PeaPod - Design Brief

Submission to the NASA/CSA Deep Space Food Challenge

Jayden Lefebvre - Lead Engineer jayden.lefebvre@mail.utoronto.ca

Revision 0.2 University of Toronto Agritech May 5th, 2021

Contents

1	Intr	oduction	2
	1.1	Purpose	2
	1.2	Framing Structure	2
	1.3	Scope and Justification	3
	1.4	Definitions	4
2	Fran	ning	5
	2.1	Opportunity	5
	2.2	Requirements	5
	2.3	Stakeholders	6
	2.4	Objectives	7
		2.4.1 High-Level	7
		2.4.2 Low-Level	7
	2.5	Metrics	8
	2.6	Constraints	10
	27	Critaria	10

1 Introduction

1.1 Purpose

The purpose of this design brief is to outline the requirements for a submission to the NASA/CSA Deep Space Food Challenge Phase 1 [1]. In doing so, it also documents the scope of a design submitted by University of Toronto Agritech (UTAG).

The goal of the Deep Space Food Challenge is for participants to "Create novel food production technologies or systems that require <u>minimal inputs</u> and <u>maximize safe</u>, <u>nutritious</u>, <u>and palatable food outputs</u> for <u>long-duration space missions</u>, and which have potential to benefit people on Earth." [2]

1.2 Framing Structure

This document achieves its purpose via "top-down" framing (Section 2), with each subsection's entries being derived from the entries of the previous¹.

- 2.1 Opportunity: A succinct scoped challenge statement.
- 2.2 Requirements: Categorical or scoping constraints.
- 2.3 Stakeholders: Persons and groups in consideration.
- 2.4.1 High-Level Objectives: Conceptual aims, DfX; derived from Requirements and Stakeholders.
- 2.4.2 Low-Level Objectives: Tactical goals; derived from HLOs.
- 2.5 Metrics: Quantitative measures of design success, fit, utility, etc; derived from LLOs.

¹Each objective and metric has a numbered reference to the entry it was derived from ($\underline{\mathbf{S}}$ takeholder $\underline{\mathbf{1}}$: S1, $\underline{\mathbf{H}}$ igh- $\underline{\mathbf{L}}$ evel Objective $\underline{\mathbf{8}}$: HL8, etc.)

1.3 Scope and Justification

Phase 1 development, testing, and assessment is scoped to terrestrial/Earth-like operational constraints [2]:

- Gravity (9.81 m/s^2) ;
- Ambient atmospheric pressure (101,325 Pa);
- Ambient atmospheric/"room" temperature (22 °C);
- Ambient atmospheric humidity (50 %RH);

In addition, it is important to note that the solution "need not meet the full nutritional requirements of future crews, but can contribute significantly to, and integrate with, a comprehensive food system." [2]

The three underlined criteria in the challenge statement in Section 1.1 have also helped to define the scope of this brief:

- 1. The longer the duration of the space mission (up to and including interplanetary travel and permanent colonization) the lesser the feasability of resupply ².
- 2. The lesser the feasability of resupply, and the more minimal the input (i.e. launch mass), the more the design will need to generate net-new food grown on-board during the mission ³.
- 3. The minimization of inputs (launch mass), the minimization of other negative criteria such as growth time, design complexity, etc. and the maximization of safety (pathogenic and otherwise) means that food animal growth has been deemed not feasible, and is outside the scope of this brief. Thus, the design should focus on food-producing plant (or crop) growth⁴.
- 4. Spacecraft are not good crop growth systems (lack of water access, proper lighting and nutrition, etc.), thus the design should encompass a crop growth environment that:
 - (a) provides of all necessary crop growth inputs (water, nutrients, lighting, etc.)

²Minimal resupply is also listed as a constraint directly in the challenge details [2].

³Any other food production technologies would be taking advantage of existing food; as such this is the basis for the problem.

⁴This is primarily an issue in-transit; for colonization, non-plant food production systems should definitely be considered.

- (b) contains or otherwise encompasses a viable crop growth environment (temperature, humidity, gas concentrations, airflow, etc.)
- (c) has control over all parameters of both a) and b) (environment parameters); these together are the (crop growth) environment conditions.
- 5. To maximise safety (of both the crops and the crew) and redundancy, and to minimize inputs (required human interaction), the environment should be automated and isolated from the spacecraft cabin with regards to all environment conditions (thermally, water-tight, etc.) unless beneficial and efficient (i.e no loss).
- 6. A greater degree of nutrition and palatability of food outputs implies a greater variety of crops (incl. leafy greens, fruits/fruiting vegetables, root vegetables, algaes, etc.); as such the food production system should be able to generate a continuous variety of environmental conditions such that any number of food crops could be grown within.
- 7. The demand for high crop variety, automation, parameter control, etc. implies the use of a hydroponic/aeroponic/hybrid crop growth method.

1.4 Definitions

A number of useful definitions have emerged from the above scoping:

- 1. (Crop Growth) Environment The environment within which the crop grows/with which the crop interacts; the environment parameters in terms of their relationship with the crop and its growth.
- 2. (Crop Growth) Environment Parameters The (often quantitative) parameters of the crop environment, as well as any and all other parameters relevant to crop growth.
- 3. Crop Growth System Includes the physical enclosure (containing the crops and the controlled environment; incl. isolation) as well as any infrastructure required to generate the crop growth environment and control all environment conditions; satisfies all requirements of this brief.

2 Framing

2.1 Opportunity

Design a fully automated and isolated hydroponic/aeroponic crop growth system for the Deep Space Food Challenge Phase 1[1], able to generate any environment from a combination of independent environment parameters.

2.2 Requirements

Compiled from DSFC Applicant Guide details [2] and an excerpt of NASA-STD-3001: Section 7.1 Food and Nutrition⁵ [3]:

- 1. Helps fill food gaps for a **three-year** round-trip mission with **no resupply**:
 - (a) Feeds a crew of **four (4)** people;
 - (b) Provides the capability to maintain food safety and nutrition **during all phases** of the mission;
 - (c) Provides food that is *acceptable* to the crew **for the duration** of the mission;
 - (d) Produces varied, safe, nutritious, and palatable food outputs that can provide all daily nutritional needs and require little processing time⁶ for crew members;
- 2. Improve the accessibility of food on Earth; in particular, via production directly in urban centres and in remote and harsh environments:
 - (a) Enhance local production;
 - (b) Reduce food supply chain shortages;
 - (c) Reduce the impact on the resources needed for food production;
 - (d) Able to operate in harsh and remote environments;

⁵Additional nutrition and caloric output constraints relative to activity level, crew details, etc. are provided; however they are not in direct consideration as of Phase 1.

