Oxygen Separation Technology for the PaCMAN PCU - overview and future perspectives-

Erik Mazzoleni –EnginSoft
Christel Paille - ESA

MELiSSA Conference
7-9 October 2025, Granada

ENGINSOFT

PaCMAN: a MELiSSA project

PaCMAN is a MeLiSSA project which designed and built a Plant Characterization Unit (PCU) for scientific research on higher plants (CIVb). The PCU was placed at University of Naples.

Engineering

Atmospheric unit, Hydroponic unit, Anti-Leak Strategy, Control unit

Procurement, Manufacturing & Validation

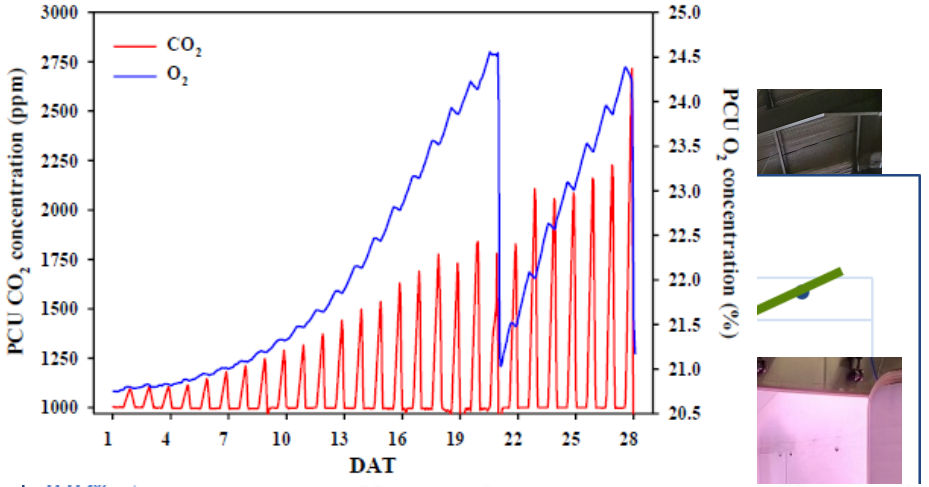
Components, sensors, DAQ, Modular design, Leak & Functional tests

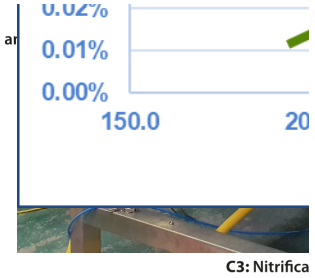
Crop research

Multiple crops, Different environmental conditions

Baseline data generation, Mass balances & Mathematical modelling

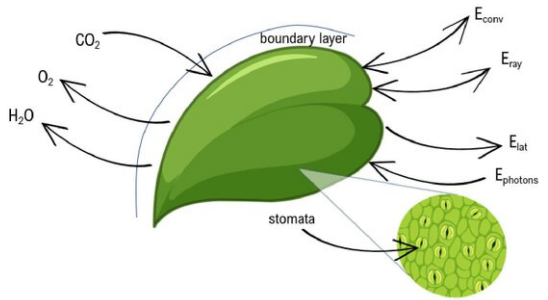
O2, CO2, H2O, Datasets for model calibration & validation

