MELISSA
MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

2022 MELISSA CONFERENCE
8-9-10 NOVEMBER 2022

CREATING A CIRCULAR FUTURE

# AlgoLight

To produce high value products in a compact controlled and intensified photobioreactor adaptable to the life support for human space exploration

**THOBIE C., PERUCHON L., PRUVOST J., BROCHIER C.**

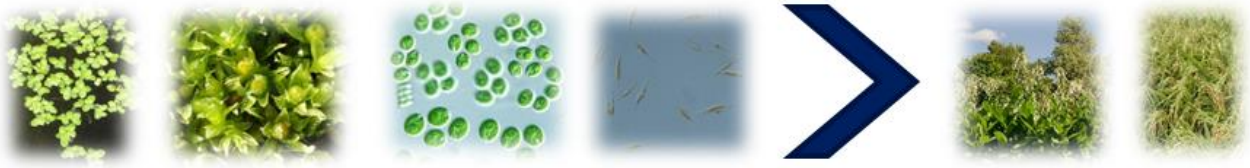
# 1- Context : Need for controlled production for the production of interested metabolites for cosmetics, nutraceuticals and biopharmaceuticals

*An example : Plant as a next generation platform to produce biopharmaceuticals*

Plant-based techniques have many advantages : Higher biosynthetic capacity, genetic engineering flexibility, absence of human pathogens

Due to successful genes expression, plants of different sizes have been proven at the development scale to be a viable option.

**Mini/microplant expression systems** → **Transgenic superior plant**



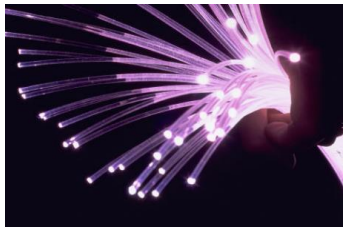
*Lemna minor* | *Physcomitrella patens* | *C.reinhardtii* | *P.tricornutum* | *tobacco, rice, alfalfa, tomato, barley, etc*

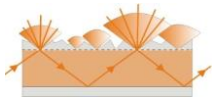
+

Public demand for high containment of genetically modified plants for their production

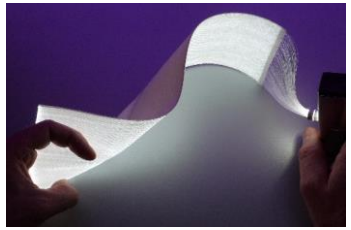
**➔ON THE WAY TO COMMERCIALIZATION, PROCESS DEVELOPMENT IS NOW CRITICAL :**
***Controlled production in closed PBR, cGMP conditions…***

# 1- Context : LIGHTEX® technology – Luminous technical fabrics made of optical fiber : from lighting to health application





*Side emitting fiber optic*



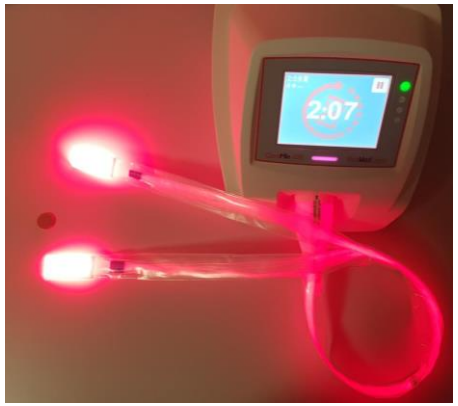
BROCHIER® TECHNOLOGIES

## Lightex® technology from :

- ❑ Weaving of optical fibers on a Jacquard loom
- ❑ Treatment of optical fiber surfaces for lateral lighting
- ❑ Coupling of optical fiber bundles with light sources (LED)
- ❑ Controlling and powering LEDs

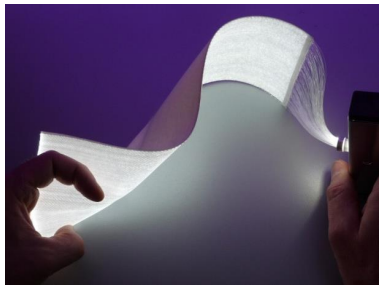
## Lightex® products are on the markets

**BiliCocoon® treating neonatal jaundice**

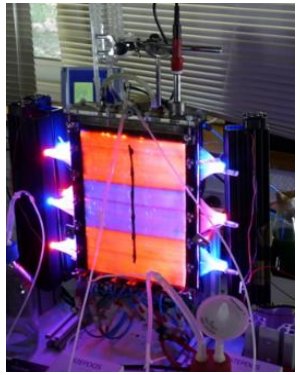



**CareMin650® treating mucositis**

# 1- Context : Development of the PBR PRIAM from idea to business creation



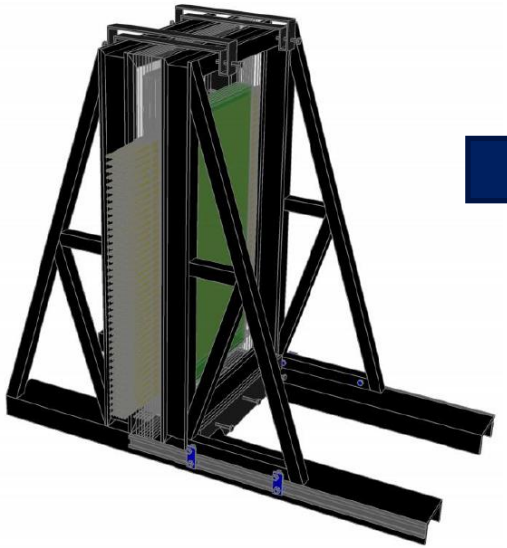
**Controlled production needs**



✓ **Design of a specific fabric for photosynthesis application**
✓ **1st mock-up (2010)**

GEPEA Environnement • Énergie Agro-alimentaire • Mer — UNIVERSITÉ DE NANTES — INSTITUT PASCAL sciences de l'ingénierie et des systèmes

