A SIMOC Technical Document

Guide to Agents and Currencies of Exchange

Phase V

www.simoc.space

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Introduction

SIMOC [see-mok] is a scalable, interactive model of an off-world community. The model is given foundation on published data derived from Environmental Control and Life Support Systems (ECLSS) and closed ecosystem research at NASA and universities world-wide. The goal is to design a habitat of minimum complexity that sustains human life through a combination of physio-chemical (machine) and bioregenerative (plant) systems, and then scale from to a self-sustaining community over time (with later phases of SIMOC development).

SIMOC is built upon an agent-based model (ABM), a class of computational models for simulating the actions and interactions of autonomous agents (individual or collective) while granting tools to assess their effects on the system as a whole.[1]

This document provides the essential research, data, and formulaic foundations for SIMOC's ABM in Phase IIIb of development. Defined here is explanation for how each agent interacts with any other agent by means of transaction values, or *currencies of exchange*, such as oxygen, carbon dioxide, and water.

As SIMOC itself evolved from Phase I to Phase II the hard-coded agent definitions and interactions were replaced with user-defined JSON files, allowing for nearly limitless configuration and exploration in modeled simulation. These agent description files may be edited by the agent configuration editor (ACE), a web-based tool installed with the SIMOC server. With Phase III the entire software package was reviewed and much of it rewritten for scalability from a personal computer to local server to a cloud platform while the web-based user interface was fully rewritten.

The SIMOC Work-flow

SIMOC consists of two principal components: a) server, and b) front-end web interface with a command line interface available for advanced users who desire to run a local SIMOC server for research.

When the server is launched, it loads the agent_desc.json file

Prior to a model run, an advanced user may redefine and/or add agents to the agent library (JSON) using the Agent Configuration Editor (ACE) or a text editor of their choice, and upload to the server. This must be done prior to launching SIMOC, as it loads the agent_desc.json file only once per server reset.

This is the basic work-flow of the SIMOC simulation engine.

1. User registers for the first time or log in, entering username and password.
2. Enter the Configuration Wizard and:
   a) Select a Preset configuration; or
   b) Develop a custom configuration.
3. Launches the SIMOC simulation run.
4. The SIMOC model engages each active agent in a per-timestep agent-based model (ABM) transaction until the selected termination criterion is met, or the user pauses the run with option to:
   a) Collect and download data; and/or
   b) Terminate run, and return to Option (3); or
   c) Exit.

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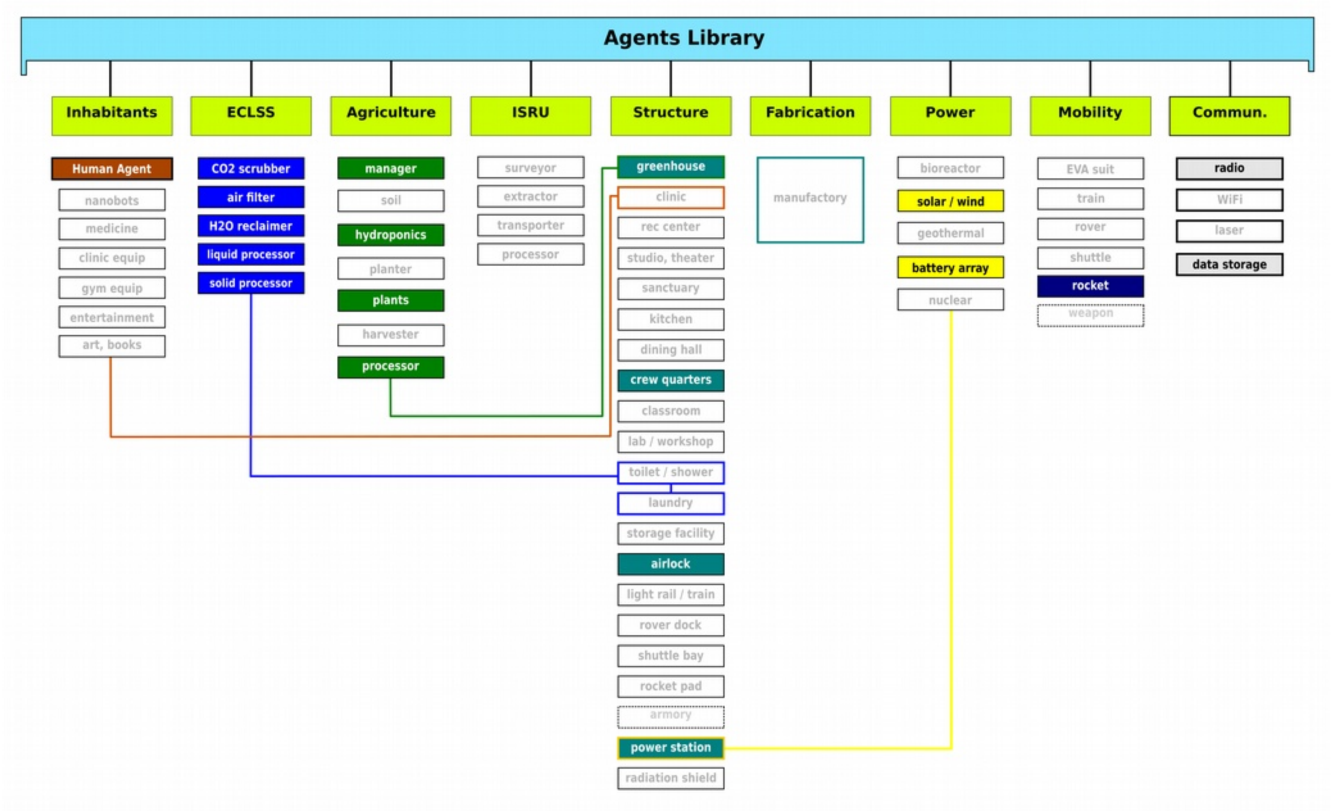
[1] https://en.wikipedia.org/wiki/Agent-based_model



SIMOC Agent Library

Each agent belongs to one of 9 principal categories: Inhabitants, ECLSS, Agriculture, ISRU, Structures, Fabrication, Power Generation, Mobility, or Communication. For this Phase IIIb launch, a sub-set of agents are made available to the SIMOC user at the point of Configuration, with any combination of two or more agents defining an experimental mission.

Whenever a currency is exchanged, it moves from one agent to another (there is no in-between space). A habitat module (greenhouse, crew quarters) is an agent that has volume that holds atmosphere, power to maintain temperature, and ultimately, an age since it was deployed.

Agent Based Model

The following pages contain all *agents* and their associated *currencies of exchange* included in the SIMOC Phase IIIb launch product. While the complete library of agents is larger, and the potential interactions more complex, this is our designated launch product with a strong baseline functionality. Future releases of SIMOC will offer a higher fidelity simulation as we incorporate additional agents, and higher resolution modeling.

