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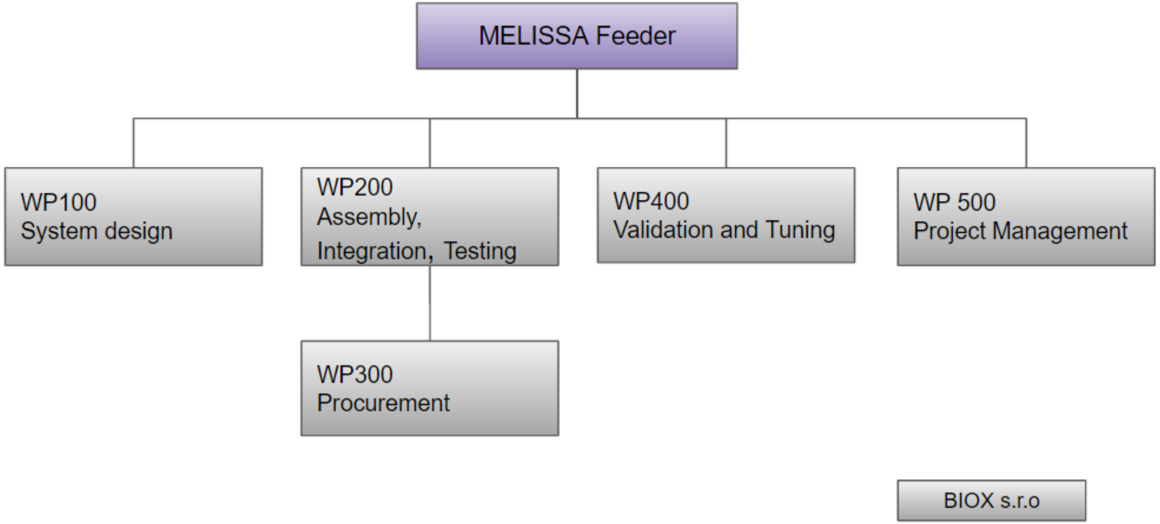
SK6_19
MELISSA Feeder: Biomass Harvesting system for food preparation

Objectives

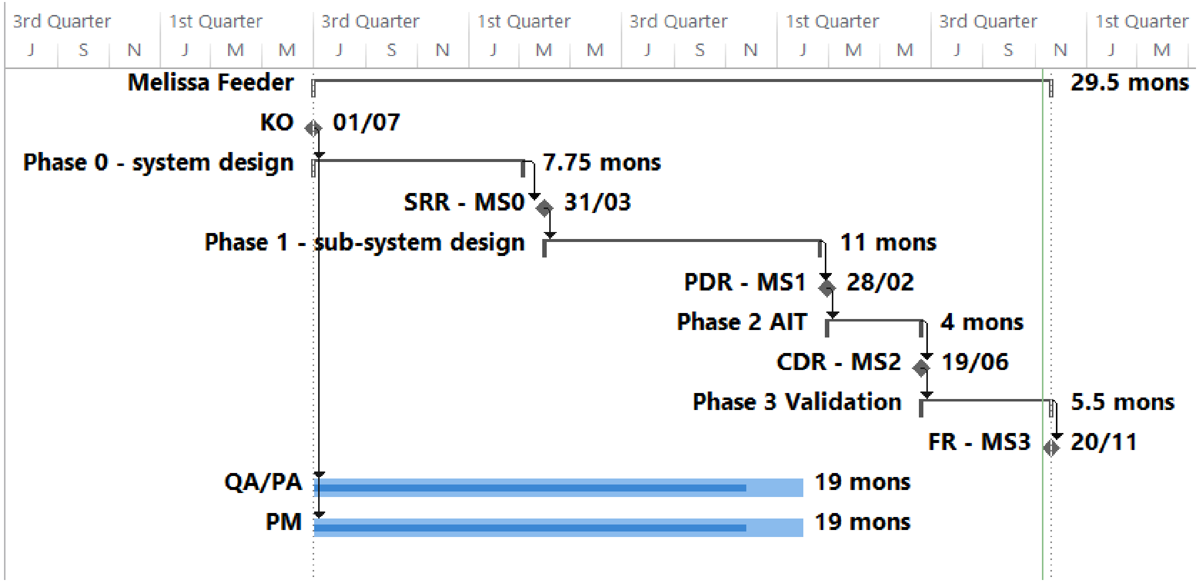
1. From existing processes and designs, the objective of this project shall be to **create the various technical parts of a recovery line** for processing of Limnospira biomass.
2. The liquid medium stream will be removing biomass and recycled back the cultivation medium and to the originating bioreactor.
3. Biomass will be further concentrated in two steps on microfilters and sieves and dried in consequent steps of vacuum drying.
4. Sterility of the reverse liquid medium loop must be kept, this is a critical system performance constraint. Contamination must be avoided. Operations of the device should be fully tested and automated, at least at the local level.

BioX Technologies	Prime

Logical work-flow



Baseline Start	Start Variance
01/07/2022	**0 mons**
01/07/2022	0 mons
01/07/2022	**0 mons**
30/09/2022	5.9 mons
03/10/2022	**5.9 mons**
09/01/2023	14.25 mons
10/01/2023	**14.25 mons**
24/07/2023	11.3 mons
25/07/2023	**11.3 mons**
23/01/2024	10.8 mons
01/07/2022	0 mons
01/07/2022	0 mons



The project went significantly overtime, namely in Phase 0 and Phase 1. Phase 1 delay was mainly caused by a critical event, specifically a large accident involving flooding between the floors of the lab (fully outside the control of Biox).

Phase 2 caught up some lost time

Original duration: 19 mo

Final duration: ~30 mo

BioX technologies

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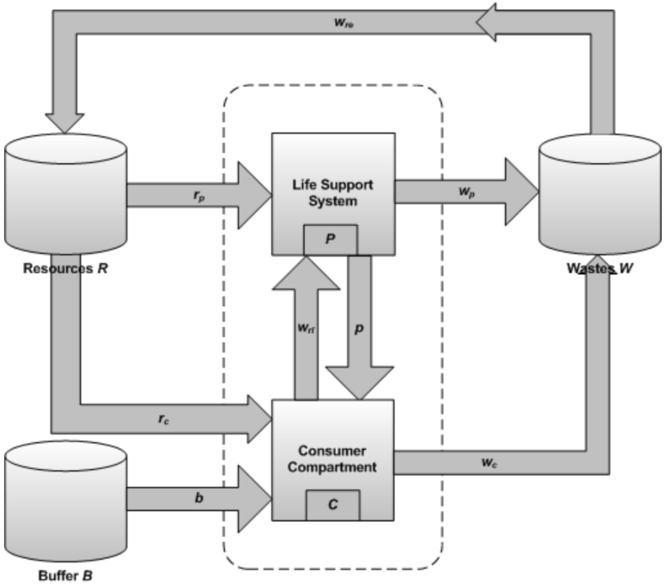
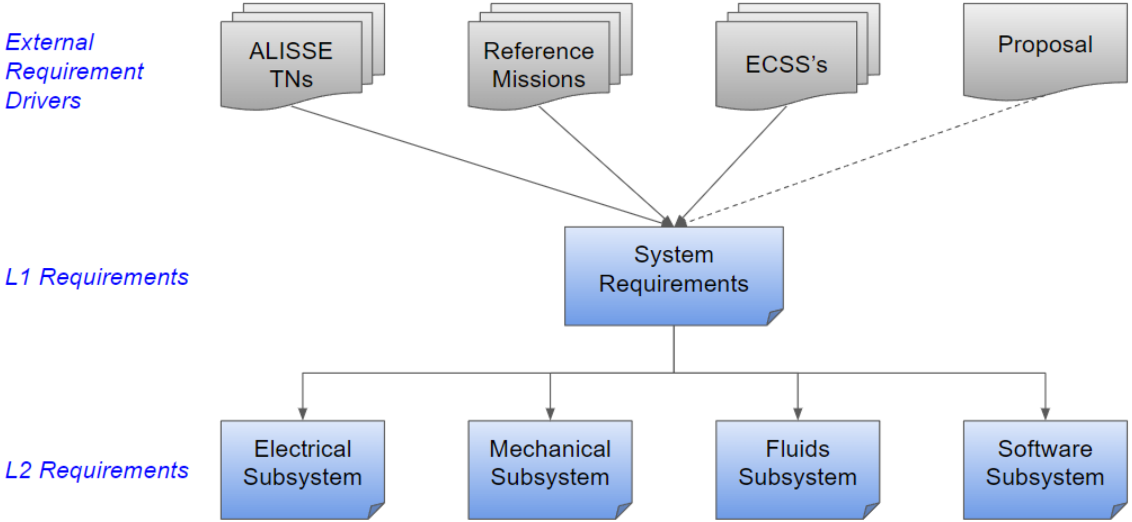
MELISSA Feeder: Biomass Harvesting system for food preparation