**Project PRIAM (ANR) 2013-2017**



**Algolight SAS (2022)**

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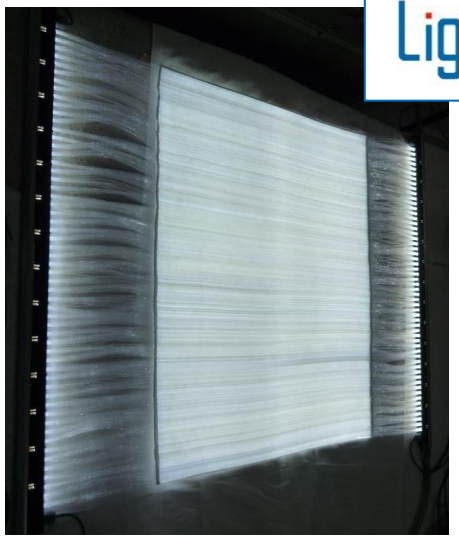
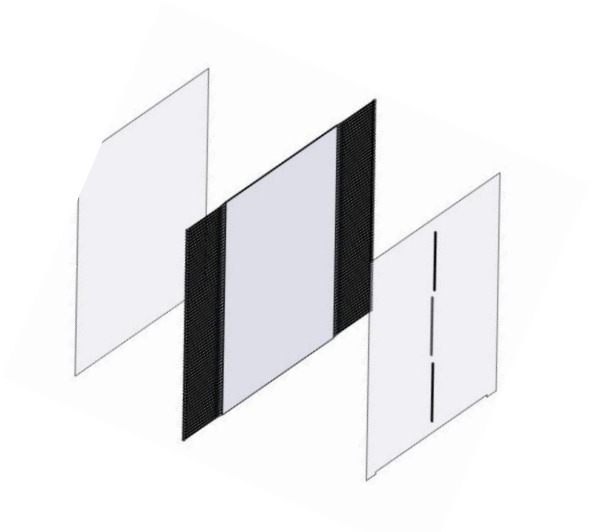
# 2- PRIAM Prototype : Photobioreactor made of multilayer of LIGHTEX® / Luminous fiber optic fabric

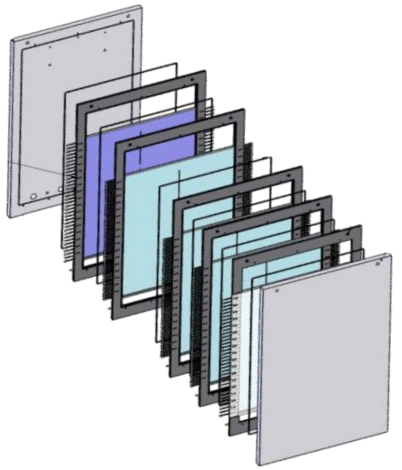
**Based on a Lightex® bright double-sided panel, a plane photobioreactor with internal volumetric illumination – PRIAM, has been developed in cooperation with University of Nantes (France).**




**hv emission**
**200 ± 25 µmol $m^{-2}$ $s^{-1}$**



**Lightex® panel between 2 polymer plates**



**Multilayer stack of Lightex plates illuminating culture chambers**

**Innovative PRIAM PBR (2015)**

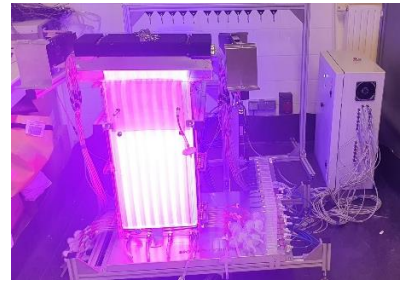
# 2- PRIAM Prototype : Photobioreactor made of multilayer of LIGHTEX® / Luminous fiber optic fabric

**PRIAM 1st PROTOTYPE :**

- ❑ floor area : 1 m²
- ❑ height : 2 m
- ❑ **specific light area : ~500 m²/ m³**
- ❑ liquid volume : ~10 liters (5 panels)
- ❑ in situ control of pH, temperature, …
- ❑ **light spectrum adapted / ratio of colors light**

**PRIAM 2nd PROTOTYPE :**

- ❑ Floor area : 0,07m²
- ❑ Liquid volume : ~10 liters (5 panels)
- ❑ Easy to clean and maintain
- ❑ Validated on several strains
- ❑ Fully automated with a control interface



**Continuous productivity**
**3.75 kg $m^{-3}$ $day^{-1}$**

**No biofilm !!**

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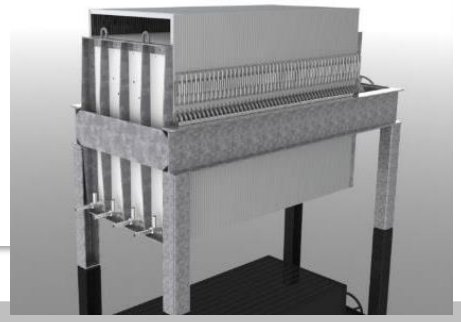
**PRE-INDUSTRIAL PLATFORM :**

- ❑ closed system in a **sterile environment**
- ❑ **cGMP** production of microalgae
- ❑ **modular design**

