MELiSSA WORKSHOP
Science and Technologies on Regenerative Life-Support
8 – 9 June 2016
Lausanne
Switzerland

Session 3: Air Recycling

Cultivation of microalgae for advanced closed life support systems as a technical and biological challenge

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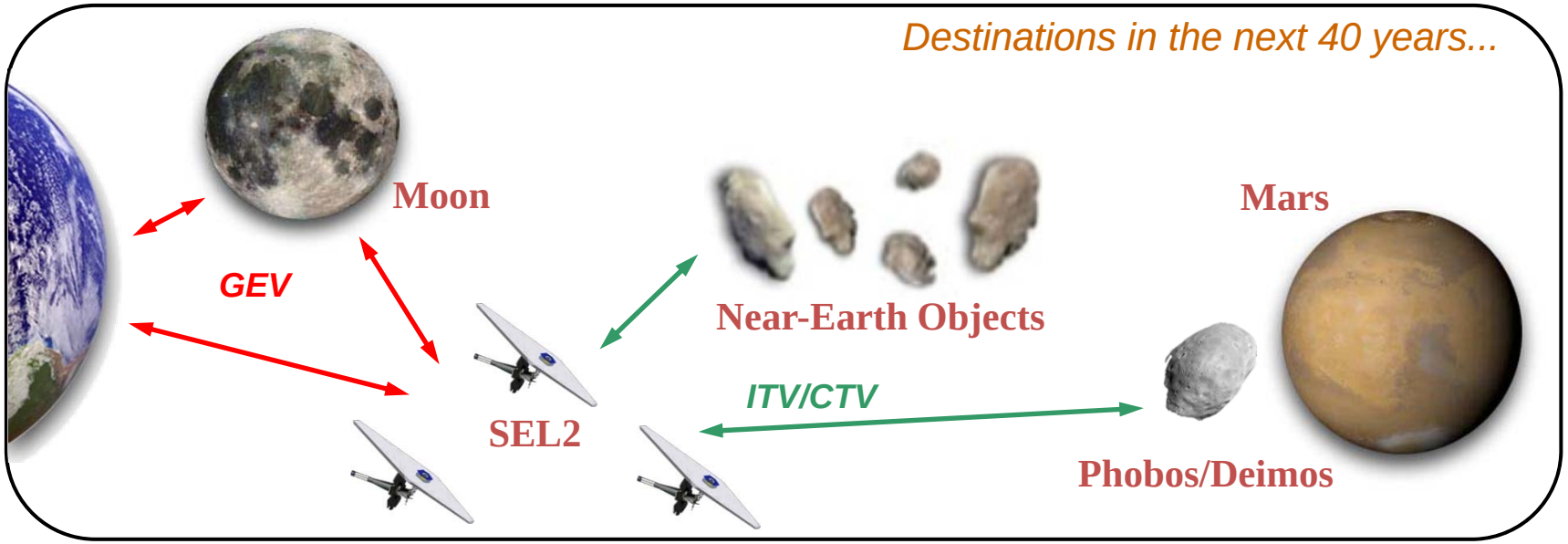
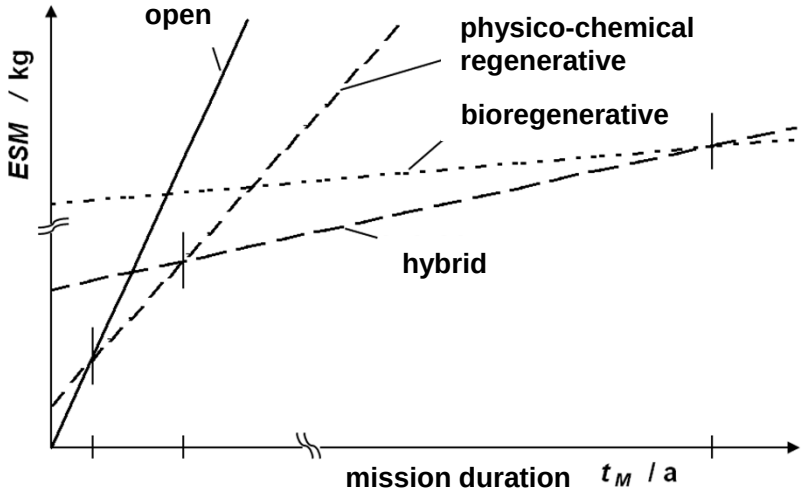
Content

- Why apply microalgae in space ?
  - Humans and microalgae
- Microalgae cultivation in photobioreactors
- Long term cultivation
- Long term cultivation in space

Space Exploration Destinations





terms:

Equivalent System Mass

$$ESM = m_{fix} + (V \cdot V_{eq} + P \cdot P_{eq} + C \cdot C_{eq}) + m' \cdot t$$