The action(s) each agent takes are defined from the point of view of the agent, as follows:

+	the agent needs this, and takes it from another agent
-	the agent is removing this from its holding, giving it to another agent

HUMAN INHABITANTS

All values are per agent, built from NASA’s *Human Integration and Design* handbook (2017)

In from Storage:

+ 0.021583 kg/hr	atmo_o2*	21% nominal at l4.7 psi
+ 0.083333 kg/hr	h2o_potb*	2.0 kg / day drink, plus (was 2.5 with food hydration)
+ 0.0825 kg/hr	h2o_potb	1.98 kg / day hygiene + urine flush
+ 0.062917 kg/hr	food_edbl	1.5 kg / day [includes rehydration; add nutrition in Phase IV]

* remove agent if it has not drank water in 3 days, or not eaten in 21 days

NOTE A: There is no single currency called “atmosphere”, rather the atmosphere is defined as the combination of atmo_co2, atmo_o2, atmo_h2o, and atmo_n2, each of which is tracked separately but stored in a single container.

NOTE B: 0.083333 (drinking water) + 0.0825 (hygiene water) = **0.165833** h2o_potb for the JSON file

SOURCE A: BVAD 2018 – Tables 3-33 (nominal), 4-1 (steady-state), 4-20 (water use for various missions)

Out to Storage:

- 0.025916 kg/hr	atmo_co2	0.622 kg / day respiration
- 0.079167 kg/hr	atmo_h2o	1.9 kg / day respiration + perspiration
- 0.0625 kg/hr	h2o_urin**	1.5 kg urine
- 0.087083 kg/hr	h2o_wste	2.09 kg wastewater balances all inputs/outputs (was 2.59)
- 120W per hour	heat_cal	[Phase IV thermal load]; temp value

** an agent will not urinate if it has not drank, nor defecate if it has not eaten

NOTE B: In Phase IIIb, human agents are treated as a zero sum for liquid and solids, where sum IN = SUM out

SOURCE B: BVAD 2018 – Table 4-21 (wastewater for various missions)

Mass & Volume:

80 kg	mass	male: https://en.wikipedia.org/wiki/Human_body_weight
60 kg	mass	female: https://en.wikipedia.org/wiki/Human_body_weight
[n] m^3	vol	not applied as of 2018 09/20

Lifetime:

525,600 hrs	days	60 years; assuming astronauts arrive at ~30 years of age

Human Metabolic Values per Crew Member

Interface	Nominal	unit	Adjusted	unit	SIMOC	unit
Basis						
Overall Body Mass - Male	82.0	kg	-		80.0	kg/hr
Overall Body Mass – Female	-	kg	-		60.0	kg/hr
Respiratory Quotient	0.92	%	-		-	
Air						
Carbon Dioxide Load	-0.622	kg/day	0.000622	kg/hr	0.025916	kg/hr
Oxygen Consumed	+0.518	kg/day	0.000518	kg/hr	0.021583	kg/hr
Food						
Food Consumed: Mass (no packaging)	+1.50	kg/day	.00150	kg/hr	0.062917	kg/hr
Food Consumed: Energy Content	+12.59	Mj/day	0.01259	Mj/hr	-	
Potable Water Consumed	+2.50	kg/day	0.00250	kg/hr	0.1042+0.0825	kg/hr
Metabolic Water	+0.40	kg/day	0.00040	kg/hr	-	
Thermal						
Total Metabolic Heat Load	-12.00	Mj/day	0.01200	Mj/hr	-	
Sensible Metabolic Heat Load	-7.35	Mj/day	0.00735	Mj/hr	-	
Latent Metabolic Heat Load	-4.65	Mj/day	0.00465	Mj/hr	-	
Waste						
Feces	-0.123	kg.day	0.005125	kg/hr	-	
Fecal Solid Waste (dry basis)	-0.03	kg/day	0.00003	kg/hr	-	
Perspiration Solid Waste (dry basis)	-0.02	kg/day	0.00002	kg/hr	-	
Urine Solid Waste (dry basis)	-0.06	kg/day	0.00006	kg/hr	-	
Water						
Fecal Water	-0.09	kg/day	0.00009	kg/hr	0.0825	kg/hr
Respiration and Perspiration Water	-1.90	kg/day	0.00190	kg/hr	0.079167	kg/hr
Urine Water	-1.62	kg/day	0.00162	kg/hr	0.0625	kg/hr
Miscellaneous Water Losses	-0.02	kg/day	0.00002	kg/hr	-	

SOURCE: NASA BVAD, Table 3-33 - Summary of Nominal Human Metabolic Interface Values, page 63

NOTE: The values given by BVAD are employed as guidelines, some used equivalently, some as guides.

Human Agent Oxygen Thresholds

O2	Description	Effect	Status	SIMOC Action
23.5%	Maximum permissible oxygen level.	No effect.	GREEN	No action
21%	Percentage of oxygen found in normal air.	No effect.	GREEN	No action
19.5%	Minimum permissible oxygen level.	No effect.	YELLOW	No action (in Phase III)
15%	Decreased ability to work strenuously.	May impair coordination and may induce early symptoms with individuals that have coronary, pulmonary, or circulatory problems.	ORANGE	No action (in Phase III)
12%	Respiration and pulse increase.	Impaired coordination, perception, and judgment occurs.	RED	No action (in Phase III)
10%	Respiration further increases in rate and depth.	Poor judgment and bluish lips occur.	RED	Suggest Terminate Model Run
8%		8 minutes - 100 percent fatal; 6 minutes - 50 percent fatal; 4-5 minutes - recovery with treatment.	RED	Terminate Model Run
6%		Coma in 40 seconds, convulsions, respiration ceases - death.	RED	Terminate Model Run

NOTE: As of 2018 11/03, Phase II has only one of the above values, a lower threshold of 0.195 or 19.5% O2

SOURCE: Dr. Thomas Walter
Departments of Geography & Computer Science
Hunter College, 695 Park Avenue, New York, NY 10065

http://www.geography.hunter.cuny.edu/tbw/wc.notes/1.atmosphere/oxygen_and_human_requirements.htm

(the above link is broken; need to find alternative)

Human Agent Carbon Dioxide Thresholds

CO2	Description	Effect	Status	SIMOC Action
0.035 - 0.045%	normal outdoor	No effect.	GREEN	No action
< 0.06%	acceptable	No effect.	GREEN	No action
0.06% - 0.10%		complaints of stiffness and odors	YELLOW	No action
0.10%	ASHRAE and OSHA standards - limit		YELLOW	CO2 Scrubber is activated
0.10 - 0.25%		general drowsiness	ORANGE	CO2 Scrubber is activated
0.25 – 0.5%		adverse health effects	RED	No action (in Phase III)
0.5 – 1.0%	max allowed concent. for an 8 hour period		RED	Terminate Model Run
3.00%	max allowed concent. for a 15 minute period		RED	Terminate Model Run

