Greenhouse: a Strategic Element to Support Humans in Space

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Introduction

- The natural evolution of the human spaceflight activities appears to be oriented toward the consolidation of a robust infrastructure in Low Earth Orbit where to test and optimise the enabling technologies for the development of planetary surface human infrastructures

- The technologies required to sustain such a demanding enterprise span from transportation and propulsion to power supply, advanced materials, structures and mechanisms, Environmental Control and Life Support (ECLS), automation & robotics, electronics and communications

- A key function required from any infrastructure devoted to support long-duration permanence of people in space is to reproduce as much as possible the Earth's natural ecosystem, aiming at the "closure" of the air, water and food cycles in the so-called Closed Ecological Life Support Systems - CELSS

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The Greenhouse Scientific Rationale

- There is a close and interdependent relationship between plants and humans. Any attempt to develop conditions for one of the two cannot ignore the necessity of this interdependence
- There is evidence that alteration of the environment where both humans and plants developed affects virtually every aspect of growth and development as well as behavior
- Removal or reduction of the effects of gravity, light, oxygen, CO_2, temperature and many other conditions typical of the Earth environment cause specific responses in both plants and humans, sometimes leading to unsustainable life
- The adaptation of plants to space conditions and the development of plant-adapted space greenhouses will help humans colonize space

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Alenia Spazio Heritage

TransHab (1998-2000)

- Alenia Spazio, as part of an integrated team working at NASA-JSC for the NASA/ASI project TransHab, was responsible for:
  - ➔ The structural core and internal removable structures, mechanisms, deployable floors
  - ➔ Alternative design solutions of the interface between the inflatable shell and the rigid core
  - ➔ Permeability characterisation of the redundant bladder material and investigation of leakage containment issues

SpeS - Strutture Pneumatiche per applicazioni Spaziali (2000-2001)

Within the ASI project Spes Alenia Spazio, in collaboration with IACSA, developed:

- ➔ new configurations based on internal collapsible structures
- ➔ higher volume packaging
- ➔ possible architecture for Moon / Mars habitable modules

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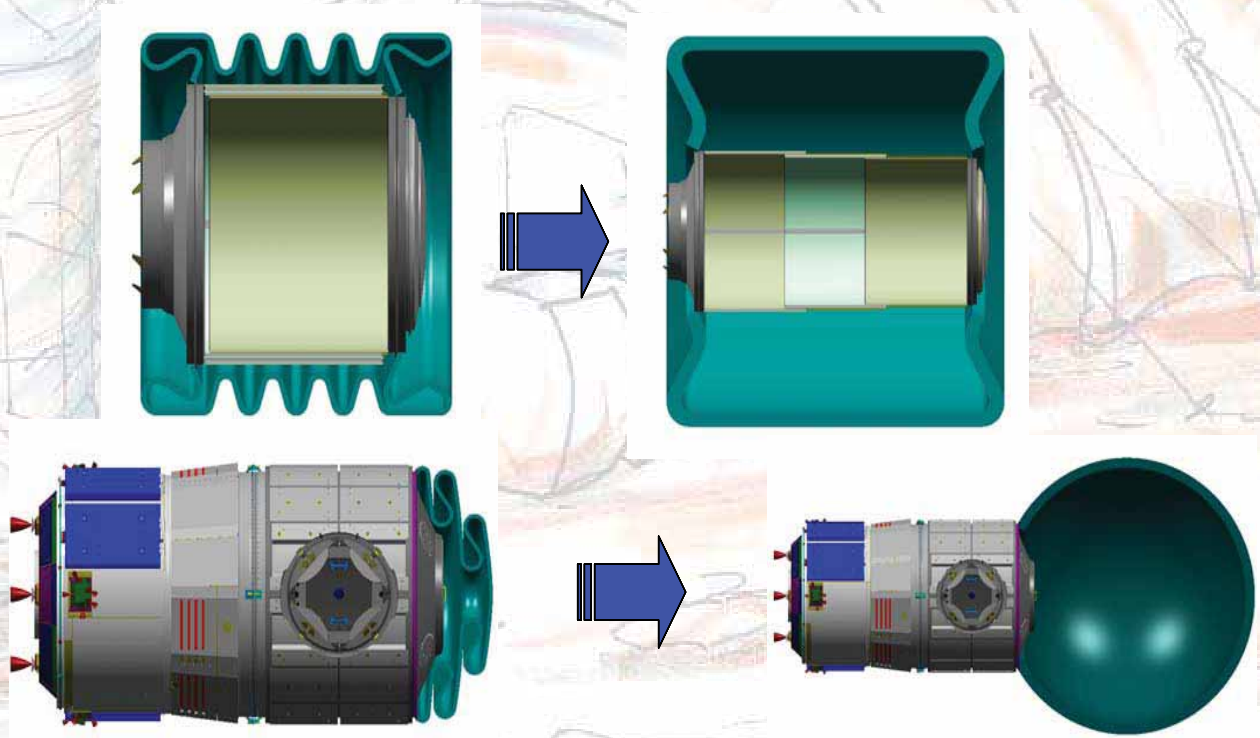
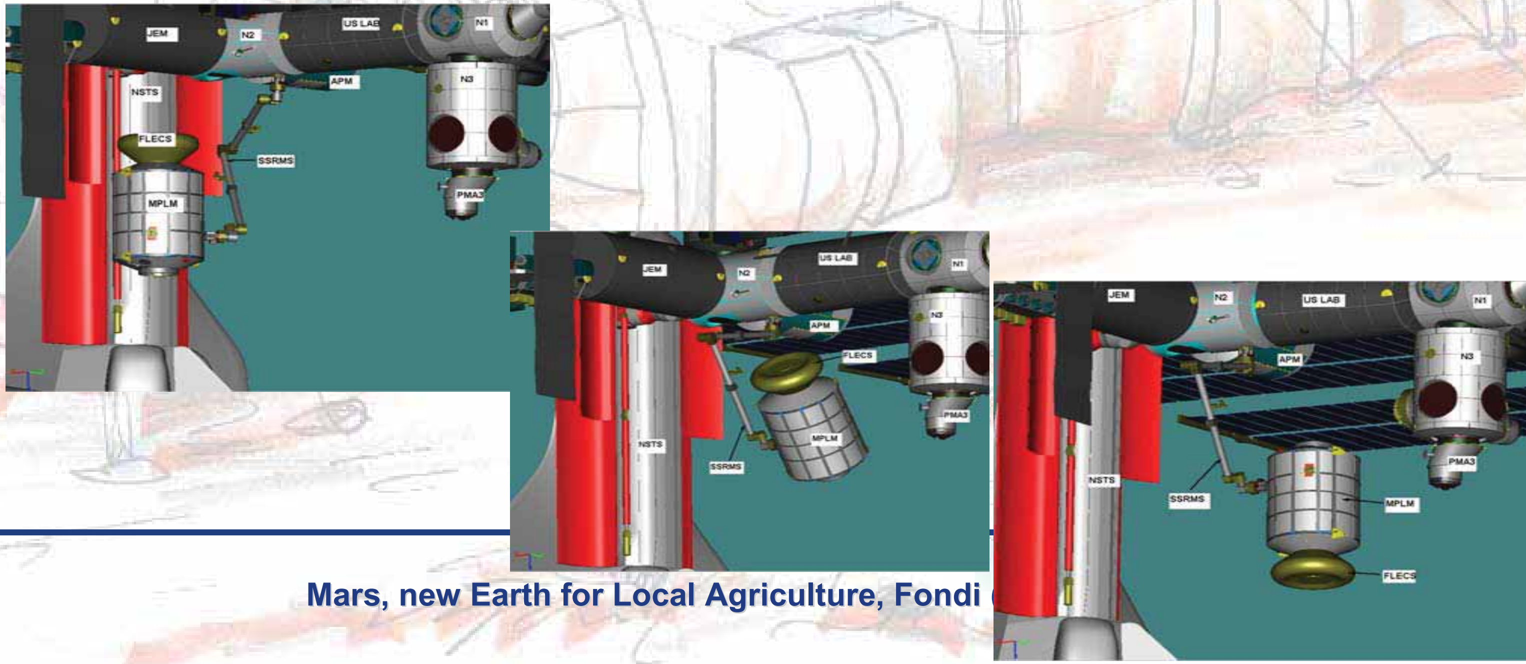
Inflatable Habitat - SpaceHaven (2004)