**To our knowledge :**
**no equivalent system !**

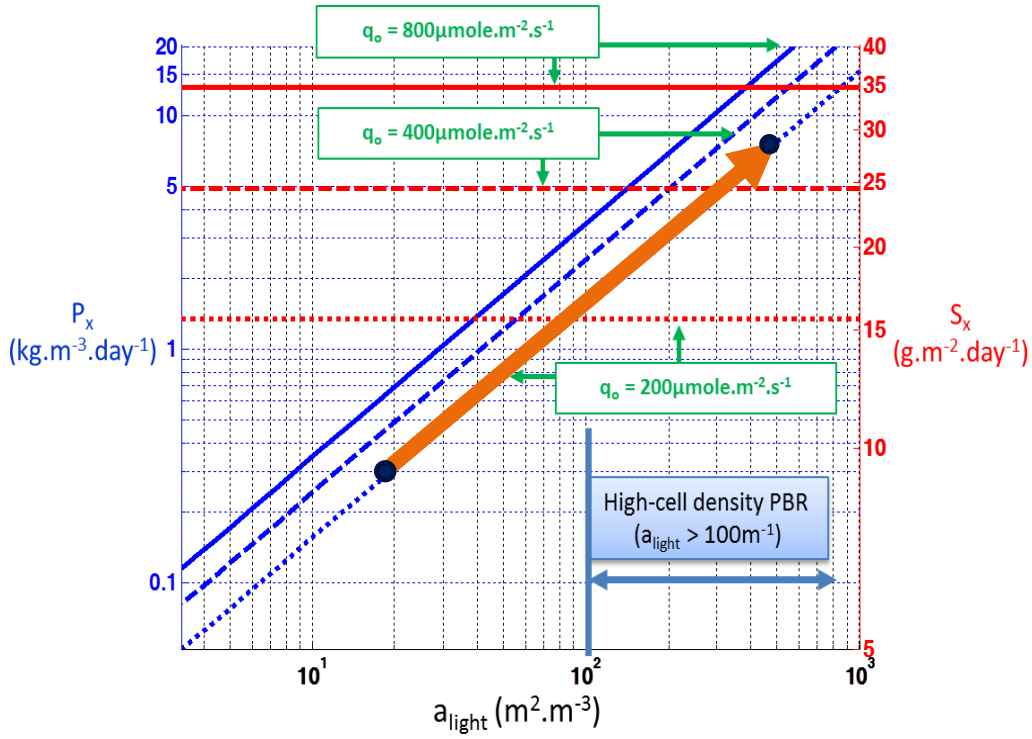


# 3- Technology positioning

**PRIAM is a breakthrough intensified culture technology suitable for controlled, industrial, and artificial light cultivation**

The productivity of photobioreactors is driven by three main parameters of engineering:

- Incident flux receives (PFD, $q_0$)
- **Specific illuminated area ($a_{light}$ = S/V)**
- Unlit design volume (fd = 0 often)



# 3- Technology positioning

**PRIAM is a breakthrough intensified culture technology suitable for controlled, industrial, and artificial light cultivation**

| Technology | Illuminated surface area $a_s$ | Production volume | Maximum volume Productivity (kg/m3/d) | Daily biomass production range (kg/d) |
|---|---|---|---|---|
| HECTOR (*C. Vulgaris*) | 18 $m^2.m^{-3}$ | 130 L | 0,13 | 0,017 |
| XANTHELLA (*A. platensis*) | ≈ 10 $m^2.m^{-3}$ | 12*1 $m^3$ | 0,1-0,3 | 2,4 |
| FPA – SUBITEC (*Haematococcus*) | | 4*27,5L = 110L | 0,4 | 0,044 |
| **PBR-PRIAM (prototype)** *(C. Vulgaris)* | **496 $m^2.m^{-3}$ (e = 3 mm)** | ≈10L | **3,7** | **0,035-0,039** |
| **PBR-PRIAM (industriel)** | **496 $m^2.m^{-3}$ (e = 3 mm)** | 1$m^3$ | **3,7** | **3,5-3,9** |

**X15-X30**

➔ **GAIN IN VOLUME PRODUCTIVY BETWEEN 15 AND 30 & MODULAR PRODUCTION**

**Volume = 1$m^3$**
**Daily production : 3.5-3.9kg/day**

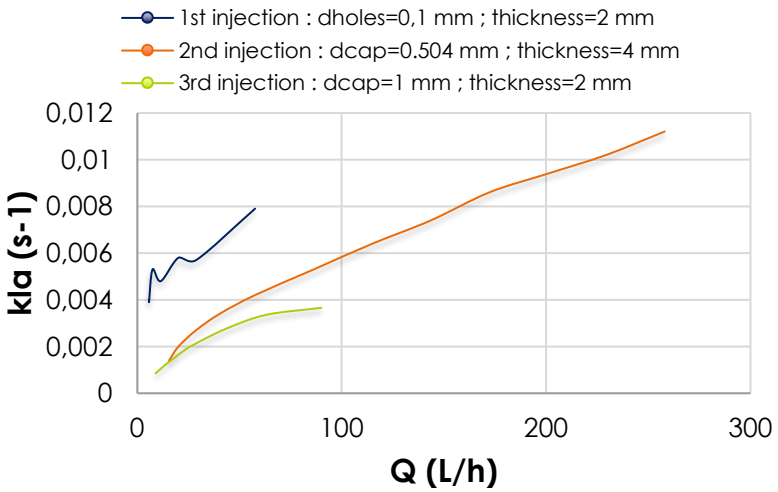
**No equivalent today …**

# 4- Main issues in intensified technologies

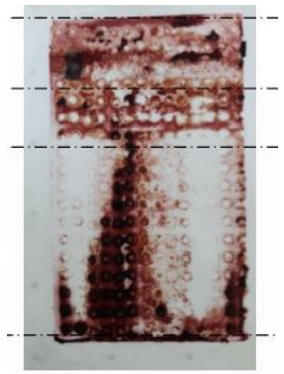
**Low culture thickness**

**Increase in culture viscosity at high cell concentration. Or even non-Newtonian behavior.**

**One of the major obstacles of intensified PBRs : HYDRODYNAMICS**




**PRIAM : Bubbling optimization**



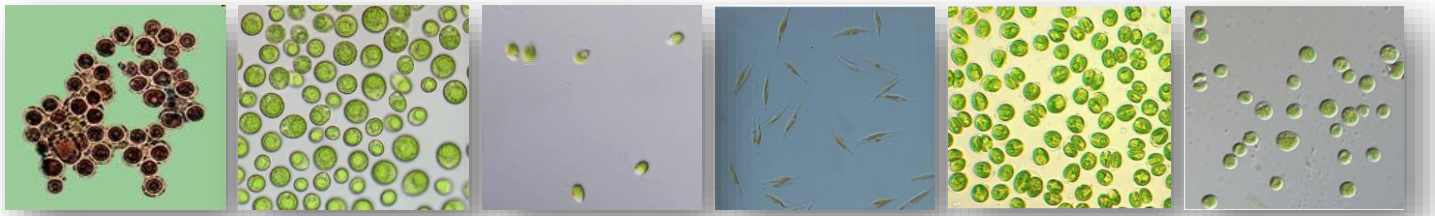
Control of gas-liquid transfer (non-limiting $CO_2$ + no accumulation of $O_2$)

Culture management (homogeneous culture, no biofilm, moss control etc.)