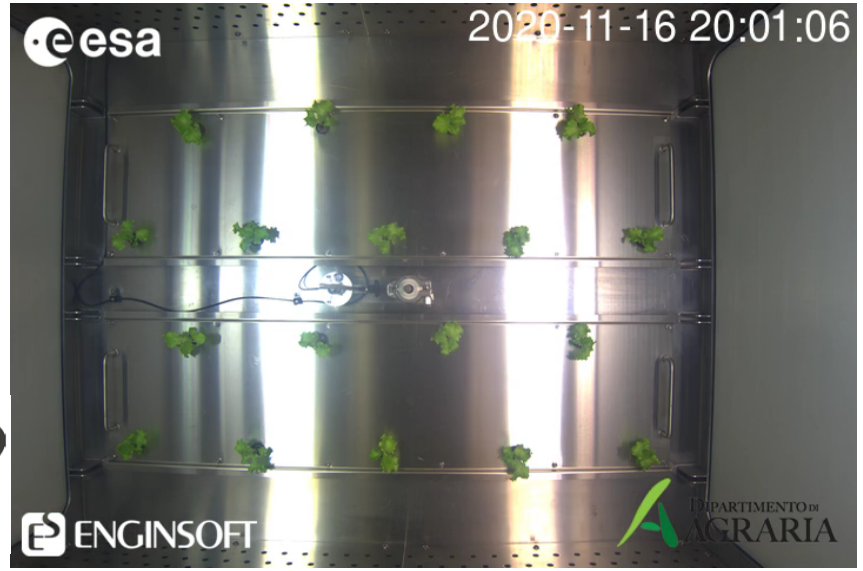




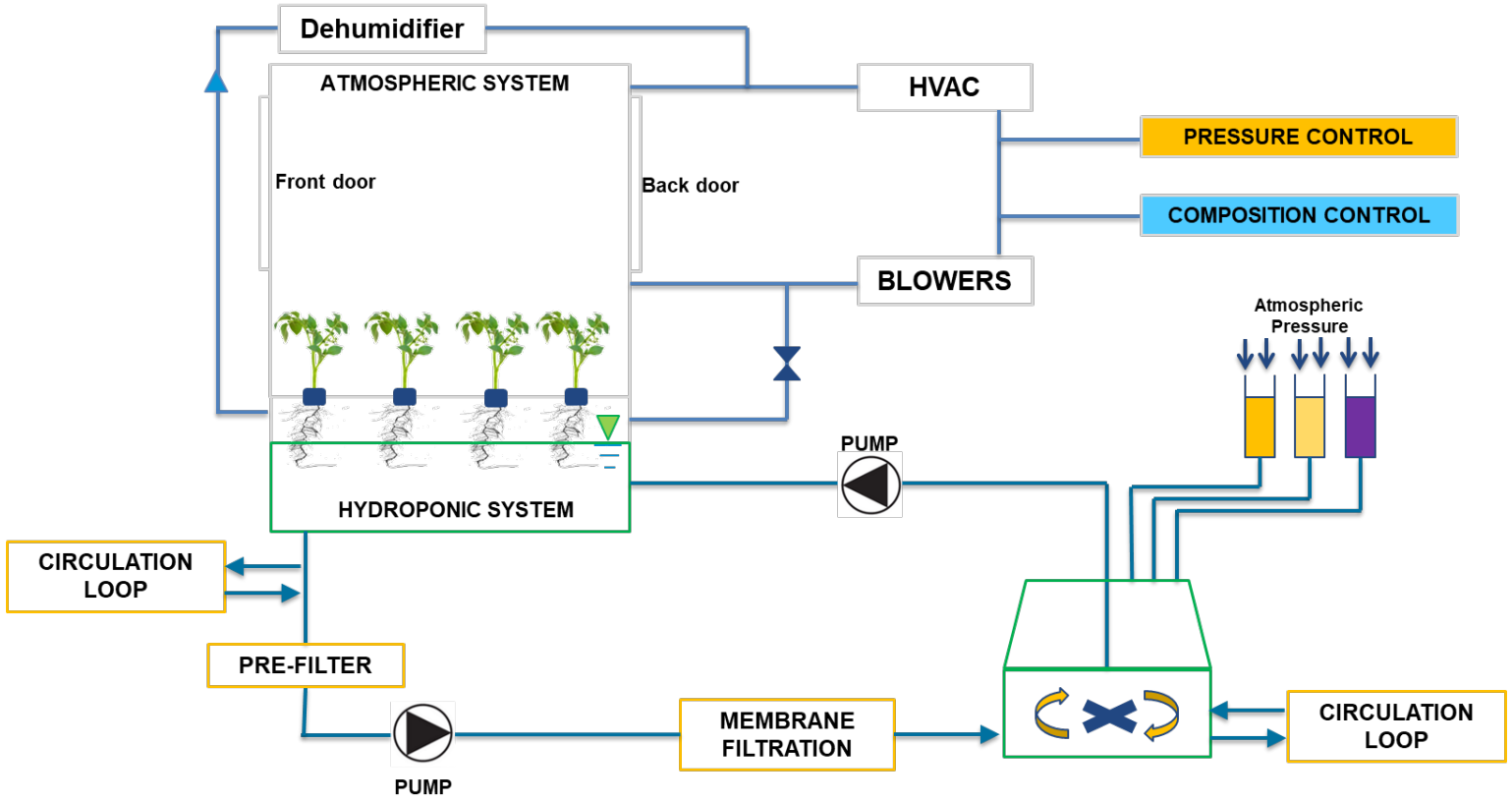
mass balance components

energy balance components



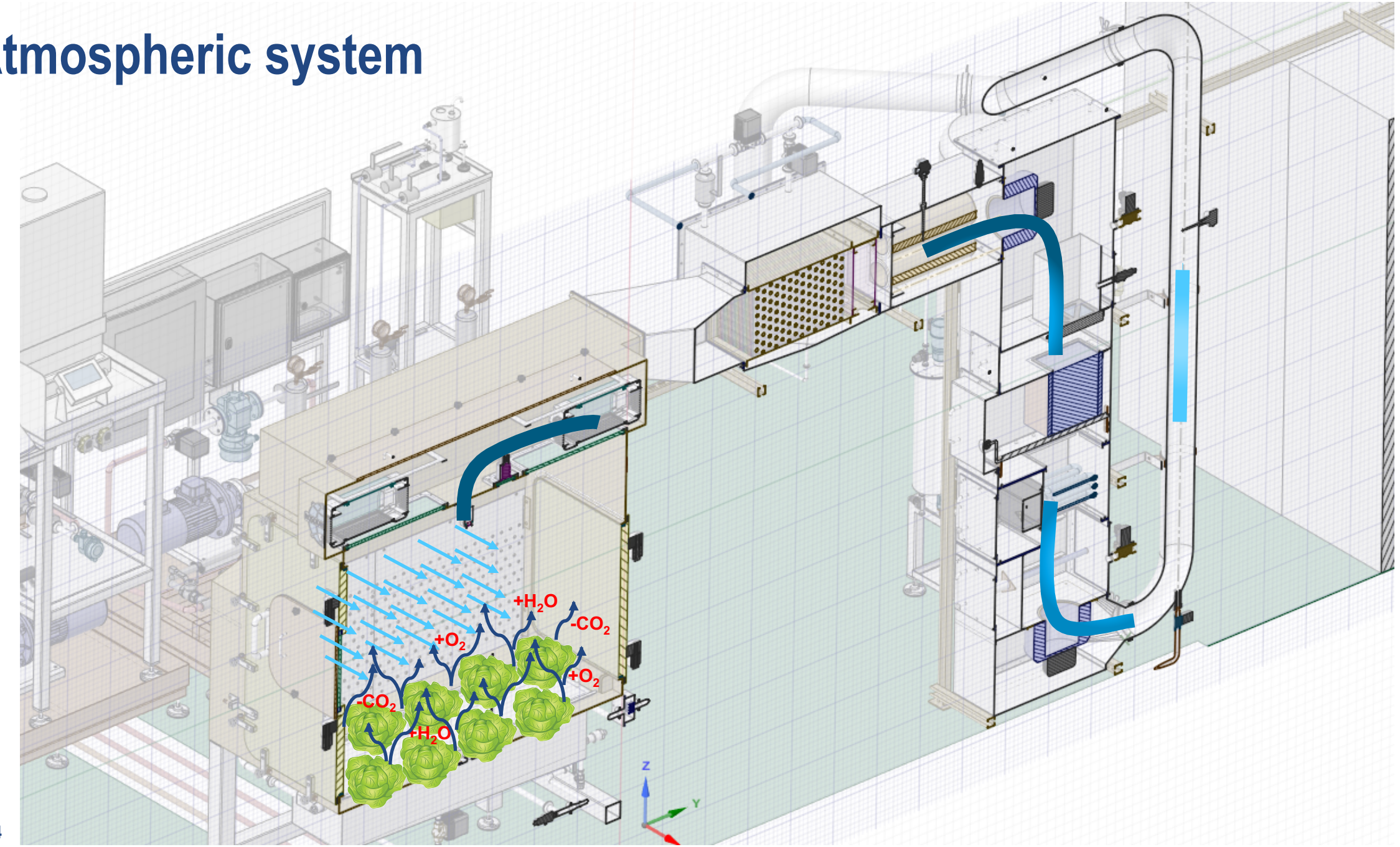


System Architecture



ENGINSOFT

Atmospheric system



Hydroponic System

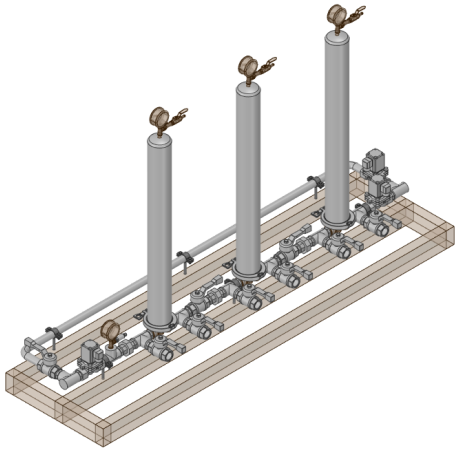
8 Stock Solutions + Acid and Base

Monitoring and automatic control of pH and EC

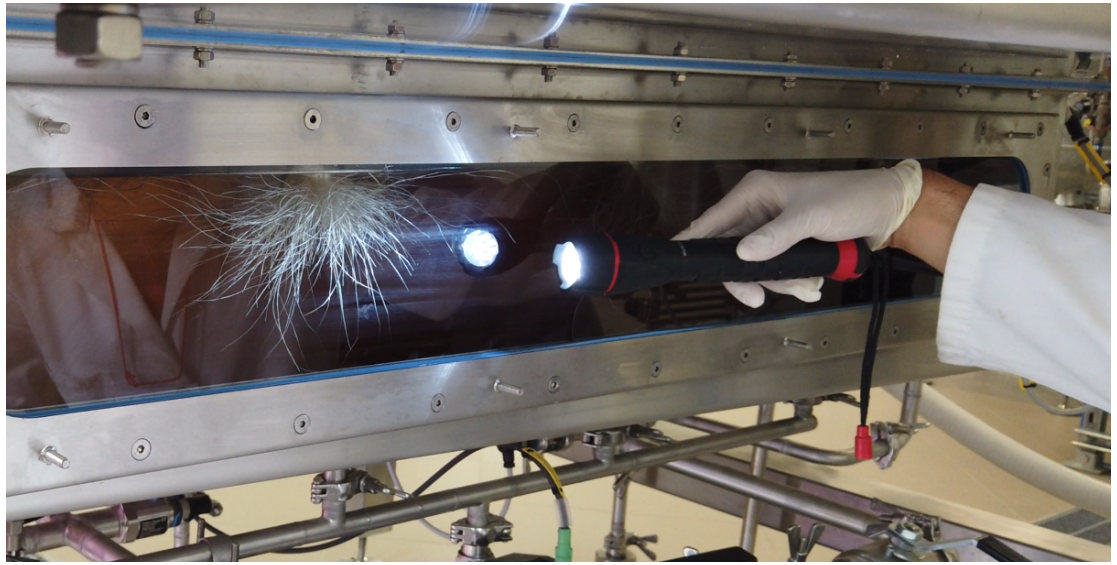