- ➔ new configurations studied in the ongoing ESA project “Inflatable Habitat”
- ➔ different missions applicability: Free-flyer, ISS-attached, Moon/Mars missions



FLECS - Flexible and Expandable Commercial Structure

- Alenia Spazio is going to lead the ASI project FLECS (Flexible and Expandable Commercial Structure) whose main objectives are:
  - ➔ exploitation of a MPLM logistic mission for on-orbit qualification of an inflatable manned habitat
  - ➔ validation of inflatable technology
  - ➔ validation of future design habitat configurations
- The industrial team includes also Aerosekur, IACSA, ALTA and Sistemi Compositi



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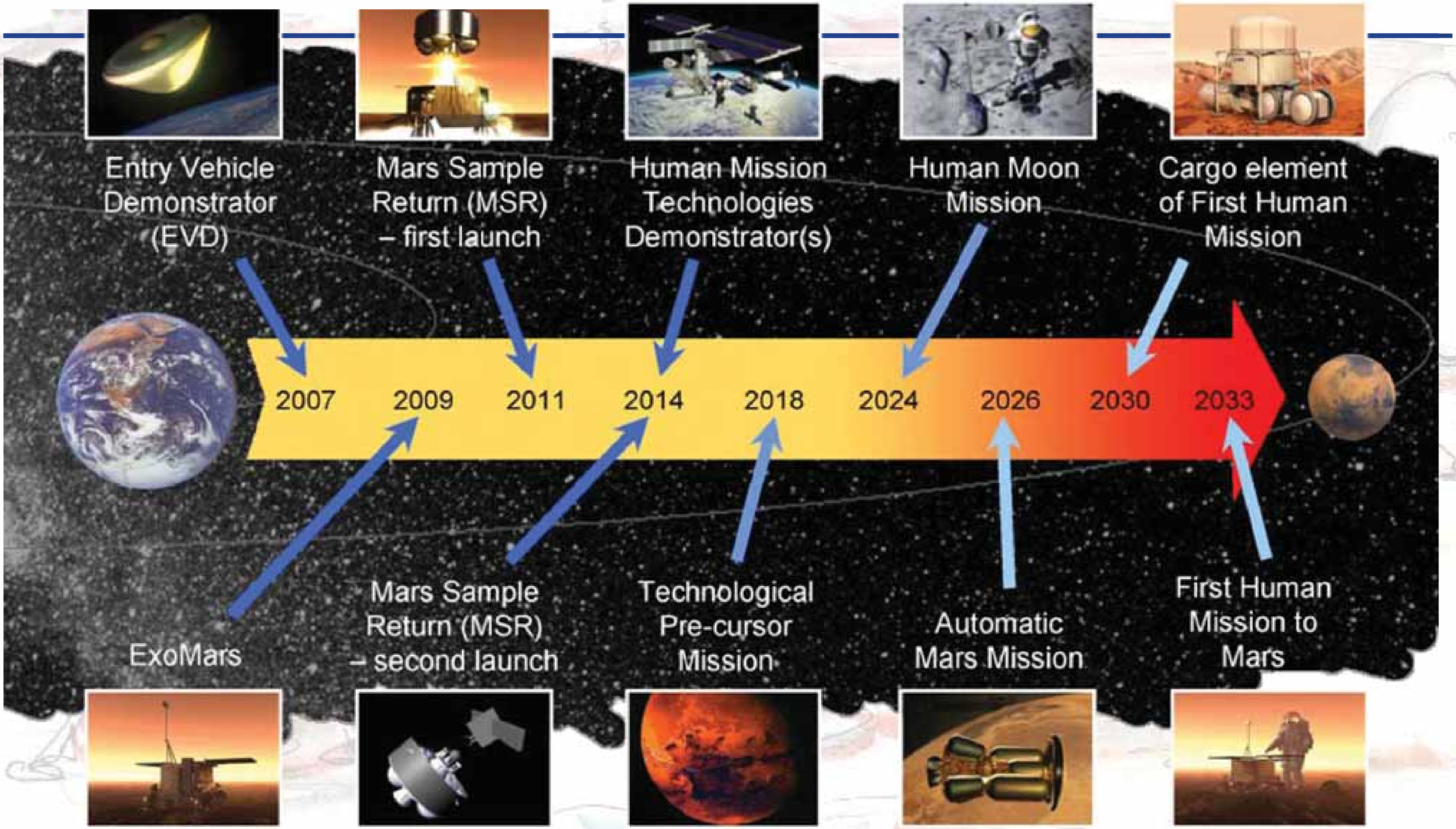
CHECS - Closed Habitat Environmental Control Sensors (2000-2004)