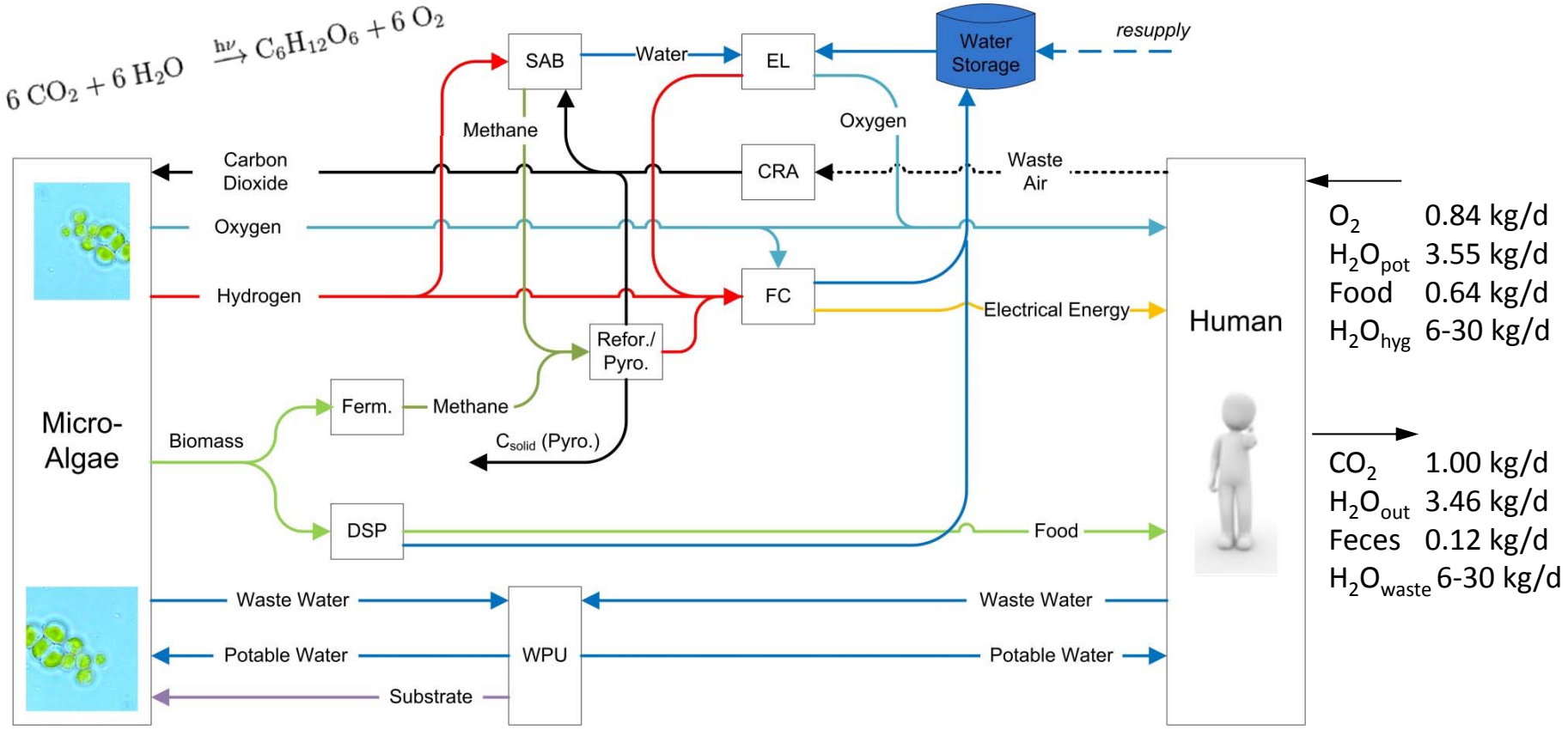
resupply mass

carbon loops

nesis → plants and algae

Humans and microalgae

"Symbiotic" Relationship



O_2 0.84 kg/d
H_2O_{pot} 3.55 kg/d
Food 0.64 kg/d
H_2O_{hyg} 6-30 kg/d

CO_2 1.00 kg/d
H_2O_{out} 3.46 kg/d
Feces 0.12 kg/d
H_2O_{waste} 6-30 kg/d

CRA – CO_2 Removal Assembly
DSP – Downstream Processing
EL – Electrolyzer
FC – Fuel Cell
Ferm. – Fermentation

Pyro. – Pyrolysis
Refor. – Reforming Unit
SAB – Sabatier Reactor
WPU – Water Processing Unit