⁶It is assumed that fresh (or packaged unprepared) edible plant products are already prepared on existing space missions, and that this preparation meets this requirement; thus, preparation time is outside the scope of this design brief.

- 3. Achieve the greatest amount of food output with minimal inputs and minimal waste;
- 4. Transmits **operational data and limited video** to a remote location, and receives periodic **operational commands**.

Extracted from scoping:

4. Must be able to operate under Earth-like conditions (See Section 1.3);

2.3 Stakeholders

- 1. Food Product Consumers
- 2. NASA/CSA Stakeholders Spacecraft feasability and optimization criteria
- 3. Crops Crop growth metrics

2.4 Objectives

2.4.1 High-Level

1.	Food Output Suitability (S1, F	R1, R1a, R2a)	4.	Cross-Contamination (S1, S	S2, R1c)
2.	Environment Control, Autor	mation, and	5.	Safety, Redundancy (S1, S2, R2	1b, R2b)
	Optimization (S2, S3, R1b, F	R2c, R2d, R3)	6.	Modularity, Repairability (S1, S	S2, R2d)
3.	Efficiency (S1, S2, R1, F	R2a, R2c, R3)	7.	Feasability	(S2)
2.4.2	Low-Level				
1.	Output Food Variety	(HL1)	20.	Gas Exchange Incentive	(HL3)
2.	Output Food Palatability	(HL1)	21.	Number of Harvests	(HL3)
3.	Nutrient Output	(HL1)	22.	Time-To-Harvest/-Reharvest	(HL3)
4.	Energy Output	(HL1, HL4)	23.	Germination Time	(HL3)
5.	Air Temperature Control	(HL2)	24.	Growth Time	(HL3)
6.	Air Humidity Control	(HL2)	25.	Potential for Cross-Contamination	n (HL4)
7.	Gas Concentration Control	(HL2)	26.	Structural Safety	(HL5)
8.	Lighting Control	(HL2)	27.	Electrical/Power Safety	(HL5)
9.	Light Isolation	(HL2)	28.	Power Supply Redundancy	(HL5)
10.	Thermal Isolation	(HL2)	29.	Infrastructure Redundancy	(HL5)
11.	Water-tightness	(HL2, HL5)	30.	Growth Container Modularity	(HL6)
12.	Airflow	(HL2)	31.	Infrastructure Modularity Suppor	t (HL6)
13.	Water Flow Rate	(HL2)	32.	Growth Container Repairability	(HL6)
14.	Water Temperature	(HL2)	33.	Infrastructure Repairability	(HL6)
15.	Germination Success	(HL2)	34.	Documentation Completion	(HL6)
16.	High Degree of Automation	(HL3)	35.	Design Complexity	(HL6)
17.	Energy Efficiency	(HL3)	36.	Tool Speciality and Number	(HL6)
18.	Water Usage Efficiency	(HL3)	37.	Cost	(HL7)
19.	Plant Matter Usage	(HL3)	38.	Size	(HL7)