- Alenia Spazio, in collaboration with National Institute Galileo Ferraris, University of Torino Biologia Vegetale Dept, INFM Brescia, FZ Julich, IMSAS Bremen, and Acies, has been involved in the ESA/ASI CHECS study
- Developed an integrated system of miniaturised sensors for the monitoring and optimisation of the environmental conditions in plant facilities, applicable also to habitat:
  - Sensors for illumination and colour of the leaves
  - Sensors for detection of humidity levels
  - Sensors for CO_2 concentration
  - Sensors for Ethylene and VOC concentration
- Plant facilities developed for integrated testing
- Illumination system based on LED technology
- Collaboration with Institute of Biomedical Problems of Moscow

Aurora Roadmap



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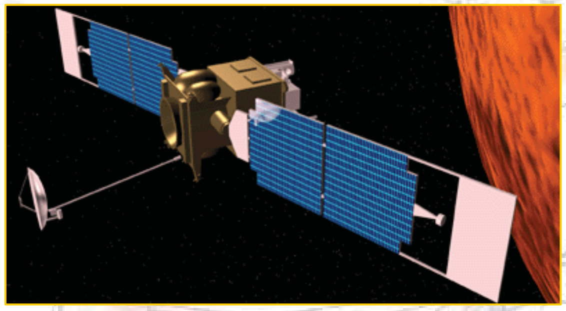
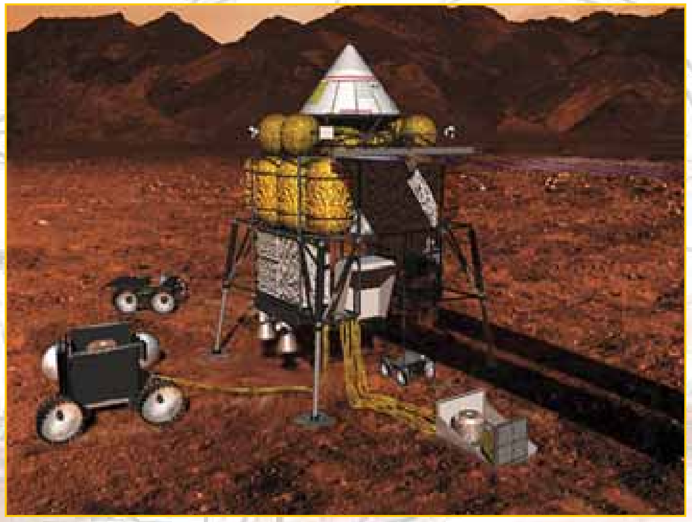
Exploration Multi-step Approach



Precursor Robotic Missions



Outpost Development

Crewed Missions

Human Mars Mission Scenarios

Typical options considered for the first human missions to Mars:

- Opposition Mission: short duration mission: +/- 400 days; short stay at Mars: 30-60 days, limited exploration; high ΔV; 3-6 people people on Mars
- Conjunction Mission: long duration mission: +/- 1000 days; long stay at Mars: 300-600 days; low ΔV; 6-8 people on Mars
- Venus Swing-by Mission: medium duration mission: +/- 600 days; short stay at Mars: 30-60 days, limited exploration; medium ΔV

	Conjunction	Opposition	Venus Swing-by
Total Mission Duration (days)	963	376	579
Possible surface Duration (days)	533	30	28
ΔV (m/s)	8368	15120	10230
Radiation Dose (GCR,Sv,BFO)	1.087	0.496	0.756
Consumables (tonnes)	10.2	4.2	6.4
Mass to LEO (tonnes)	1336	45938	2481