# 5- Performance obtained in PRIAM - Strains tested

**Photosynthetic microorganisms :**

*Porphyridium cruentum*
*Chlamydomonas reinhardtii*
*Dunaliella salina*
*Phaeodactylum tricornutum*
*Tetraselmis suecica*
*Chlorella Vulgaris*



➔**SUCCESSFUL CULTIVATION OF MANY PHOTOSYNTHETIC MICROORGANISMS**

# 5- Performance obtained in PRIAM – Productivity obtained

| Species | Volume productivity ($kg/m^3/j$) V≈10L |
|---|---|
| 100 µmol/m²/s⁻¹ | |
| *Porphyridium cruentum* | 1,41 ± 8 % |
| *Chlamydomonas reinhardtii* | 1,06 ± 6 % |
| *Dunaliella salina* | 0,87 ± 10 % |
| *Phaeodactylum tricornutum* | 2,47 ± 6 % |
| *Tetraselmis suecica* | 1,75 ± 8 % |
| 200 µmol/m²/s⁻¹ | |
| *Chlorella Vulgaris* | 3,75 ± 6 % |
| *Porphyridium cruentum* | 1,68 ± 8 % |
| *Haematococcus* | (en cours) |

➔SUCCESSFUL CULTIVATION OF MANY PHOTOSYNTHETIC MICROORGANISMS

# 5- Performance obtained in PRIAM - Optimization of light spectrum and hydrodynamics

**Hydrodynamic optimization**

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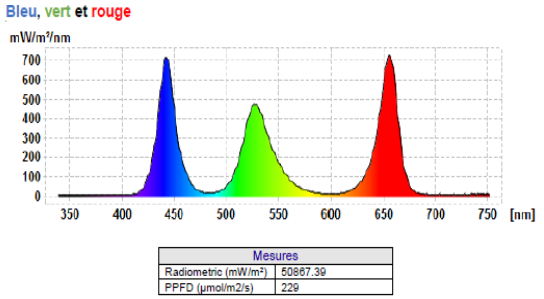
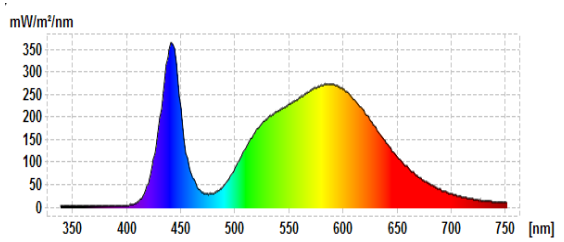
**Technology PRIAM uses LEDs :** light spectrum can be adapted to the microalgae and the metabolites of interest that we want to produce




**Increased productivity of some metabolites of interest**

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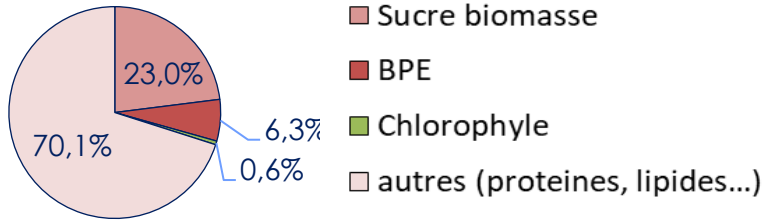
$P_{BPE}$ = 23➔63 mg/L/j