NOTE A: As of 2018 11/03, SIMOC has only one of the above values, a lower threshold of 0.001 or 0.1% CO2

NOTE B: As of 2018 11/28, SIMOC has 4 levels hard-coded, per the CO2 chart

SOURCE A: *(see SIMOC Developers Skype session, October 21, 2018)*

https://www.quora.com/How-can-carbon-dioxide-be-toxic?share=1 (see John Flavin)

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5380556/

https://en.wikipedia.org/wiki/Hypercapnia#Tolerance

https://www.epa.gov/sites/default/files/2015-06/documents/co2appendixb.pdf

SOURCE B:

- Respiration dP: ((gas in g) / (molar mass of gas in g/mol)) * (temperature in K) * (gas constant in m^3 mol^-1 K^-1 kPa) / (volume in m^3)
  - Heat Output: 2,866,835 cal/hr (was 12,000 kj/hr)
- Metabolic Rate: (622-9.53 * (age in Earth years) + 1.25 * (15.9 * (mass in kg) + 539.6 * (height in m))) / (0.238853e3 * 0.04166)
  - Male (assumed 40 yrs, 80 kg): 12.996 MJ/(CM* day)
  - Female (assumed 40 yrs, 60 kg): 11.292 MJ/(CM* day)
- Metabolic temperature change: (average body temp in K) - (temperature of the room in K)

ECLSS Agents

The Environmental Control and Life Support Systems (ECLSS) is the physico-chemical system that supplies breathable air, potable water, and deals with human waste products. While it also maintains habitat temperature and pressure, this current version of SIMOC does not track thermal properties or atmospheric pressure following the initial starting conditions.

In SIMOC, there are 9 ECLSS modules:

- Solid Waste Aerobic Bioreactor Agent
- Urine recycling processor VCD Agent
- MultiFiltration Purifier post-treatment Agent
- Particulate Removal TCCS Agent
- Oxygen Generation SFWE Agent
- Carbon Dioxide Reduction Sabatier Agent
- Carbon Dioxide Removal SAWD Agent
- Dehumidifier Agent
- Methane Removal Agent

Solid Waste Aerobic Bioreactor Agent

Agent name: *solid_waste_aerobic_bioreactor*

Purpose: First stage recovery of wastewater, using microbial degradation. Isolates nutrients from urine.

In from Storage:

+ 1.5 kg/hr	h2o_wste	feces (solid, liquid) is transported through h2o_wste
+ 0.00045 kg/hr	atmo_o2	used in the processing of h2o_wste
+ 0.678 kw/hr	enrg_kwh	

Out to Storage:

- 0.002175 kg/hr	sold_n	[Phase IV: nutrients for plants]
- 0.000261 kg/hr	sold_p	[Phase IV: nutrients for plants]
- 0.000615 kg/hr	sold_k	[Phase IV: nutrients for plants]
- 1.199041 kg/hr	h2o_urin	1.495 (original) less 19.78 dry food component
- 0.0015 kg/hr	atmo_co2	
- 0.00075 kg/hr	atmo_ch4	
- 95% cal/hr	heat_cal	[Phase IV thermal load]; temp value

Mass & Volume:

150 kg	mass	[not employed at this time]
0.075 m^3	vol	[not employed at this time]

SOURCE: Salehi Pourbavarsad, Maryam, Ritesh Sevanthi, Daniela Ducon, Audra Morse, Andrew Jackson, and Michael Callahan. "A Two-Stage Biological Reactor for Treatment of Space Based Waste Waters." 48th International Conference on Environmental Systems, 2018.

Urine recycling processor VCD Agent

Agent name: *urine_recycling_processor_VCD*

Purpose: First stage recovery of urine, both that captured directly and as isolated from wastewater.

In from Storage:

+ 2.0 kg/hr	h2o_urin	principally liquid with approximately 2% salt
+ 1.501 kw/hr	enrg_kwh	

Out to Storage:

- 1.96 kg/hr	h2o_tret	this is not potable until after the *MultiFiltration* agent
- 0.04 kg/hr	sold_wste	2% by mass unrecoverable salts
- 95% cal/hr	heat_cal	[Phase IV thermal load]; temp value

Mass & Volume:

193.3 kg	mass	[not employed at this time]
0.39 m^3	vol	[not employed at this time]

SOURCE: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100039639.pdf

MultiFiltration Purifier post-treatment Agent

Agent name: multifiltration_purifier_post_treatment

Purpose: Second stage recovery of urine, producing relatively clean water following VCD.

In from Storage:

+ 4.75 kg/hr	h2o_tret	in from the VCD agent
+ 0.012 kw/hr	enrg_kwh	may not require electricity if pressure delivered from prior system

Out to Storage:

- 4.75 kg/hr	h2o_potb	this is drinkable (if you don’t think about it)
+ 95% cal/hr	heat_cal	[Phase IV thermal load]; temp value

Mass & Volume:

114.6 kg	mass	[not employed at this time]
0.11 m^3	vol	[not employed at this time]

SOURCE: Standard, Hamilton. "Trade-off Study and Conceptual Designs of Regenerative Advanced Integrated Life support Systems." *NASA CR-1458* (1970).

https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19700015646.pdf

Particulate Removal TCCS Agent

Agent name: particulate_removal_TCCS

Purpose: Remove potentially hazardous volatile trace contaminants generated from processes, including metabolism.

In from Atmosphere:

+ 0.12533 kg/hr	atmo_cont*	*criteria > 0.1% and no activation buffer*
+ 1.120 kw/hr	enrg_kwh	

* atmo_cont is a generic atmosphere storage container

Out to Storage:

- 0.123533 kg/hr	atmo_cont	-
- 95% cal/hr	heat_cal	[Phase IV thermal load]; temp value

Mass & Volume:

137.35 kg	mass	[not employed at this time]
0.31 m^3	vol	[not employed at this time]

NOTE: In Phase II, no atmosphere contaminates are generated, so this agent is in place, but not activated.