2.5 Metrics

CO ₂ Concentration Control Range (LL7) min, max ppm CO ₂ CO ₂ Concentration Control Rate (LL7) ppm CO ₂ /sec at each ppm CO ₂ CO ₂ Concentration Control Stability (LL7) ±ppm CO ₂ at each ppm CO ₂ CO ₂ Concentration Control Range (LL7) min, max ppm O ₂ CO ₂ Concentration Control Rate (LL7) ppm O ₂ /sec at each ppm O ₂ CO ₂ Concentration Control Rate (LL7) ppm O ₂ /sec at each ppm O ₂ CO ₂ Concentration Control Stability (LL7) ±ppm O ₂ at each ppm O ₂ Light Spectrum Wavelength Control Range (LL8) min, max nm Light Spectrum Intensity Control Range (LL8) min, max \(\mu\)mol m ⁻² sec ⁻¹ at each nm Light Spectrum Intensity Control Stability (LL8) ±\(\mu\)mol m ⁻² sec ⁻¹ at each nm Light Captured by Non-Photosynthetic Surfaces (LL9) % COutside Light Penetration (LL9) % Heat Transfer (LL10) ±W at each °C Water Loss due to Leaks, Evaporation (LL11) mL/hr Internal Circulation Airflow Control Range (LL12) min, max m ³ /min Gas Exchange due to Leaks (LL12) m ³ /min Maximum Intentional Gas Exchange (LL12) min, max mL/plant/sec Nutrient Solution Delivery Rate Control Range (LL13) min, max mL/plant/sec	#	Metric		Units
Crop Nutrient Concentration	1	Number of Suitable Crop Species	(LL1)	# (per crop)
4 Protein Output Density (LL3) g/kg 5 Protein Output (LL3) KCal/crewmember (%TDEI) 6 Carbohydrate Output (LL3) KCal/crewmember (%TDEI) 7 Lipid Output (LL3) KCal/crewmember (%TDEI) 8 Ω-6 Fatty Acid Output (LL3) g/day/crewmember 9 Ω-3 Fatty Acid Output (LL3) g/day/crewmember 10 Saturated Fat Output (LL3) KCal/crewmember (%TDEI) 11 Trans Fatty Acids Output (LL3) KCal/crewmember (%TDEI) 12 Cholesterol Output (LL3) KCal/crewmember 13 Fiber Output (LL3) g/day/crewmember 14 Caloric Output per Day (LL4) KCal/24hr 15 Air Temperature Control Range (LL5) min, max °C 16 Air Temperature Control Rate (LL5) πin, max °C 17 Air Temperature Control Stability (LL5) πin, max %RH 18 Air Humidity Control Range (LL6) min, max %RH 19 Air Humidity Control Range (LL6) min, max %RH 20 Air Humidity Control Range (LL6) min, max mRH 21 CO₂ Concentration Control Range (LL7) min, max ppm CO₂ 22 CO₂ Concentration Control Rate (LL7) ppm CO₂/sec at each ppm CO₂ 23 CO₂ Concentration Control Rate (LL7) ppm CO₂/sec at each ppm CO₂ 24 O₂ Concentration Control Rate (LL7) ppm CO₂/sec at each ppm CO₂ 25 CO₂ Concentration Control Range (LL7) min, max ppm O₂ 26 O₂ Concentration Control Range (LL7) ppm O₂/sec at each ppm CO₂ 27 Light Spectrum Intensity Control Range (LL8) min, max mm 28 Light Spectrum PAR Match (LL8) πin, max mm 29 Light Spectrum PAR Match (LL8) πin, max mm 20 Light Spectrum Intensity Control Range (LL8) min, max mm 21 Light Spectrum Intensity Control Range (LL8) min, max mm 22 Light Spectrum Intensity Control Range (LL8) min, max mm 23 Light Spectrum Intensity Control Stability (LL9) πin, max mm 24 Light Spectrum Intensity Control Range (LL8) min, max mm 25 Light Spectrum Intensity Control Range (LL8) min, max mm 26 Light Spectrum Intensity Control Range (LL9) πin, max mm 27 Light Spectrum Intensity Control Range (LL9) πin, max mm 28 Light Spectrum Intensity Control Range (LL9) πin, max mm 30 Light Spectrum Intensity Control Range (LL9) πin, max mm 31 Light Captured by Non-Photosynthetic Surfaces (LP9) πin, max mm/nin min, max mp/nin mi	2	Quality/Palatability of Crop Output	(LL2)	1-10 (per crop)
Protein Output	3	Crop Nutrient Concentration	(LL3)	% (per crop)
Carbohydrate Output	4	Protein Output Density	(LL3)	g/kg
Lipid Output	5	Protein Output	(LL3)	kCal/crewmember (%TDEI)
8 Ω-6 Fatty Acid Output (LL3) g/day/crewmember 9 Ω-3 Fatty Acid Output (LL3) g/day/crewmember 10 Saturated Fat Output (LL3) kCal/crewmember (%TDEI) 11 Trans Fatty Acids Output (LL3) kCal/crewmember (%TDEI) 12 Cholesterol Output (LL3) mg/day/crewmember 13 Fiber Output (LL3) g/day/crewmember 14 Caloric Output per Day (LL4) kCal/24hr 15 Air Temperature Control Range (LL5) min, max °C 16 Air Temperature Control Rate (LL5) min, max °RH 17 Air Temperature Control Range (LL6) min, max °RH 18 Air Humidity Control Range (LL6) min, max °RH 19 Air Humidity Control Rate (LL6) *RRH/sec at each °C 20 Air Humidity Control Range (LL7) min, max ppm CO ₂ 21 CO ₂ Concentration Control Range (LL7) min, max ppm CO ₂ 22 CO ₂ Concentration Control Stability (LL7) <t< td=""><td>6</td><td>Carbohydrate Output</td><td>(LL3)</td><td>kCal/crewmember (%TDEI)</td></t<>	6	Carbohydrate Output	(LL3)	kCal/crewmember (%TDEI)
9 Ω-3 Fatty Acid Output (LL3) g/day/crewmember 10 Saturated Fat Output (LL3) kCal/crewmember (%TDEI) 11 Trans Fatty Acids Output (LL3) kCal/crewmember (%TDEI) 12 Cholesterol Output (LL3) mg/day/crewmember (%TDEI) 13 Fiber Output (LL3) g/day/crewmember 14 Caloric Output per Day (LL4) kCal/24hr 15 Air Temperature Control Range (LL5) min, max "C 16 Air Temperature Control Rate (LL5) "C/sec at each "C 17 Air Temperature Control Stability (LL5) ±°C at each "C 18 Air Humidity Control Range (LL6) min, max %RH 19 Air Humidity Control Rate (LL6) "&RH/sec at each "RH 20 Air Humidity Control Range (LL6) #\$\frac{1}{2}\$ xRH at each %RH 21 CO2 Concentration Control Range (LL7) min, max ppm CO2 22 CO2 Concentration Control Stability (LL7) ±ppm CO2/sec at each ppm CO2 23 CO2 Concentration Control Stability (LL7) ±ppm CO2/sec at each ppm CO2 24 O2 Concentration Control Range (LL7) min, max ppm O2 25 O2 Concentration Control Range (LL7) min, max ppm O2 26 O2 Concentration Control Rate (LL7) ppm O2/sec at each ppm O2 27 Light Spectrum Wavelength Control Range (LL8) min, max mm 28 Light Spectrum Intensity Control Range (LL8) min, max μmol m "2 sec "1 at each nm 30 Light Spectrum Intensity Control Stability (LL8) ±μmol m "2 sec "1 at each nm 31 Light Captured by Non-Photosynthetic Surfaces (LL9) " 32 Outside Light Penetration (LL9) " 33 Heat Transfer (LL10) ±W at each "C 34 Water Loss due to Leaks, Evaporation (LL11) mL/hr 35 Internal Circulation Airflow Control Range (LL12) min, max m³/min 36 Gas Exchange due to Leaks (L112) min, max mL/plant/sec 39 Nutrient Solution Delivery Rate Control Range (LL13) min, max mL/plant/sec	7	Lipid Output	(LL3)	kCal/crewmember (%TDEI)