- Automatic delivery of acid, base and 8 nutrient stock solutions (10 tanks)
- Stock solutions delivered by peristaltic pumps
- Liquid volume in tanks monitored by automatic logging of scales

Membrane filtration:

Three membranes with different pore-size to separate microorganisms and suspended particles



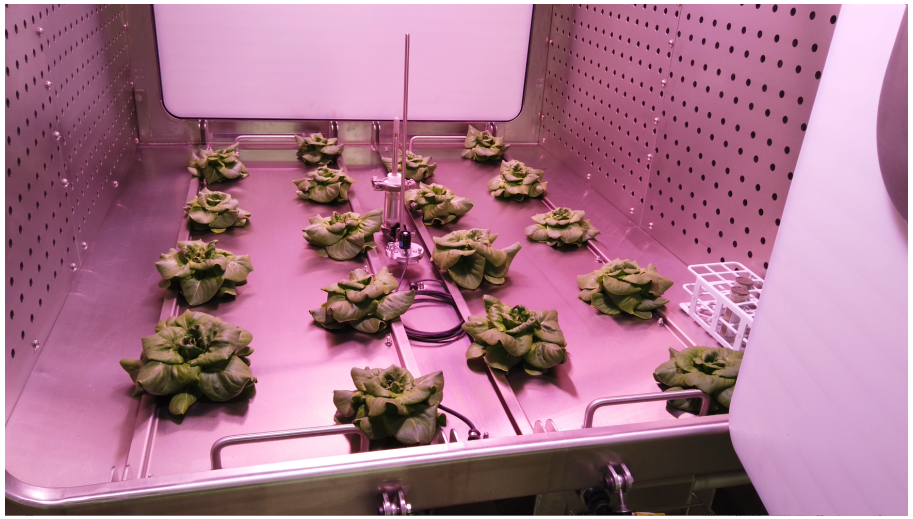
Gully



ENGINSOFT

Project PACMAN –Phase 3

PACMAN
PlAnt Characterization unit for closed life support system MaiNtenance, subsystem integration, review and scientific deployment - PHASE 3



OBJECTIVES

- System maintenance, upgrade & debugging
- Life tests campaign for scientific purpose (higher plants, high CO2 levels)
- Seedling protocol to improve homogeneity and scientific repeatability
- Oxygen removal technology: Breadboard to validate the process