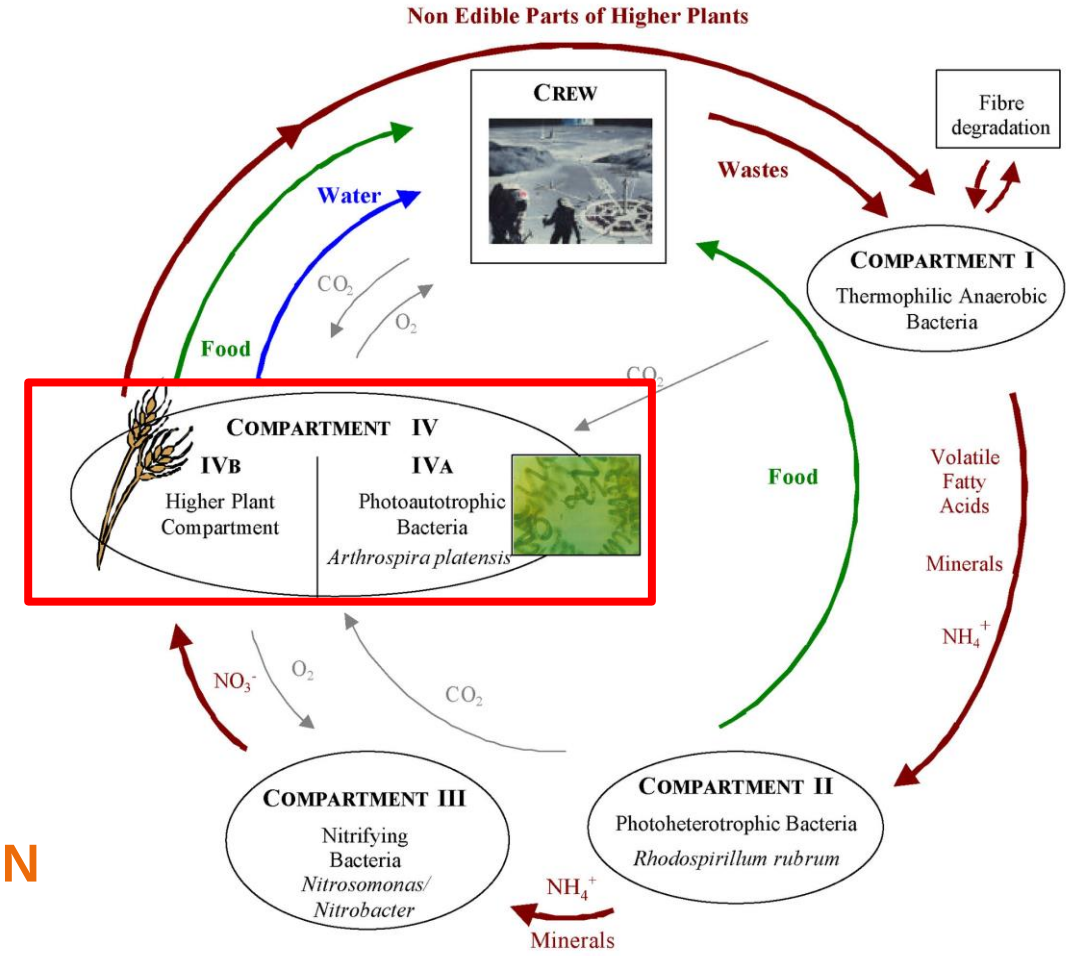


# 6 - Photobioreactors for A life support For the human space exploration

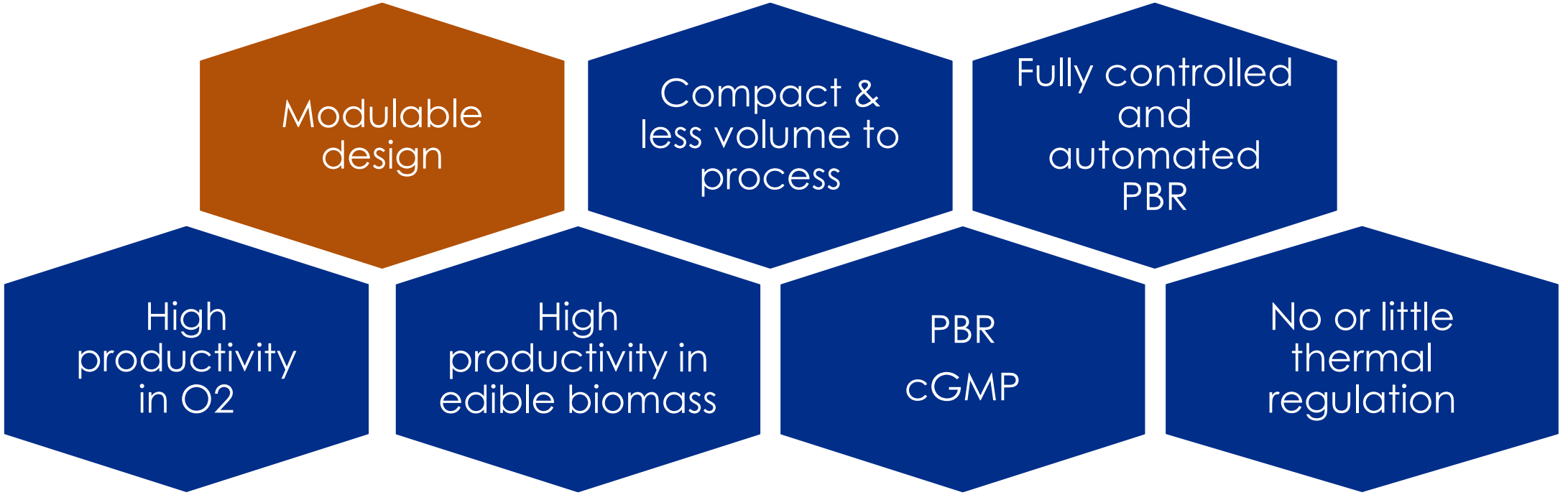
## COMPARTMENT IV a - MAIN OBJECTIVES :

- Used to answer the problem of the atmosphere regeneration ➔ **produces oxygen and fixes CO2**.
- Used to the food production ➔ micro-organism **edible**, **enough biomass**
- Used to the liquid waste treatment.
- One of the main constraints to cultivate microorganisms in space is that it is necessary to produce **sufficient food in a restricted place**

➔ **SOLUTION : PHOTOBIOREACTOR INTENSIFICATION**

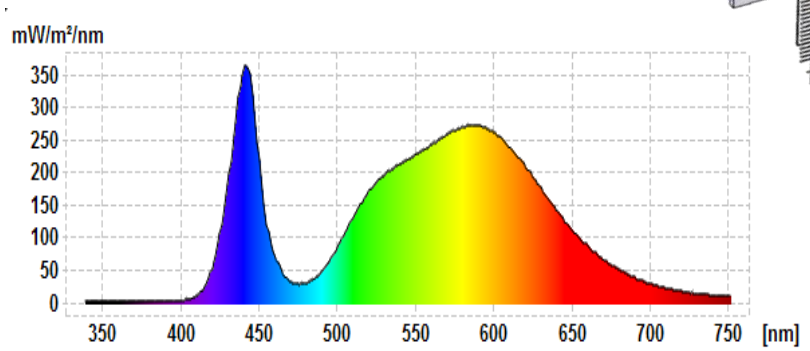


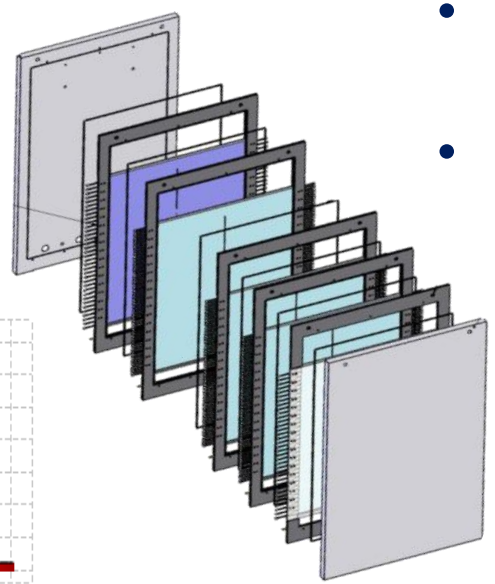
# 6 – PRIAM : Intensified photobioreactor that could be adapted to life support for human space exploration