Saturated Fat Output	8	Ω-6 Fatty Acid Output	(LL3)	g/day/crewmember
11 Trans Fatty Acids Output (LL3) kCal/crewmember (%TDEI) 12 Cholesterol Output (LL3) mg/day/crewmember 13 Fiber Output (LL4) mg/day/crewmember 14 Caloric Output per Day (LL4) kCal/24hr 15 Air Temperature Control Range (LL5) min, max °C 16 Air Temperature Control Rate (LL5) *C/sec at each °C 17 Air Temperature Control Stability (LL5) *£°C at each °C 18 Air Humidity Control Range (LL6) min, max %RH 19 Air Humidity Control Rate (LL6) *RH/sec at each %RH 20 Air Humidity Control Stability (LL6) *#RH at each %RH 21 CO ₂ Concentration Control Range (LL7) min, max ppm CO ₂ 22 CO ₂ Concentration Control Range (LL7) ppm CO ₂ /sec at each ppm CO ₂ 24 O ₂ Concentration Control Range (LL7) min, max ppm O ₂ 25 O ₂ Concentration Control Stability (LL7) *ppm O ₂ /sec at each ppm O ₂ 26 O ₂ Concentration Control Stability (LL8) min, max nm	9	Ω-3 Fatty Acid Output	(LL3)	g/day/crewmember
Cholesterol Output (LL3) mg/day/crewmember	10	Saturated Fat Output	(LL3)	kCal/crewmember (%TDEI)
Fiber Output (LL3) g/day/crewmember Caloric Output per Day (LL4) kCal/24hr Air Temperature Control Range (LL5) min, max °C Air Temperature Control Rate (LL5) ±°C at each °C Air Temperature Control Stability (LL5) ±°C at each °C Air Humidity Control Range (LL6) min, max %RH Air Humidity Control Rate (LL6) %RH/sec at each %RH Air Humidity Control Stability (LL6) ±%RH at each %RH Air Humidity Control Range (LL7) min, max ppm CO₂ CO₂ Concentration Control Range (LL7) min, max ppm CO₂ CO₂ Concentration Control Rate (LL7) ppm CO₂/sec at each ppm CO₂ CO₂ Concentration Control Range (LL7) min, max ppm O₂ CO₂ Concentration Control Range (LL7) min, max ppm O₂ CO₂ Concentration Control Range (LL7) min, max ppm O₂ Co₂ Concentration Control Range (LL7) min, max ppm O₂ Co₂ Concentration Control Range (LL7) min, max ppm O₂ Co₂ Concentration Control Rate (LL7) ppm O₂/sec at each ppm O₂ Co₂ Concentration Control Range (LL8) min, max nm Light Spectrum Wavelength Control Range (LL8) min, max nm Light Spectrum Intensity Control Range (LL8) min, max µmol m⁻² sec⁻¹ at each nm Light Spectrum Intensity Control Stability (LL8) ±µmol m⁻² sec⁻¹ at each nm Light Captured by Non-Photosynthetic Surfaces (LL9) % Outside Light Penetration (LL9) % Heat Transfer (LL10) ±W at each °C Water Loss due to Leaks, Evaporation (LL11) mL/hr Internal Circulation Airflow Control Range (LL12) min, max m³/min Gas Exchange due to Leaks (LL12) min, max mL/plant/sec Nutrient Solution Delivery Rate Control Range (LL13) min, max mL/plant/sec	11	Trans Fatty Acids Output	(LL3)	kCal/crewmember (%TDEI)
14Caloric Output per Day(LL4)kCal/24hr15Air Temperature Control Range(LL5)min, max °C16Air Temperature Control Rate(LL5)°C/sec at each °C17Air Temperature Control Stability(LL5)±°C at each °C18Air Humidity Control Range(LL6)min, max %RH19Air Humidity Control Rate(LL6)%RH/sec at each %RH20Air Humidity Control Stability(LL6)±%RH at each %RH21CO₂ Concentration Control Range(LL7)min, max ppm CO₂22CO₂ Concentration Control Rate(LL7)ppm CO₂/sec at each ppm CO₂23CO₂ Concentration Control Stability(LL7)±ppm CO₂ at each ppm CO₂24O₂ Concentration Control Range(LL7)min, max ppm O₂25O₂ Concentration Control Rate(LL7)ppm O₂/sec at each ppm O₂26O₂ Concentration Control Stability(LL7)±ppm O₂ at each ppm O₂27Light Spectrum Wavelength Control Range(LL8)min, max nm28Light Spectrum Intensity Control Range(LL8)min, max μmol m⁻² sec⁻¹ at each nm30Light Spectrum Intensity Control Stability(LL8)±μmol m⁻² sec⁻¹ at each nm31Light Captured by Non-Photosynthetic Surfaces(LL9)%32Outside Light Penetration(LL9)%33Heat Transfer(LL10)±W at each °C34Water Loss due to Leaks, Evaporation(LL11)miL/hr35Internal Circulation Airflow Control	12	Cholesterol Output	(LL3)	mg/day/crewmember
Air Temperature Control Rate Air Temperature Control Rate (LL5) "C/sec at each "C Air Temperature Control Stability (LL5) ± °C at each °C Air Temperature Control Stability (LL6) min, max %RH Air Humidity Control Rate (LL6) min, max %RH Air Humidity Control Rate (LL6) %RH/sec at each %RH Air Humidity Control Stability (LL6) ± **RH at each %RH CO₂ Concentration Control Range (LL7) min, max ppm CO₂ CO₂ Concentration Control Rate (LL7) ppm CO₂/sec at each ppm CO₂ CO₂ Concentration Control Stability (LL7) ±ppm CO₂ at each ppm CO₂ CO₂ Concentration Control Range (LL7) min, max ppm O₂ CO₂ Concentration Control Range (LL7) min, max ppm O₂ Light Spectrum Wavelength Control Range (LL7) ppm O₂/sec at each ppm O₂ Light Spectrum PAR Match (LL8) min, max nm Light Spectrum Intensity Control Range (LL8) min, max μmol m⁻² sec⁻¹ at each nm Light Captured by Non-Photosynthetic Surfaces Light Captured by Non-Photosynthetic Surfaces Light Captured by Non-Photosynthetic Surfaces Light Penetration (LL9) % Heat Transfer (LL10) ± W at each °C Mater Loss due to Leaks, Evaporation Light Captured by Leaks, Evaporation Light Captured Solution Airflow Control Range (LL12) min, max m³/min Maximum Intentional Gas Exchange (LL12) min, max mL/plant/sec Nutrient Solution Delivery Rate Control Range (LL13) min, max mL/plant/sec	13	Fiber Output	(LL3)	g/day/crewmember
Air Temperature Control Rate (LL5) °C/sec at each °C 17 Air Temperature Control Stability (LL5) ±°C at each °C 18 Air Humidity Control Range (LL6) min, max %RH 19 Air Humidity Control Rate (LL6) %RH/sec at each %RH 20 Air Humidity Control Stability (LL6) ±%RH at each %RH 21 CO₂ Concentration Control Range (LL7) min, max ppm CO₂ 22 CO₂ Concentration Control Rate (LL7) ppm CO₂/sec at each ppm CO₂ 23 CO₂ Concentration Control Stability (LL7) ±ppm CO₂ at each ppm CO₂ 24 O₂ Concentration Control Range (LL7) min, max ppm O₂ 25 O₂ Concentration Control Rate (LL7) ppm O₂/sec at each ppm O₂ 26 O₂ Concentration Control Stability (LL7) ±ppm O₂/sec at each ppm O₂ 27 Light Spectrum Wavelength Control Range (LL8) min, max nm 28 Light Spectrum Intensity Control Range (LL8) % (each crop) 29 Light Spectrum Intensity Control Range (LL8) min, max μmol m⁻² sec⁻¹ at each nm 30 Light Spectrum Intensity Control Stability (LL8) ±μmol m⁻² sec⁻¹ at each nm 31 Light Captured by Non-Photosynthetic Surfaces (LL9) % 32 Outside Light Penetration (LL9) % 33 Heat Transfer (LL10) ±W at each °C 34 Water Loss due to Leaks, Evaporation (LL11) mL/hr 35 Internal Circulation Airflow Control Range (LL12) min, max m³/min 36 Gas Exchange due to Leaks (LL12) min, max m1/plant/sec 39 Nutrient Solution Delivery Rate Control Range (LL13) min, max mL/plant/sec	14	Caloric Output per Day	(LL4)	kCal/24hr