Photosynthesis: 1 kg CO_2 → 0.72 kg/d O_2
Respiration: 1 kg CO_2 ← 0.84 kg/d O_2

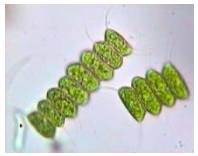
Microalgae as food source

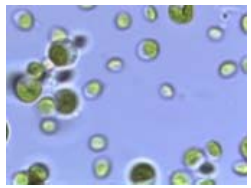
Euglena

Haematococcus

Nannocloropsis

Scenedesmus





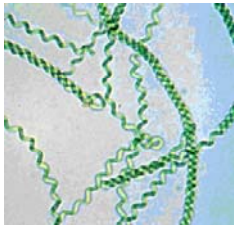
Chlorella

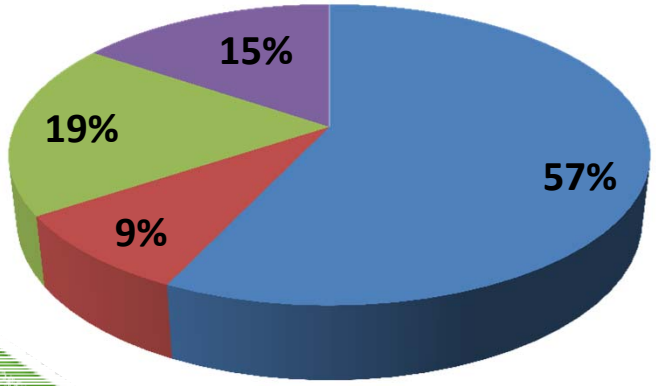
Phaeodactylum

Chlamydomonas

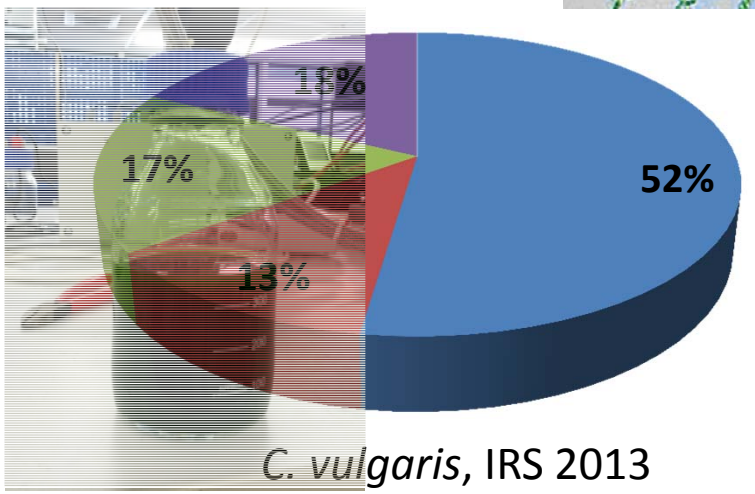
Nostoc

Spirulina



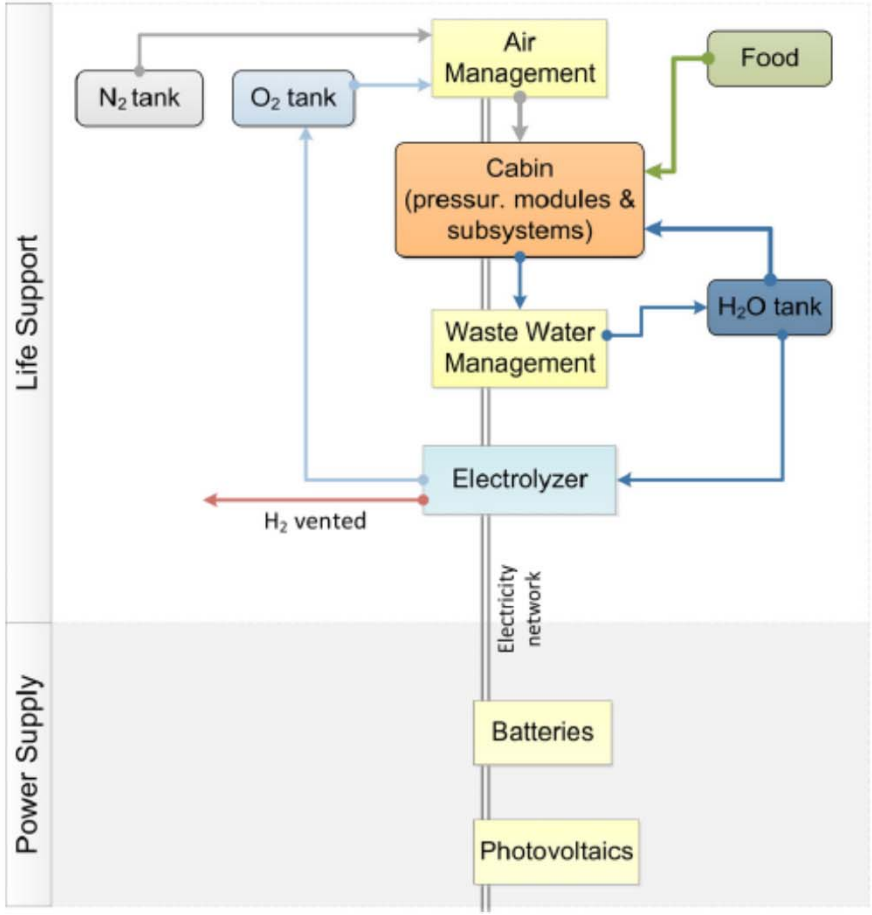


C. vulgaris, IRS 2010



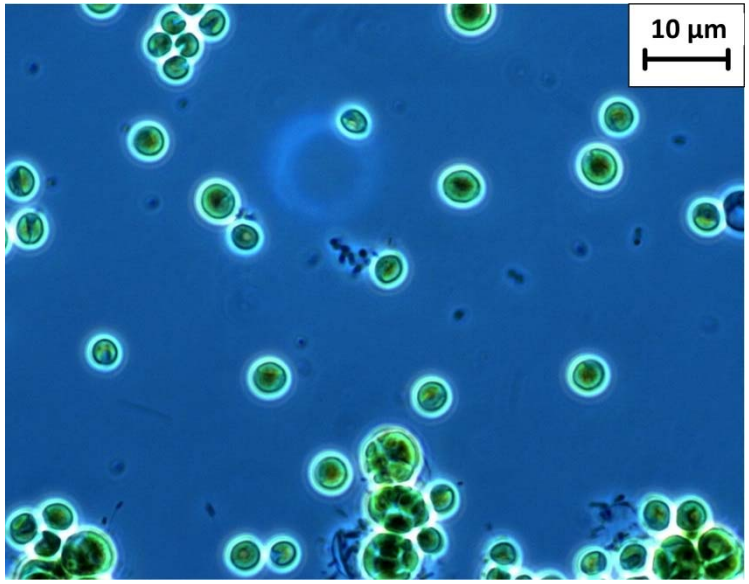
C. vulgaris, IRS 2013

Life Support System architecture including *photobioreactors*



Microalgae species selection

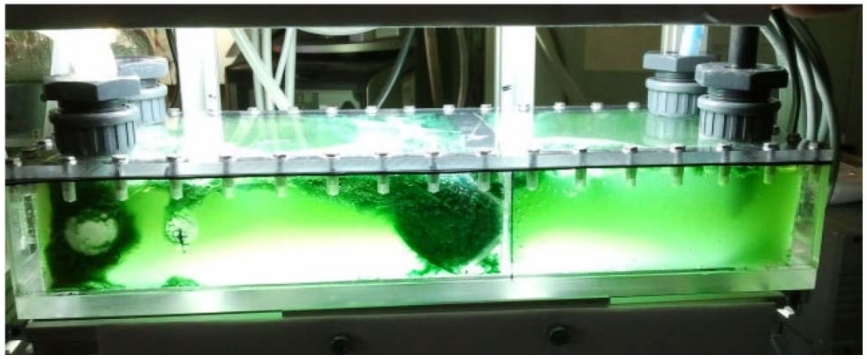
Our favourite: *Chlorella vulgaris*



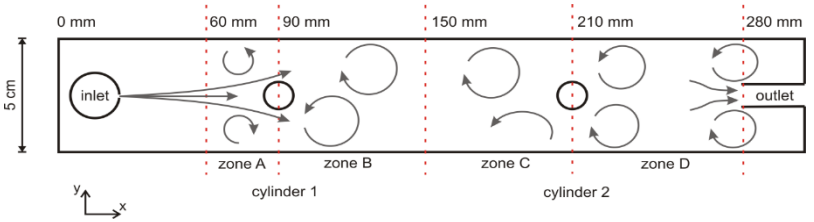
- Immotile, single cell, spherical shape
- Not forming complex agglomerates
- Wide range for T, pH and CO_2
- Growth controllable by selective lighting strategy
- Cultivation and proliferation controllable by medium composition
- non-axenic cultivation
- Space experience up to 40 days