TECHNICAL DETAILS

Objective 1 - Requirements synthesis



LLS Architecture concept from TN4 - Mission Level



Requirements Hierarchy

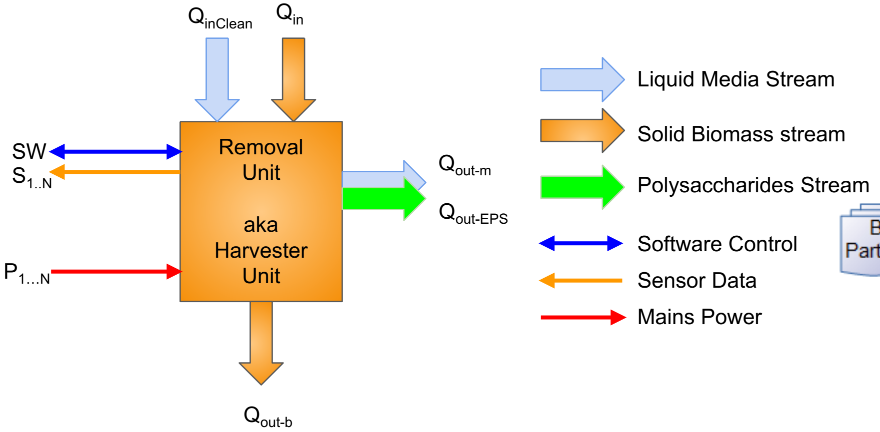
Objective 1 - Requirements synthesis

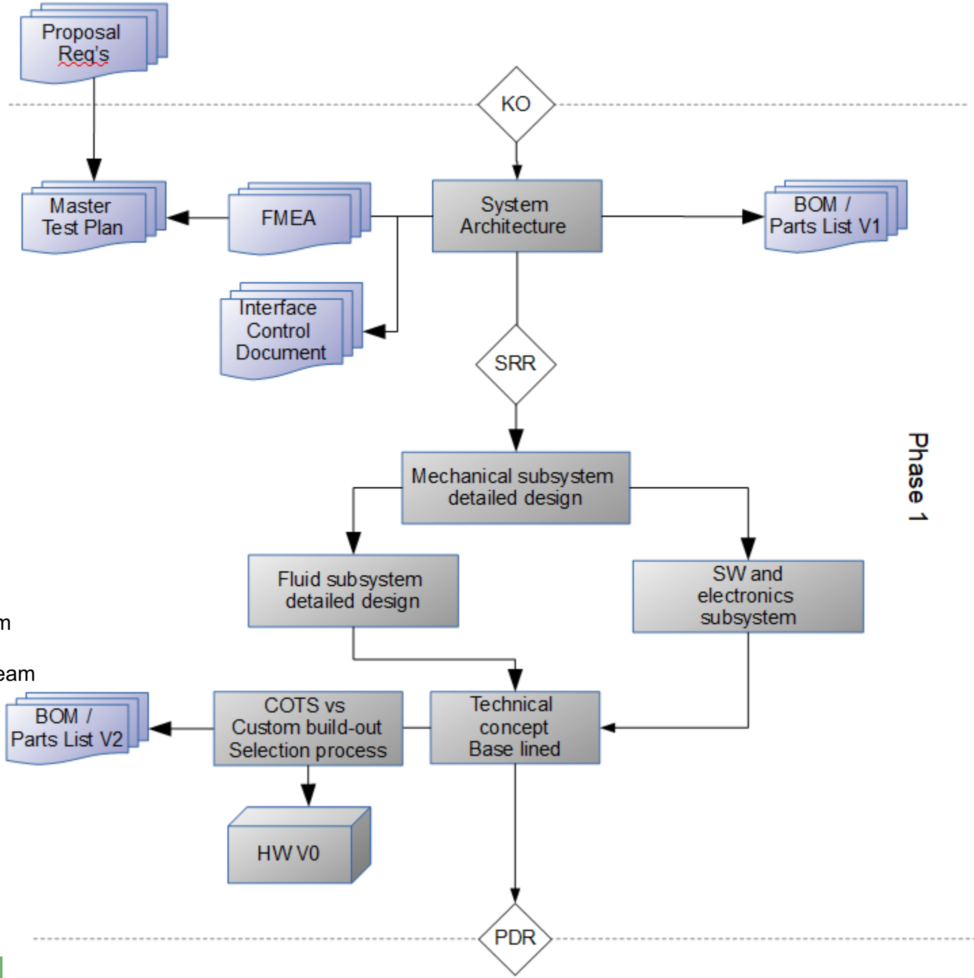
1	New ID	Standard Melissa Categories	Standard Melissa Sub-Categories	Requirement	Remark	Status	Rq Version #	Rq Level	Criticality	Traceability	Verif. Procedure	Reviewed/Inspected By	Test Procedure	Test Case	Pass/ Fail	Report Reference	Mass
13	CONST-DES-03	Constraint	Design	The extraction unit (RU) is expected to have at least 2 fluid outputs: 1) biomass paste 2) permeate outflow		Active	1.0	System Level (L1)	Low	System of interest	Inspection				-		Yes
14	CONST-PHY-03	Constraint	Physical	The extraction unit shall allow for the removal of cake buildup	Its TBD on the mechanism how to do this. As manual removal will violate axenicity.	Active	1.0	System Level (L1)	Critical	AD01	Test		UT-2		PASS		No
15	CONST-PROD-01	Constraint	Production	The volume of the active PBR shall be at least 50L	Its expected that an 80+L reactor can generate enought Spirulina within a nominal growth curve, to allow for 5G of harvesting.,	Active	1.0	System Level (L1)	Critical	Constraint	Analysis				-		Yes
16	CONST-PROD-02	Constraint	Production	The jig (support structure) shall be constructed from stainless steel	Steels typically used in food-grade equipment is assumed to be the baseline	Active	2.0	System Level (L1)	Normal	Context - Food	Review				-		Yes
17	FUN-PERF-01	Functional	Functional/Performance	System shall separate cultivation broth to solid and liquid fraction	GENERAL requirement	Active	2.0	System Level (L1)	Normal	Context - Lifecycle	Review				-		
18	FUN-PERF-02	Functional	Functional/Performance	*Arthrospira platensis strain PCC8005*		Active	1.0	System Level (L1)	Low	Melissa Needs	Analysis				-		No
19	FUN-PERF-03	Functional	Functional/Performance	The system shall keep the integrity of the cells at 90% (system inlet) and avoid cell lysis.		Active	1.0	System Level (L1)	Low	Melissa Needs	Analysis						Yes
20	FUN-CTRL-01	Functional	Control	The target concentration factor shall be 10x or higher	Calculation shall be used to determine concentration factor	Active	2.0	System Level (L1)	Low	AD01	Analysis				-		No
21	FUN-PERF-04	Functional	Functional/Performance	End to end system performance shall be measured in weight percent	This shall be recorder for each drier/medium flow in operation and in tandem Min yield in stable state: 80%	Active	1.0	System Level (L1)	Critical	ALISSE - Mass	Test		PT-3		-		No
22	FUN-CTRL-02	Functional	Control	There shall be at minimum two independantly controllable steams: 1) biomass recovery stream 2) liquid medium return streram	ie. each system shall not be dependant on each other	Active	2.0	System Level (L1)	Low	Context - Lifecycle	Inspection				-		Yes
23	FUN-PERF-05	Functional	Functional/Performance	It shall be TBD, if the system requires vibrational actuation for the purpose of continous use. If the system does require it to meet performance needs, then the vibrational capability of the extraction unit shall be controlable.	Ie the unit's vabration can be turned on and off	Active	1.0	System Level (L1)	Normal	AD01	Test		QT-3		PASS		No
24	FUN-CTRL-03	Functional	Control	The volumetic flow across the extraction unit shall be minimum TBC and Maximum TBC		Active	1.0	System Level (L1)	Normal	System of interest	Test		QT-1		PASS		No
25	FUN-CTRL-04	Functional	Control	The SW framework shall be COTS, no feature coding is expected	Labview is baselined, alternative RedLion industrial SW	Active	1.0	System Level (L1)	Normal	Software Section	Inspection				-		No
26	FUN-PERF-06	Functional	Functional/Performance	The fluid medium in transfer pipes shall allow for the following flow rate: 100 mL/min	Expected: Min: 2 mL/min Max: 500 mL/min	Active	2.0	Sub-system (L2)	Normal	??	Test		QT-1		PASS		Yes
27	FUN-PERF-07	Functional	Functional/Performance	The fluid medium in MF/UF recirculation shall allow for the following flow rate: 25 L/min	Expected: Min: 5 L/min Max: 50 L/min	Active	2.0	Sub-system (L2)	Normal	??	Test		QT-1		PASS		Yes
28	INT-FUN-01	Interface	Functional Interface	The SW shall allow of semi-automatic / automatic control of the system, and prevent unsafe operation	Alarms are expected to be visible/audible in the GUI	Active	1.0	System Level (L1)	Normal	ALISSE - Crew	Test		QT-3		PASS		No
29	INT-PHY-01	Interface	Physical Interface	The fluid medium shall not leak unless explicitly desired by the system		Active	1.0	System Level (L1)	Normal	ALISSE - RAMS	Test		QT-1		PASS		Yes
30	INT-PHY-02	Interface	Physical Interface	Liquid flow connection should be designed from stainless piping with soft edges, or from silicone hoses		Active	1.0	System Level (L1)	Normal	Context - Food	Review				-		Yes
31	INT-PHY-03	Interface	Physical Interface	Recirculation and transfer tanks should be designed from stainless steel or glass, with further possibility to change the shape	PP/PE bags can be foreseen in the future to comply with zero-g, Steels typically used in food-grade equipment is assumed to be the baseline	Active	1.0	System Level (L1)	Normal	??	Inspection				-		Yes
32	OP-RESS-01	Operational	Resources	The entire PBR system, including jig, shall be weighed at 1) dry mass and 2) wet mass during operation	Its assumed the entire system shall be mounted on a jig, which itself can be weighed in both circumstances	Active	1.0	System Level (L1)	Normal	ALISSE - Mass	Inspection						Yes
33	OPS-MODE-01	Operational	Modes & Scenarios	System shall be designed in continous mode	assumed for this bioreactor type / harvesting unit	Active	1.0	System Level (L1)	Low	Melissa Needs	Inspection				-		Yes
34	OP-ENV-01	Operational	Operational Environment	The cultivation temperature shall be 36°C +/- 2	updated	Active	3.0	System Level (L1)	Low	Melissa Needs	Test		UT-1		PASS		No
35	OP-RESS-02	Operational	Resources	System shall be design to allow external buffer addition (return tank)		Active	2.0	System Level (L1)	Low	Melissa Needs	Review						No
36	OP-RESS-03	Operational	Resources	The mass balance of each production run shall be recorded	This assumes the system is a LSS per TN9, and shall use the ALISSE model as a reference	Active	1.0	System Level (L1)	Normal	ALISSE - Mass	Analysis				-		Yes
37	OP-DOC-00	Operational	Documentation	All Qualification Tests shall be accompanied by data logs for each run	From the control SW	Active	1.0	System Level (L1)	Normal	Derived	Inspection				-		No
38	OP-DOC-01	Operational	Documentation	All Qualification Tests shall be accompanied by input (bacteria culture) source reports/note	No additional reports need to be generated, only that the final qualification tests shall not have contamination present	Active	2.0	System Level (L1)	Normal	Derived	Inspection				-		No
39	OPS-RAMS-01	Operational	RAMS	The system shall be ROHS compliant	No hazardous wiring should be present on HW configs	Active	1.0	System Level (L1)	Low	ALISSE - RAMS	Inspection				-		No
40	OPS-HUMAN-01	Operational	Human factors & ergonomics	Failure on any part of the system shall not endanger the operator in any way	In tandem with requirement below, a DFMEA shall be continously updated	Active	1.0	System Level (L1)	Normal	ALISSE - Crew	Review				-		No

BioX technologies

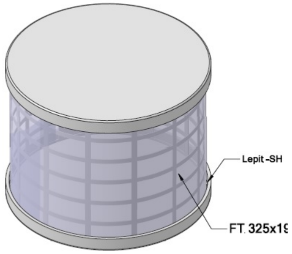
Objective 1 - Harvesting skid design

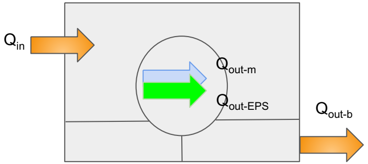
From existing processes and designs, the objective of this project shall be to **create the various technical parts of a recovery line** for processing of Limnospira biomass.





Objective 1 - Mechanical design - solid/liquid loop





Mains Power

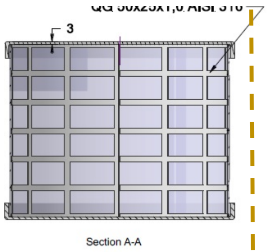
230V ~
but can be optimized to LOW voltage

Sensor Data

I2C or 0-20mA bus
-Temperature
-Rotation
-Vacuum (if any)

Software Control

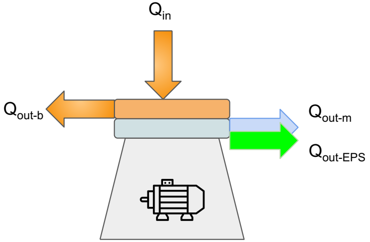
-Rotation
-Inlet pump flow
-Vacuum I/O (if applicable)
-sieve discharge (if applicable)



Rotary filter

Vibrating filter

Biomass separation unit design, testing and future steps



Mains Power

400V ~
but can be optimized to 230V ~
or to LOW voltage

Sensor Data

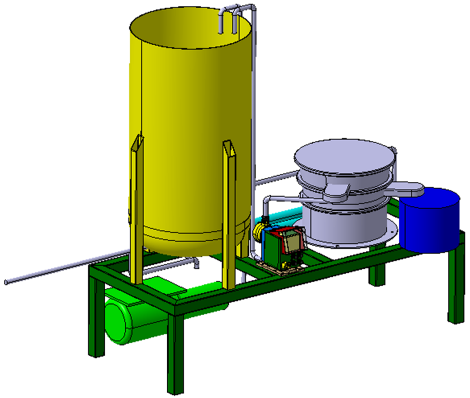
I2C or 0-20mA bus
-Temperature

Software Control

-Vibration
-Inlet pump flow

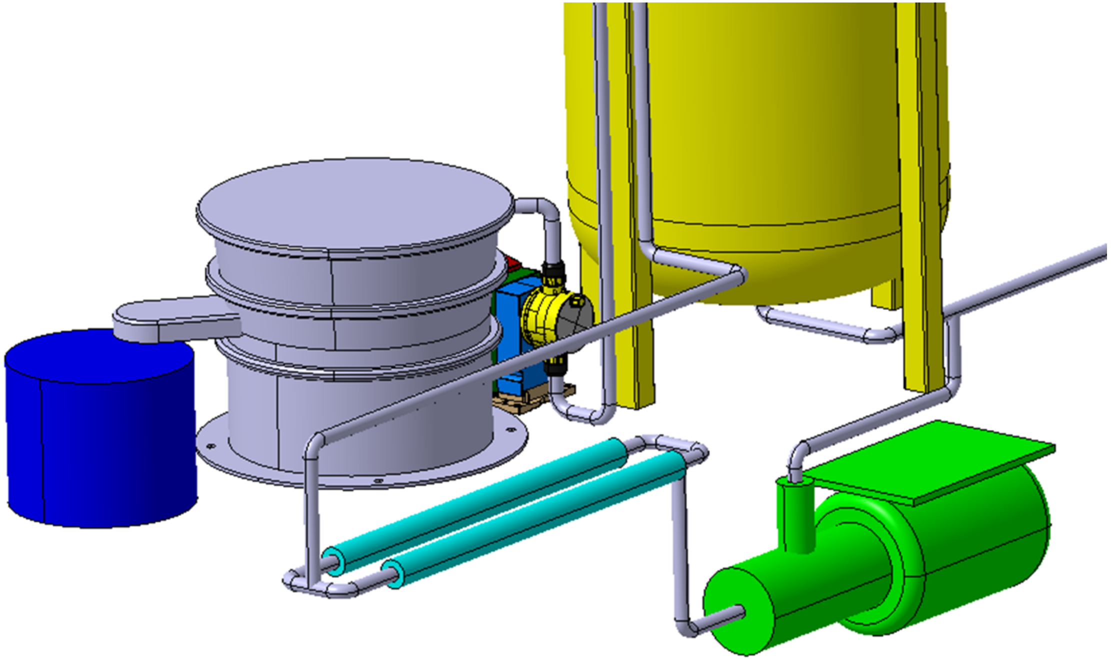
Core harvesting technology

Objective 1 - Mechanical design

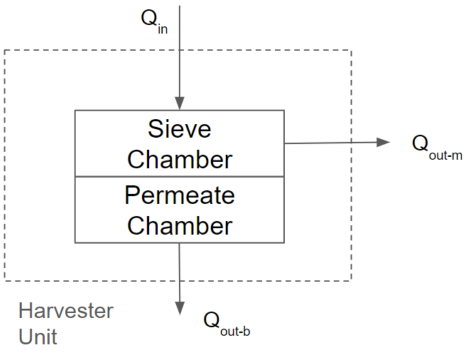


Mechanical design ver.1

Designed as continuous harvesting technology using vibration filtration screen, ceramic filters and pumps based on solid construction rig from Stainless Steel