Air Temperature Control Stability Air Humidity Control Range (LL6) min, max %RH Air Humidity Control Rate (LL6) %RH/sec at each %RH Air Humidity Control Stability (LL6) ±%RH at each %RH CO ₂ Concentration Control Range (LL7) min, max ppm CO ₂ CO ₂ Concentration Control Rate (LL7) ppm CO ₂ /sec at each ppm CO ₂ CO ₂ Concentration Control Stability (LL7) ±ppm CO ₂ at each ppm CO ₂ CO ₂ Concentration Control Stability (LL7) ±ppm CO ₂ at each ppm CO ₂ CO ₂ Concentration Control Range (LL7) min, max ppm O ₂ CO ₂ Concentration Control Range (LL7) ppm O ₂ /sec at each ppm O ₂ CO ₂ Concentration Control Rate (LL7) ppm O ₂ /sec at each ppm O ₂ Light Spectrum Control Stability (LL7) ±ppm O ₂ at each ppm O ₂ Light Spectrum Wavelength Control Range (LL8) min, max mm Light Spectrum PAR Match (LL8) % (each crop) Light Spectrum Intensity Control Range (LL8) min, max µmol m ⁻² sec ⁻¹ at each nm Light Spectrum Intensity Control Stability (LL8) ±µmol m ⁻² sec ⁻¹ at each nm Light Captured by Non-Photosynthetic Surfaces (LL9) % Coutside Light Penetration (LL9) % Heat Transfer (LL10) ±W at each °C Water Loss due to Leaks, Evaporation (LL11) mL/hr Internal Circulation Airflow Control Range (LL12) min, max m³/min Maximum Intentional Gas Exchange (LL12) m³/min Maximum Intentional Gas Exchange (LL13) min, max mL/plant/sec	15	Air Temperature Control Range	(LL5)	min, max °C
Air Humidity Control Range (LL6) min, max %RH Air Humidity Control Rate (LL6) %RH/sec at each %RH CO Air Humidity Control Stability (LL6) ±%RH at each %RH CO ₂ Concentration Control Range (LL7) min, max ppm CO ₂ CO ₂ Concentration Control Rate (LL7) ppm CO ₂ /sec at each ppm CO ₂ CO ₂ Concentration Control Stability (LL7) ±ppm CO ₂ at each ppm CO ₂ CO ₂ Concentration Control Range (LL7) min, max ppm O ₂ CO ₂ Concentration Control Range (LL7) min, max ppm O ₂ CO ₂ Concentration Control Range (LL7) ppm O ₂ /sec at each ppm O ₂ CO ₂ Concentration Control Range (LL7) ppm O ₂ /sec at each ppm O ₂ Light Spectrum Wavelength Control Range (LL8) min, max nm Light Spectrum PAR Match (LL8) % (each crop) Light Spectrum Intensity Control Range (LL8) min, max μmol m ⁻² sec ⁻¹ at each nm Light Spectrum Intensity Control Stability (LL8) ±μmol m ⁻² sec ⁻¹ at each nm Light Captured by Non-Photosynthetic Surfaces (LL9) % Outside Light Penetration (LL9) % Heat Transfer (LL10) ±W at each °C Water Loss due to Leaks, Evaporation (LL11) mL/hr Internal Circulation Airflow Control Range (LL12) min, max m³/min Gas Exchange due to Leaks (LL12) mi/min min, max mL/plant/sec Nutrient Solution Delivery Rate Control Range (LL13) min, max mL/plant/sec	16	Air Temperature Control Rate	(LL5)	°C/sec at each °C
Air Humidity Control Rate (LL6) %RH/sec at each %RH 20 Air Humidity Control Stability (LL6) ±%RH at each %RH 21 CO ₂ Concentration Control Range (LL7) min, max ppm CO ₂ 22 CO ₂ Concentration Control Rate (LL7) ppm CO ₂ /sec at each ppm CO ₂ 23 CO ₂ Concentration Control Stability (LL7) ±ppm CO ₂ at each ppm CO ₂ 24 O ₂ Concentration Control Range (LL7) min, max ppm O ₂ 25 O ₂ Concentration Control Rate (LL7) ppm O ₂ /sec at each ppm O ₂ 26 O ₂ Concentration Control Rate (LL7) ppm O ₂ /sec at each ppm O ₂ 27 Light Spectrum Wavelength Control Range (LL8) min, max nm 28 Light Spectrum PAR Match (LL8) % (each crop) 29 Light Spectrum Intensity Control Range (LL8) min, max μmol m ⁻² sec ⁻¹ at each nm 30 Light Spectrum Intensity Control Stability (LL8) ±μmol m ⁻² sec ⁻¹ at each nm 31 Light Captured by Non-Photosynthetic Surfaces (LL9) % 32 Outside Light Penetration (LL9) % 33 Heat Transfer (LL10) ±W at each °C 34 Water Loss due to Leaks, Evaporation (LL11) mL/hr 35 Internal Circulation Airflow Control Range (LL12) min, max m³/min 36 Gas Exchange due to Leaks (LL12) m³/min 37 Maximum Intentional Gas Exchange (LL13) min, max mL/plant/sec 39 Nutrient Solution Delivery Rate Control Range (LL13) mL/plant/sec ² at each mL/plant/sec	17	Air Temperature Control Stability	(LL5)	±°C at each °C
Air Humidity Control Stability (LL6) ±%RH at each %RH CO ₂ Concentration Control Range (LL7) min, max ppm CO ₂ CO ₂ Concentration Control Rate (LL7) ppm CO ₂ /sec at each ppm CO ₂ CO ₂ Concentration Control Stability (LL7) ±ppm CO ₂ at each ppm CO ₂ CO ₂ Concentration Control Range (LL7) min, max ppm O ₂ pmin, max ppm O ₂ CO ₂ Concentration Control Rate (LL7) ppm O ₂ /sec at each ppm O ₂ CO ₂ Concentration Control Rate (LL7) ppm O ₂ /sec at each ppm O ₂ Light Spectrum Control Stability Light Spectrum PAR Match (LL8) min, max nm Light Spectrum Intensity Control Range (LL8) min, max μmol m ⁻² sec ⁻¹ at each nm Light Spectrum Intensity Control Stability Light Spectrum Intensity Control Stability (LL8) ±μmol m ⁻² sec ⁻¹ at each nm Light Captured by Non-Photosynthetic Surfaces (LL9) % Outside Light Penetration (LL9) % Heat Transfer (LL10) ±W at each °C Water Loss due to Leaks, Evaporation (LL11) mL/hr Internal Circulation Airflow Control Range (LL12) min, max m³/min Gas Exchange due to Leaks (LL12) m³/min Maximum Intentional Gas Exchange (LL12) min, max mL/plant/sec Nutrient Solution Delivery Rate Control Range (LL13) mL/plant/sec ² at each mL/plant/sec	18	Air Humidity Control Range	(LL6)	min, max %RH
CO ₂ Concentration Control Range (LL7) min, max ppm CO ₂ CO ₂ Concentration Control Rate (LL7) ppm CO ₂ /sec at each ppm CO ₂ CO ₂ Concentration Control Stability (LL7) ±ppm CO ₂ at each ppm CO ₂ Lipht Concentration Control Range (LL7) min, max ppm O ₂ CO ₂ Concentration Control Range (LL7) ppm O ₂ /sec at each ppm CO ₂ Light Spectrum Control Stability Light Spectrum Wavelength Control Range Light Spectrum Intensity Control Stability Light Spectrum Intensity Control Stability Light Captured by Non-Photosynthetic Surfaces Light Spectrum Intensity L	19	Air Humidity Control Rate	(LL6)	%RH/sec at each %RH