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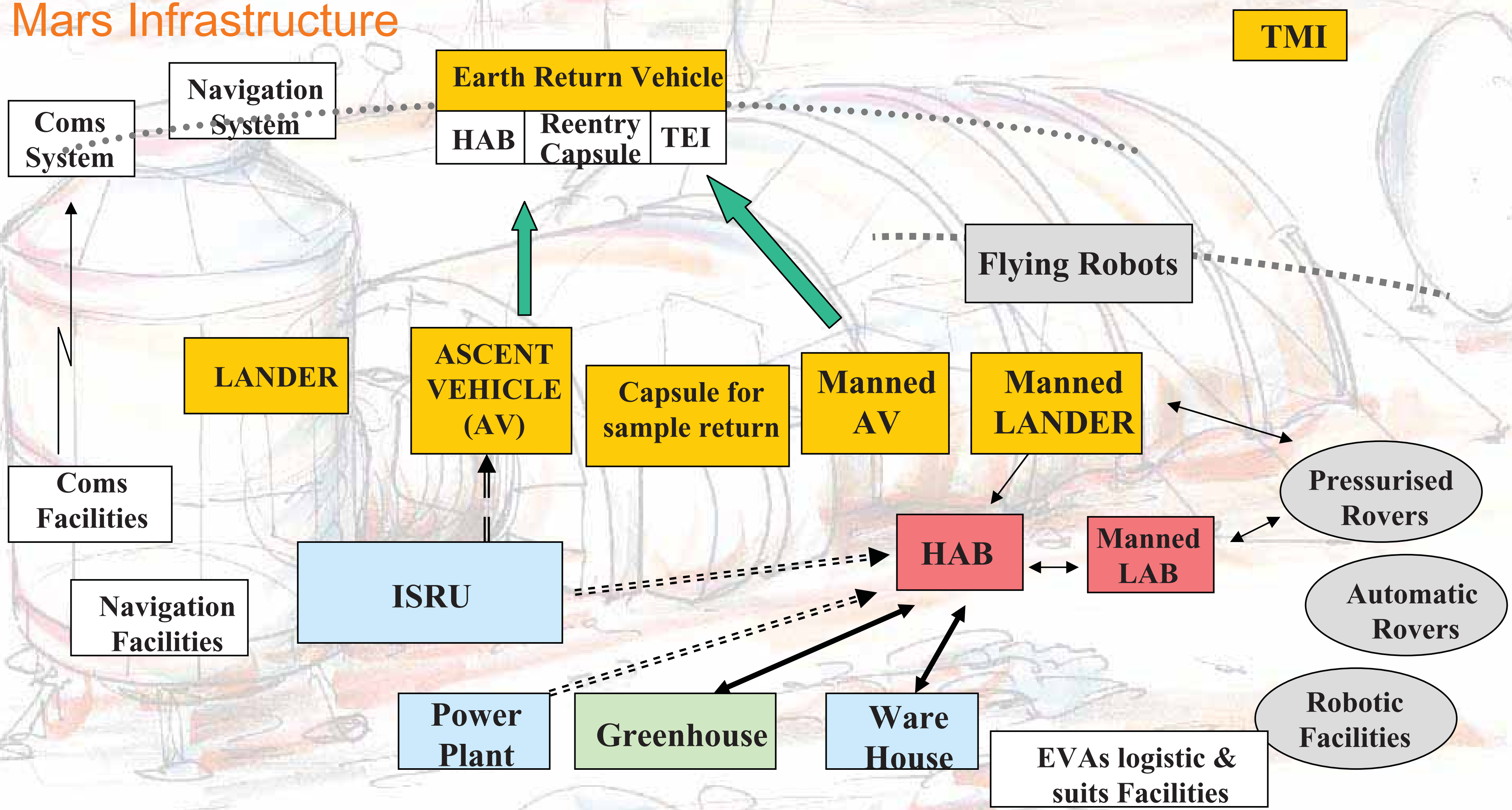
Mars Infrastructure



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Mars Greenhouse

- Depending on the mission scenario, the required infrastructure expands from the typical (orbiter + lander + rover) architecture to a complex cluster of different elements including rovers, trucks, habitation and laboratory modules, power generators, ISRU, greenhouse, ...

- Different potential, self-standing European missions were analyzed by Alenia within the ESA study "European Mission Architectures and Technologies in the Mars Exploration Scenario" as possible strategic contributions to the International Human Exploration of Mars, currently envisioned around 2030

- Among the various elements required to properly develop a surface infrastructure able to sustain human presence on Mars, a Biology/Greenhouse Mission was retained as an important component of a future Mars settlement-oriented scenario

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Greenhouse Mission Objectives

The Biology/Greenhouse mission aims at providing a facility

- ➔ to conduct biological experiments on Mars with respect to the Mars ancient life analysis
- ➔ to study plants biology in a reduced-gravity environment
- ➔ to study radiation effects on cells
- ➔ to validate the possibility to grow food on Mars (to complement the crew diet)
- ➔ to validate bio-regenerative life support systems

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Greenhouse Mission Requirements

Two major mission requirements were identified:

to support the module habitability and operability →

- **Total Pressure** 99.9 – 102.7 kPa
- **ppO_2** 19.5 – 23.1 kPa
- **ppN_2** 79 kPa
- **$ppCO_2$** 0.4 kPa
- **Temperature** 18.3 – 23.9 deg C
- **Relative Humidity** 30-70 %
- **Trace Gas Conc.** < SMAC Levels
- **Ventilation** 0.08 – 0.20 m/s

to produce food for partial crew diet integration →

Inputs [Kg/person/day]	Outputs [Kg/person/day]
Oxygen 0.83	Carbon Dioxide 1.00
Dry Food 0.62	Water (Resp and Persp.) 2.28
Water in food 1.15	Urine 1.5
Food Prep. Water 0.79	Urine Solids 0.06
Drinking Water 1.61	Hygiene Water 7.18