SOURCE: [insert literature reference]

Carbon Dioxide Reduction Sabatier Agent

Agent name: co2_reduction_sabatier

Purpose: Reduce CO2 in air, without requiring venting; better for closing the loop and preferred over the Carbon Dioxide Removal SAWD Agent

In from Cabin or Greenhouse:

+ 0.00163 kg/hr	atmo_h2*	*criteria > 0.1% and no activation buffer*
+ 0.006534 kg/hr	atmo_co2	
+ 0.291 kw/hr	enrg_kwh	

* free hydrogen is generated by the Oxygen SFWE agent

Out to Storage:

- 0.0025 kg/hr	atmo_ch4	[Phase IV capture for energy production and rocket fuel]
- 0.00567 kg/hr	h2o_wste	is recovered
- 95% cal/hr	heat_cal	[Phase IV thermal load]; temp value

Mass & Volume:

47.9 kg	mass	[not employed at this time]
0.06 m^3	vol	[not employed at this time]

Carbon Dioxide Removal SAWD Agent

Agent name: co2_removal_SAWD

Purpose: Remove CO2 from air; used only if Carbon Dioxide Reduction Sabatier Agent is overwhelmed

In from Cabin or Greenhouse:

+ 0.085 kg/hr	atmo_co2	*criteria > 0.1% and 8 hrs activation buffer*
+ 0.65 kw/hr	enrg_kwh	

Out to Storage:

- 0.00 kg/hr	atmo_co2	a null value in agent_desc.json vents CO2 to space
- 95% cal/hr	heat_cal	[Phase IV thermal load]; temp value

Mass & Volume:

137.35 kg	mass	[not employed at this time]
0.31 m^3	vol	[not employed at this time]

NOTE A: In Phase IIIb, Crew Quarters and the Greenhouse define a single, shared volume without differentiation of levels of carbon dioxide. In a future version, the Greenhouse will be able to maintain a higher level of CO2.

NOTE B: In Phase IIIb, the CO2 is vented to the outside of the habitat, creating a non-zero sum event.

SOURCE: [need to reference]

Oxygen Generation SFWE Agent

Agent name: oxygen_generation_SFWE

Purpose: Generate O2 for crew

In from Storage

+ 0.413 kg/hr	h2o_potb*	*criteria < 19.5% and no activation buffer*
+ 0.959 kw/hr	enrg_kwh	

* uses electrolysis to break water into H2+O

Out to Storage:

- 0.367 kg/hr	atmo_o2	
- 0.0454 kg/hr	atmo_h2	free hydrogen is released and used by the CO2 Sabatier agent
- 95% cal/hr	heat_cal	[Phase IV thermal load]; temp value

Mass & Volume:

83.43 kg	mass	[not employed at this time]
0.05 m^3	vol	[not employed at this time]

SOURCE: [need to reference]

Dehumidifier

Agent name: dehumidifier

Purpose: Condenses water vapor into potable water.

In from Storage:

+ 0.5 kg/hr	atmo_h2o	*criteria* > 1.0% *and no activation buffer*
+ 0.5 kw/hr	enrg_kwh	

Out to Storage:

- 0.5 kg/hr	h2o_potb	assumed to be 100% efficient in this model
- 95% cal/hr	heat_cal	[Phase IV thermal load]; temp value

Mass & Volume:

50.0 kg	mass	[not employed at this time]; temp value
0.2 m^3	vol	[not employed at this time]; temp value

NOTE: This agent was added to Phase IIIb to force water vapor back into potable water.

Methane Removal Agent

Agent name: ch4_removal_agent

Purpose: Removes methane from the total system.

In from Storage:

+ 0.02 kg/hr	atmo_ch4*	*criteria > 0.1% and 6 hrs activation buffer*
+ 0.2 kw/hr	enrg_kwh	

* only two agents produce CH4: 0.00075 (bioreactor) + 0.0025 (sabatier)

Out to Storage:

- 0.02 kg/hr	atmo_ch4	assumed to be 100% efficient in this model
- 95% cal/hr	heat_cal	[Phase IV thermal load]; temp value

Mass & Volume:

20.0 kg	mass	[not employed at this time]; temp value
0.1 m^3	vol	[not employed at this time]; temp value

NOTE: This agent was added to Phase IIIb to remove the methane generated by the Solid Waste Aerobic Bioreactor and Carbon Dioxide Reduction Sabatier Agents

AGRICULTURE

Plant Agents

In this Phase II model, crops are produced using a “*Nutrient film technique* [which is] amenable to a range of species, including root zone crops, reduced the need for large volumes of standing water, eliminated the need for solid media, and permitted close tracking of water and nutrient uptake. On the other hand, because of the limited water volume and buffering capacity, NFT systems are susceptible to crop stress or possible loss if system malfunctions are not dealt with promptly (e.g., loss of circulating pumps).” **—**Wheeler, R. M., and J. C. Sager. "Crop production for advanced life support systems." (2006).

- Plant agent(s):
  - food_cers: Rice, Wheat
  - food_leaf: Cabbage, Celery, Chard, Lettuce, Spinach
  - food_legumes: Dry Bean, Peanut, Soybean
  - food_frut: Pepper, Strawberry, Tomato
  - food_vegi: Green Onion, Onion, Pea, Snap Bean
  - food_root: Carrot, Radish, Red Beet, Sweet Potato, White Potato
  - food_othr: (none at this time)
- Robotic Greenhouse Manager [not in use at this time; human labor is assumed]
- Composter (see Inedible Biomass Agent)
- Storage (seeds, fertilizer, produce, compost)