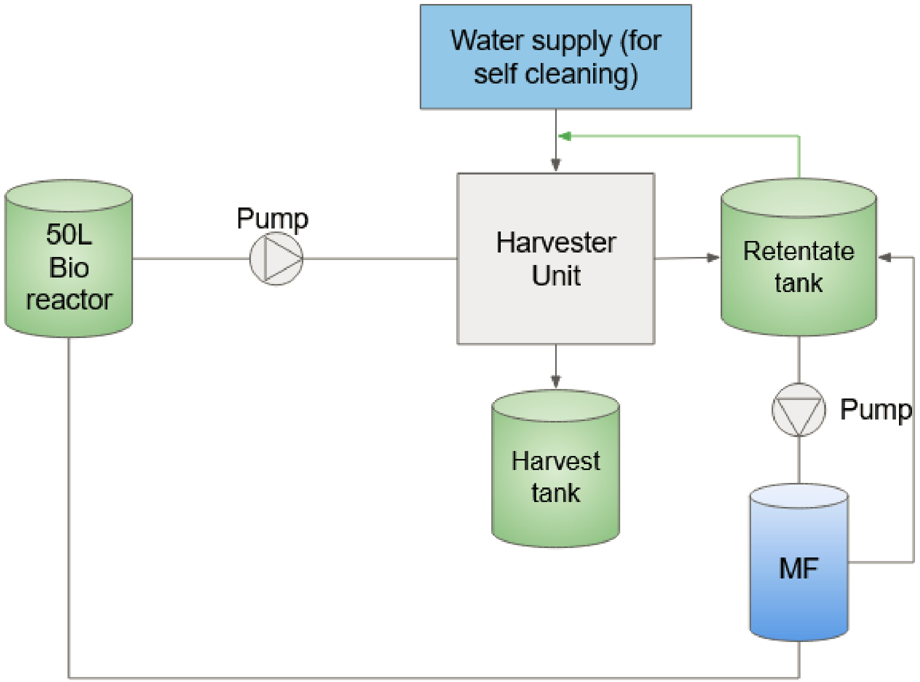


Objective 1 - Fluid design

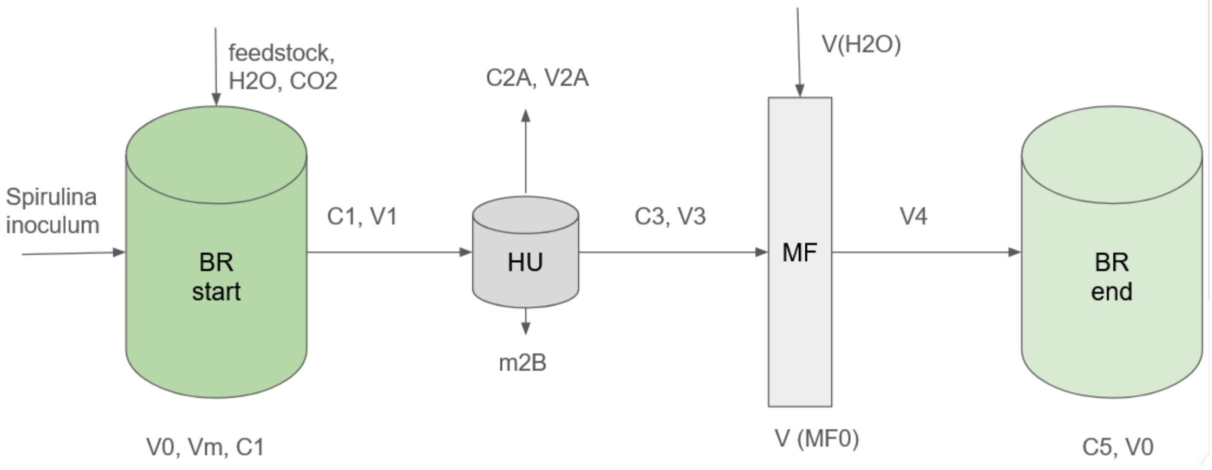


Fluid interfaces

Designed as continuous harvesting technology using vibration filtration screen, ceramic filters and pumps based on solid construction rig from Stainless Steel



Fluid design - Harvesting Mass Balance



BR	bioreactor		
HU	harvesting unit	m2B	spirulina paste, that stays on the sieve
MF	microfiltration	C3, V3	filtrate stream
V0	bioreactor volume	V(H2O)	deionised H2O, that needs to be added to cover dead volume of microfiltration and product stream V2A
Vm	media volume left in the bioreactor for the next cycle		
C1	concentration of spirulina calculated from OD	V (MF0)	dead volume of microfiltration
V1	harvested volume	V4	stream of purified media
C2A, V2A	harvested product	C5	concentration of spirulina after harvesting cycle

Some sample calculations...

V0 =V1 + Vm
C1*V1 = C2A*V2A + m2B + C3*V3
m (wet product) = C2A*V2A + m2B
V1 = V4
V4 = V1-V2A+V(H2O)-V(MF0)
C5*V0 = C1*Vm

100 mL bioreactor vessel, batch filtration

V0 = 100 mL
Vm = 0 mL
C1 = 2.11 g/L
m2B = 5.3 g
C2A = 0 g/L
V2A = 0 L

V1 = V0 – Vm = 100 mL – 0 mL = 100 ml
*m (wet product) = C2A*V2A + m2B = 0 + 5.3 g = 5.3 g*
*m (dry product) = 10% * 5.3 g/L = 0.53 g*

10L PBR, semi-continuous filtration

V0 = 10 L
Vm = 1 L
C1 = 1.62 g/L
m2B = 45.2 g
C2A = 21.5 g/L
V2A = 0.02 L

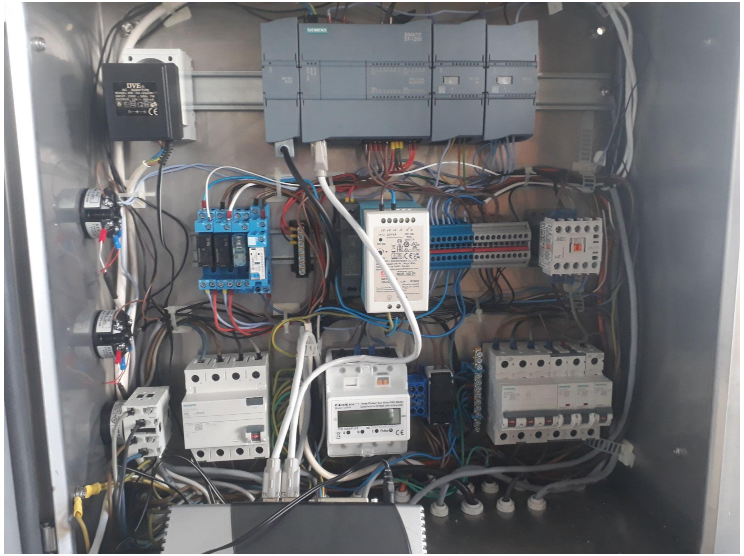
V1 = V0 – Vm = 10 L – 1 L = 9 L
*m (wet product) = C2A*V2A + m2B*
*= 21.5 g/L*0.02L + 45.2 g = 45.63 g*
*m (dry product) = 10% * 45.63 g/L = 4.56 g*
*C5 = (C1*Vm)/V0 = (1.62 g/L*1L)/10 L = 0.162 g/L*

45L PBR, semi-continuous filtration

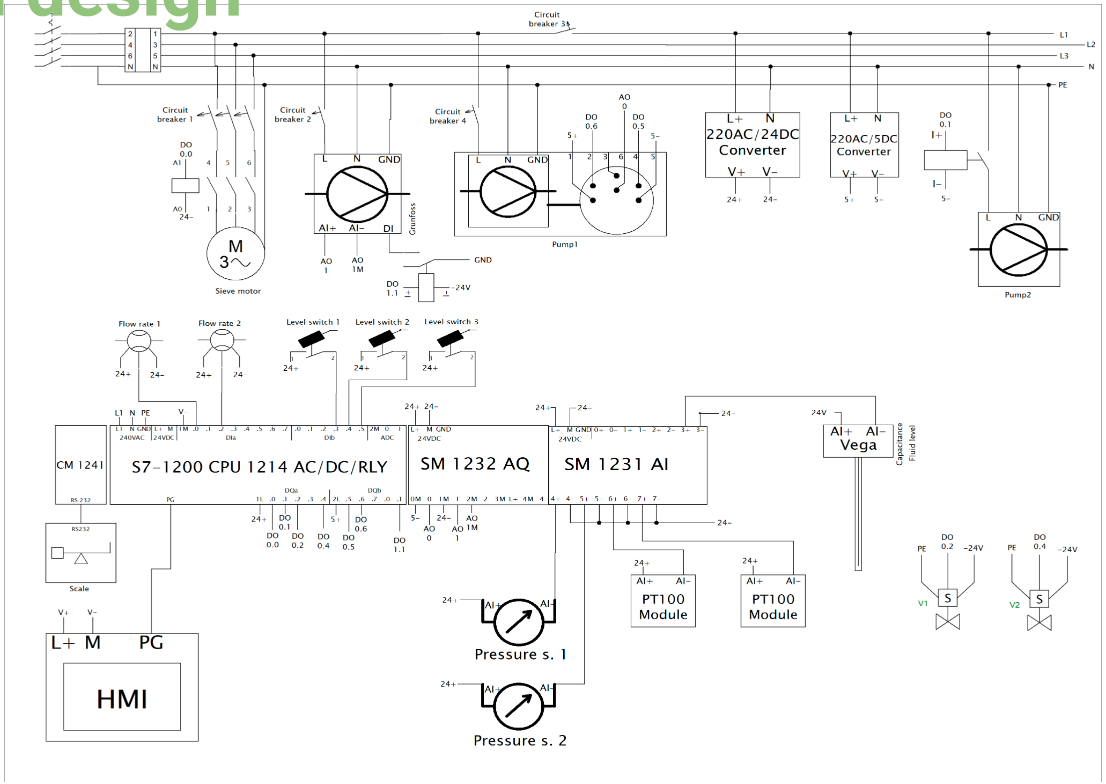
V0 = 45 L
Vm = 7 L
C1 = 1.05 g/L
m2B = 200 g
C2A = 20.4 g/L
V2A = 0.12 L

V1 = V0 – Vm = 45 L – 7 L = 38 L
*m (wet product) = C2A*V2A + m2B*
*= 20.4 g/L*0.12L + 200g = 202.4 g*
*m (dry product) = 10% * 202.4 g/L = 20.24 g*
*C5 = (C1*Vm)/V0 = (1.05 g/L*7L)/45 L = 0.16 g/L*