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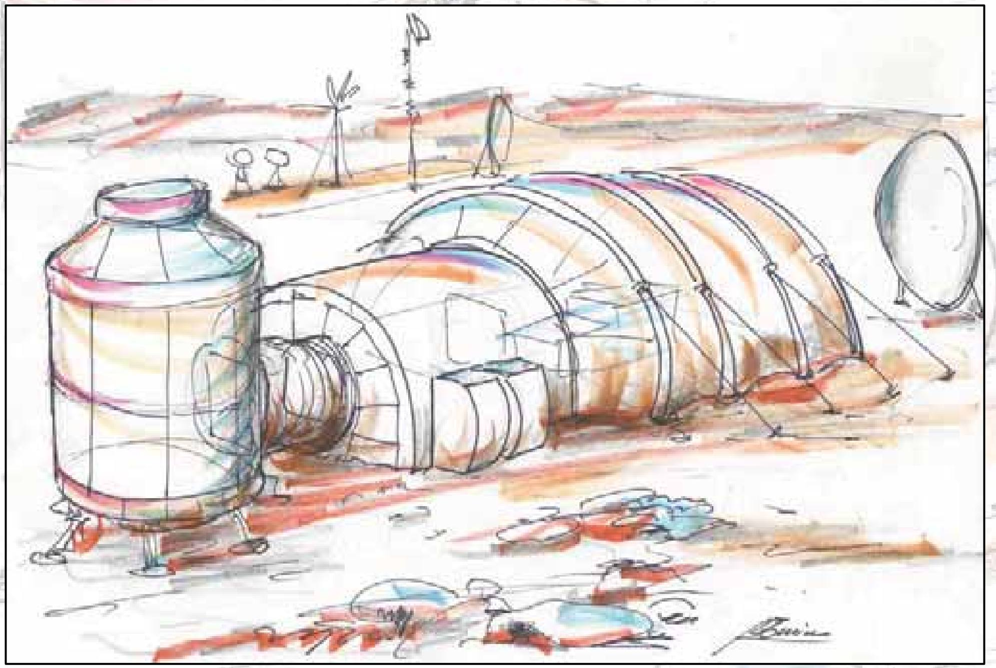
Greenhouse Architecture

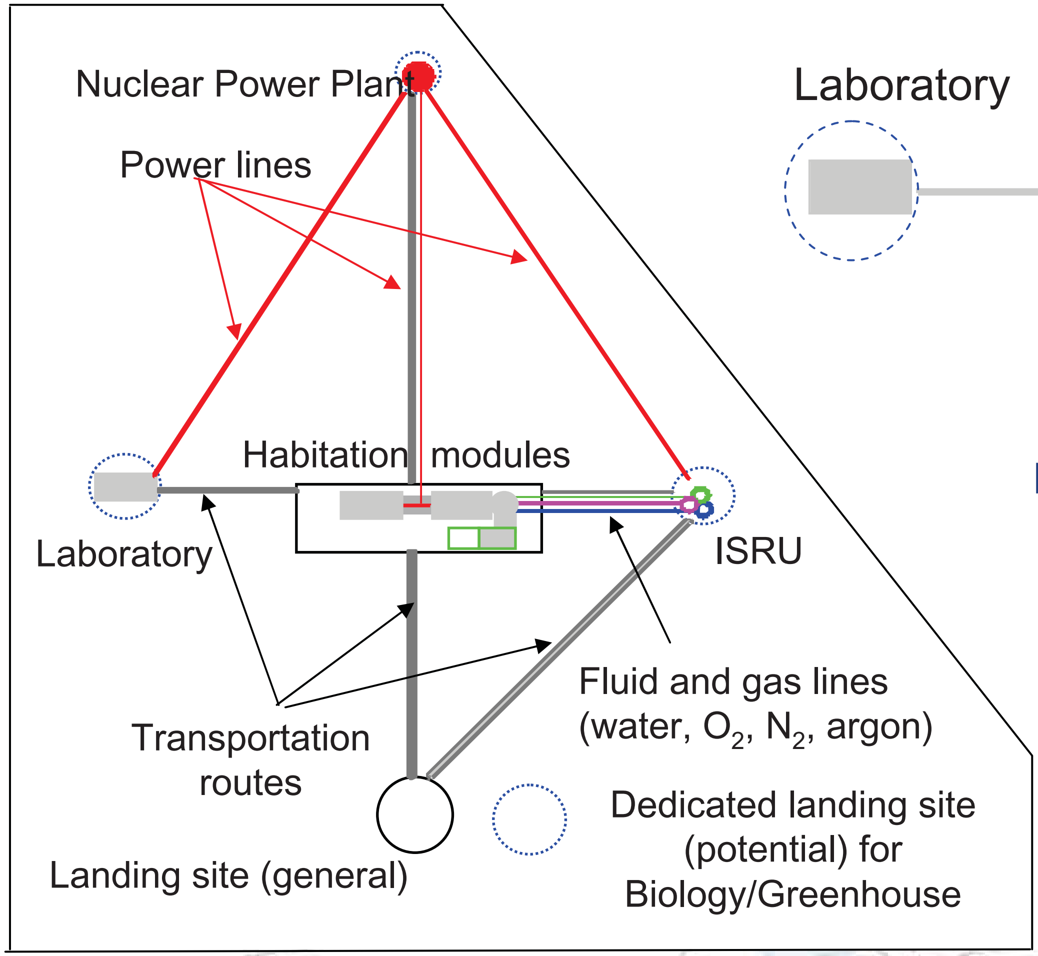
The Biology Greenhouse is composed of two distinct segments:

- Rigid Segment => for the accommodation of the support systems and biology payloads
- Inflatable Segment => for the accommodation of plant growth devices

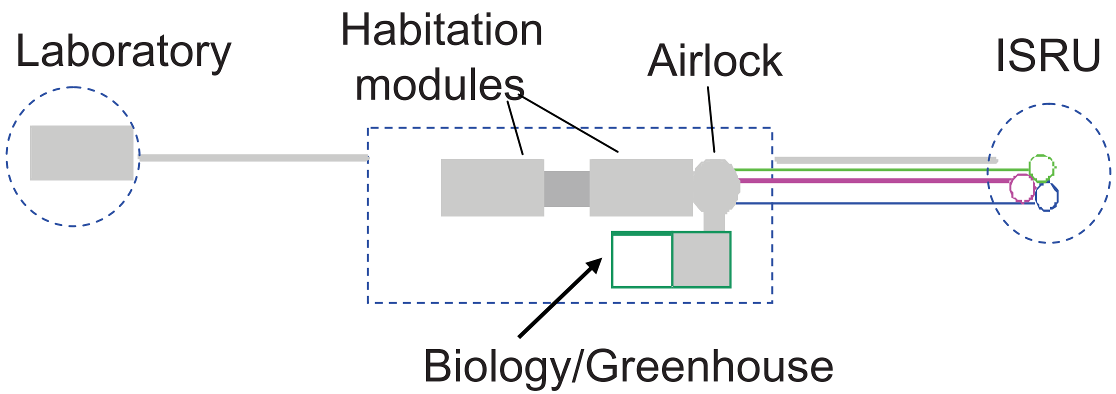


- Directly connected to Mars Habitat base (where crew live)
- No external walkways are necessary to reach the Biology Greenhouse from the Habitat (internal interfacing hatch)