CO ₂ Concentration Control Rate CUL7) ppm CO ₂ /sec at each ppm CO ₂ CO ₂ Concentration Control Stability (LL7) tppm CO ₂ at each ppm CO ₂ CO ₂ Concentration Control Range (LL7) min, max ppm O ₂ CO ₂ Concentration Control Rate (LL7) ppm O ₂ /sec at each ppm CO ₂ CO ₂ Concentration Control Rate (LL7) ppm O ₂ /sec at each ppm O ₂ CO ₂ Concentration Control Stability (LL7) tppm O ₂ at each ppm O ₂ Light Spectrum Wavelength Control Range (LL8) min, max nm Light Spectrum Intensity Control Range (LL8) min, max \(\mu\)mol m ⁻² sec ⁻¹ at each nm Light Spectrum Intensity Control Stability Light Spectrum Intensity Control Stability Light Captured by Non-Photosynthetic Surfaces (LL9) % Cutside Light Penetration (LL9) % Heat Transfer (LL10) twat each °C Water Loss due to Leaks, Evaporation (LL11) mL/hr Internal Circulation Airflow Control Range (LL12) min, max m³/min Gas Exchange due to Leaks (LL12) m³/min Maximum Intentional Gas Exchange (LL12) min, max mL/plant/sec Nutrient Solution Delivery Rate Control Range (LL13) mL/plant/sec ² at each mL/plant/sec	20	Air Humidity Control Stability	(LL6)	±%RH at each %RH
CO ₂ Concentration Control Stability (LL7) ±ppm CO ₂ at each ppm CO ₂ O ₂ Concentration Control Range (LL7) min, max ppm O ₂ D ₂ Concentration Control Rate (LL7) ppm O ₂ /sec at each ppm O ₂ CO ₂ Concentration Control Stability (LL7) ±ppm O ₂ at each ppm O ₂ Light Spectrum Wavelength Control Range (LL8) min, max nm Light Spectrum PAR Match (LL8) % (each crop) Light Spectrum Intensity Control Range (LL8) min, max μmol m ⁻² sec ⁻¹ at each nm Light Spectrum Intensity Control Stability (LL8) ±μmol m ⁻² sec ⁻¹ at each nm Light Captured by Non-Photosynthetic Surfaces (LL9) % Outside Light Penetration (LL9) % Heat Transfer (LL10) ±W at each °C Water Loss due to Leaks, Evaporation (LL11) mL/hr Internal Circulation Airflow Control Range (LL12) min, max m³/min Gas Exchange due to Leaks (LL12) m³/min Maximum Intentional Gas Exchange (LL13) min, max mL/plant/sec Nutrient Solution Delivery Rate Control Range (LL13) mL/plant/sec² at each mL/plant/sec	21	CO ₂ Concentration Control Range	(LL7)	min, max ppm CO ₂
O ₂ Concentration Control Range (LL7) min, max ppm O ₂ O ₂ Concentration Control Rate (LL7) ppm O ₂ /sec at each ppm O ₂ Concentration Control Stability (LL7) ±ppm O ₂ at each ppm O ₂ Light Spectrum Wavelength Control Range (LL8) min, max nm Light Spectrum PAR Match (LL8) % (each crop) Light Spectrum Intensity Control Range (LL8) min, max μmol m ⁻² sec ⁻¹ at each nm Light Spectrum Intensity Control Stability (LL8) ±μmol m ⁻² sec ⁻¹ at each nm Light Captured by Non-Photosynthetic Surfaces (LL9) % Coutside Light Penetration (LL9) % Light Transfer (LL10) ±W at each °C A Water Loss due to Leaks, Evaporation (LL11) mL/hr Light Captured Delivery Rate Control Range (LL12) min, max m³/min Maximum Intentional Gas Exchange (LL12) m³/min Nutrient Solution Delivery Rate Control Range (LL13) mL/plant/sec Nutrient Solution Delivery Rate Control Range (LL13) mL/plant/sec	22	CO ₂ Concentration Control Rate	(LL7)	ppm CO ₂ /sec at each ppm CO ₂
O ₂ Concentration Control Rate (LL7) ppm O ₂ /sec at each ppm O ₂ Light Spectrum Wavelength Control Range Light Spectrum PAR Match Light Spectrum Intensity Control Range Light Spectrum Intensity Control Range Light Spectrum Intensity Control Range Light Spectrum Intensity Control Stability Light Captured by Non-Photosynthetic Surfaces Light Spectrum Intensity Control Stability Light Captured by Non-Photosynthetic Surfaces Light Spectrum Intensity Control Stability Light Spectrum Intensity Control Stabil	23	CO ₂ Concentration Control Stability	(LL7)	±ppm CO ₂ at each ppm CO ₂
Concentration Control Stability Light Spectrum Wavelength Control Range Light Spectrum PAR Match Light Spectrum Intensity Control Range Light Spectrum Intensity Control Range Light Spectrum Intensity Control Range Light Spectrum Intensity Control Stability Light Spectrum Intensity Control Stability Light Captured by Non-Photosynthetic Surfaces Light Spectrum Intensity Control Stability Light Captured man min, max μmol m ⁻² sec ⁻¹ at each nm Light Captured by Non-Photosynthetic Surfaces (LL19) % Light Spectrum Intensity Control Stability Light Spectrum Intensity Control Stability Light Spectrum Intensity Control Stability Light Spectrum Intensity Control Range (LL19) % Light Spectrum Intensity Control Range (LL10) #W at each nm Light Captured by Non-Photosynthetic Surfaces (LL10) #W at each nm Light Captured by Non-Photosynthetic Surfaces (LL11) #W at each nm Light Captured by Non-Photosynthetic Surfaces (LL11) #W at each nm Light Captured by Non-Photosynthetic Surfaces (LL11) #W at each nm Light Captured by Non-Photosynthetic Surfaces (LL10) #W at each nm Light Captured by Non-Photosynthetic Surfaces (LL11) #W at each nm Light Captured by Non-Photosynthetic Surfaces (LL11) #W at each nm Light Captured by Non-Photosynthetic Surfaces (LL10) #W at each nm Light Captured by Non-Photosynthetic Surfaces (LL11) #W at each nm Light Captured by Non-Photosynthetic Surfaces (LL11) #W at each nm Light Captured by Non-Photosynthetic Surfaces Light Park Intensity Control Range (LL10) #W at each nm Light Captured by Non-Photosynthetic Surfaces Light Park Intensity Control Range (LL10) #W at each nm Light Captur	24	O ₂ Concentration Control Range	(LL7)	min, max ppm O ₂
Light Spectrum Wavelength Control Range Light Spectrum PAR Match Light Spectrum Intensity Control Range Light Spectrum Intensity Control Range Light Spectrum Intensity Control Stability Light Spectrum Intensity Control Stability Light Captured by Non-Photosynthetic Surfaces Light Spectrum Intensity Control Stability Light Spectrum Intensity Control Range Light Spectrum Intensity Control Range Light Spectrum Intensity Control Range (LL10) ### Water Loss due to Leach nm Light Captured by Non-Photosynthetic Surfaces (LL10) ### Water Loss of the each nm Light Captured by Non-Photosynthetic Surfaces (LL10) ### Water Loss of the each nm ### Water Loss due to Leaks, Evaporation Light Captured by Non-Photosynthetic Surfaces (LL10) ### Water Loss of the each nm ### Water Loss due to Leaks, Evaporation Light Spectrum Intensity Control Range Light Spectrum Intensity Control Range Light Spectrum Intensity Control Range Light Spectrum Intensity Inte	25	O ₂ Concentration Control Rate	(LL7)	