Objective 1 - Electrical design



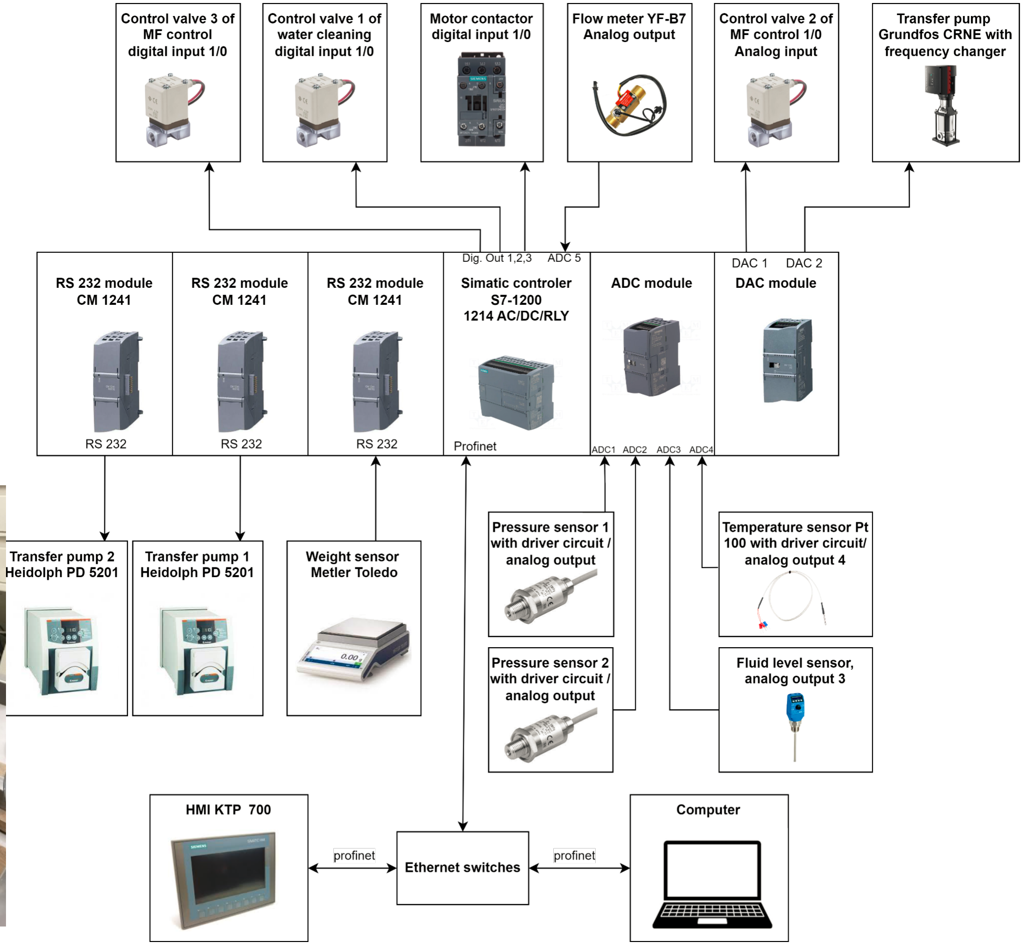
Wiring - Feeder unit



Skid wiring electrical diagram

Objective 1 - electrical design & automation

Feeder system control automation architecture, with HMI, interfaces and sensors

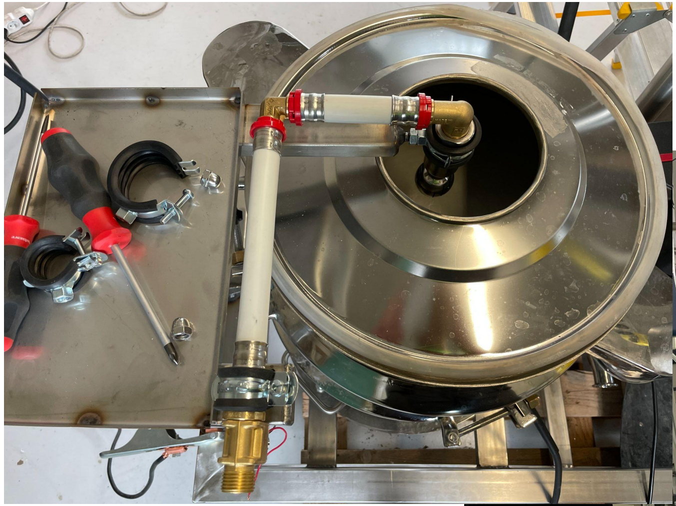


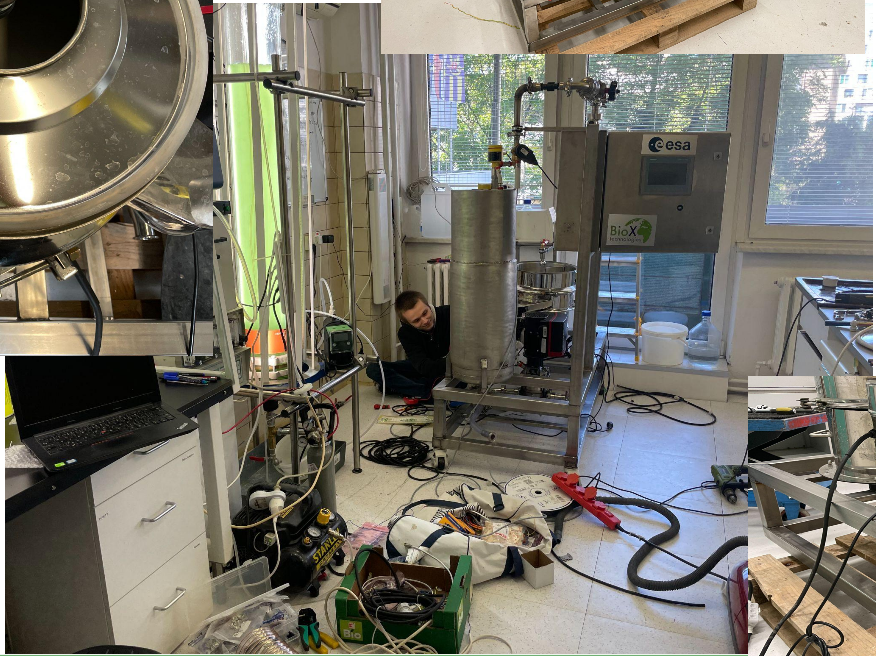
List of sensors and actuators and power consumption

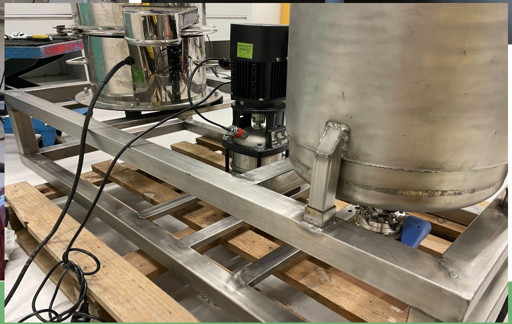
#	Component Name	Purpose	Interface	Consuption per Spec Sheet [W]	Recorded Power Consuption (Test)	Unit	Operational Range	Tolerance/ Resolution	Accura
1	Computer	Used to connect to the master control unit S7-1200. Only to be used for programming and changing system setup, not a permanent unit	Ethernet Cable			N/A - communications	N/A	N/A	N/A
2	KTP 700	HMI of the system. It is used for monitoring data, and controlling the system.	Ethernet Cable	5.5		N/A - communications	N/A	N/A	N/A
3	Weight sensor	Measuring the mass of the Biopasta. Based on this information, warning is send to HMI to empty the buffer tank	RS 232	27		Grams	0-250	0.1g	
4	Transfer pump	Transporting the fluid from reactor to the feeder.	RS 232	78		%	0-100	N/A	N/A
5	Control valve of water cleaning	Valve for water supply for purpose of cleaning	Digital input 1/0	18		%	0-100	N/A	N/A
6	Motor contactor	Turning on and off 3 phase motor	Digital input 1/0	6		%	0-100	N/A	N/A
7	Temperature sensor	Measuring temperature of incoming fluid into the feeder, before it drops into the sieve	Analog output	0.5		°C	0-100°C	0.1 °C	0.1°C
8	Pressure sensor	measuring fluid pressure of incoming fluid, AFTER the transfer pump. It checks operation, or if pipeline is damaged somewhere	Analog output	0.5		MPa	0-3	0.03MPa	1% F.C
9	ADC module	For converting analog signals into the digital	Directly connected to S7-1200			N/A - power equipment			
10	RS 232 module	Communication with devices via RS 232	Directly connected to S7-1200	1.1		N/A - communications			
11	Controler S7-1200	main microcontroller unit	Ethernet	14		N/A - communications			
TOTAL				**150.6**					

Consumers	Design Rate (W)	Duration (h)	Test Reference	Estimated power Consumption (kWh)
Sensors and Actuator	150.6	360	15 days for PT-1	54.216
Vibrational Motor	500	2.5	10 mins for PT-1 (estimated)	1.25
				55.466

