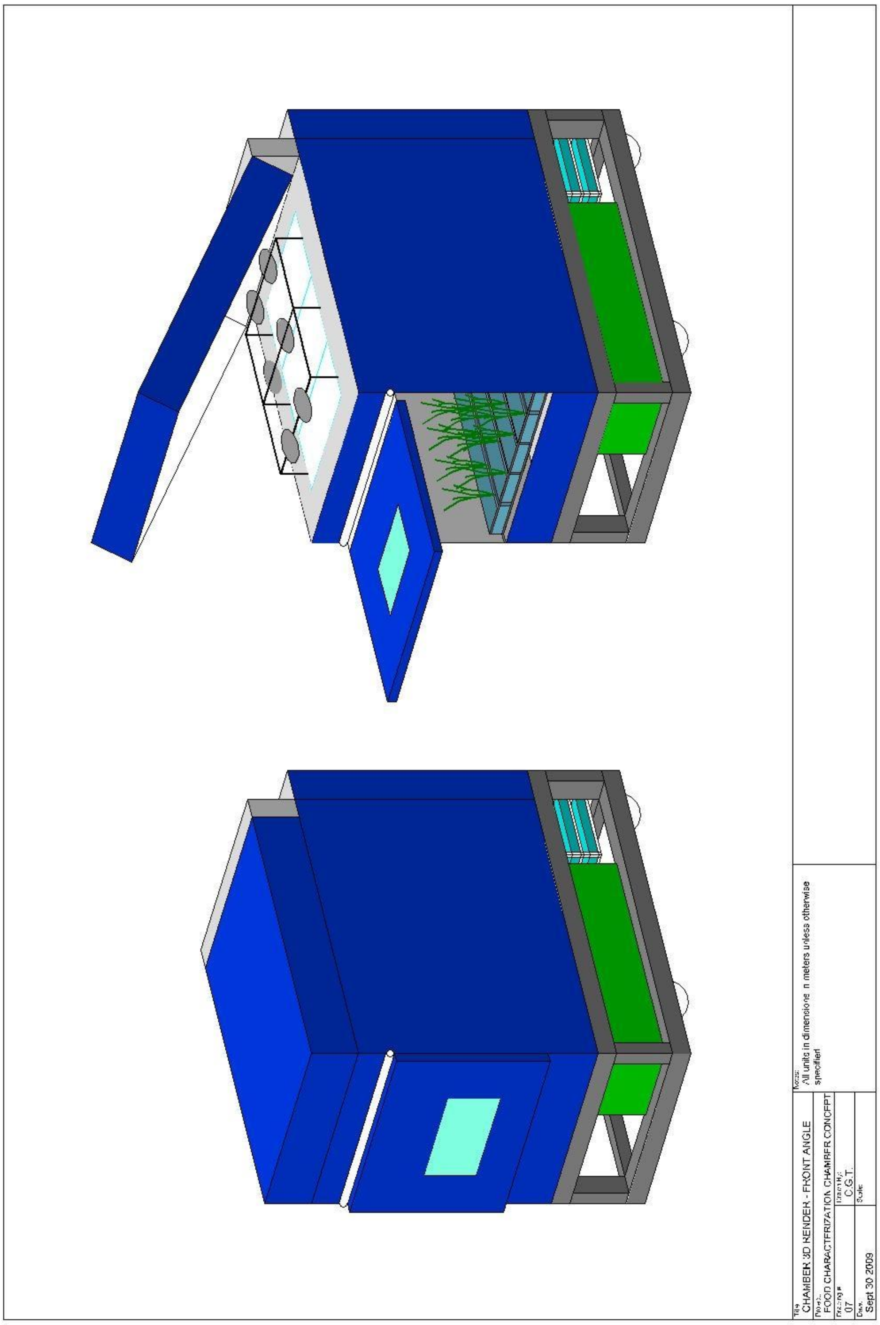

TOP
SIDE
BACK
FRONT
upper compartment of rear-chamber isolated and under negative pressure (relative to chamber)
dual blower fans routed into common ductwork
heat exchanger unit c/w heating and cooling coil & condensate collection
air distribution duct reduces diameter to promote uniform flow
fine adjustments to air flow uniformity to be made using air dampers and manual flow valves
small blower fans (3) for lamp ventilation
condensate collector
air sampling/gas addition occurs as air re-enters production chamber
curved duct to improve ventilation efficiency
TEFLON exp. bag connected to chamber through access plate
Intake grill for lamp ventilation
baffel to dir. air over lights
manual adjust. valve for air flow tuning
210L TEFLON expansion bag to accomodate gas expansion
dampers to adjust air flow
ARGUS
Title:
AIR-HANDLING SYSTEM OVERVIEW
Client:
CESRF - University of Guelph
Project:
FOOD CHARACTERIZATION CHAMBER CONCEPT
Drawing #:
03
Drawn By:
C.G.T.
Date:
Sept 30 2009
Scale:
Legend:

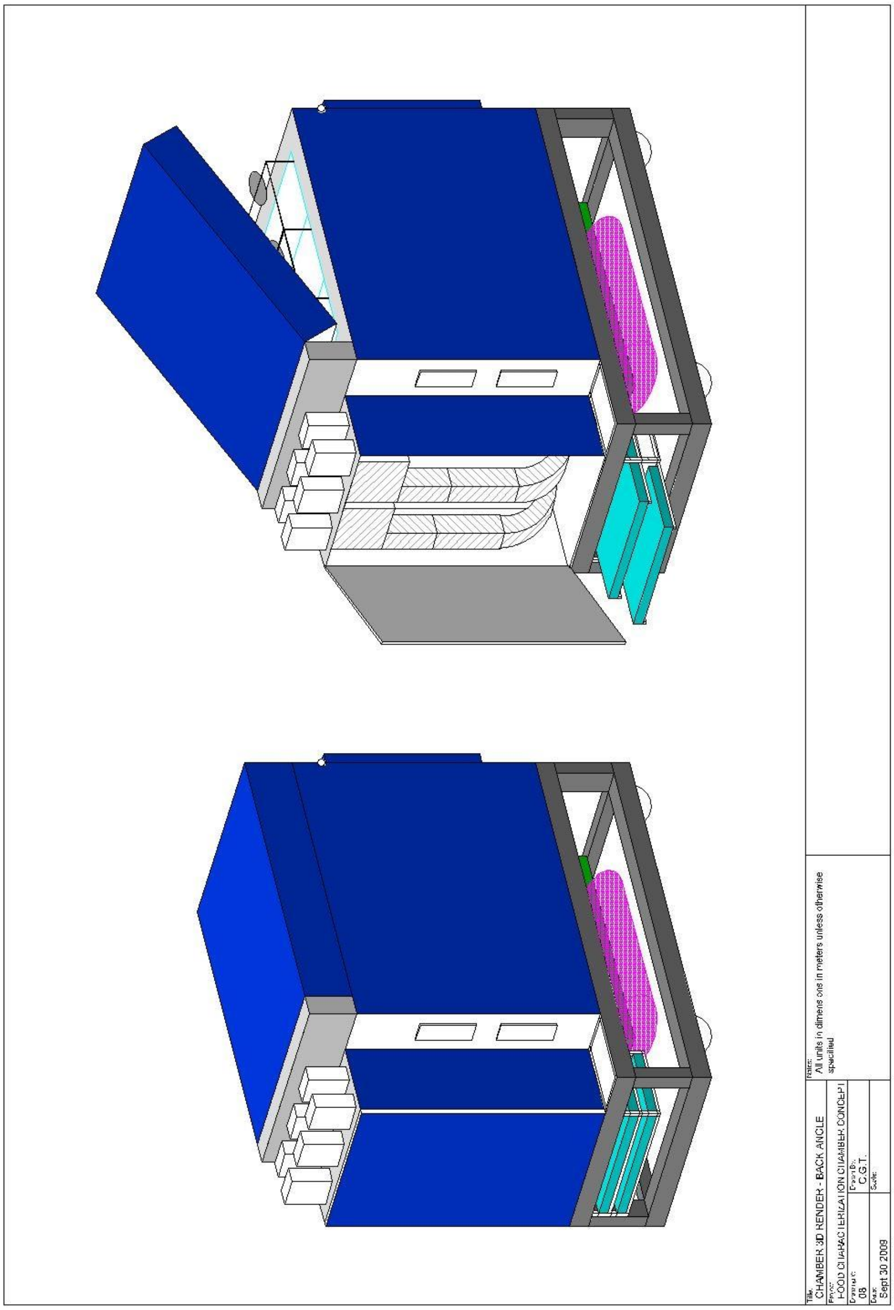

TOP
SIDE
FRONT
BACK
light fixutres 6x1000W MH or HPS bulbs operated by ARGUS controller
chamber environment monitored by sensors which provide data to ARGUS controller
nutrient delivery system sensor bank: pH, E.C.
elec. conduit to route nutrient system sensor and pump ctrl. network
irrigation pump operated by ARGUS controller
ventilation and temperature devices operated by ARGUS controller based on sensor data
flexible wire harness on lighting rig to allow canopy to open
lamp ballasts
upper chamber access port ~qck-dsct on sensor wires
elec. conduit for wire routing
lower chamber access port ~qck-dsct on sensor wires
ARGUS controller boxes (relays & control circuits) mounted on roll-out trays
sensor/control wires routed to ARGUS using flexible harness
ARGUS
P
ELECTRICAL SYSTEM OVERIVEW
FOOD CHARACTERIZATION CHAMBER CONCEPT
CESRF - University of Guelph
Drawing #: 04
Drawn By: C.G.T.
Date: Sept 30 2009
Legend:


SIDE
200 L Mixing Reservoir
P
ARGUS
ARGUS
casters equipped with jacking mech. to lower frame onto steel stands
TEFLON bag connects to air-line which routes into chamber
automotive style frame to accom. wheel-system
roll-out trays for ARGUS boxes require sufficient clearance behind the chamber
chamber frame made of high-strength steel, slotted to reduce weight and promote customization
ultra heavy-duty casters to allow easy mobility
BACK
ARGUS
ARGUS
TEFLON bag to be secured within a protective barrier to prevent damage
rear access to lower compart. allows serv./maint. of control systems & plumbing/elec. connections
all nutrient delivery system and control system components housed within frame beneath chamber
"shipping-crate" style mounting unions to connect multiple production chambers
steel frame stands can be adjusted to level chamber
front access to lower compart. allows serv./maint. of nutrient tank, sensor bank, irrigation pump & plumbing/elec. connections
FRONT
P
front-end casters c/w swivel to allow steering
Title: CHASIS DETAIL
Project: FOOD CHARACTERIZATION CHAMBER CONCEPT
Drawing #: 05
Date: Sept 30 2009
Client: CESRF - University of Guelph