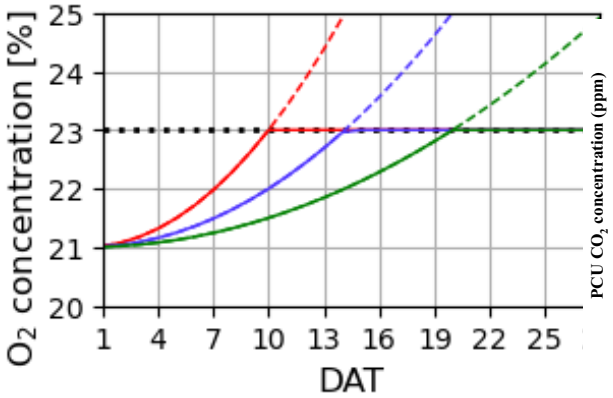
esa
ENGINSOFT
UNIVERSITÉ Clermont Auvergne
ETH zürich
ODYS Advanced Controls & Optimization
HOSOKAWA MICRON
CIRIS
ENGINSOFT

Oxygen removal breadboard: motivations

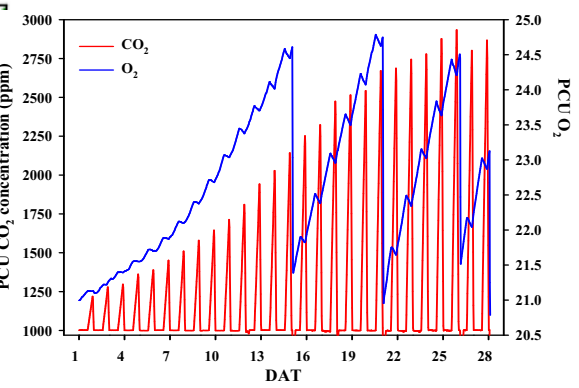
- The PCU facility has a very low leakage which generates an accumulation of oxygen during the life-tests
- The results demonstrated that the crops produce different total amounts of oxygen during the life test. In particular, the concentration of oxygen increases during the tests up to a point where it can exceed a threshold level
- The safety protocol which foreseen a venting procedure: this requires to physically open the PCU, which determines a signal interruption on the data acquisition
- Moreover, the intention is to carry out experiments with a constant oxygen level, which is more suitable for scientific research on plant in standard environment

Oxygen separation technology should be enviseged and tested with a breadboard

O2 concentration – Lettuce, Kale and Swiss chard



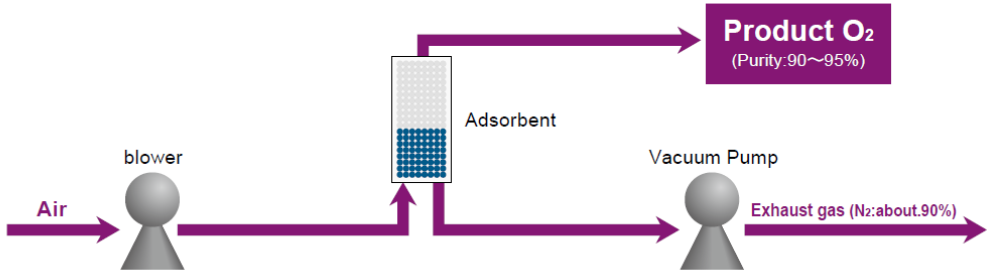
O2 and CO2 concentration for Kale



Oxygen removal breadboard: objectives

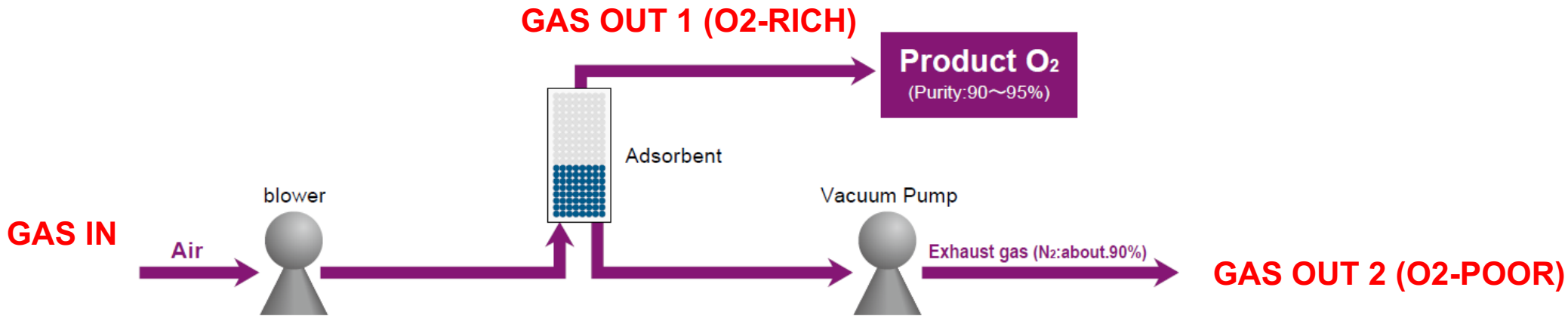
- Envision and implement **an advanced technology that can effectively remove excess oxygen** from the system, ensuring that its concentration always remains well below the safety hazard threshold
- It is crucial to be able to **measure the quantity of oxygen removed**
- Requirements are defined to validate the selected technology and then applied to a breadboard build by Hosokawa Micron Ltd with the support of EnginSoft