Assembly of Feeder unit

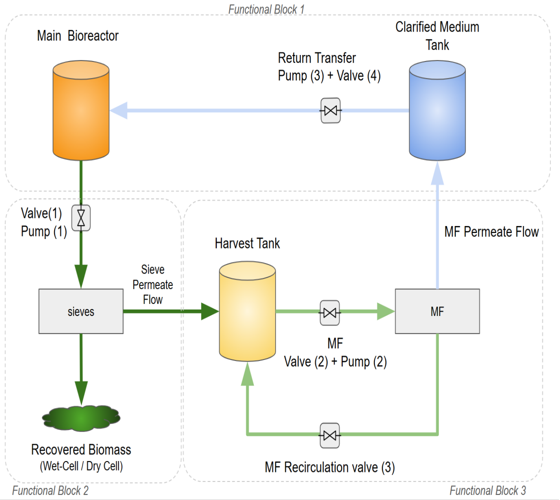


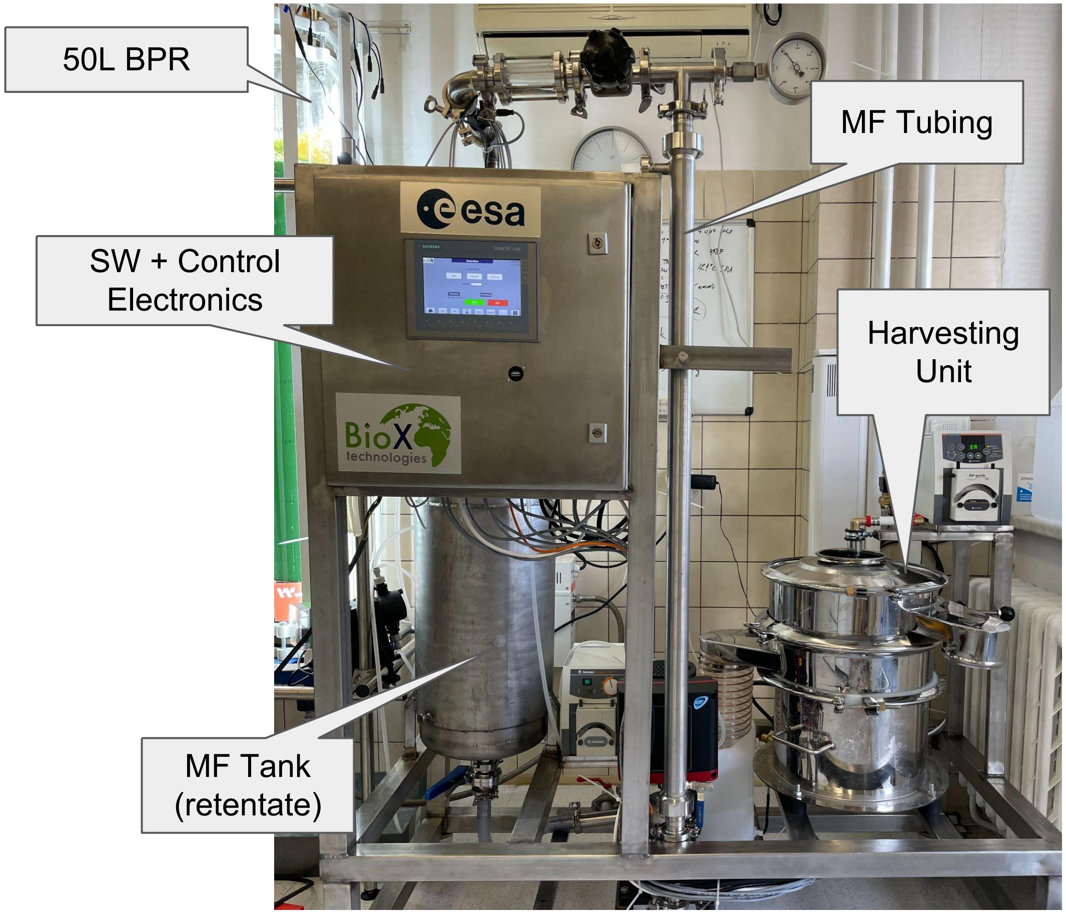




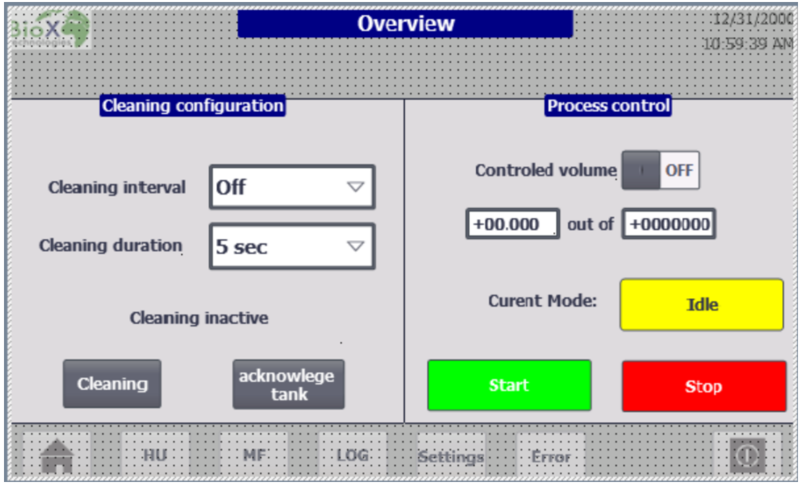
Objective 1

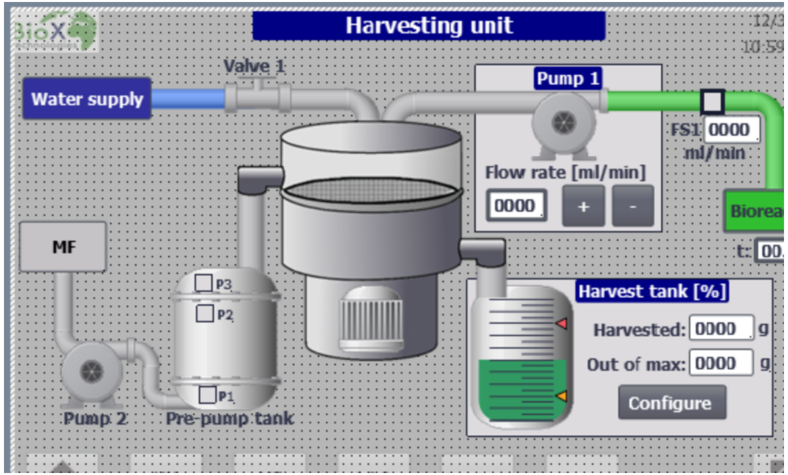
From existing processes and designs, the objective of this project shall be to **create the various technical parts of a recovery line** for processing of Limnospira biomass.

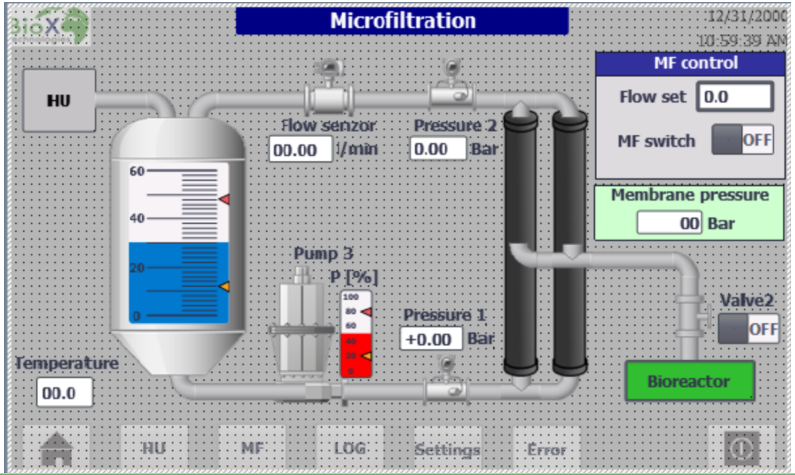




GUI Main Interface







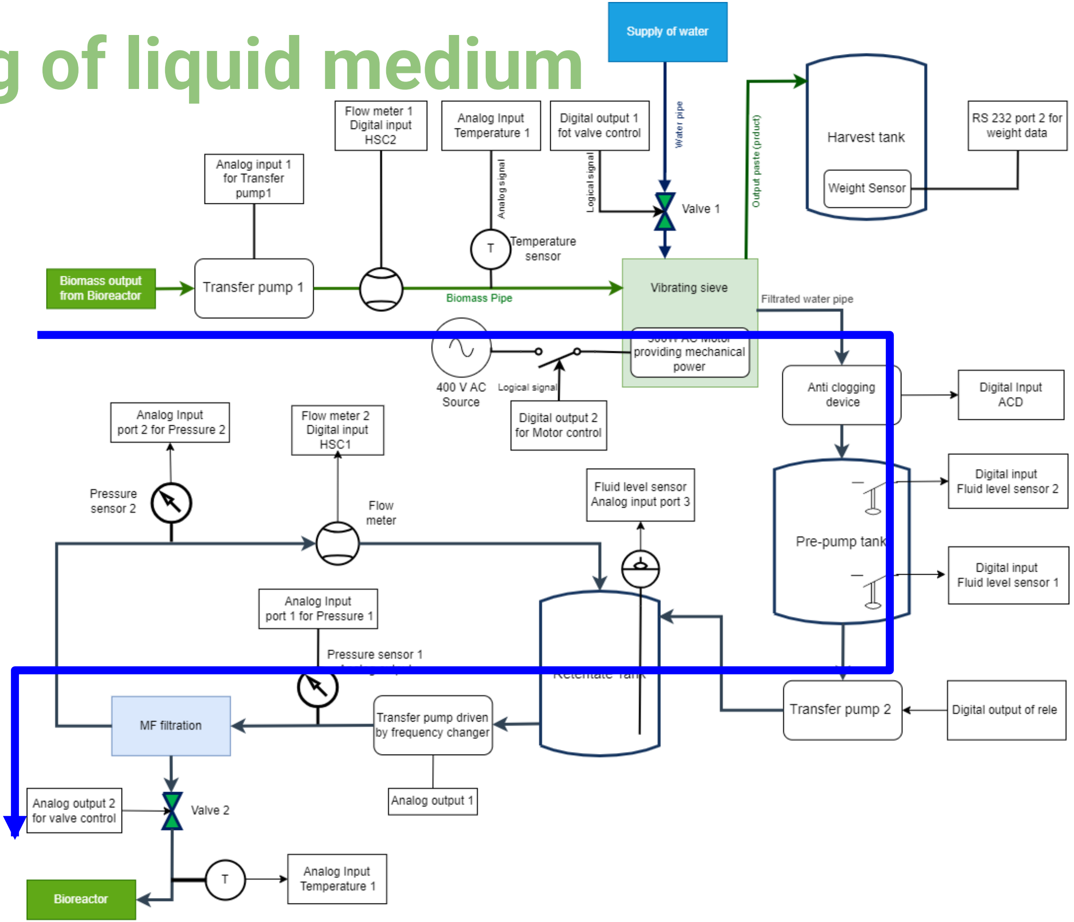
Mass balance of the components

#	Component Name	Purpose	Interface	per Spec Sheet (w)	component (g)		QA Status	Spec Sheet A
1	Computer	Used to connect to the master control unit S7-1200. Only to be used for programming and changing system setup, not a permanent unit	Ethernet Cable				Accepted	Not Needed
2	KTP 700	HMI of the system. It is used for monitoring data, and controlling the system.	Ethernet Cable	5.5	780		Accepted	Available
3	Weight sensor	Measuring the mass of the Bio Pasta. Based on this information, warning is send to HMI to empty the buffer tank	RS 232	27	5900		Accepted	not available
4	Transfer pump	Transporting the fluid from reactor to the feeder.	RS 232	78	8300		Accepted	Available (mar
5	Control valve of water cleaning	Valve for water supply for purpose of cleaning	Digital input 1/0	18	1000		In Procurement	
6	Motor contactor	Turning on and off 3 phase motor	Digital input 1/0	6	240		In Procurement	
7	Temperature sensor	Measuring temperature of incoming fluid into the feeder, before it drops into the sieve	Analog output	0.5	50		In Procurement	
8	Pressure sensor	measuring fluid pressure of incoming fluid, AFTER the transfer pump. It checks operation, or if pipeline is damaged somewhere	Analog output	0.5	100		In Procurement	
9	ADC module	For converting analog signals into the digital	Directly connected to S7-1200	0.5	35		In Procurement	Available
10	RS 232 module	Communication with devices via RS 232	Directly connected to S7-1200	1.1	150		In Procurement	Available
11	Controler S7-1200	main microcontroller unit	Ethernet	14	455		Accepted	Available
11	Various Wiring	TBD amount of basic wiring		N/A	2000		Accepted	
12	SIEVES MOTOR	Drive the sieve vibration		500	See next sheet		Per sieve system	
			Total basic power consumption	651.1		Watts		
			Total Weight - control system		19010	grams		
			Sieves machine		45130	grams		
			TOTAL SYSTEM		**64140**	**grams**		

Objective 2 - recycling of liquid medium

The liquid medium stream will be removing biomass and recycled back the cultivation medium and to the originating bioreactor.

Liquid medium flow points
1. From Bioreactor
2. Goes via the vibrating science
3. Enters Pre-pump tank
4. Enters Retentate Tank
5. Is processed via MF filtration
6. Is returned back to the PBR

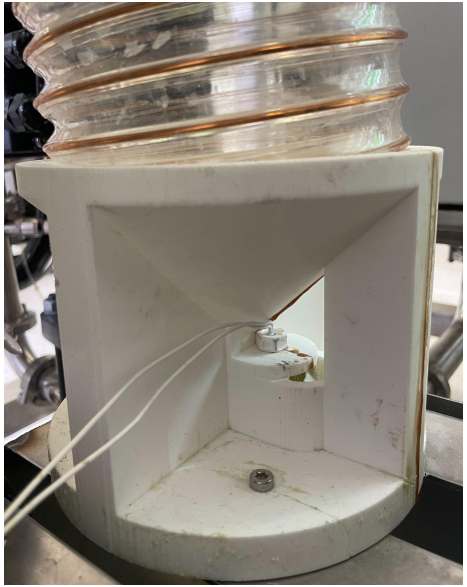


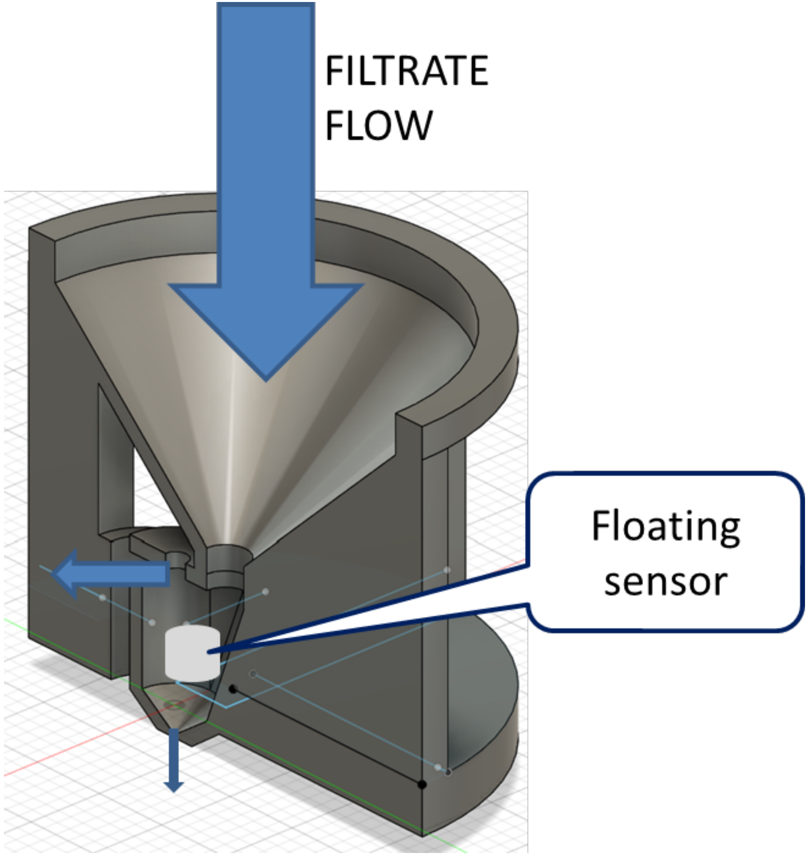
Anti-clogging device

Filtration detecting funnel was added to watch the harvesting unit clogging

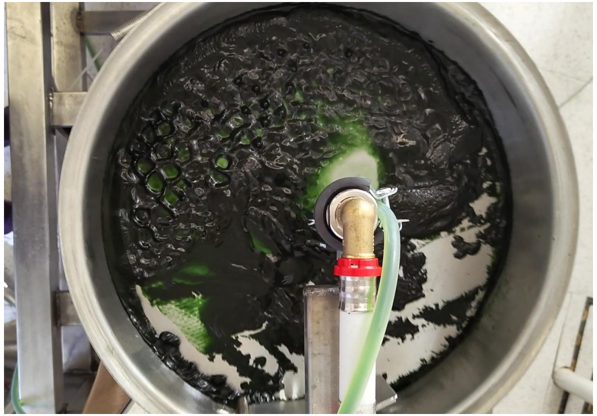
1. Filtrating funnel
2. Floating sensor

Flow is indicated by blue arrows



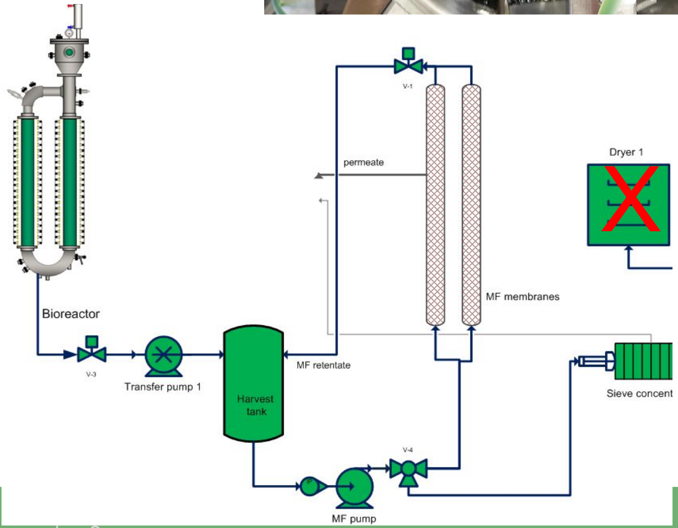


Objective 3 - biomass concentration



Biomass will be further concentrated in two steps on microfilters and sieves and dried in consequent steps