Greenhouse Location



General lay out of the Martian outpost



Location of the Biology/Greenhouse module near the habitation modules

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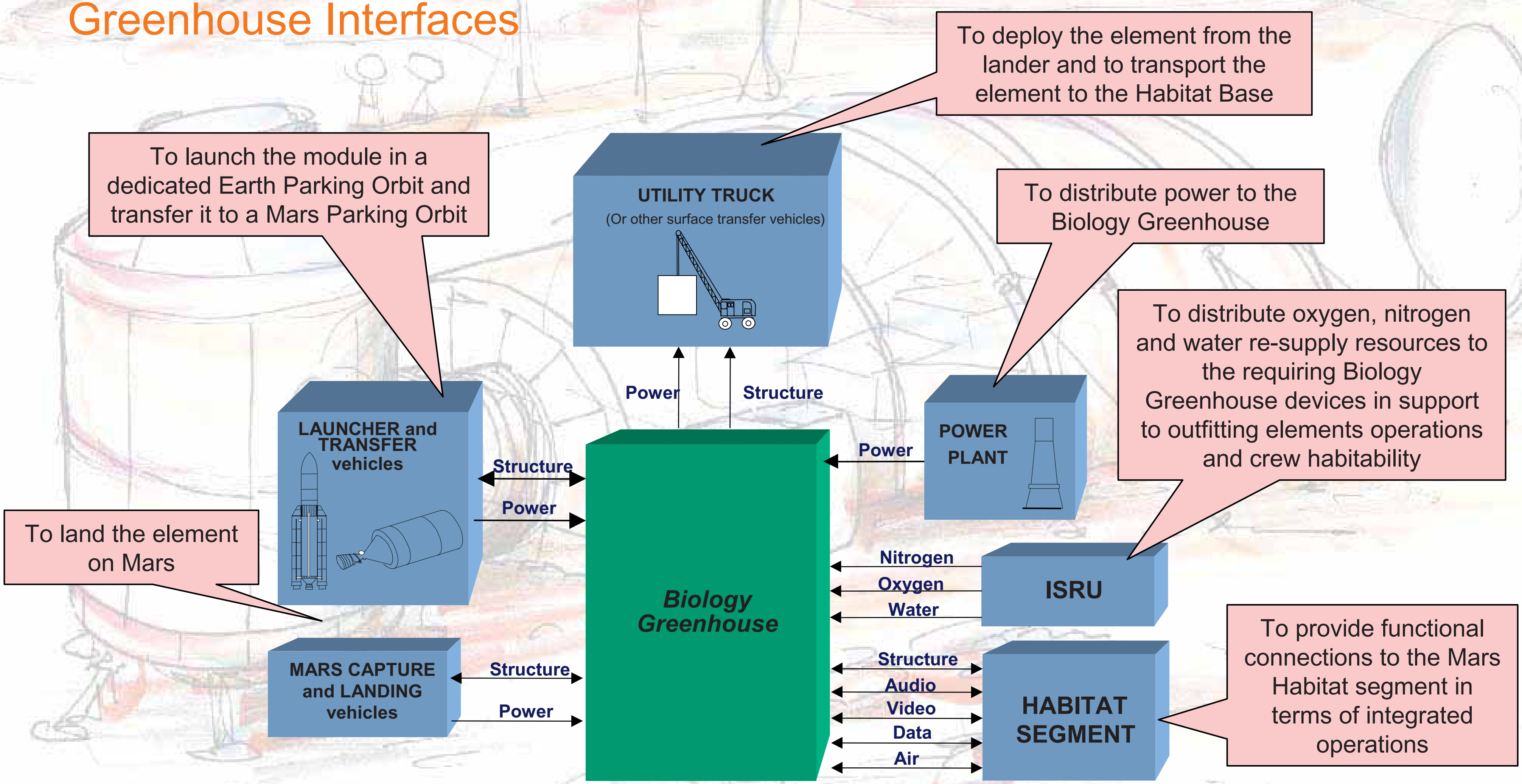
Greenhouse Interfaces