Table of Plant Growth

Crop	Category	Light *	Period	Growth **	Grams / hr	Total	Edible	sold_n	sold_p	sold_k	h2o_potb	atmo_o2	atmo_co2
Rice	cereal grain	0.2300870147	12	85	1.2595833333	2569.55	770.95	-0.0206755062	-0.0003270886	-0.002466768	-7.9341666667	1.1201294643	-1.5399905754
Wheat	cereal grain	0.8018183846	22	79	2.0833333333	3950	1580	-0.034197	-0.000541	-0.00408	-11.25	1.8526785714	-2.547123016
Cabbage	leafy green	0.1952253458	24	85	0.2804166667	572.05	515.1	-0.0098276438	-0.0003632356	-0.0027380959	-0.2529166667	0.2752949011	-0.3777302131
Chard	leafy green	0.1185296743	16	45	0.44875	484.65	315	-0.0157271507	-0.0002493329	-0.001878111	-1.4133333333	0.440553653	-0.6044805936
Celery	leafy green	0.1185296743	24	75	0.4783333333	861	774.75	-0.0167639452	-0.0002657699	-0.0020019233	-0.43	0.4695966514	-0.6443302892
Lettuce	leafy green	0.1185296743	16	28	0.3041666667	204.4	183.96	-0.01066	-0.000169	-0.001273	-0.27375	0.2986111111	-0.4097222222
Spinach	leafy green	0.1185296743	16	30	0.3041666667	219	197.1	-0.01066	-0.000169	-0.001273	-0.27375	0.2986111111	-0.4097222222
Dry Bean	legume	0.1673360107	18	85	1.0416666667	2125	850	-0.0300195313	-0.0005058594	-0.0038085938	-5.625	1.5010127315	-2.0616319444
Peanut	legume	0.188253012	12	104	0.9379166667	2341.04	585.52	-0.0270295859	-0.0004554758	-0.0034292578	-6.3258333333	1.3515118634	-1.8562934028
Soybean	legume	0.1952253458	12	97	0.5333333333	1241.6	582	-0.01537	-0.000259	-0.00195	-2.5516666667	0.7685185185	-1.0555555556
Strawberry	fruit	0.1533913432	12	85	0.9270833333	1891.25	662.15	-0.0184122632	-0.0002913426	-0.0021961615	-5.4183333333	0.5763666242	-0.7907178481
Tomato	fruit	0.188253012	12	85	0.9654166667	1969.45	886.55	-0.019173579	-0.000303389	-0.002286969	-4.77875	0.6001984127	-0.823412698
Green Onion	vegetable	0.1812806783	24	50	0.4166666667	500	450	-0.0146027397	-0.0002315068	-0.0017438356	-0.375	0.4090563166	-0.5612633181
Onion	vegetable	0.1185296743	24	50	0.46875	562.5	450	-0.0164280822	-0.0002604452	-0.0019618151	-0.84375	0.4601883562	-0.6314212329
Pea	vegetable	0.1673360107	24	75	1.1179166667	2012.25	804.75	-0.0391791507	-0.0006211329	-0.004678711	-6.0375	1.0974980974	-1.5058694825
Pepper	vegetable	0.188253012	24	85	0.9654166667	1969.45	886.55	-0.0338345479	-0.0005364014	-0.0040404671	-4.7775	0.9477834855	-1.3004471081
Snap Bean	vegetable	0.1673360107	18	85	1.2375	2524.5	1009.8	-0.043370137	-0.0006875753	-0.0051791918	-6.6825	1.2148972603	-1.6669520548
Radish	root vegetable	0.1812806783	16	25	0.4583333333	275	137.5	-0.0091026919	-0.0001440346	-0.0010857428	-2.0625	0.5393177194	-0.7452059028
Red Beet	root vegetable	0.1185296743	16	38	0.4166666667	380	247	-0.0082751745	-0.0001309405	-0.0009870389	-1.3125	0.4902888358	-0.6774599116
Carrot	root vegetable	0.1952253458	24	75	0.62375	1122.75	673.5	-0.0123879362	-0.0001960179	-0.0014775972	-2.245	0.7339623872	-1.0141574877
Sweet Potato	root vegetable	0.1952253458	12	85	1.5625	3187.5	1275	-0.031031904	-0.000491027	-0.003701396	-8.4375	1.8385831342	-2.540474668
White Potato	root vegetable	0.1952253458	12	132	1.25375	3971.88	2779.9	-0.0249	-0.000394	-0.00297	-3.3841666667	1.4752791069	-2.038476874

See plant_nutrient_use-WHEELER-2008.xls (original) and plant_nutrient_use-WHEELER-SIMOC.xls (simplified)

* kWh/m^2/hr

** number of days until harvest

NOTE A: Each Plant consumes (sold_p, sold_n, sold_k, h2o_potb, amto_co2) and produces atmo_o2 for each hour. Each plant uses energy in the form of light, and produces edible food (food_edbl) with the completion of its growth period. Keep in mind that some plants are illuminated part of each day, while others can be illuminated for 24 hours.

NOTE B: Many of the nutrient consumption rates are calculated based upon empirical rates for similar plants, then adjusted based upon ratio of the biomasses. See the original spreadsheet for calc / emp notations.

NOTE C: We need to determine which plants can continue to produce edible biomass (and how much) after their first harvest. With Phase II plants are harvested only once, and then replanted.

NOTE D: (see Inedible biomass Agent)

NOTE E: All values noted above assume 1m x 1m plots

Plant Agent Atmospheric Thresholds

O2:CO2	Description	Effect	Status	SIMOC Action
210:1	*Minimum level* 21% O2 / 0.1% CO2 = 210x in a 70% nitrogen atmosphere	Ideal growth rate for plants	YELLOW	If crew quarters and greenhouse share same volume, CO2 scrubbers activated
350:1	*Nominal level* 21% O2 / 0.06% CO2 in a 70% nitrogen atmosphere	Slower growth rate for plants	GREEN	No action
583:1	*Maximum level* 35% O2 / 0.06% CO2 in a 70% nitrogen atmosphere	Plants are not happy	YELLOW	In Phase IV, an oxygen concentrator will be activated

SOURCE: [need to review SIMOC / development / Phase II / atmosphere_components-20181101.txt]

ISRU

In situ resource utilization will be employed in SIMOC Phase IV such that resources local to the habitat can be extracted, processed, and employed. A key example will be the extraction of water from the sub-surface of Mars to replenish the vital yet limited supply of water in the habitat.

STRUCTURES

Crew Habitat Agent

Agent name: crew_habitat_[small, medium, large]

Purpose: Provide a place for humans to live, work, sleep, and eat.

In from: atmo_o2, atmo_co2, atmo_n2, atmo_hum – treating the atmosphere as a storage unit

Out to: atmo_o2, atmo_co2, atmo_n2, atmo_hum – treating the atmosphere as a storage unit

SMALL

Power Consumption, Heat Production:

+ 2.711 kw/hr	enrg_kwh	electricity consumed: 0.711 light (79 bulbs), 2.0 heat
+ ??? kw/hr	enrg_kwh	[not employed at this time]; robotic manager
- 95% cal/hr	heat_cal	[not employed at this time]; temp value

Mass & Volume:

20000 kg	mass	[not employed at this time]
1000 m^3	vol	80% of [pi * 10m^2 * 4m height]*

* Paragon suggests that we reduce the usable space to 50% of total volume

NOTE A: As of Phase IIIb we are *not* tracking thermal heat produced by equipment nor maintenance of habitat heat, but are consuming electricity for generic heat generation.

NOTE B: Concerning illumination, these are our assumptions for the Crew Quarters:

www.noao.edu/education/QLTkit/ACTIVITY_Documents/Safety/LightLevels_outdoor+indoor.pdf

- Private area with dark surroundings: 20-50 lumens
- Home / warehouse: 150 lumens
- Office / work space: 250 lumens

SOURCE: Amazon.com: 100W equivalent at 14 watts, color temperature - 5000 kelvin, brightness - 1400.0 lumen -or- 60 W equivalent at 9 watts, color temperature: - 800 kelvin, brightness - 800.0 lumen; portable cal-rod space heaters are typically 1200-2400W

MEDIUM

Power Consumption, Heat Production:

+ 6.113 kw/hr	enrg_kwh	1.593 light (177 bulbs), 4.52 heat
+ ??? kw/hr	enrg_kwh	[not employed at this time]; robotic manager
- ??? cal/hr	heat_cal	[not employed at this time]; temp value

Mass and Volume:

45200 kg	mass	[not employed at this time]
2260 m^3	vol	80% of [pi * 15m^2 * 4m height]

LARGE

Power Consumption, Heat Production:

+ 10.866 kw/hr	enrg_kwh	2.826 light (314 bulbs), 8.04 heat
+ ??? kw/hr	enrg_kwh	[not employed at this time]; robotic manager
- ??? cal/hr	heat_cal	[not employed at this time]; temp value

Mass and Volume:

80400 kg	mass	[not employed at this time]
4020 m^3	vol	80% of [pi * 20m^2 * 4m height]

NOTE A: As of Phase IIIb we are *not* tracking thermal heat produced by equipment nor maintenance of habitat heat, but are consuming electricity for generic heat generation.