- The final construction contains only one sieve to concentrate the biomass and vacuum dryer was retracted during the project timeline.
- Concentration of biomass on vibration sieve shows 3 critical points: Transport of the pasta to the exit along the sieve, Dead volume of the sieve, Large variability in paste consistency and thus resultant bio-product amounts



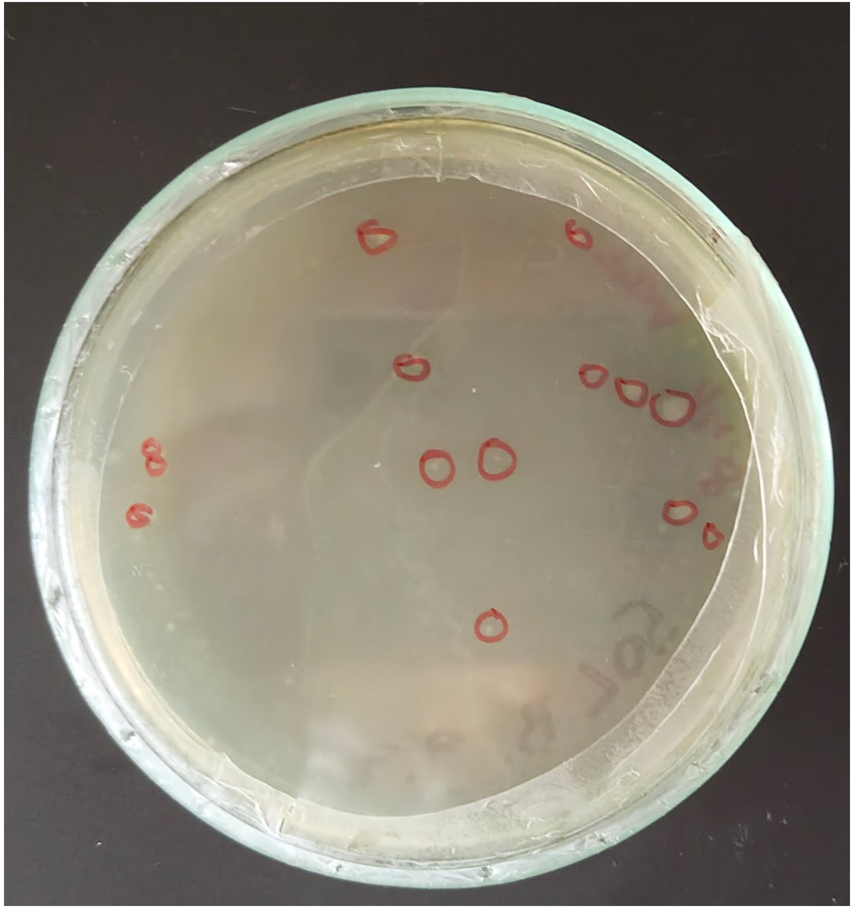
NO FINAL DRY

- Vacuum was de-prioritiezed during the project as a requirement/objective, but was performed regardless in conventional drying ovens

Objective 4 - axenicity

Sterility of the reverse liquid medium loop must be kept, this is a critical system performance constraint. Contamination must be avoided. Operations of the device should be fully tested and automated, at least at the local level.

- After several cycles, contamination cannot be fully avoided, but because of the microfiltration, it is significantly reduced
- Microfiltration membranes cannot be sterilised in our conditions (they are too big for lab autoclave), we disinfected them between the runs with sodium hypochlorite ($NaClO$)
- Axenicity was sampled in bioreactor between harvesting cycles



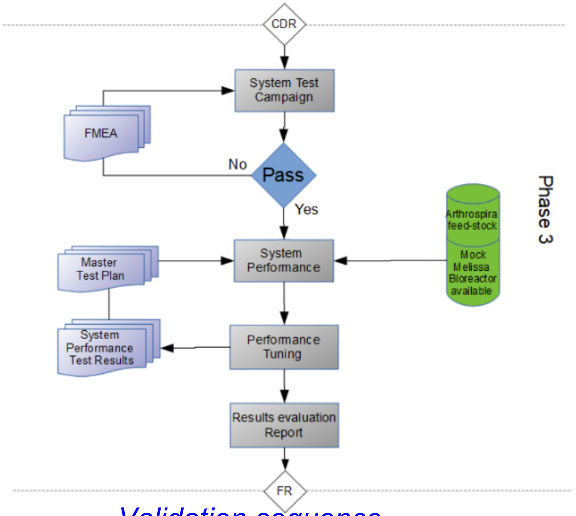
Harvesting and contamination

We worked with two different Spirulina strains:

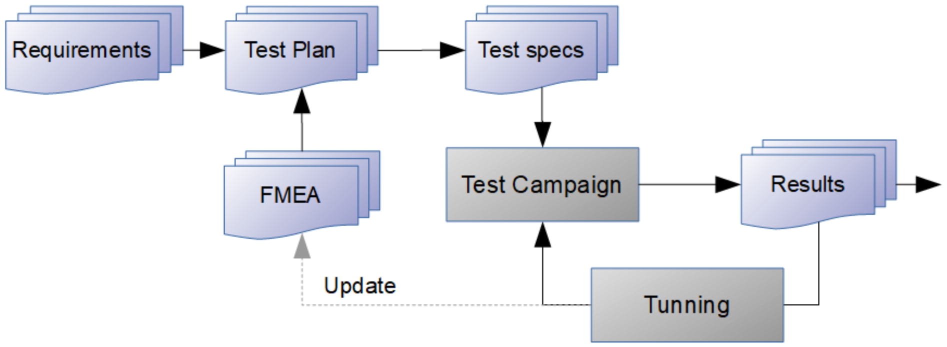
- Strain PCC8005 (3AI) is an axenic culture, the highest level of sterility was kept in our conditions before and during the process.
- Strain HA is not an axenic culture, so while still providing some level of sterilisation before cultivation, we did not test axenicity during the process.

Run	Before harvest	After 1st harvest	After 2st harvest
PT-3 Strain 3AI	Axenic	Not axenic, 28 CFU / ML	Not axenic 110 CFU/ ML
PT-2 Strain HA	N/A	N/A	N/A
PT-1 Strain HA	N/A	N/A	N/A

Test campaign: Use Cases



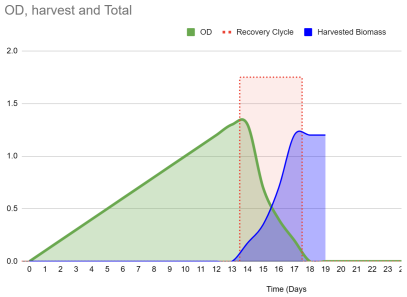
Validation sequence

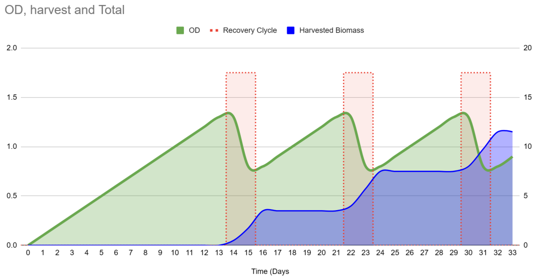


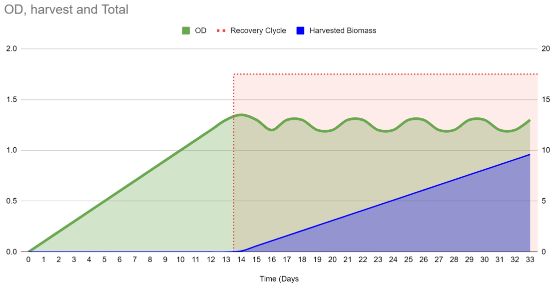
Original test plan

ID	Run #	Total Days	Cumulative Total Yield (DryYield grams)	Total Yield (Wet Yield grams)	Total Power Consumption (W)	Calculated Average Daily Production (g)	Type	Notes
PT-1	1	10	12.6	1900	-	190	Wet	~1.3g to 1.9g dry per day, or 0.66% dry w/w
PT-2	1	24	11.1	-	-	0.46	Dry	~0.5 g dry per day
PT-3	1	20.5	23.5	-	0.8 kWh	1.15	Dry	Power for 4 harvesting runs.

Use Cases - Mission Level







Use Case 1 - "Bang-bang harvesting"
The core aspect of this UC/mode of operation is a single growth cycle, followed by a complete harvesting of the bioreactor.
Performance Test 1 (PT1)

Use Case 2 - "Pulsed harvesting"
The core aspect of this UC/mode of operation is a multi growth cycle. Multi-stage harvesting. After the initial cultivation phase, multiple harvest cycles are taken. The main purpose of this UC is to aim for continuous bio-product products, and subsequent harvesting.
Performance Test 2 (PT2)

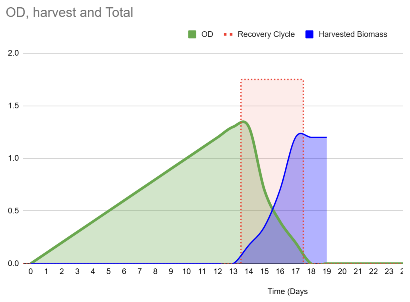
Use Case 3 - "Continous harvesting"
Continuous, "steady state siphon" cycle timing concept

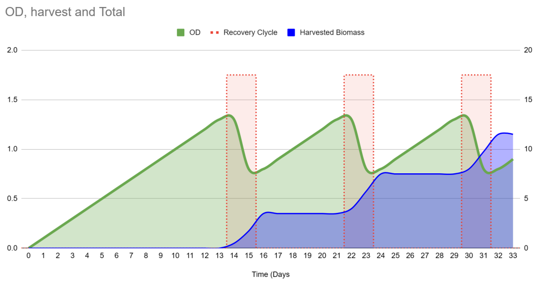
Not Tested

ID	Run #	Total Days	Cumulative Total Yield (DryYield grams)	Total Yield (Wet Yield grams)	Total Power Consumption (W)	Calculated Average Daily Production (g)	Type	Notes
PT-1	1	10	12.6	1900	-	190	Wet	~1.3g to 1.9g dry per day, or 0.66% dry w/w
PT-2	1	24	11.1	-	-	0.46	Dry	~0.5 g dry per day
PT-3	1	20.5	23.5	-	0.8 kWh	1.15	Dry	Power for 4 harvesting runs.