Revisions:
Drawn by: C.G.T.
Scale:
Export:


DETAIL 06-1
ACCESS PANEL DETAIL
electrical and plumbing connections to access plates c/w qck-ds.ct fittings
sensor/control wires and irrigation plumbing enter the production chamber through 1 of 2 access plates
access plates are easy to remove for service/replacement
each access plate is sealed with a Viton gasket
electrical and plumbing connections routed through opening into frame section
TOP
trays connected to roller system allowing for easy installation of seedlings and removal of mature crops
pH and E.C. are monitored constantly at sensor bank for control feedback
nutrient soln. is pumped into the chamber and is distributed by irrigation lines to each tray
experimental crops growing in rockwool on 1 of 5 continuous-feed hydro-trays
SIDE
heat-load generated by lamps will determine ventilation requirments
a trough collects run-off water which returns to the nutrient tank for re-use
sensors monitor [co2], [o2], RH, Temperature, PAR
access plates secured using thumb screws
recycled air enters at base of chamber after gas addition
Title:
PRODUCTION CHAMBER DETAIL
Client:
CESRF - University of Guelph
Project:
FOOD CHARACTERIZATION CHAMBER CONCEPT
Revisions:
Drawing #:
06
Drawn By:
C.G.T.
Date:
Sept 30 2009
Scale:
Legend


Concentrated Stock Solutions
A
B
pH ↑
pH ↓
Chambers will access common concentrated stock solutions for nutrients (A,B) and pH control
Steel brackets used to secure adjacent chambers using heavy duty hardware
Title: CHAMBER 3D RENDER - CONNECTION DGM
Project: FOOD CHARACTERIZATION CHAMBER CONCEPT
Drawing #: 09
Drawn by: C.G.T.
Scale:
Date: Sept 30 2009
Notes: All units in dimensions in meters unless otherwise specified


Title
CHAMBER 3D RENDER - FRONT ANGLE
Project:
FOOD CHARACTERIZATION CHAMBER CONCEPT
Drawing #
07
Drawn By:
C.G.T.
Date:
Sept 30 2009
Scale:
Notes:
All units in dimensions in meters unless otherwise specified


Title:
CHAMBER 3D RENDER - BACK ANGLE
Project:
FOOD CHARACTERIZATION CHAMBER CONCEPT
Drawing #:
08
Drawn By:
C.G.T.
Date:
Sept 30 2009
Scale:
Notes:
All units in dimensions in meters unless otherwise specified