- **PSA (pressure swing absorption) technique with Zeolite material has been selected as technology for Oxygen separation**
- PSA technology has been selected because it is reliable, cost-efficient method for generating high purity oxygen (92%-95%). Other methods (cryogenic distillation or membrane separation) generate moderate purity oxygen



Hosokawa Micron Ltd (HML) supplies containment and integrated materials processing systems throughout the world.
Many HML projects include the integration of our own materials processing equipment as well as the integration and adaptation of 3rd party equipment to improve the cleanability and maintainability when installed into containment systems.

Oxygen Separation Technology: Functional requirements



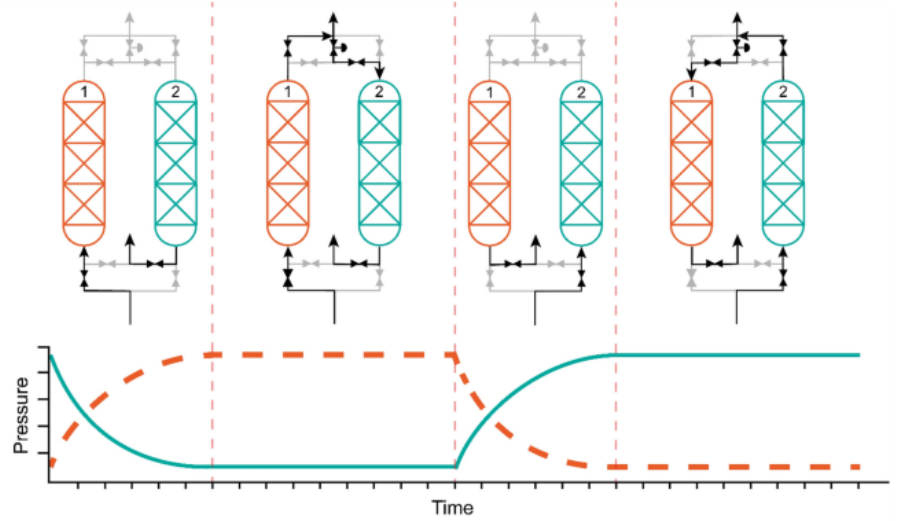
- The functional requirements will be based on the following criteria:
  - SEPARATION -> Separation Efficiency
  - MEASURE -> Sensor precision
  - SCALE/ SIZING -> Mass flow, pipe diameters, according to the breadboard design
  - GENERAL -> Mode of operation (on-off; not continuous); Maintenance (Adsorbent replacement)

ENGINSOFT

Oxygen Separation Technology

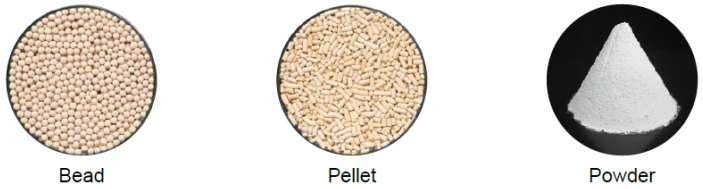
- Oxygen separation technology will be based on PSA (pressure swing absorption) with Zeolite material
- PSA Pressure Swing Adsorption (PSA) is a gas separation and purification technology that uses adsorbent materials, like zeolites, to exploit differences in how gases bind to their surfaces. The methodology involves a cycle of stages: pressurizing a column to adsorb a specific gas (e.g., nitrogen), then depressurizing it (blowdown/exhaust) to release the adsorbed gas, allowing the other component (e.g., oxygen) to remain. This cycle alternates between multiple columns to ensure a continuous flow of the purified gas
- Zeolites have with different crystalline structures allowing the precise adsorption of diverse target materials (for example Oxygen).