… but also cultivation experience with species *Spirulina* and *Scenedesmus*

Cultivation in photobioreactors

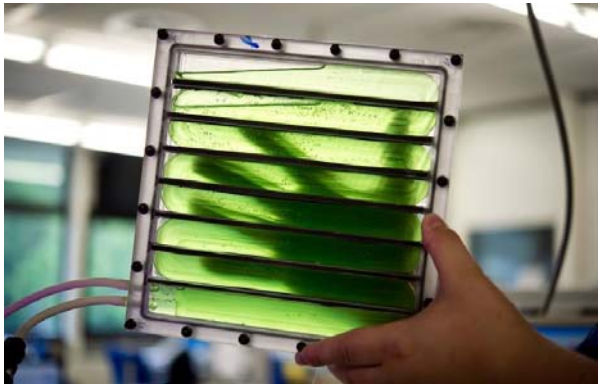


vortex street

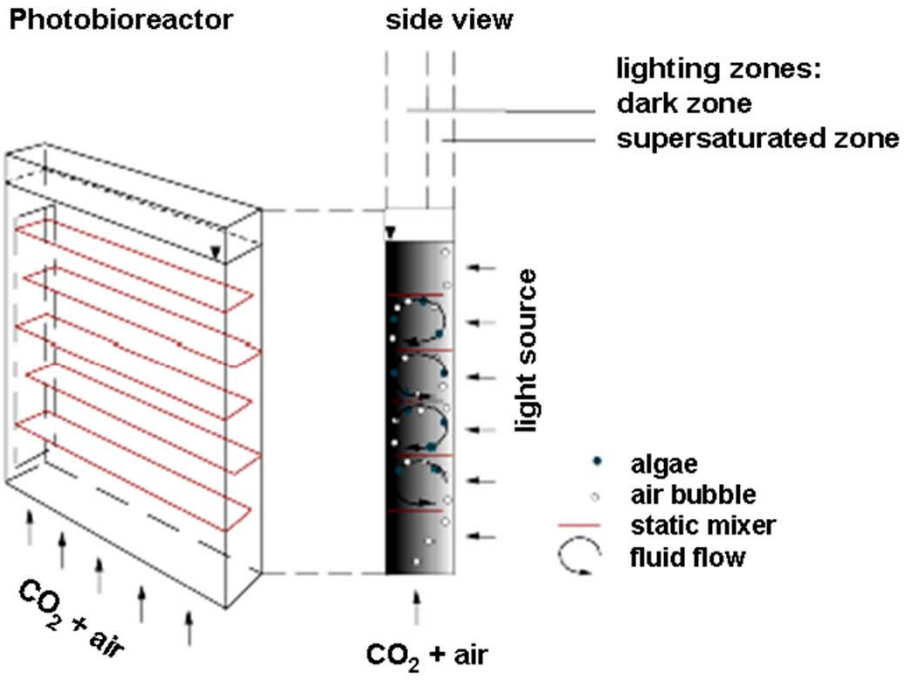


tubular

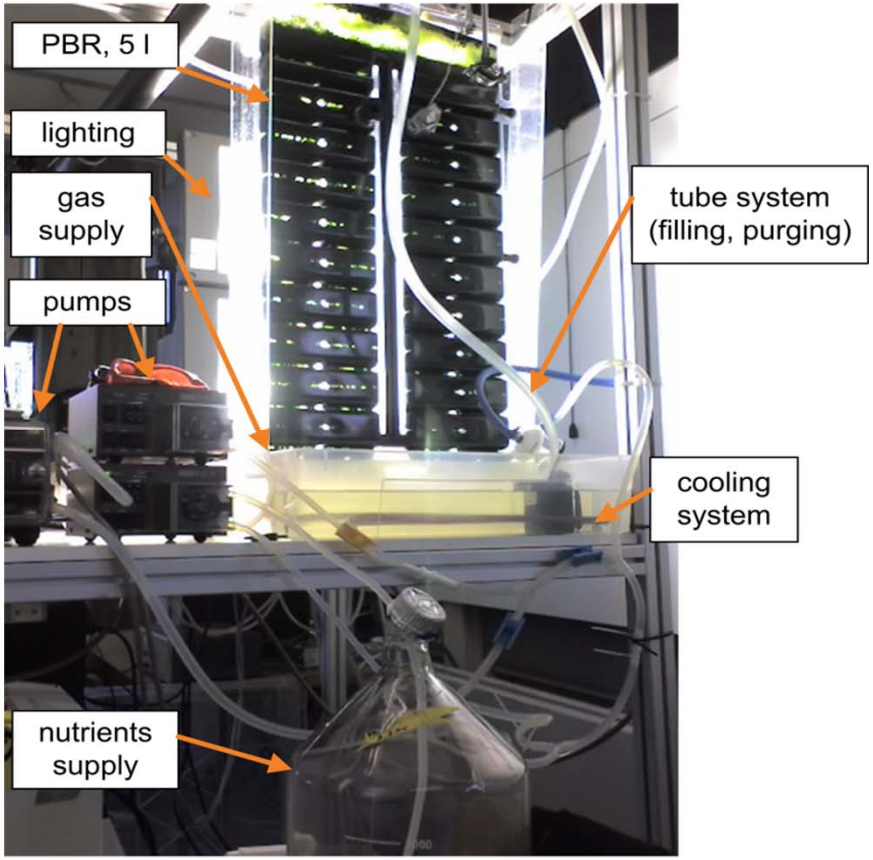
flow field membrane



Cultivation in photobioreactors



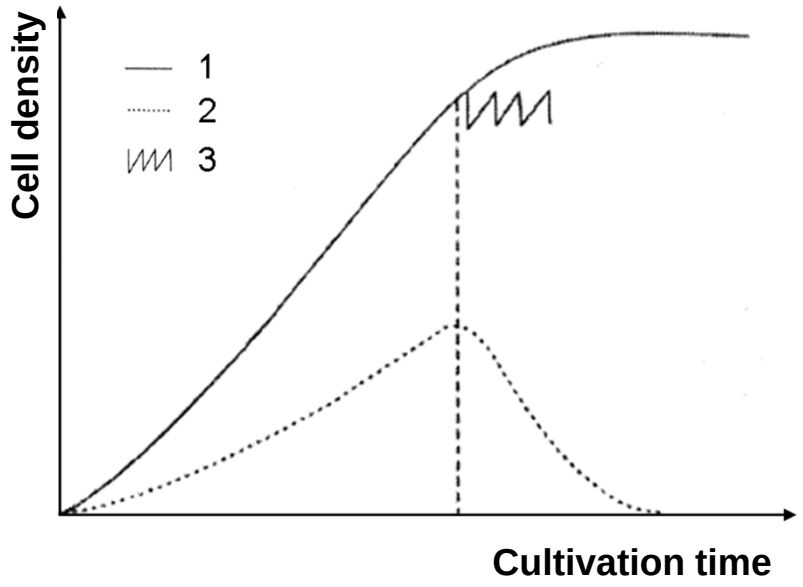
airlift



Terrestrial flat plate airlift reactor at IRS (from company Subitec, Stuttgart)

… cultivation at high cell densities (high biomass in low volume)

Microalgae growth

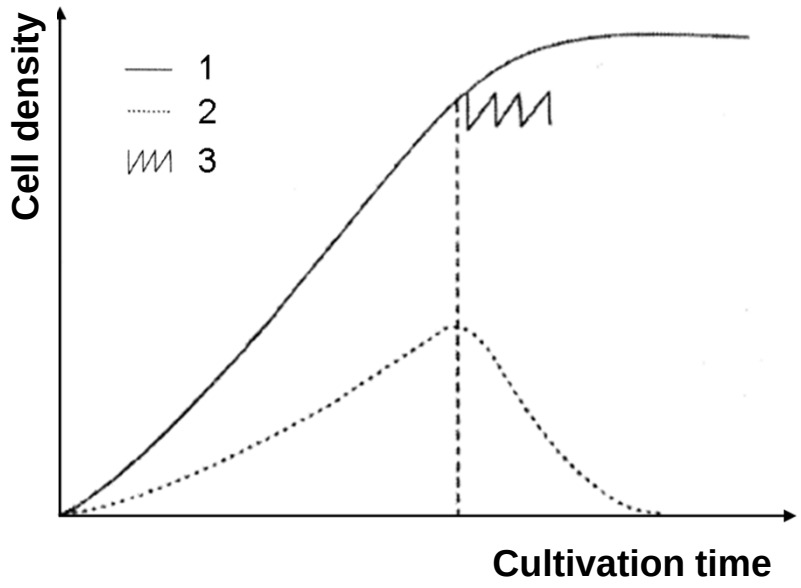


1: growth f(x)
2: growth rate f‘(x)
3: continuous cultivation

Cultivation parameters:

- CO_2 concentrations
- max. O_2 concentrations
- nutrients (ammonium/nitrate, phosphate, FeCi, DSN medium, …)
- light(ing)
- non-axenic environment
  → good growth conditions for *Chlorella* beside other MOs

Microalgae growth



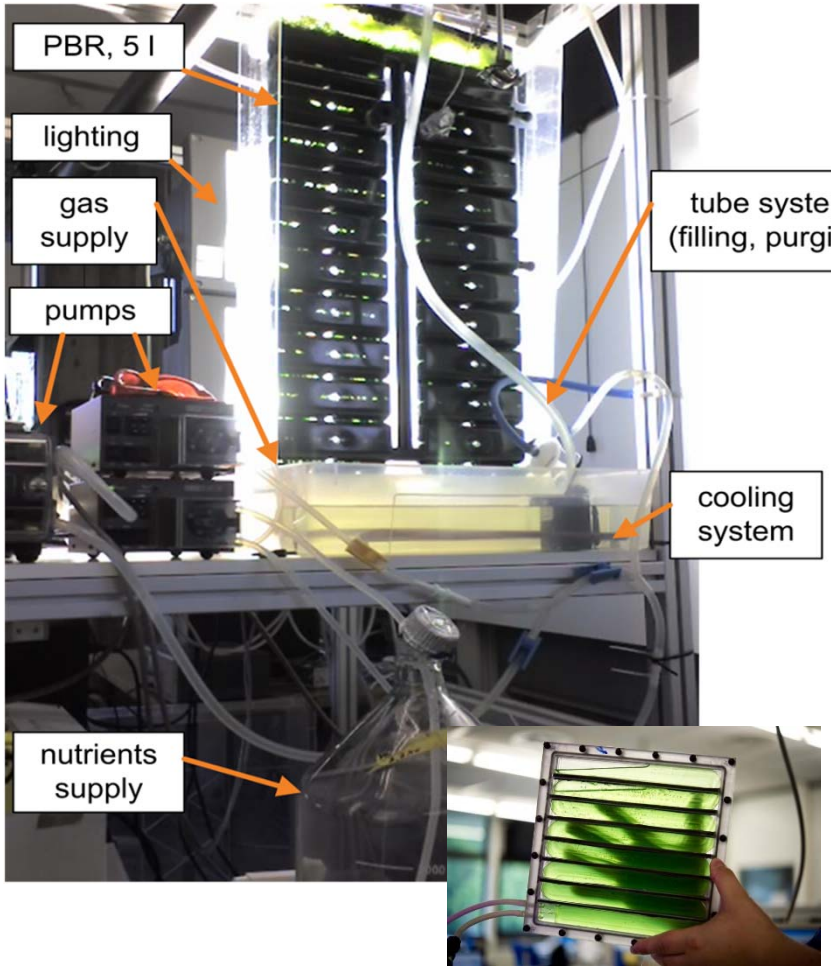
1: growth f(x)
2: growth rate f‘(x)
3: continuous cultivation

Biological questions:

- cell morphology
- biomass composition
- cell-cell interaction
- photosynthetic performance (O_2 synthesis rate)
- regeneration potential
- genetic evolution under space conditions (µg, radiation)

… biology defines the cultivation requirements

Microalgae growth



Engineering questions:

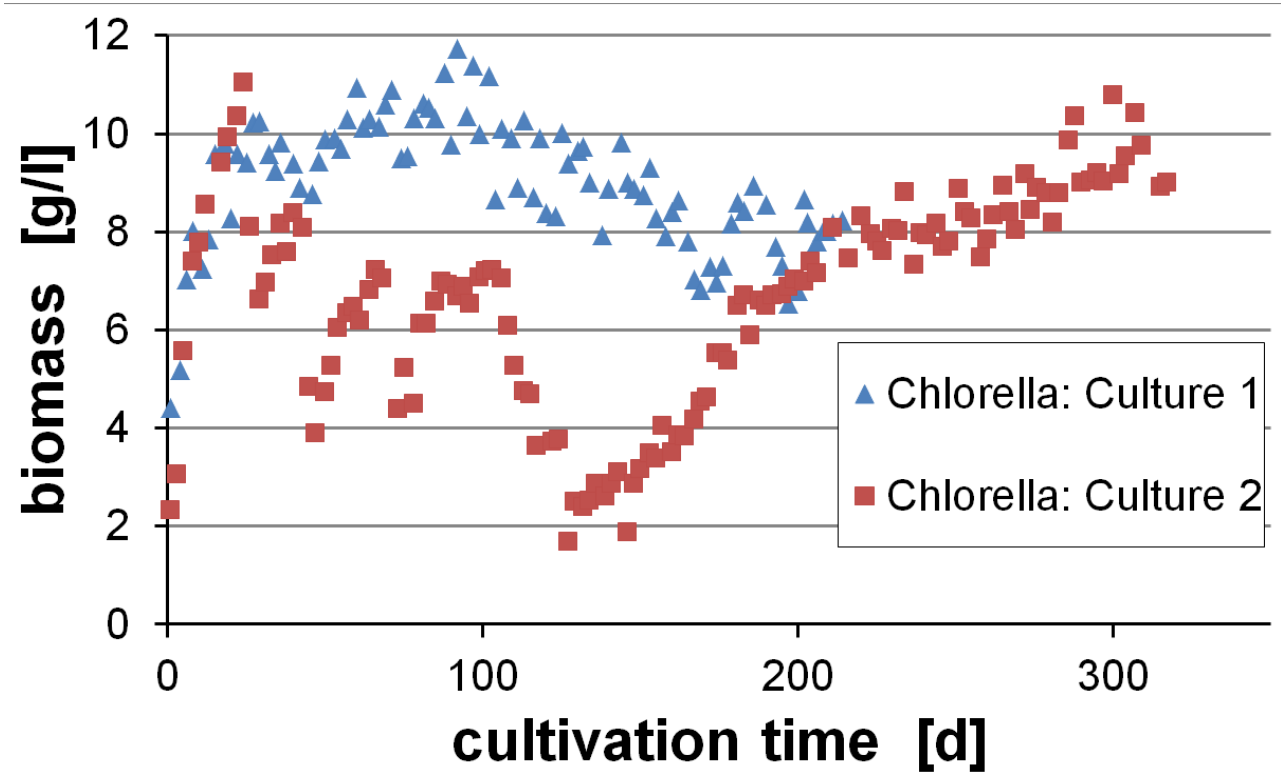
- Ensure a controlled environment
- nutrients supply
- lighting
- gas exchange (CO_2 supply, O_2 removal)
- thermal control
- media/solution control
- harvesting and stowage (downstream processing)