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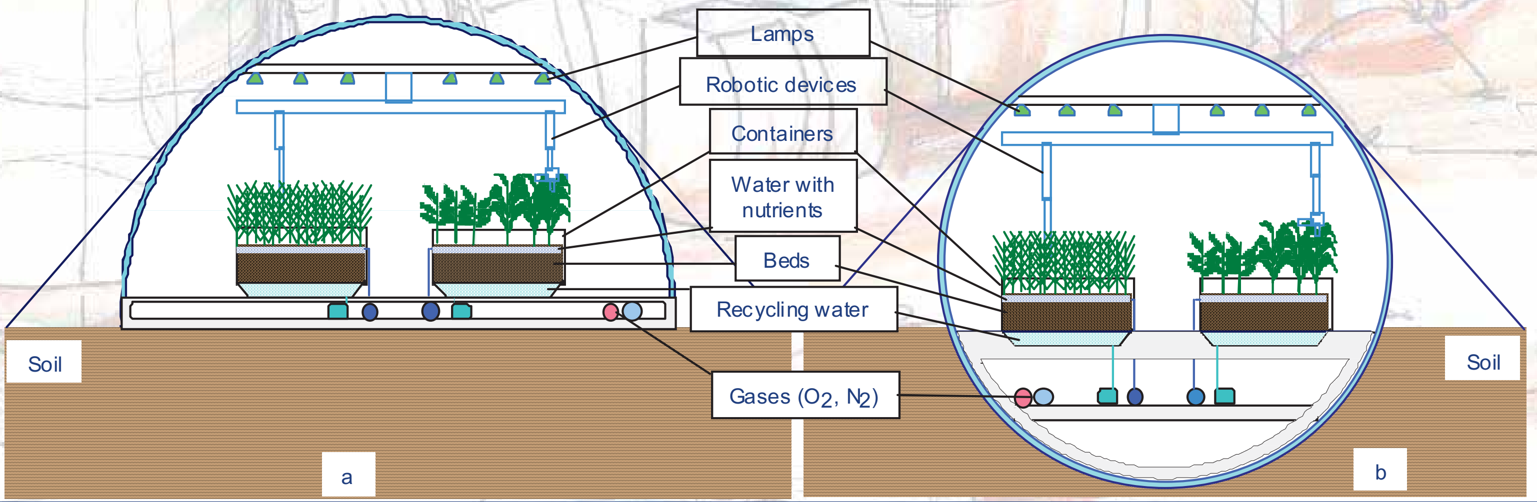
Greenhouse Utilisation: Plant Growth Methodology

HYDROPONICS PLANT GROWTH	
PROs	**CONs**
– Ample root-area oxygen distribution – Minimisation of the clogged irrigation nozzles and cleaning of culture – Good roots reproduction – Good performances in microgravity and reduces pressure atmospheric conditions	– No ample root-area nutrient and nitrogen distribution – More equipment required to control the system



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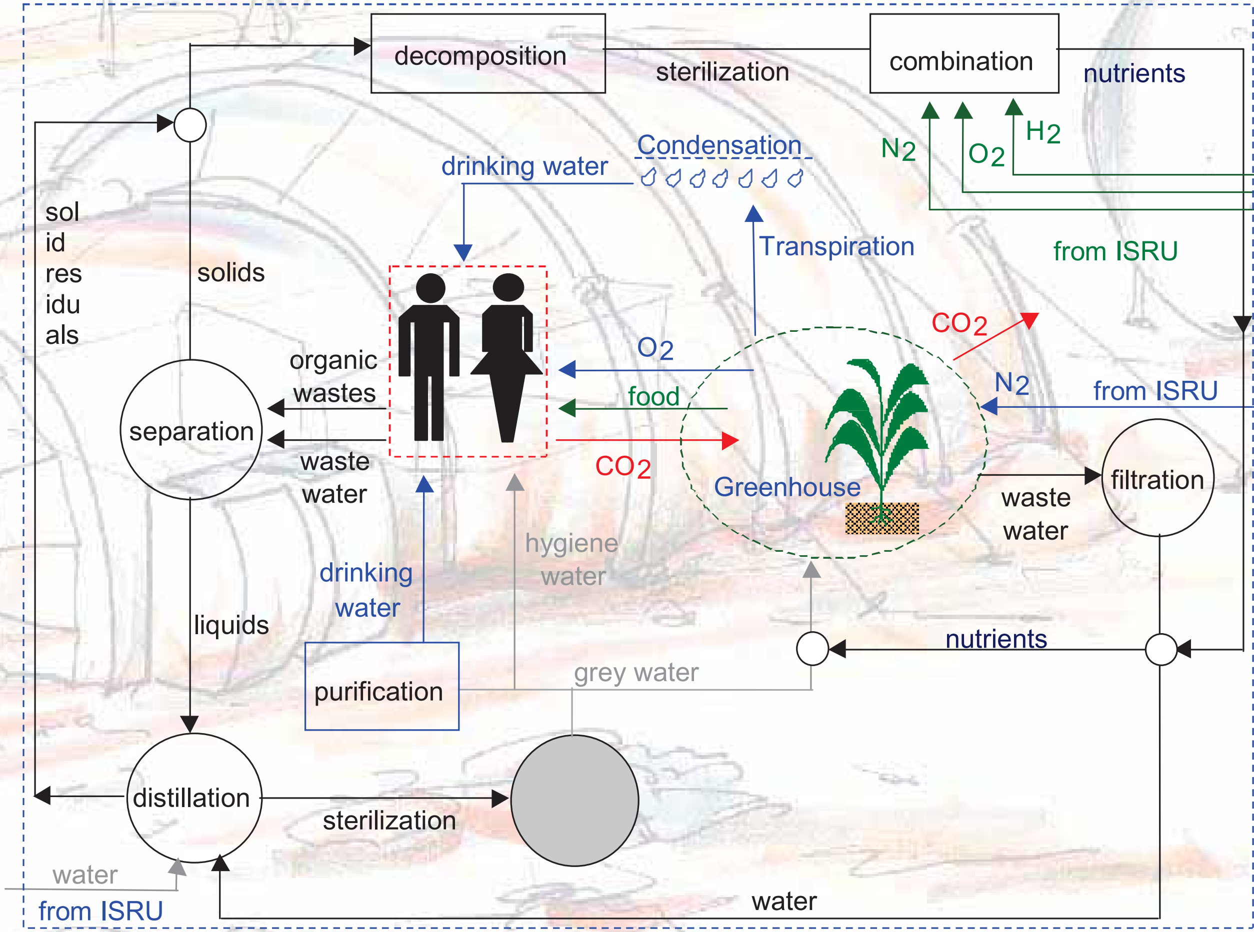
Greenhouse Role in a CELSS

- Food production
- CO_2 removal
- O_2 generation
- Grey water purification
- Waste management