PSA absorption technique



Step	I	II	III	IV
Bed 1	Pressurization	Adsorption	Blowdown	Purge
Bed 2	Blowdown	Purge	Pressurization	Adsorption

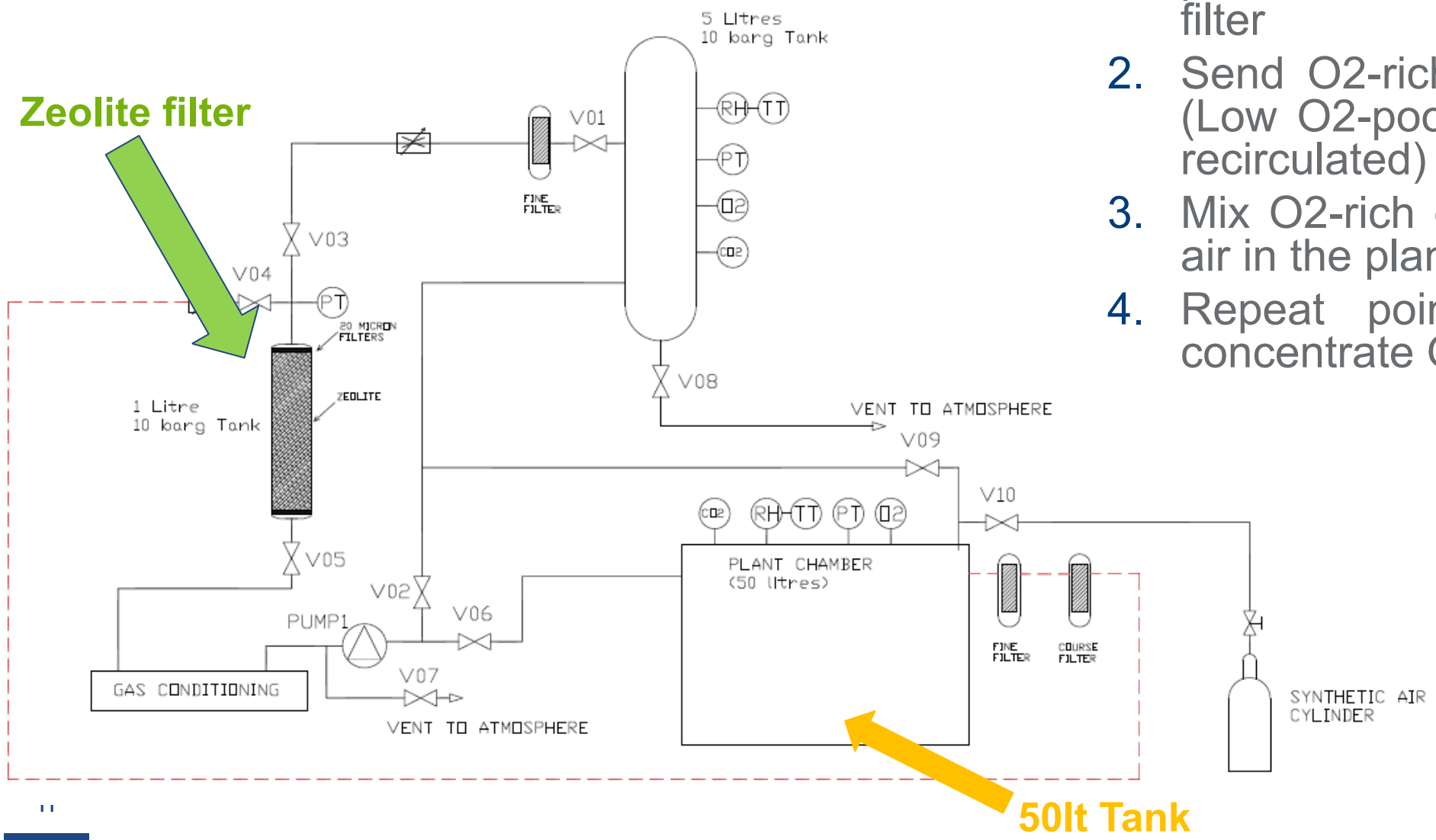
Different sizes of Zeolite



ENGINSOFT

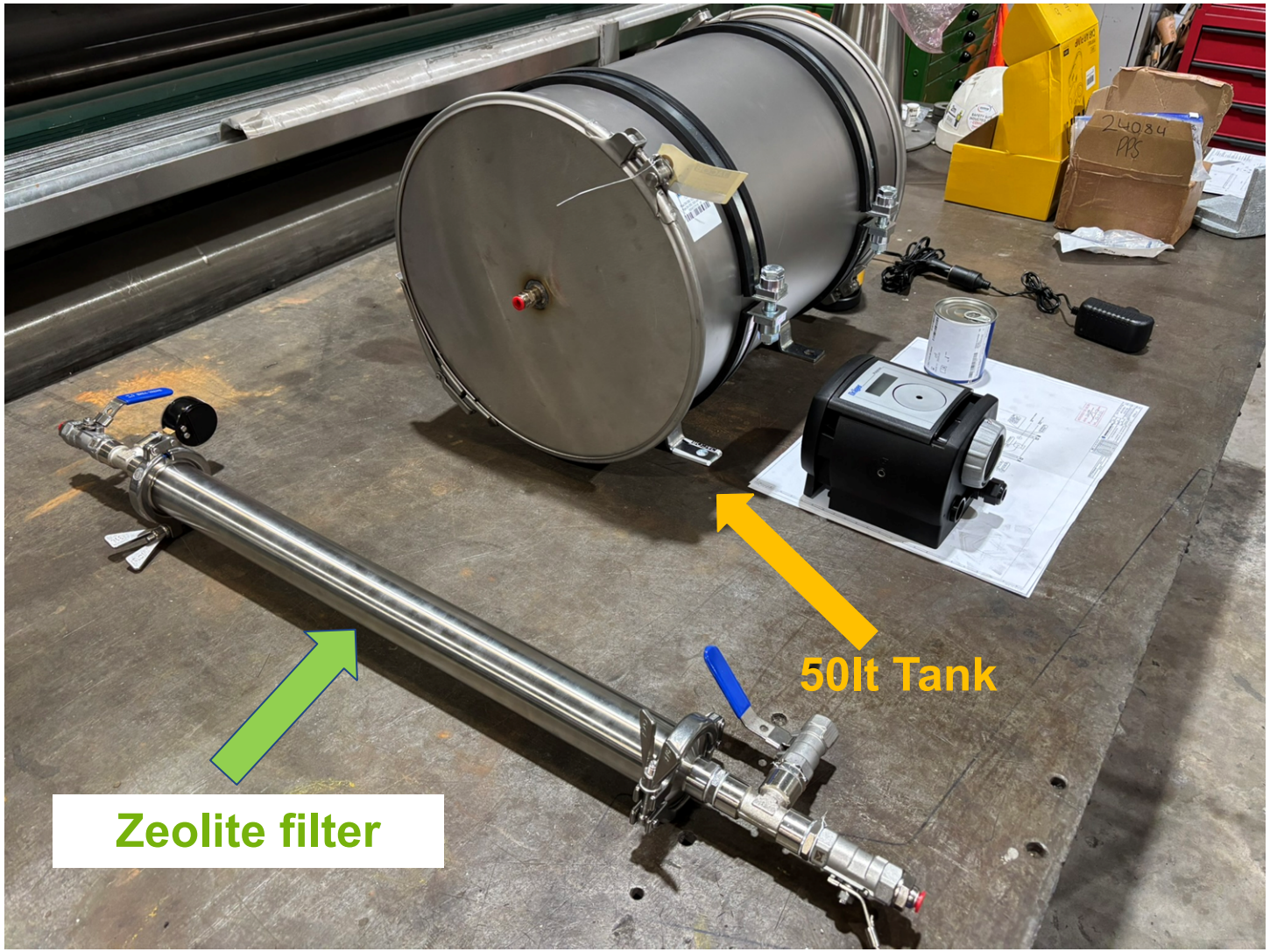
Preliminary PFD and P&ID

Preliminary PFD



- Process main steps:
  1. Push the synthetic air from plant chamber in the zeolite filter
  2. Send O2-rich gas to 5L Tank (Low O2-poor air is vented or recirculated)
  3. Mix O2-rich gas with Syntenic air in the plant chamber
  4. Repeat point 1 and 2 to concentrate O2 in 5L tank

Starting of the assembly (ongoing process)



ENGINSOFT

Achievements and Future Perspective

ACHIEVEMENTS:

- Oxygen separation technology is been selected and it is based on PSA (pressure swing absorption) technique with Zeolite material
- Requirements for a breadboard, where the technology will be tested, are defined
- Preliminary **PFD of the breadboard has been designed.** Assembly and testing phase is on-going

FUTURE PERSPECTIVE:

- Validate the oxygen separation technology **performance and limits**
- **Engineering a system adapted to the PCU facility**
- This technology will allow long life-test without venting and keeping a constant O2 concentration

ENGINSOFT

Thank you!

ENGINSOFT

www.enginsoft.com