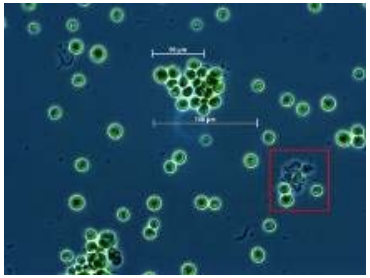
long term exploration missions
=
long term and stable cultivation

… Engineering: building a PBR system for long term and stable cultivation

Long term cultivation in PBR (airlift)

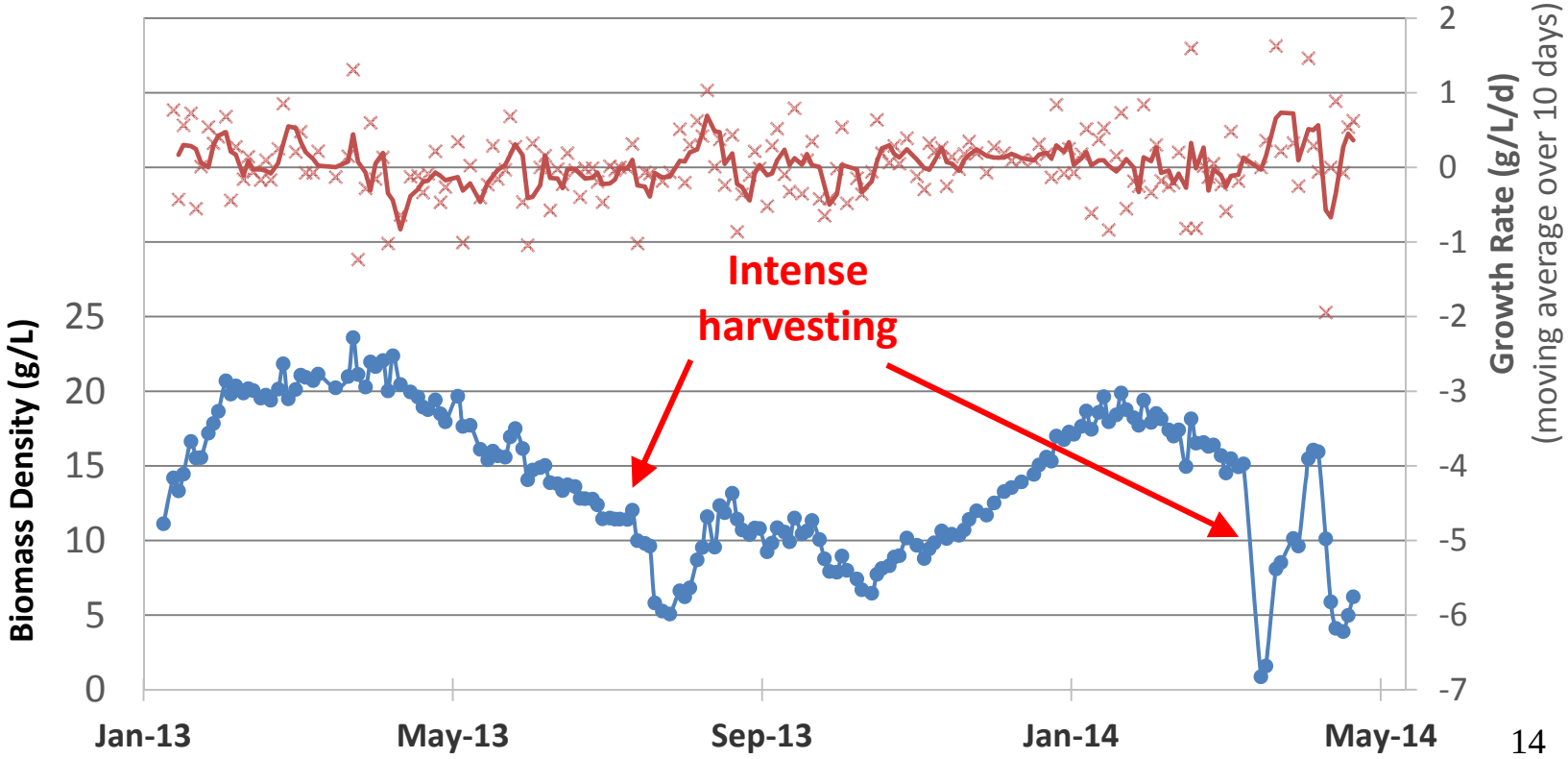
- *Chlorella vulgaris*
- long term cultivation (cont./batch mode, regeneration/stability)