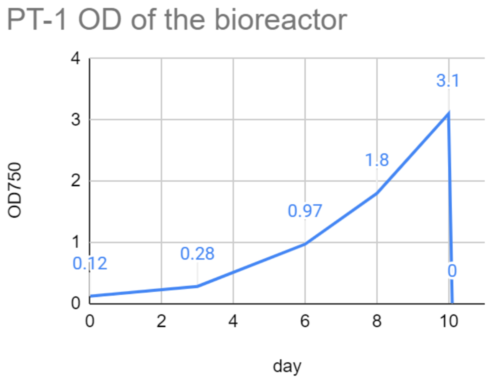
BioX technologies

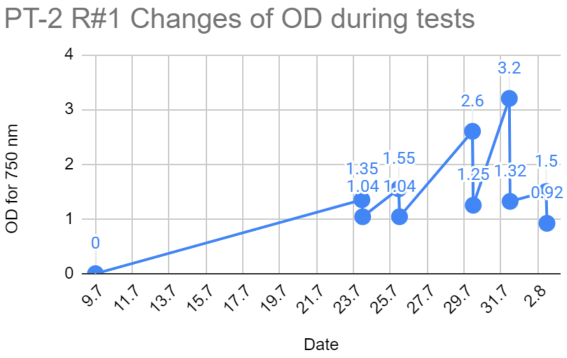
Use Cases - Mission Level

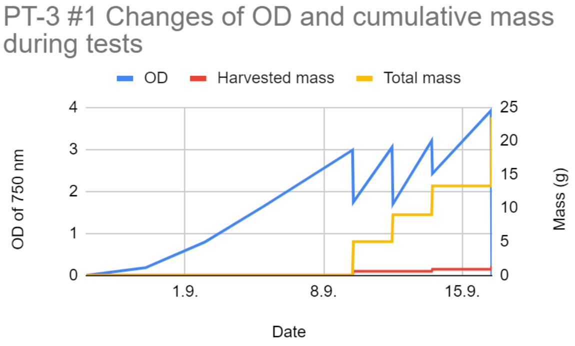




Actual results are below. In general the real world results were somewhat flaky (inconsistent), however matched the ideal Use Case OD curves as planned

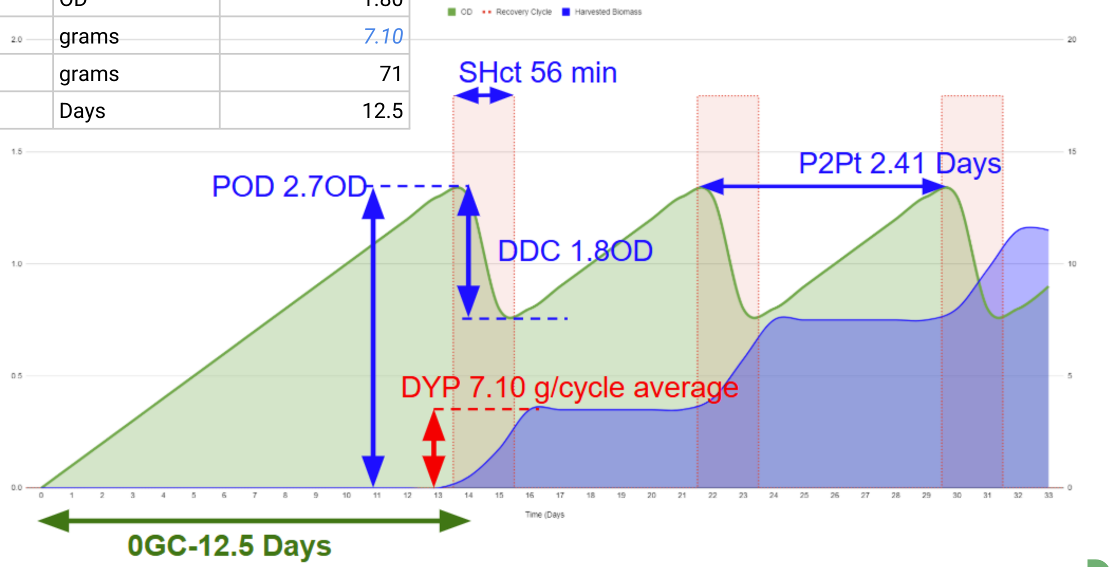






Use Cases - Average performance results

	Variable	Test Run	unit	Averages
1	**POD**	Peak OD before Harvest	OD	2.70
2	**SHct**	Single Harvest cycle time	Minutes	56.27
3	**P2Pt**	Peak to Peak time	Days	2.41
4	**DDC**	Delta Drop in Concentration	OD	1.80
5	**DYP**	Dry Yield Potential	grams	*7.10*
6	**WYP**	Wet Yield Potential	grams	71
7	**0GC**	0-Growth Curve	Days	12.5

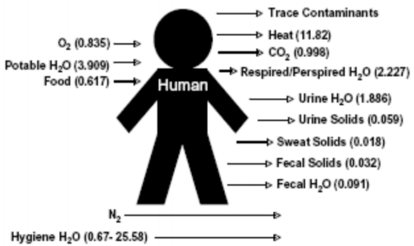


Use Cases -Variable Details

	Variable	Variable long name	unit	What is it	How is the value calculated
1	**POD**	Peak OD before Harvest	OD	The First measurement of OD in the bioreactor, prior to harvesting. In UC1, there is only 1 harvesting. In UC2, there are multiple harvest peaks, thus each peak is taken into account.	It is the AVERAGE of all of the THP's across all tests, ie [(x) + (x+1) .. (x+n)] / total # of samples experiments
2	**SHct**	Single Harvest cycle time	Minutes	The amount of time needed to filter X liter of volume.	-Calculated by subtracting 2 timestamps from the data logs for each test run. -In the able above its the AVERAGE across all experiments.
3	**P2Pt**	Peak to Peak time	Days	The amount of time between harvests.	Calculated by subtracting 2 timestamps from the data logs for each test run.
4	**DDC**	Delta Drop in Concentration	OD	The OD value of the PBR after a single harvesting action has been taken	It is the AVERAGE of all of the DDC's across all tests, ie [(x) + (x+1) .. (x+n)] / total # of samples experiments
5	**DYP**	Dry Yield Potential	grams	Measured after biomass is dried in heat ovens. Measure during each sampling test for each test run.	It is the AVERAGE of all of the DDC's across all tests
6	**WYP**	Wet Yield Potential	grams	The raw harvested biomass, directly weighted in the harvest tank plus the mounts left on the sieve	Raw amount of biomass. Measure during each sampling test.
7	**0GC**	0-Growth Curve	Days	The amount of time from start of experiment run to the 1st harvesting cycle. Calculated by subtracting 2 timestamps from the data logs In other words the amount of time needed to start production.	Calculated by subtracting 2 timestamps from the data logs for each test run. Only recorded once per test.

Reference Mission - End to End performance Targets

Requirement Target in TN88	Standard value (kcal per day) For crew of 4	Appx Reference Value of 333 kcals / 100g In Spirulina	Updated Target Dry Product / Day	Updated Target WetProduct / Day
5% metabolic requirement	566	1.7	170 g	1,700 g
40% metabolic requirement	4,528	13.60	1360 g	13,600 g

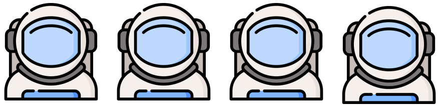


Thus for the 1st initial target, to supply 5% of food nutritional energy for a crew of 4 we would need to product **170 g / day,** or **42.5 g/d per person**

As a sanity check, recommended daily doses of spirulina are cited as **5 - 10 grams per day** (source 1, source 2)
However it should be noted that spirulina is generally considered a food supplement, not a main source of food.
Nonetheless, below are the resulting biomass yields (per harvest) produced during the Validation Test Campaign:

	Average
Dry Yield Potential - continuous	3.5
Dry Yield Potential - bang harvest	18.2

crew



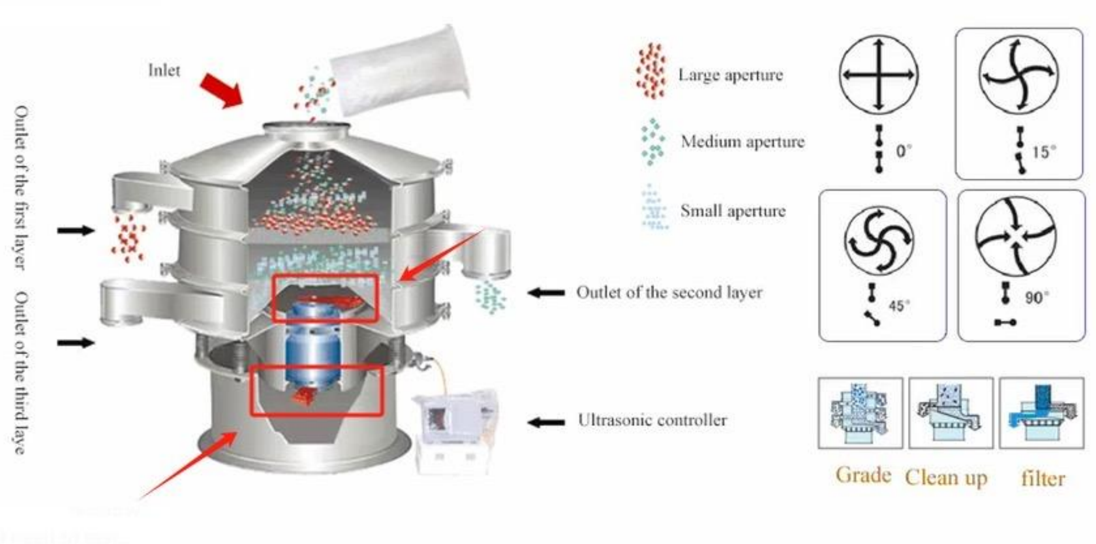
Critical Points

Transport of the pasta to the exit along the sieve

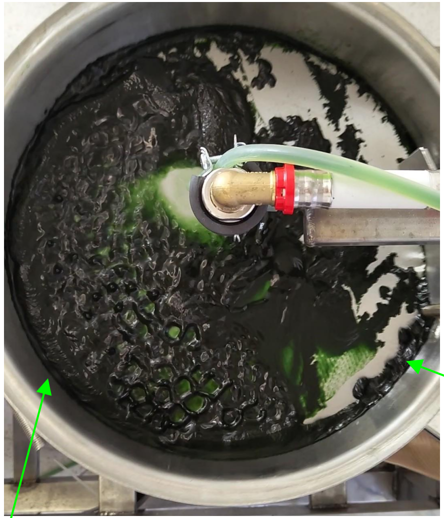
- The sieve's position and angle affect pasta movement, ideally directing it toward the harvesting exit.

- Despite multiple adjustments, **the impact of position is less significant than expected**, leading to spirulina accumulating on one side of the sieve, far from the exit.

- This behavior is likely due to stronger forces, such as vibrational bias from the motor and structural resonance, which outweigh gravitational effects.

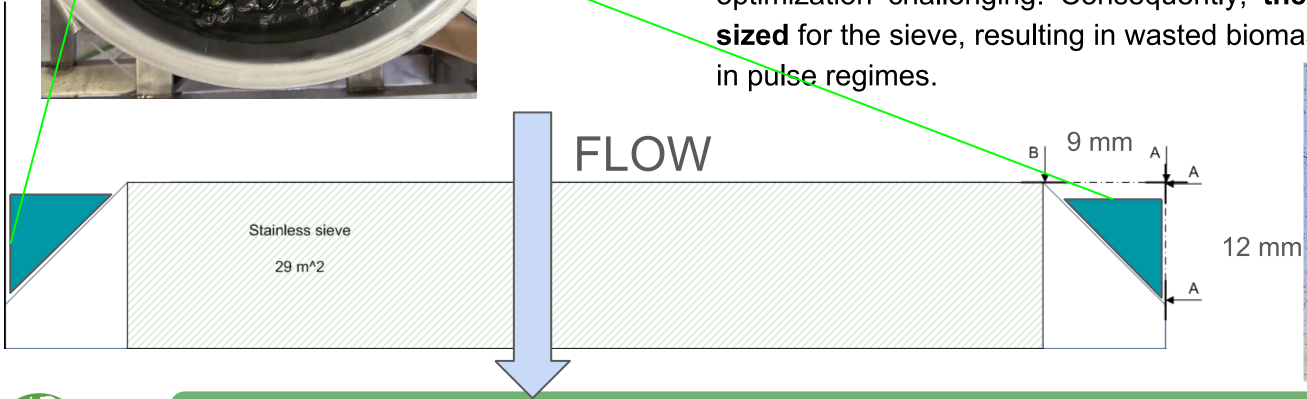


Critical Points



Dead volume of the sieve

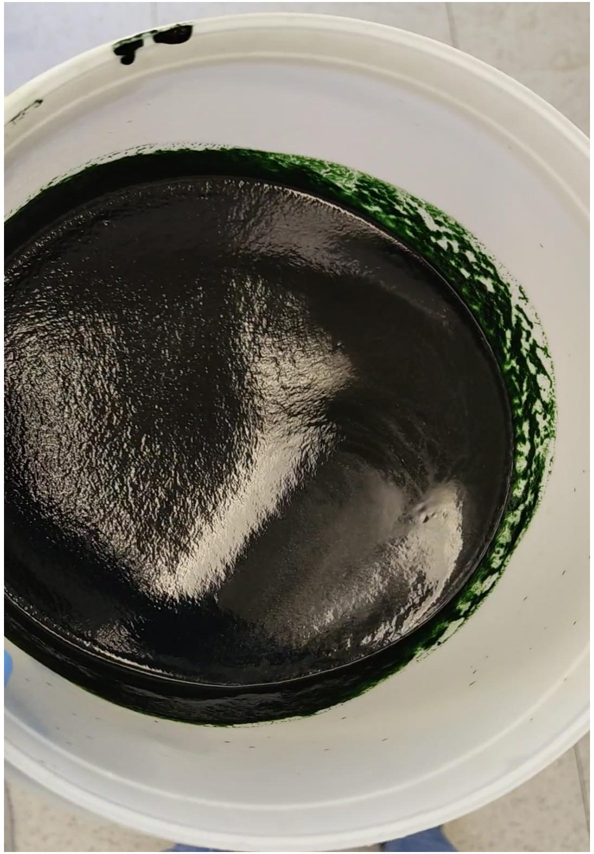
- The dead volume problem consists of two parts: **the gap between the sieve and the wall**, and **the volume of blobs** that form directly on the sieve.
- The gap, which was unsuccessfully addressed with a metal ring, leads to pasta accumulation and complicates separation due to vibrational forces.
- The blobs must reach a certain size to move to the exit, making optimization challenging. Consequently, **the bioreactor is improperly sized** for the sieve, resulting in wasted biomass in each cycle, particularly in pulse regimes.