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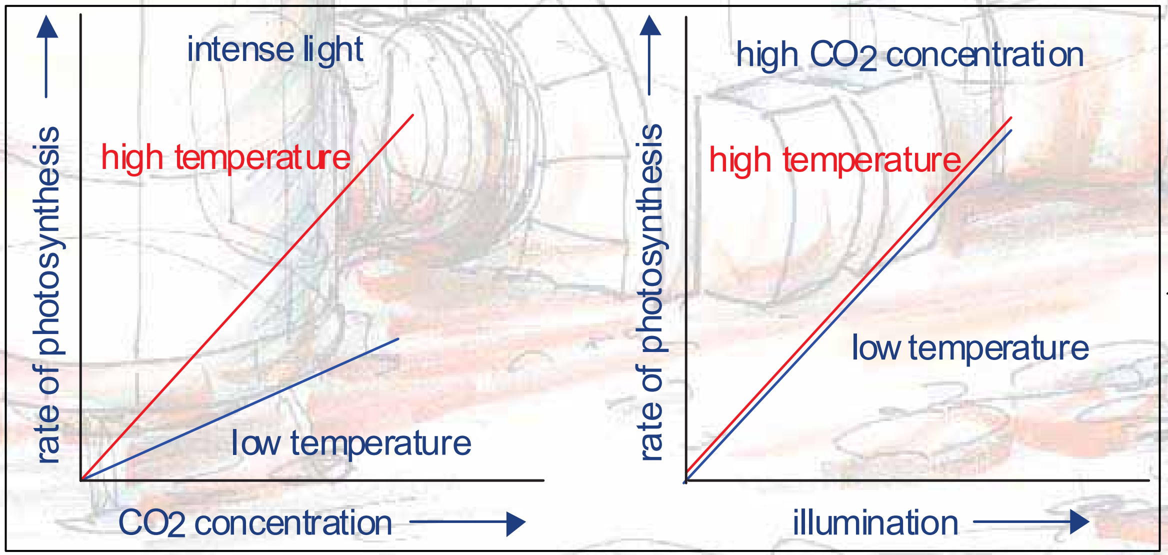
Greenhouse Main Parameters

- CO_2 partial pressure: about 1 kPa (to guarantee plant growth and crew habitability)
- Temperature Control: between 22 °C and 30°C
- Illumination level: 300-600 lux; reproduction of the terrestrial day-night cycle
- Mass estimation: 11 ton
- Power estimation: 10-70 kW



Dependence of the rate of photosynthesis from temperature, illumination and CO_2 concentration

Greenhouse Enabling Technologies

BG Critical Technologies	*Key Characteristics*	*Europe Interest (TBC)*
Inflatable Structures	***Scope***: – Minimisation of weight and volume to reduce costs – Thermal, particle impact, and radiation protection ***Areas of investigation***: - Inflatable rigidizable materials (thermoplastic UV cured and shape memory composites, and composites) - Controlled deployment mechanisms and manufacturing	High
Large thermal shock resistant materials	***Scope***: – Development of resistant materials able to withstand large thermal shock ***Areas of investigation***: – Materials treatment technologies for structural items (aluminium), payloads (furnaces) and chemicals (hot gas filters, particle separators)	Medium/High

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Greenhouse Enabling Technologies

Greenhouse Critical Technologies	*Key Characteristics*	*Europe Interest (TBC)*
Sample collection and storage devices	***Scope***: – Sample/Coil Rocks collection and storage devices ***Areas of investigation***: – Rocks origin and history analyses (visual information such as colour and texture)/ Storage and Protection from alteration by the Martian atmosphere – Drilling into rocks and retrieve cores from the inside	Medium/ High
Advanced sensors for contamination control	***Scope***: – to safeguard the planets during space exploration ***Areas of investigation***: – Control of terrestrial microbial contamination (sensitivity "life-detection" instrument) and of the Earth by extraterrestrial solar-system material collected and returned by such missions.	High
Small lightweight sensor and equipment	***Scope:*** – to reduce the amount of mass to be transported ***Areas of investigation***: – Lightweight Materials and structures	Medium/ High

Greenhouse Enabling Technologies

Greenhouse Critical Technologies	Key Characteristics	Europe Interest (TBC)
Miniaturised radiation-hardened electronics/ MEMS	***Scope:*** – to reduce the amount of mass to be transported ***Areas of investigation***: – Infrared sensors, pressure, optical, flow, and temperature sensors for remote sensing – Chemical sensors for atmospheric moisture studies – Low-power, low-mass and low-volume (batteries, micro-switches items, micro-actuators, etc. – High reliability and Long-life instruments	High
Closed Life Support Systems (air, water, waste recycling	***Scope:*** – to support space human missions ***Areas of investigation***: - air revitalisation/atmosphere composition control and monitoring/ water recycling and quality control/ solid waste management/ - bioregenerative life support systems.	High

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Greenhouse Enabling Technologies

Greenhouse Critical Technologies	Key Characteristics	Europe Interest (TBC)
Food Production	***Scope:*** – to feed astronauts during long duration missions ***Areas of Investigation:*** – extending food shelf life – management and recycling of food wastes – improvement of food safety – food storage systems – crops grown on planetary outposts into food products	High
Automated processing and control	***Scope:*** – to reduce crew workload and to maximise the safety controls ***Areas of Investigation:*** – Object oriented analysis, design, and implementation/ Client-server architectures and distributed systems – High speed network design and implementation/Real-time software architectures – Artificial intelligence, vehicle diagnostic systems	Medium/High

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Conclusions

- Any infrastructure devoted to support long-duration permanence of people in space aims at the “closure” of the air, water and food cycles in the so-called Closed Ecological Life Support Systems - CELSS
- Different experiments in this field are currently on-going and/or planned on-board the Space Station
- A Biology / Greenhouse Module would be a strategic element for a Mars surface human infrastructure, both to complement the astronaut’s diet and to carry out significant biological science studies
- Many technological “building bricks” are required to develop a “greenhouse capability”, from the small greenhouse box experiment on-board the Space Station to an inflatable greenhouse module on Mars