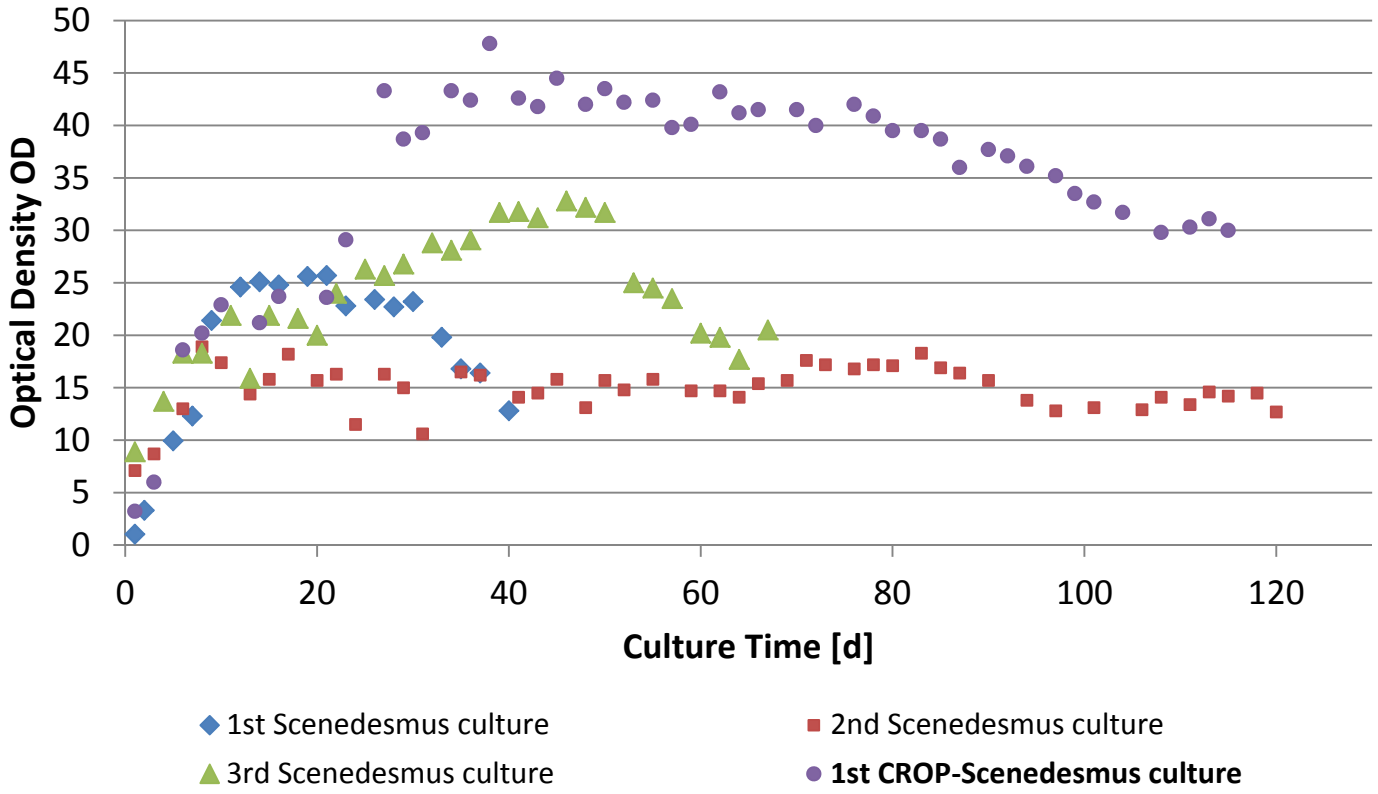
Long term cultivation in PBR (airlift)

- *Chlorella vulgaris*
- long term cultivation (cont. mode, regeneration/stability)

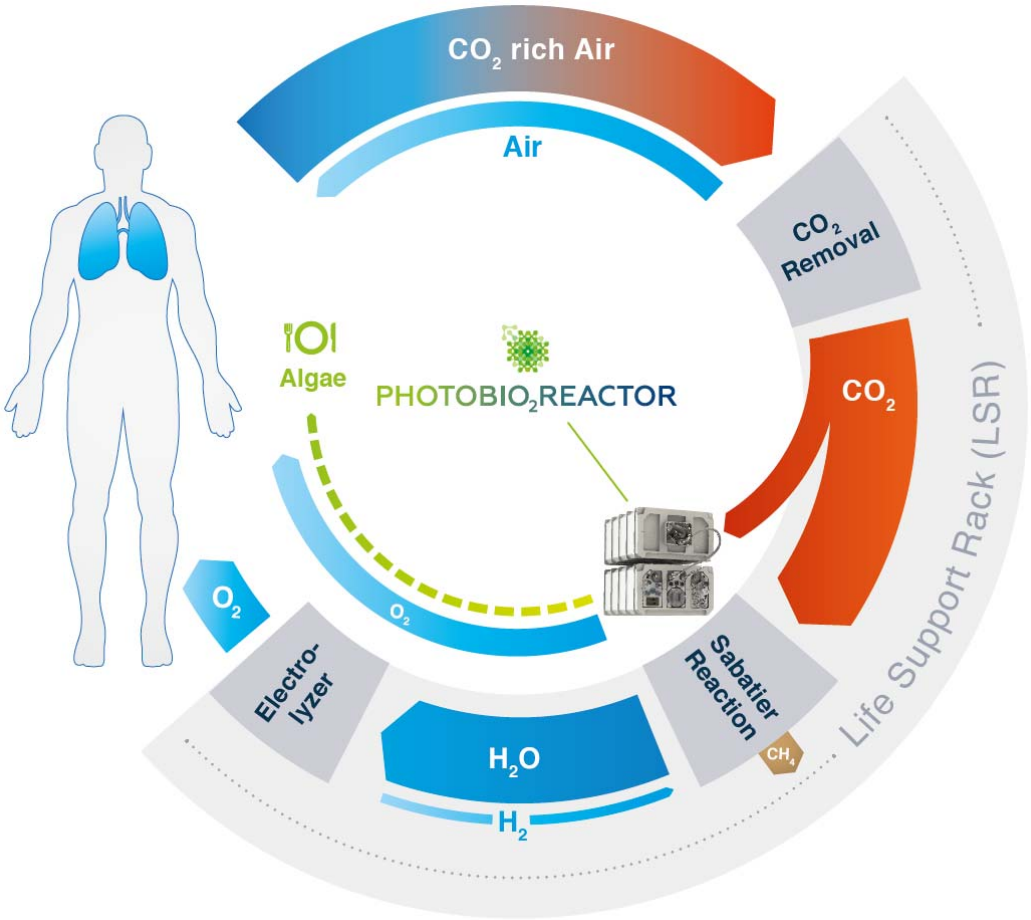


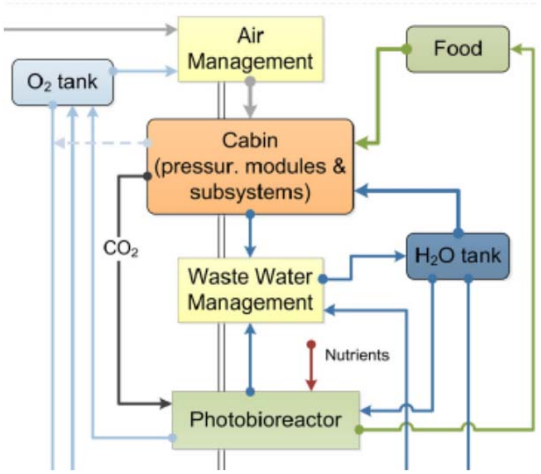
Long term cultivation in PBR (airlift)

- *Scenedesmus obliquus*
- long term cultivation (cont. mod, regenerated nitrate source)