Critical Points

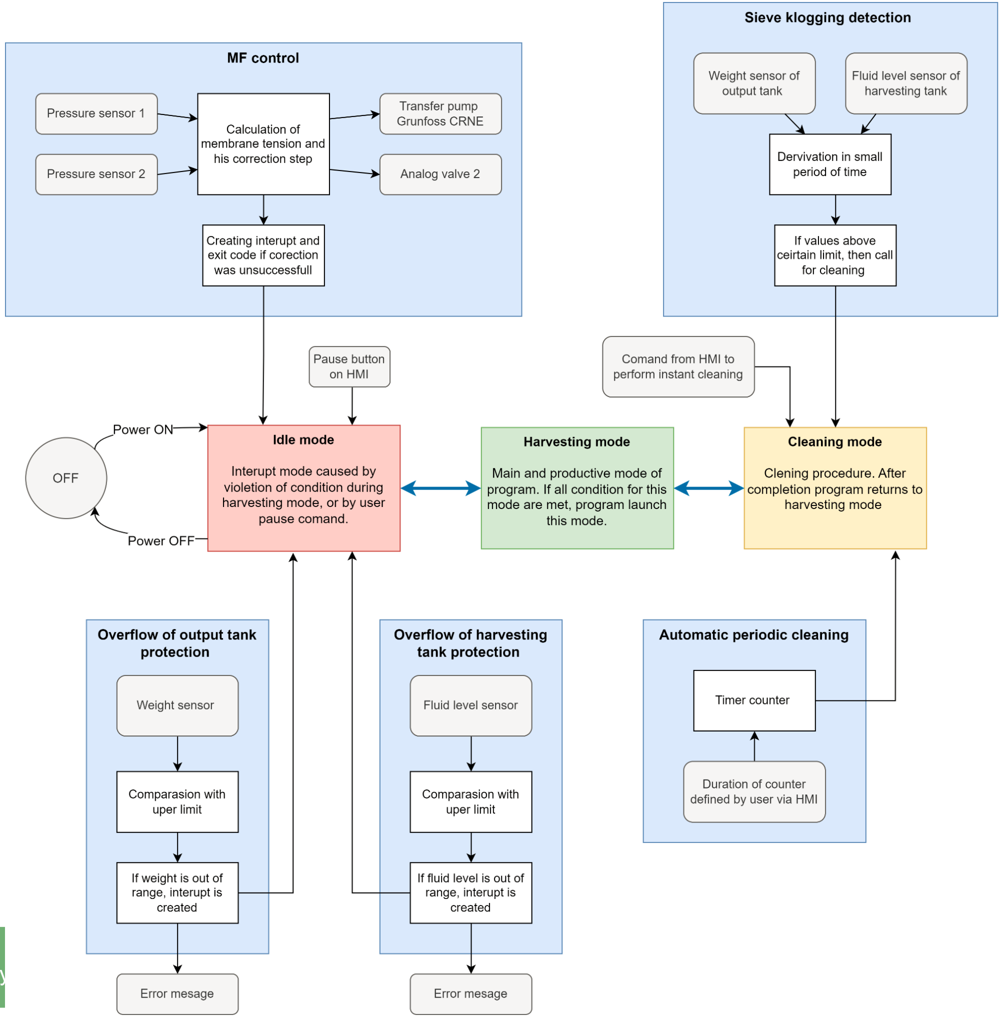
Large variability in paste consistency and thus resultant bio-product amounts

- The unstable performance of the sieve and unpredictable biomass transport lead to **significant variability in paste quality regarding water content**, making pure mass measurements of the bioproduct misleading.
- While paste consistency can be adjusted by changing the flow rate of the harvested spirulina media, a low flow rate increases dead volume, reducing the bioproduct yield.
- The variability of filtration performance, thus paste quality is mainly affected by the microbial cultivation process. I.e. prolonging cultivation, contamination, other unknown factors.



SW operation mode

Feeder operation at BioX labs



FMEA

3	Medium Stream	Transfer pump not working	No medium can be used as an input to the process	Fluid	5	Pump worn out	2	Process can not continue - must be stopped	visually, pump error at the control panel	1	10	preventive maintana
4	Medium stream	High pressure at MF membrane	reduced microfiltration abilty and yield	Fluid	5	MF membrane is clogged	2	MF process will be terminated soon	pressure transducer - digitally	1	10	optimized process d
5	Medium stream	High pressure at UF membrane	reduced ultrafiltration abilty and yield	Fluid	5	UF membrane is clogged	2	UF process will be terimated soon	pressure transducer - digitally	1	10	optimize proces
6	Medium stream	Spirulina cells in MF/UF permeate	Contamined medium flow from biomass, disintegration of UF membrane	Fluid	5	MF membrane is phisically broken	1	Further UF sytem will be clogged, process must be terminated	visually - microscope	2	10	better handling with membrane
7	Poly. stream	Concentration factor too low in UF retentate loop	Polysaccharides has low concentration for the next step drying operation	Fluid	1	Low amount of polysaccharides in the bioreactor, small amount has been separated on UF	2	UF process needs to continue	Lab analysis method	3	6	optimized medium processing
8	Biomass stream	Sieve concentrator does not separate effectively	Biomass has high residual water	Fluid	5	sieves concentration process is not robust	2	Loosing water/medium from the loop	Biomass concentration at the output from sieve concentrator	3	30	optimize the sieve concentrator proces
9	Software	Data log is not available	Test run or validation run is invalidated	Software	2	Incorrect setup at start of execution	2	Loss of valueable data, loss of system-level modelling	Visual or random spot inspection	3	12	Checklist
10	Software	Software not able to drive key component	Degradation of overall system performance	Software	7	Sensor or interface failure	4	Loss of primary function	filtered biomass amounts do not correspond to analytical estimations	3	84	Integration test
11	Software	Software not able to drive secondary component	Pumps fail to operate an needed performance	Software	4	Device driver or low lever incompatibility	3	Flow through rate of various stages can be impacted.	Secondary flow meters, on-screen device feedback	3	36	Integration test
12	HW - general	Power loss	Loss of functionality of all main and secondary components (pumps)	Electrical	8	Various, typically out of control of lab conditions	2	Complete loss of system functionaly, possibly stability	By user, data logger if possible	1	16	Backup power suppl

SK6_19
MELISSA Feeder: Biomass Harvesting system for food preparation

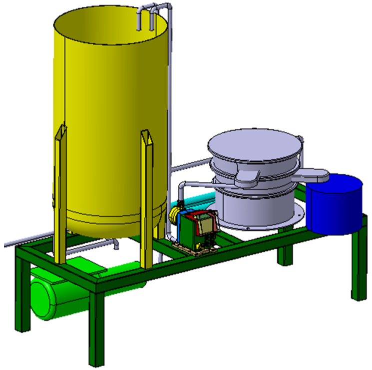
TECHNICAL DETAILS

Conclusion and Recommendations

Conclusion and Recommendations

Objectives	Results
From existing processes and designs, the objective of this project shall be to **create the various technical parts of a recovery line** for processing of Limnospira biomass.	This was accomplished, albeit with varying levels of difficulty.
The liquid medium stream will be removing biomass and recycled back the cultivation medium and to the originating bioreactor	Accomplished
Biomass will be further concentrated in two steps on microfilters and sieves and dried in consequent steps of vacuum drying.	This was altered during the process, in the final construction there is only one step of biomass concentration (vibration sieve) and the vacuum dryer has been cancelled
Sterility of the reverse liquid medium loop must be kept, this is a critical system performance constraint. Contamination must be avoided. Operations of the device should be fully tested and automated, at least at the local level.	After several cycles, contamination cannot be fully avoided, but due to the microfiltration, it is still significantly reduced. Operations of the device were fully tested and automated.

Biomass Harvesting system for food preparation



Capabilities	
Harvesting MAX rate	2.5 L / min or 3.6m^3 / day
Power MAX Consumption	650 W
Product Yield at Continuous Production / Day	3.5 g / day
Product Yield in Batch production mode	11.4 g / day
Internal Processing volume	83 L
Sieve porosity	5 µm to 200 µm
MW cutoff	100 nm to 2 kDa
Dead volume	Approx. 4000 ML
Size - dimensions	1400x700x1850MM (LxWxH)
Weight	150 kg

Future Work

1. **Data Connectivity to bioreactor**

   Useful for end-to-end performance optimization. This includes mostly data TX between parameters such as fill level, temperatures, etc to better optimize the settings of the Harvesting Unit

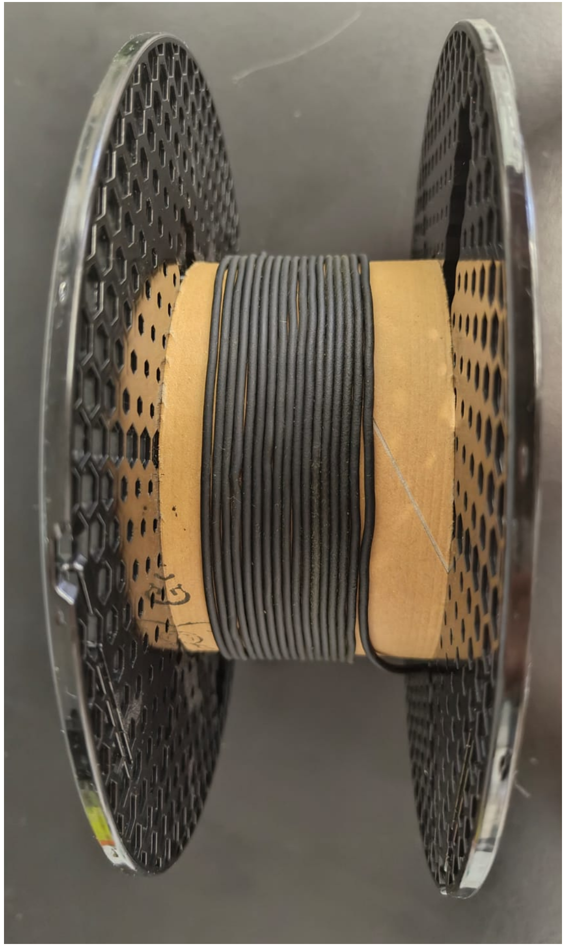
1. **Sweeper - Address critical point #2**

   The main expected of the sieve that needs to be improved (besides the scaling) is the mechanical removal of the captured biomass by a ‘spatula like’ automated rotating appendage

1. **Scaling Factors Study/optimization** - Address critical point #2
   Optimization of the radius of the sieve, when compared to the
   1) BPR size,
   2) pump speeds and
   3) mission expected daily production rates

2. **Downscaling of the unit for future parabolic flights or space missions**

   Miniaturisation, new technology concepts of resonance sieves. Liquid and solid flow driving



CONTACT US

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