# 6 – PRIAM : Main features of this intensified PBR

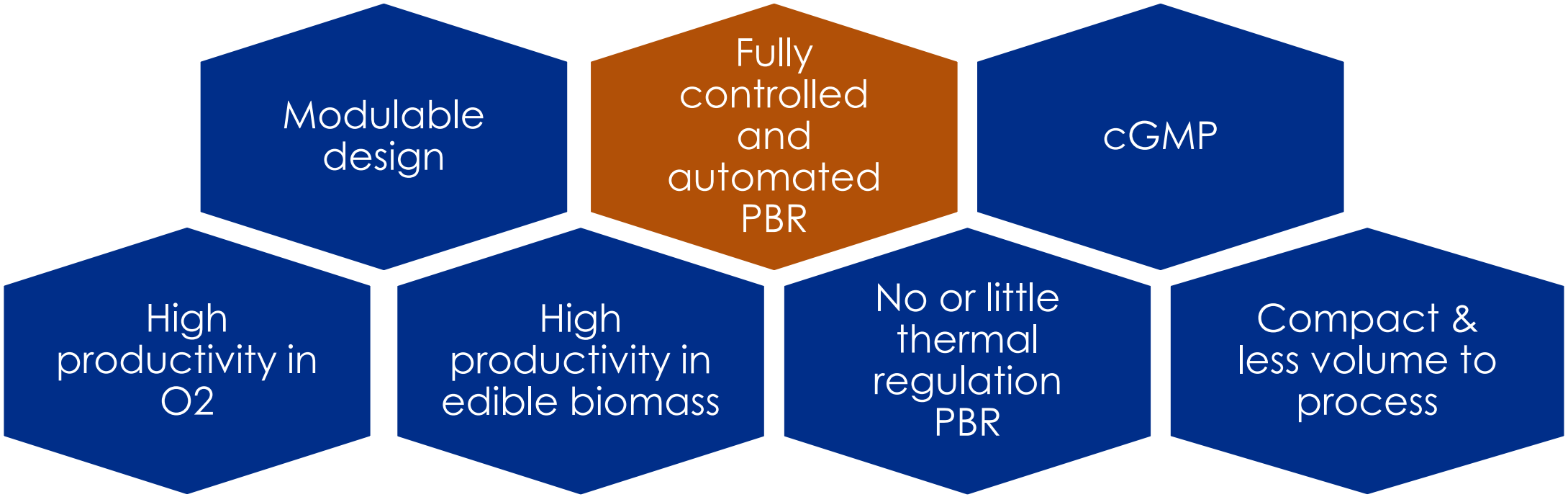
Modulable design



- Ease of extrapolation in volume without changing the productivity obtained
- Possibility of deintensifying the PBR to accomodate to certain strains
- Ease of change the spectrum of light

# 6 – PRIAM : Intensified photobioreactor that could be adapted to life support for human space exploration

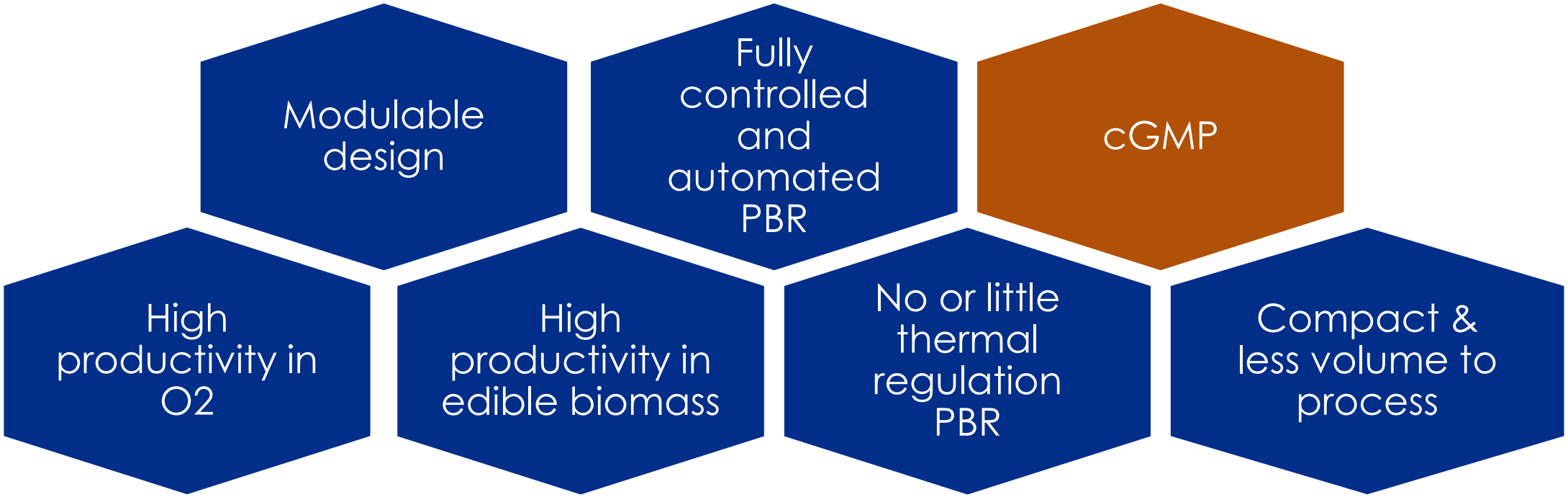


# 6 – PRIAM : Main features of this intensified PBR

Fully controlled and automated PBR

- pH, T,
- Gas inlet and outlet analyzes ($O_2$,$CO_2$...)
- Pump control (culture medium, harvest)
- Control of the desired spectrum and light ratios
- Day/night cycle
- Foam level control
- ...