Greenhouse Agent

Purpose: A space to grow and harvest plants.

In from: [all] atmo_o2, atmo_co2, atmo_n2, atmo_hum (treat as a storage unit)

Out to: [all] atmo_o2, atmo_co2, atmo_n2, atmo_hum (treat as a storage unit)

SMALL

Agent name: greenhouse_small

Power Consumption, Heat Production:

+ 1.0 kw/hr	enrg_kwh	½ of 2kw heater (light is included with plants)
+ ??? kw/hr	enrg_kwh	[not employed at this time]; robotic manager
- ??? cal/hr	heat_cal	[not employed at this time]

Mass and Volume:

453.59 kg	mass	[not employed at this time]
490 m^3	vol	85% of [5.5m h x 7m w x 15m l = 577.5 m^3]
267 m^2	→	(see *Greenhouse Volumes* below)

MEDIUM

Agent name: greenhouse_medium

Power Consumption, Heat Production:

+ 1.5 kw/hr	enrg_kwh	¾ of 2kw heater (light is included with plants)
+ ??? kw/hr	enrg_kwh	[not employed at this time]; robotic manager
- ??? cal/hr	heat_cal	[not employed at this time]

Mass and Volume:

1728 kg	mass	[not employed at this time]
2454 m^3	vol	85% of [5.5m h x 15m w x 35m l = 2887 m^3]
1338 m^2	→	(see *Greenhouse Volumes* below)

NOTE A: As of Phase IIIb we are not tracking thermal heat produced by equipment nor maintenance of habitat heat, but are consuming electricity for generic heat generation.

LARGE

Agent name: greenhouse_large

Power Consumption, Heat Production:

+ 2.0 kw/hr	enrg_kwh	2kw heater (light power consumption is included with plant agents)
+ ??? kw/hr	enrg_kwh	[not employed at this time]; robotic manager
- ??? cal/hr	heat_cal	[not employed at this time]

Mass and Volume:

4535.9 kg	mass	[not employed at this time]
5610 m^3	vol	85% of [5.5m h x 20m w x 60m l = 6600 m^3]
3060 m^2	→	(see *Greenhouse Volumes* below)

Greenhouse Volume Calculations

- sm gh: 5.5 x 7 x 15m = 577.5 m^3
- md gh: 5.5 x 15 x 35m = 2887 m^3
- lg gh: 5.5 x 20 x 60m = 6600 m^3

Bryan says to retain 85% usable, to provide room to walk around:

- sm gh: @ 85% = 490 m^3
- md gh: @ 85% = 2454 m^3
- lg gh: @ 85% = 5610 m^3

This is the total volume. But our plants are measured in square meters so we need to go back to the footprint:

- sm gh: 7 x 15m = 105 @ 85% = 89 m^2
- md gh: 15 x 35m = 525 @ 85% = 446 m^2
- lg gh: 20 x 60m = 1200 @ 85% = 1020 m^2

Ultimately, we need to determine how many trays can be stacked in 5.5m on the z axis, per plant (as strawberries will stack far more compactly than wheat or bananas (for sure). But until we have that data (not certain it is in the BVAD), let's assume a 3x stack for all plants.

- sm gh: 89 x 3 = 267 m^2 total
- md gh: 446 x 3 = 1338 m^2 total
- lg gh: 1020 x 3 = 3060 m^2 total

NOTE A: see “[simoc] meeting minutes: 2018 11/11”

SOURCE: “*The New Organic Grower*” by John Jeavons

POWER GENERATION

Solar PV Array Agent

Agent name: [need to define]

Purpose: Passively generate electricity from the Sun

In from Sun:

- + 0.354 kw/hr/m^2 enrg_kwh (see below)

Out to Battery:

- - 0.354 kw/hr enrg_kwh all power goes to batteries without line-loss

Mass and Volume:

- 3 kg mass
- 0.0254 m^3 vol

** 590 W/m^2 max solar gain on Mars * 30% solar panel efficiency = 177 * 2 for a 2 sq-meter panel = 354 W/m^2

NOTE: With Phase II, the solar panel agent itself accounted for the total number of hours in a Martian sol of illumination (8 hrs, or 30%) was * 30% = 53.1 W/m^2. With Phase III Iurii introduced sigmoid production functions, therefore we need to give the agent its full Martian capacity.

Solar Gain on Earth, Mars, and the Moon

According to https://en.wikipedia.org/wiki/Sunlight and nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html

"If the extraterrestrial solar radiation is 1367 watts per square meter (the value when the Earth–Sun distance is 1 astronomical unit), then the direct sunlight at Earth's surface when the Sun is at the zenith is about 1050 W/m2, but the total amount (direct and indirect from the atmosphere) hitting the ground is around 1120 W/m^2. In terms of energy, sunlight at Earth's surface is around 52-55 percent infrared (above 700 nm), 42-43 percent visible (400 to 700 nm), and 3-5 percent ultraviolet (below 400 nm)."

Earth surface: 1120 W/m^2

Mars surface: 590 W/m^2

Moon surface: 1367 W/m^2

Solar cell efficiency: en.wikipedia.org/wiki/Solar_cell_efficiency

STORAGE AGENTS

Storage containers agents are buffers to the transaction of *currencies of exchange*. Some of them represent physical containers in a habitat, others virtual containers for the sake of ABM book keeping. All currencies of exchange have some kind of storage. By definition, storage agents:

- absorb currencies of exchange when there is an excess of [type] in the system; and
- release currencies of exchange when the system no longer has ample supply, and more is needed; and
- overflow will be vented out of the habitat, and to space.