Long term cultivation in space

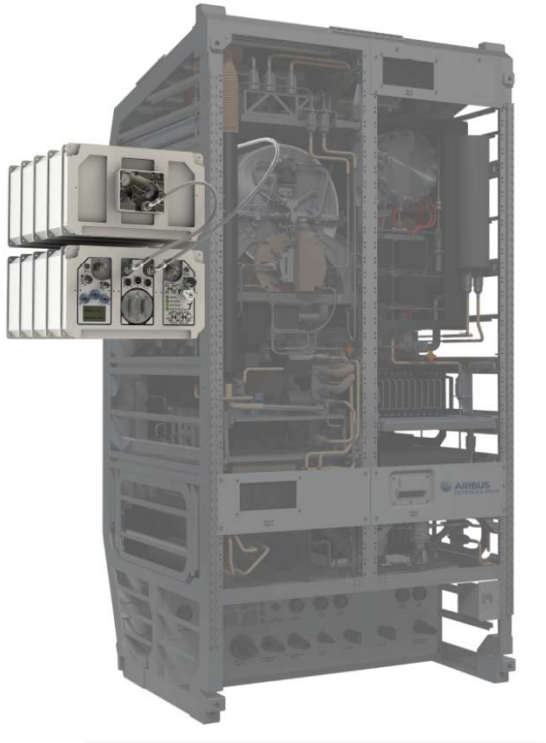


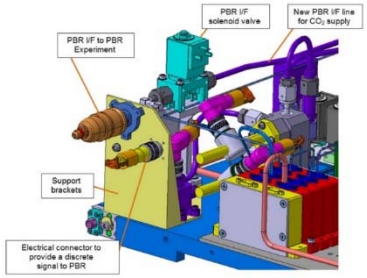


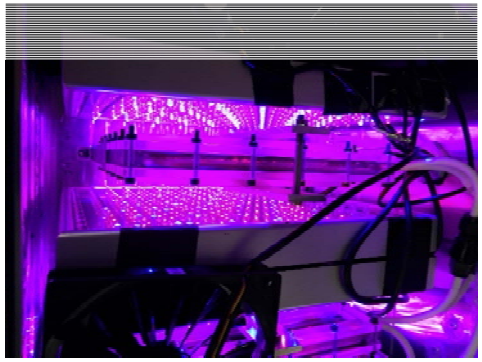
Efficient integration
in an existent
LSS infrastructure

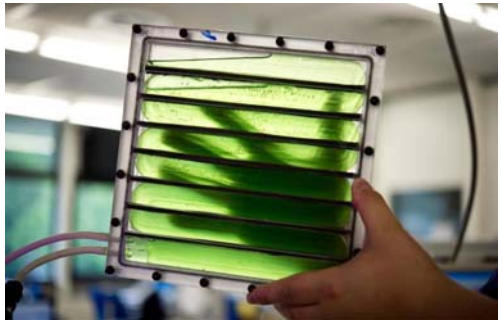
Long term cultivation in space

- PBR@LSR: a technology demonstration experiment on ISS for long term cultivation of *C. vulgaris*
  - Hybrid link realized by CO_2 supply from LSR (CO_2 interface)
  - Long-term cultivation (180 days)
  - Functionality, feasibility, performance, stability









Long term cultivation in space

- Reliable and robust PBR system design

  - Reactor chamber
  - Pumped algae medium loop
  - LED lighting
  - Gas management
  - Gas exchange through membrane
  - Thermal control
  - Liquid exchange (inoculation, feeding and harvesting, termination)
  - Algae storage, transport, backup culture

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… thank you for your attention …

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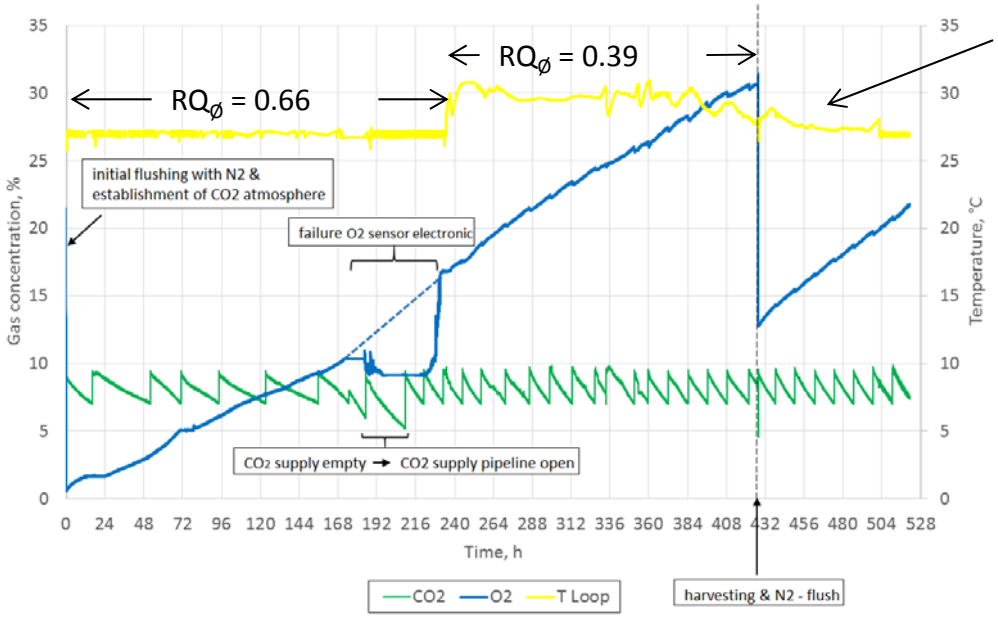
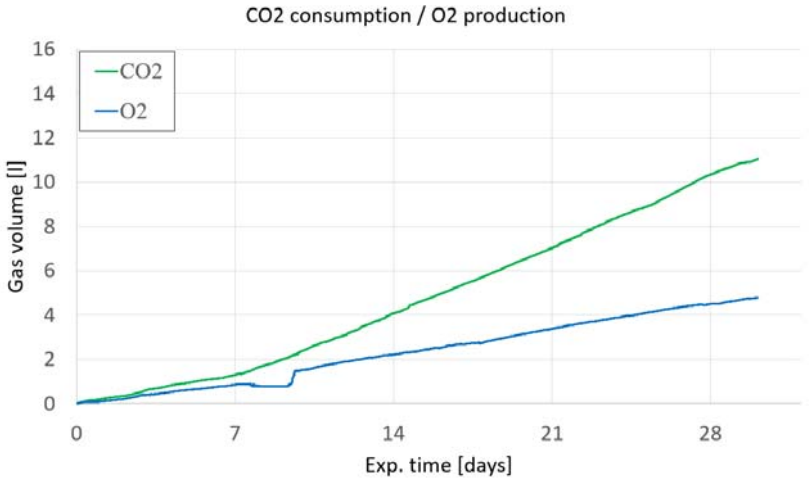
Long term cultivation in space





- Preparation on ground
- very stable breadboard
  - RQ = c_{O2}/c_{CO2}
  - RQ_{FPA} = 0.3-0.4
  - RQ = 1:
    1 kg CO2 → 0.72 kg O2

$$6\,CO_2 + 6\,H_2O \xrightarrow{h\nu} C_6H_{12}O_6 + 6\,O_2$$

→ Real data for gas rates