# 6 – PRIAM : Intensified photobioreactor that could be adapted to life support for human space exploration



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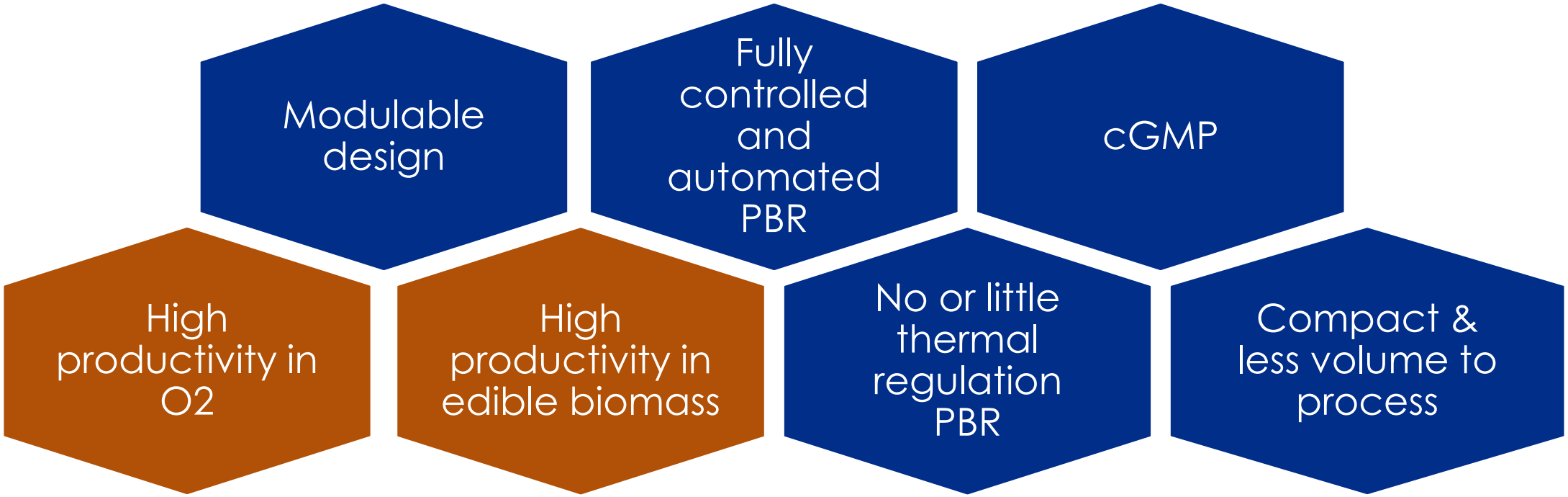


# 6 – PRIAM : Main features of this intensified PBR

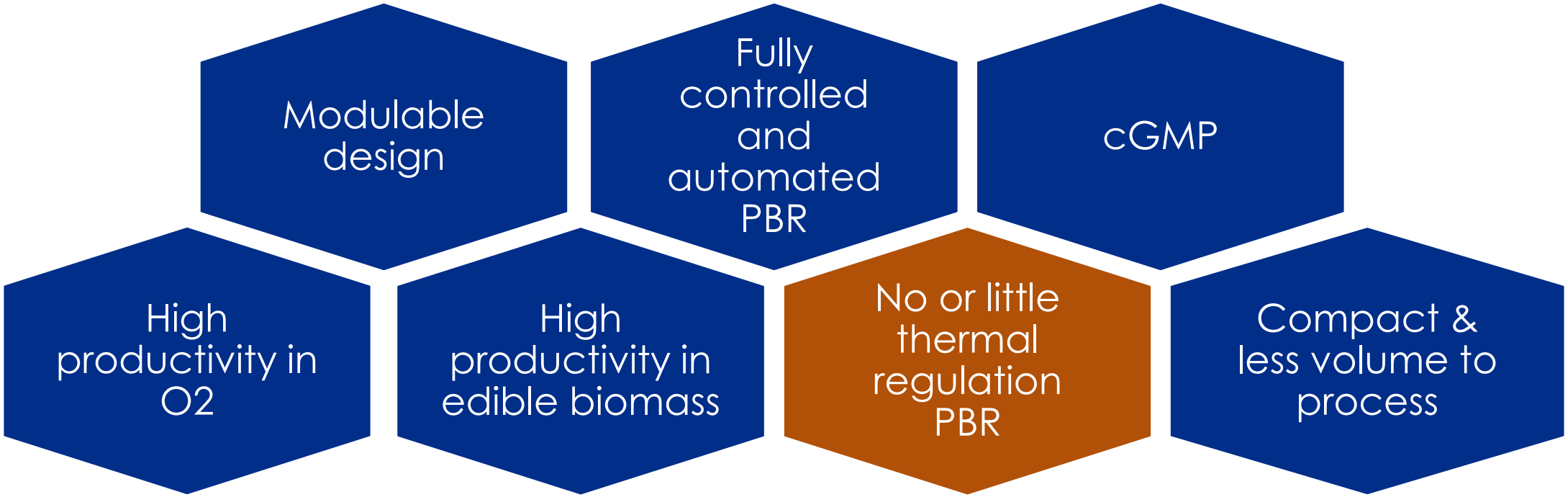
High productivity in O2

High productivity in edible biomass

Pour un PBR de 10L / 100L / 1m3 avec *C.Vulgaris* à 200 µmol/m²/s

Px=3,75 kg/m3/j
$PO_2$=7,5 kg/m3/j

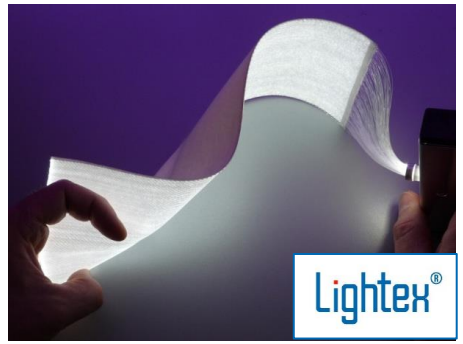
# 6 – PRIAM : Intensified photobioreactor that could be adapted to life support for human space exploration