The list of currencies and their English title are as follows (as displayed on the Dashboard, Storages panel):

Atmosphere:

'atmo_o2': 'Oxygen',

'atmo_co2': 'Carbon dioxide',

'atmo_n2': 'Nitrogen',

'atmo_ch4': 'Methane',

'atmo_h2': 'Free hydrogen',

'atmo_h2o': 'Water vapor',

Water:

'h2o_potb': 'Potable',

'h2o_urin': 'Urin',

'h2o_wste': 'Waste (carries feces)’,

'h2o_tret': 'Treated',

'h2o_totl': 'Total',

Nutrients:

'sold_n': 'Nitrogen',

'sold_p': 'Phosphorus',

'sold_k': 'Potassium',

'sold_wste': 'Solid waste', Used to hold the 2% of urin that contains heavy salts

Food:

'food_edbl': 'Food rations',

'biomass_edible': 'Edible (greenhouse)',

'biomass_totl': 'Total (edible, inedible)',

Electrical Energy:

'enrg_kwh': 'Energy (battery)',

Atmosphere Storage Agent

Agent name: air_storage

Purpose: By default, this agent holds the total volume of atmosphere of a single Crew Quarters + a single Greenhouse, in a virtual storage unit, given the volumes of the habitat structures.

The following example reflects a *small* crew quarters and *small* greenhouse combined:

1000 m^3 crew quarters (sm)

490 m^3 greenhouse (sm)

1490 m^3 (1,490,000 liters) total uncompressed atmosphere

Mass (of empty tanks) and Volume

- 4348.5 kg mass (223 tanks * 19.5 kg ea)
- 3.568 m^3 vol

SOURCES:

- An average of 1.25 kg / m^3: https://en.wikipedia.org/wiki/Density_of_air and a search for "mass of 1 cubic meter of humid air" at Wolfram Alpha
- Compressed air: https://understanding-air-compressors.com/how-much-does-air-compress-at-100-psi/
- SCUBA: https://en.wikipedia.org/wiki/Diving_cylinder where "Cylinders used for scuba typically have an internal volume of between 3 and 18 litres and a maximum working pressure rating from 2,670 to 4,350 psi."
- cylinders: applied-inc.com/oxygen-cylinder-sizes-and-info
- free methane: en.wikipedia.org/wiki/Atmospheric_methane
- free hydrogen: en.wikipedia.org/wiki/Hydrogen

NOTE A: What is the mass of this total volume of gas?

1490 * 1.25 = 1862.5 kg

NOTE B: How small can we compress one full backup of the total habitat atmosphere?

3000 psi over 14.7 standard atmosphere = 204x compression (gas, not liquid)

NOTE C: What is the volume of the gas compressed to 3000 psi?

1,490,000 / 204 = 7304 liters

NOTE D: How many SCUBA styled tanks at 16 liters each?

7304 liters / 16 = 456.5 tanks

NOTE E: Consider industrial storage tanks: https://applied-inc.com/oxygen-cylinder-sizes-and-info

Atmosphere component breakdown

Per the information provided here: https://en.wikipedia.org/wiki/Atmospheric_chemistry

Average composition of dry atmosphere (mole fractions)

Gas	Percent (NASA)	Mass	Agent
Nitrogen, N_2	78.084 %	1.2506 g/L	atmo_n2
Oxygen, O_2	20.946 %	1.429 g/L	atmo_o2
Argon, Ar	9340 ppm	1.784 g/L	-
Carbon dioxide, CO_2	400 ppm	1.977 g/L	atmo_co2
Neon, Ne	18.18 ppm	0.9002 g/L	-
Helium, He	5.24 ppm	0.1786 g/L	-
Methane, CH_4	1.7 %	0.657 g/L	atmo_ch4
Krypton, Kr	1.14 ppm	3.749 g/L	-
Hydrogen, H_2	0.55 %	0.08988 g/L	atmo_h2
Nitrous oxide, N_2O	0.5 ?	1.977 g/L	-
Xenon, Xe	0.09 ?	5.894 g/L	-
Nitrogen dioxide, NO_2	0.02 ?	1.880 g/L	-
Water vapour, H_2O	1.00 %	1000 g/L	atmo_h2o

NOTE A: Concerning water vapor: https://en.wikipedia.org/wiki/Humidity

The percentage of water vapor in air varies based on temperature. The percent of water vapor in the cold Arctic and Antarctic (and highest Alpine regions) may reach as low as 0.2 percent while the warmest tropical air may contain up to 4 percent water vapor. This can also be expressed as from nearly 0 to 30 grams per cubic meter, or 30/1250 g, which is 2.5%.

NOTE B: 7080 liters gas compressed at 3000 psi would require 223 x 16 liter SCUBA tanks, at 19.5 kg each *

NOTE C: Grant Anderson, Paragon, states “At 3,000 psi, the tank to contents ratio is about .3 to .5 to 1 (e.g. 3000 kg of 3000 psi air takes a 1,000 kg to 1,500 kg tank. *Don't forget tank weight!*”

NOTE D: Due to the increasing potential for a higher water vapor partial pressure at higher air temperatures, the water content of air at sea level can get as high as 3% by mass at 30°C (86°F) compared to no more than about 0.5% by mass at 0°C (32°F): https://en.wikipedia.org/wiki/Relative_humidity

Water Storage Agent

400kg h2o = 110.23 gal So storage unit is based on a Duracast 110 gal RV water tank.

In/Out: +/-	h2o_tret	400 kg tank limit
In/Out: +/-	h2o_potb	400 kg tank limit
In/Out: +/-	h2o_urin	400 kg tank limit
In/Out: +/-	h2o_wste	400 kg tank limit
27.6691 kg	mass	
0.4288 m^3	vol	

NOTE: The volumes and mass do not directly represent those employed in SIMOC. With Phase IIIb, water storage is auto-calculated based upon the size of the crew quarters and greenhouse.

Nutrient Storage Agent (Fertilizer)

Based on Snyder 35 gallon Heavy Duty cone bottom mixing tank

In/Out: +/-	sold_n	100 kg tank limit
In/Out: +/-	sold_p	100 kg tank limit
In/Out: +/-	sold_k	100 kg tank limit
6.35029 kg	mass	
0.354 m^3	vol	

NOTE: With Phase II, we are auto-calculating the amount of fertilizer included per plant.

Power Storage Agent (Batteries)

In/Out: +/-	enrg_kwh	1000 kWh battery
226.796 kg	mass	(need to revise)
0.368 m^3	vol	(need to revise)

NOTE: While we researched the Based on Blue Planet Energy Blue Ion 2.0 Battery and others, we applied a little bit of science fiction and determined that each battery is capable of holding 1000 kWh

FUTURE AGENTS

Power Generation

Future power generation agents will include Geothermal, Wind Turbine, Radioisotope Generator, and Nuclear.

Structure

Future structure agents will include Fabrication, Laboratory, Health Services, Recreation, and Mobility.

Radio Agent

Purpose: Communication to an orbiter and relay station; ground-to-ground communication

Computers and Lab Equipment Agents

Purpose: Laptops, servers, cameras, atmosphere and soil analysis equipment; medical emergency; kitchen, etc.