Light Spectrum PAR Match Light Spectrum Intensity Control Range Light Spectrum Intensity Control Stability Light Spectrum Intensity Control Stability Light Captured by Non-Photosynthetic Surfaces Light Captured by Non-Photosynthetic Surfaces Light Captured Light Penetration Light Captured Light Penetration Light Captured by Non-Photosynthetic Surfaces LL9) Heat Transfer LL10) Water Loss due to Leaks, Evaporation LL11) Internal Circulation Airflow Control Range LL12) Gas Exchange due to Leaks LL12) Maximum Intentional Gas Exchange LL12) Maximum Intentional Gas Exchange LL12) Min, max mJ/plant/sec Nutrient Solution Delivery Rate Control Range LL13) ML/plant/sec² at each mL/plant/sec	26	O ₂ Concentration Control Stability	(LL7)	±ppm O ₂ at each ppm O ₂
Light Spectrum Intensity Control Range Light Spectrum Intensity Control Stability Light Spectrum Intensity Control Stability Light Captured by Non-Photosynthetic Surfaces CLL9) Outside Light Penetration LL10) Heat Transfer LL10) Water Loss due to Leaks, Evaporation Internal Circulation Airflow Control Range LL11) Gas Exchange due to Leaks (LL12) Maximum Intentional Gas Exchange LL12) Maximum Intentional Gas Exchange LL12) Maximum Intentional Gas Exchange LL12) Min, max m³/min Maximum Intentional Gas Exchange (LL12) Min, max mL/plant/sec Mutrient Solution Delivery Rate Control Range (LL13) ML/plant/sec² at each mL/plant/sec	27	Light Spectrum Wavelength Control Range	(LL8)	min, max nm
Light Spectrum Intensity Control Stability Light Captured by Non-Photosynthetic Surfaces Light Captured by Non-Photosynthetic Surfaces Light Captured by Non-Photosynthetic Surfaces LL9) Mutrient Solution Delivery Rate Control Range LL8) ±μmol m ⁻² sec ⁻¹ at each nm (LL9) kullet Light Penetration (LL9) LL10) ±W at each °C LL11) μL/hr μmin, max m³/min (LL12) μm³/min μmin, max m²/min μmin, max m²/min LL12) Maximum Intentional Gas Exchange (LL12) Min, max mL/plant/sec μmol m ⁻² sec ⁻¹ at each nm μποι max m²/min μμποι m ⁻² sec ⁻¹ at each nm μποι m²/min μμποι m ⁻² sec ⁻¹ at each nm μεται αποι μποι m²/min μεται αποι μποι μποι μποι μποι μποι μποι μποι μ	28	Light Spectrum PAR Match	(LL8)	% (each crop)
Light Captured by Non-Photosynthetic Surfaces (LL9) % Outside Light Penetration (LL9) % Heat Transfer (LL10) ±W at each °C Water Loss due to Leaks, Evaporation (LL11) mL/hr Internal Circulation Airflow Control Range (LL12) min, max m³/min Gas Exchange due to Leaks (LL12) m³/min Maximum Intentional Gas Exchange (LL12) m³/min Nutrient Solution Delivery Rate Control Range (LL13) min, max mL/plant/sec Nutrient Solution Delivery Rate Control Rate (LL13) mL/plant/sec² at each mL/plant/sec	29	Light Spectrum Intensity Control Range	(LL8)	min, max μ mol m ⁻² sec ⁻¹ at each nm
Outside Light Penetration (LL9) % Heat Transfer (LL10) ±W at each °C Water Loss due to Leaks, Evaporation Internal Circulation Airflow Control Range Gas Exchange due to Leaks (LL12) min, max m³/min (LL12) m³/min Maximum Intentional Gas Exchange (LL12) m³/min Nutrient Solution Delivery Rate Control Range (LL13) min, max mL/plant/sec Nutrient Solution Delivery Rate Control Rate (LL13) mL/plant/sec² at each mL/plant/sec	30	Light Spectrum Intensity Control Stability	(LL8)	±μmol m ⁻² sec ⁻¹ at each nm
Heat Transfer Water Loss due to Leaks, Evaporation Internal Circulation Airflow Control Range Gas Exchange due to Leaks (LL12) min, max m³/min Maximum Intentional Gas Exchange (LL12) m³/min Maximum Intentional Gas Exchange (LL12) m³/min Nutrient Solution Delivery Rate Control Range (LL13) min, max mL/plant/sec Nutrient Solution Delivery Rate Control Rate (LL13) mL/plant/sec² at each mL/plant/sec	31	Light Captured by Non-Photosynthetic Surfaces	(LL9)	%
Water Loss due to Leaks, Evaporation (LL11) mL/hr Internal Circulation Airflow Control Range (LL12) min, max m³/min Gas Exchange due to Leaks (LL12) m³/min Maximum Intentional Gas Exchange (LL12) m³/min Nutrient Solution Delivery Rate Control Range (LL13) min, max mL/plant/sec Nutrient Solution Delivery Rate Control Rate (LL13) mL/plant/sec² at each mL/plant/sec	32	Outside Light Penetration	(LL9)	%
Internal Circulation Airflow Control Range (LL12) min, max m³/min Gas Exchange due to Leaks (LL12) m³/min Maximum Intentional Gas Exchange (LL12) m³/min Nutrient Solution Delivery Rate Control Range (LL13) min, max mL/plant/sec Nutrient Solution Delivery Rate Control Rate (LL13) mL/plant/sec² at each mL/plant/sec	33	Heat Transfer	(LL10)	±W at each °C
Gas Exchange due to Leaks Maximum Intentional Gas Exchange KLL12) m³/min Nutrient Solution Delivery Rate Control Range Nutrient Solution Delivery Rate Control Rate KLL13) min, max mL/plant/sec mL/plant/sec² at each mL/plant/sec	34	Water Loss due to Leaks, Evaporation	(LL11)	mL/hr
Maximum Intentional Gas Exchange (LL12) m³/min Nutrient Solution Delivery Rate Control Range (LL13) min, max mL/plant/sec Nutrient Solution Delivery Rate Control Rate (LL13) mL/plant/sec² at each mL/plant/sec	35		(LL12)	min, max m³/min
Nutrient Solution Delivery Rate Control Range (LL13) min, max mL/plant/sec Nutrient Solution Delivery Rate Control Rate (LL13) mL/plant/sec ² at each mL/plant/sec	36	Gas Exchange due to Leaks	(LL12)	m ³ /min
Nutrient Solution Delivery Rate Control Rate (LL13) mL/plant/sec ² at each mL/plant/sec	37	Maximum Intentional Gas Exchange	(LL12)	m³/min
	38	Nutrient Solution Delivery Rate Control Range	(LL13)	min, max mL/plant/sec
Nutrient Solution Delivery Rate Control Stability (LL13) ±mL/sec/plant at each mL/sec/plant	39	<u>-</u>	(LL13)	mL/plant/sec ² at each mL/plant/sec
	40	Nutrient Solution Delivery Rate Control Stability	(LL13)	±mL/sec/plant at each mL/sec/plant