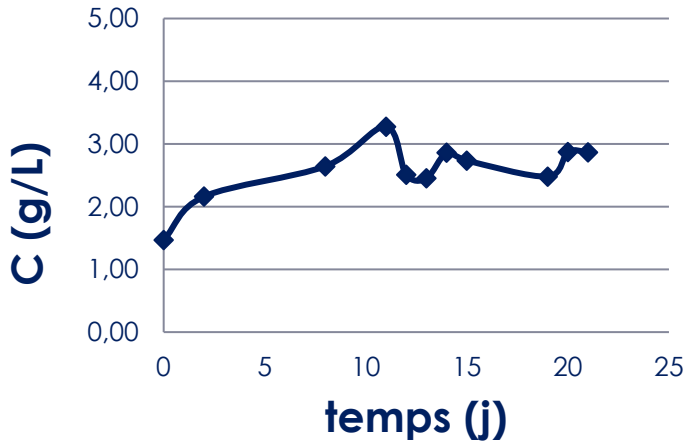


# 6 – PRIAM : Main features of this intensified PBR

No or little thermal regulation PBR

LED source remote from the photobioreactor ➔ Don't heat the culture

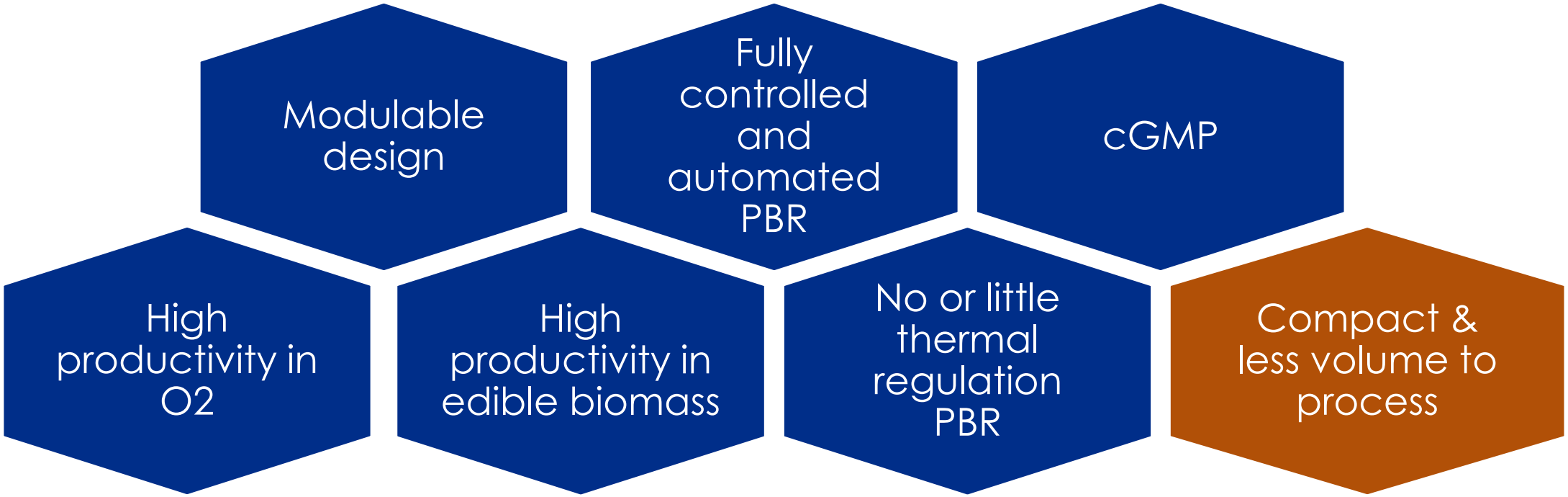



**55 µmol/m²/s :**

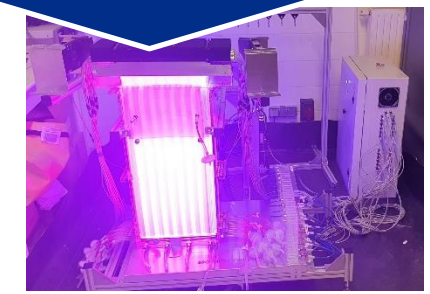
- $C_x$ =2,8 g/L (in continuous mode)
- Dilution rate = 0.020 $h^{-1}$
- $P_X$= 1.29 $kg/m^3/j$.
- **Without thermal regulation** ($T_{culture}$ < 25°C)

# 6 – PRIAM : Intensified photobioreactor that could be adapted to life support for human space exploration



# 6 – PRIAM : Main features of this intensified PBR

Compact & less volume to process



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| | 10L | 100 L | 1 m³ |
|---|---|---|---|
| Floor area | 0,1 m² | 1 m² | 10 m² |
| Yearly Production | 11 kg/an | 110 kg/an | 1,1 t/an |

- At volume equivalent, 20 times more biomass is produced in the PBR PRIAM than in closed conventional technologies
- To produce X amount of biomass, 20 times less volume is needed in PRIAM.

➔ Less water needed

# 6 – PRIAM : Intensified photobioreactor that could be adapted to life support for human space exploration

The concept of this technology could be transposed to the space application :

- atmosphere regeneration
- edible biomass production
- liquid waste treatment in a restricted place

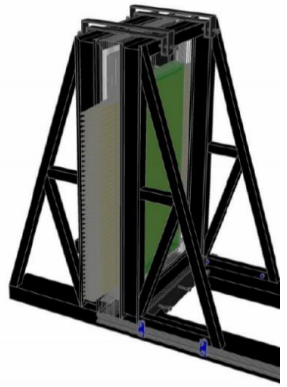
➔The main problem would be taking into account the **absence of gravity** and therefore **the hydrodynamics** and the gas/liquid transfer

# 7- Algolight start-up

PRODUCE HIGH-VALUE METABOLITES FROM PHOTOSYNTHETIC MICROALGAE AND CYANOBACTERIA IN A CLOSED, **COMPACT, CONTROLLED, STERILE SYSTEM !**

AlgoLight

| | 10L | 100 L | 1 m³ |
|---|---|---|---|
| Floor area | 0,1 m² | 1 m² | 10 m² |
| Yearly Production | 11 kg/an | 110 kg/an | 1,1 t/an |



**You ?**

**Interesting metabolites ?**

- ❑ **Cosmetics**
- ❑ **Biopharmaceuticals**
- ❑ **Life support for human space exploration ?**
- ❑ **Nutraceutical**
- ❑ **Recombinant proteins? GMO microalgae ?**

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# THANK YOU.

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