Appendix A: Global Variables

Hours in a day:

sol_hrs	24.67	Mars: quantity of Earth hours included in an off-world day
sol_hrs	???	Moon: quantity of Earth hours included in an off-world day

Solar Gain* – Hours:

solr_hrs	8	Mars: average # Earth hours of solar illumination per day
solr_hrs	14 days	Moon: average # Earth hours of solar illumination per month

Solar Gain – Watts:

solr_gain	53.1 w/m^2	Mars: average solar gain, at the given distance of the habitat **
solr_gain	??? w/m^2	Moon: average solar gain, at the given distance of the habitat

Temperatures:

temp_int	291K / 18C	ambient temperature internal to habitat [not in use at this time]
temp_ext	210K / -63C	ambient temperature external to habitat [not in use at this time]

Gravity:

grav_fld	gravitational field strength on given location for habitat

Atmosphere Pressures:

pres_hab	atmospheric pressure internal to habitat
pres_hab_o2	partial O2 pressures
pres_hab_co2	partial CO2 pressure
pres_hab_n	partial N2 pressure
pres_gh	atmospheric pressure internal to greenhouse
pres_gh_o2	partial O2 pressures
pres_gh_co2	partial CO2 pressure
pres_gh_n	partial N2 pressure
pres_ext	ambient atmospheric pressure
pres_ext_o2	partial O2 pressures
pres_ext_co2	partial CO2 pressure
pres_ext_n	partial N2 pressure
pres_ext_ch4	partial methane pressure
pres_ext_???	[not in use at this time]

Appendix B: Currencies of Exchange

The following are Currencies of Exchange, that which any given agent transacts with any other agent, listed by type:

Atmosphere

atmo_o2	kg	oxygen
atmo_co2	kg	carbon dioxide
atmo_h2	kg	hydrogen
atmo_n2	kg	nitrogen
atmo_h2o	kg	water vapor [calculated as a % of atmo_*, not relative humidity]
atmo_ch4	kg	methane
atmo_cont	kg	trace contaminants; break down later

Solid

sold_n	kg	nitrogen (fertilizer)
sold_p	kg	phosphorous (fertilizer)
sold_k	kg	potassium (fertilizer)
sold_wste	kg	[not in use at this time]

Biomass

- [need to add total]
- [need to add inedible]
- [need to add edible]

Food

food_totl	kg	total food
food_stor	kg	freeze dried; categories combined by NASA
food_edbl	kg	edible food
food_ined	kg	total inedible biomass (see Biomass)
○ food_legu	kg	legumes
○ food_leaf	kg	leafy greens
○ food_vegi	kg	vegetables ???
○ food_frut	kg	fruits
○ food_cers	kg	cereals
○ food_root	kg	root vegetables
○ food_othr	kg	other, e.g. mushrooms

Water

h2o_totl	kg	total water
h2o_tret	kg	treated water
h2o_potb	kg	potable water
h2o_urin	kg	urine water
h2o_wste	kg	waste water (used in place of sold_wste)

Nutritients

nutr_???	kg	plant fertilizer [not in use at this time]

NOTE: The composter is currently assumed to be a 100% efficient bioreactor in which all inedible biomass is converted into usable fertilizer. Until we learn how to break inedible biomass back into the constituent sold_n, sold_p, and sold_k we are combining these currencies of exchange into a single variable “fertilizer”. We need to return to a discussion of a bioreactor as described in the literature.

Energy

enrg_kw	kw	power, e.g. solar PV array
enrg_kwh	kwh	energy, e.g. battery storage
enrg_???	kwh	[we need to differentiate power demand vs power delivered]

Heat

heat_cal	cal	energy lost to heat of an engine [not in use at this time]

NOTE: A calorie, or gram calorie (cal), is the amount of heat energy needed to raise the temperature of one gram of water by one degree Celsius at a pressure of one atmosphere. The kilogram calorie (Cal, kcal) or *food calorie* is the heat energy required to raise the temperature of one kilogram (rather than a gram) of water by one degree Celsius. One small calorie is approximately 4.2 joules, therefore, one Calorie is about 4.2 kilojoules.[2]

---

[2] https://en.wikipedia.org/wiki/Calorie

Appendix C: Agent Library I/O Functions

The input and output arrays for each agent define the flow of currencies through an agent. A basic input/output in the agent library is a json object with these three properties:

Type:	The associated currency of exchange, e.g. h2o_potb for Potable Water.
Value:	The numeric value of said currency. Can be int or float.
Flow Rate:	A json object with two properties for units over time.
Unit:	A physical unit that must be acceptable by python quantities
Time:	A unit of time that also must be acceptable by python quantities

Each agent in the json library can be created with various functions that define extra characteristics of the input/output. These must be created as a property of the input/output object.

Criteria

Type: JSON object with three properties. Name must be a string, limit can be “<” or “>”, and value can be an int or float.

Use: Input or output

Description: The criteria that must be met for this input/output to take place. The criteria can be a currency or ratio with an upper or lower limit.

Example:

```
{
    "type": "enrg_kwh",
    "value": 0.959,
    "required" : true,
    "flow_rate": {
      "unit": "kWh",
      "time": "hour"
    },
    "criteria": {
      "name": "atmo_o2_ratio",
      "limit": "<",
      "value": 0.195
    }
  }
```

Deprive

Type: JSON object with value and unit properties. Value must be an int, and unit must be a quantities accepted unit of time.

Use: Inputs and outputs

Description: If the agent goes the specified time without this input or output, it is destroyed.

Example:

```
"type": "food_edbl",
"value": 2.394,
"flow_rate": {
  "unit": "kg",
  "time": "day"
"deprive": {
  "value": 21,
  "unit": "day"
```

Growth

Type: [need to complete]

Use: [need to complete]

Description: [need to complete]

Example:

```
"type": "atmo_co2",
"value": 0.0015399905754,
"flow_rate": {
  "unit": "kg",
  "time": "hour"
"growth": {
  "daily": {
    "type": "norm",
    "center": 12
```

Required

Type: boolean

Use: Inputs only

Description: A boolean value to determine if the input is required for the agent to take a step in the model. Without a required input, the agent will produce 0 values for all outputs in a step.

Example:

```
"type": "enrg_kwh",
"value": 0.678,
"required" : true,
"flow_rate": {
  "unit": "kWh",
  "time": "hour"
```

Requires

Type: array of strings

Use: Outputs only

Description: An array of inputs that must have occurred for this output to take place. The array must be formed of currencies of exchange. Without the inputs defined in the array, the agent will not produce this output in a step.

Example:

```
"type": "atmo_o2",
"value": 0.367,
"requires": ["h2o_potb", “enrg_kwh”],
"flow_rate": {
  "unit": "kg",
  "time": "hour"
```