2.5 Metrics (Cont'd)

#	Metric		Units
41	Nutrient Solution Temperature Control Range	(LL14)	min, max °C
42	Nutrient Solution Temperature Control Rate	(LL14)	°C/sec at each °C
43	Nutrient Solution Temperature Control Stability	(LL14)	±°C at each °C
44	Germination Success Rate	(LL15)	%
45	Required Human Intervention Time - Maintenance	(LL16)	hrs/week
46	Required Human Intervention Time - Setup	(LL16)	hrs
47	Energy Efficiency - In (Power) vs. Out (kCal + Loss)	(LL17)	%
48	Necessary Water Waste per Day	(LL18)	L/day
49	Water Recycling from Spacecraft Systems	(LL18)	L/day
50	Initial Water Requirement	(LL18)	L
51	Plant Matter Usage	(LL19)	%
52	CO ₂ Capture - Fraction of Typical Reclaimer Consumption	(LL20)	%
53	O ₂ Production - Fraction of Typical Reclaimer Production	(LL20)	%
54	Number of Harvests per Planting	(LL21)	# (each crop)
55	Harvest to Reharvest - Fruiting Crops	(LL22)	min (each crop)
56	Seedling to Harvest (LL22	2, LL24)	min (each crop)
57	Germination Time	(LL23)	min (each crop)
58	Potential for Cross-Contamination - Germination	(LL25)	% (each event)
59	Potential for Cross-Contamination - Planting	(LL25)	% (each event)
60	Potential for Cross-Contamination - Harvest	(LL25)	% (each event)
61	Factor of Safety	(LL26)	FOS (each structure)
62	Mounting Stability - System to Surroundings	(LL26)	FOS (each mount)
63	Mounting Stability - Infrastructure to System	(LL26)	FOS (each mount)
64	Risk of Electrical Malfunction	(LL27)	%
65	Backup Power Systems?	(LL28)	Y/N
66	Incremental Power-On?	(LL28)	Y/N
67	Backup Water Systems?	(LL29)	Y/N
68	Infrastructure Failure Notification?	(LL29)	Y/N
69	Independent Crop Growth Environments?	(LL30)	Y/N
70	Support for N+1 Crop Growth Environments?	(LL31)	Y/N
71	Lighting System Swappable?	(LL32)	Y/N
72	Heating/Cooling System(s) Swappable?	(LL32)	Y/N
73	Water Delivery System(s) Swappable?	(LL32)	Y/N
74	Lighting System Swappable?	(LL32)	Y/N
75	Computer Subsystems Swappable?	(LL33)	Y/N
76	All Fabrication Procedures, Tools, and Materials Documented?	(LL34)	Y/N
77	All Assembly Procedures, Tools, and Materials Documented?	(LL34)	Y/N
78	All Repair Procedures, Tools, and Materials Documented?	(LL34)	Y/N
79	Total Fabrication, Assembly, and Startup Time	(LL35)	min
80	Total Number of Tools Required	(LL36)	#

2.5 Metrics (Cont'd)

#	Metric	Units
81	Number of New Tools Required (LL36) #
82	Cost (LL37) CAD
83	Outer Dimensions (LL38) m (W, D, H)
84	Outer Volume (LL38) m ³
85	Power Consumption (LL38) W
86	Mass (LL38) kg

2.6 Constraints

Metric	Constraint	Source
M45	4 hrs/week	[2]
M83	Fits through 1.07m x 1.90m doorway; W<1.829m, D<2.438m, H<2.591m	[2]
M84	$\leq 2 \text{ m}^3$	[2]
M85	Avg. <1500W; Peak < 3000W	[2]

2.7 Criteria

Metric	Criteria; Reason	Source
M34	Minimize; Reduce System Inputs	[2]
M48	Minimize; Reduce System Inputs	[2]
M49	Maximize; Reduce System Inputs	[2]
M50	Minimize; Reduce System Inputs	[2]
M86	Minimize; Reduce System Inputs	[2]

References

- [1] "Deep Space Food Challenge," Impact Canada, launched by NASA/CSA. [Online]. Available: https://impact.canada.ca/en/challenges/deep-space-food-challenge
- [2] "DSFC Applicant Guide," Impact Canada, launched by NASA/CSA. [Online]. Available: https://impact.canada.ca/en/challenges/deep-space-food-challenge/application-guide
- [3] "Excerpt of NASA-STD-3001: Section 7.1 Food and Nutrition," National Aeronautics and Space Administration, Standard, 02 2015. [Online]. Available: https://impact.canada.ca/challenges/deep-space-food-challenge/excerpt