HABSIM – *Unique R&D infrastructure for closed-loop food production in space and on earth*

Tor Blomqvist

Bildquelle hier angeben


EDEN ISS
DLR


EDEN ISS

HUMANS RETURN TO THE MOON

The goal is to have an established constant human presence on the Moon by 2030 to then continue to Mars

FOOD IS A **LIMITING FACTOR** FOR HUMAN SPACE FLIGHT

Supplying from Earth:
Costly and Limiting

- Expensive
- Not always possible
- Greatly limits the selection

Beyond nutrients:
The multifaceted significance of food

- Sensorial qualities
- Emotional
- Social
- Environmental
- Cultural

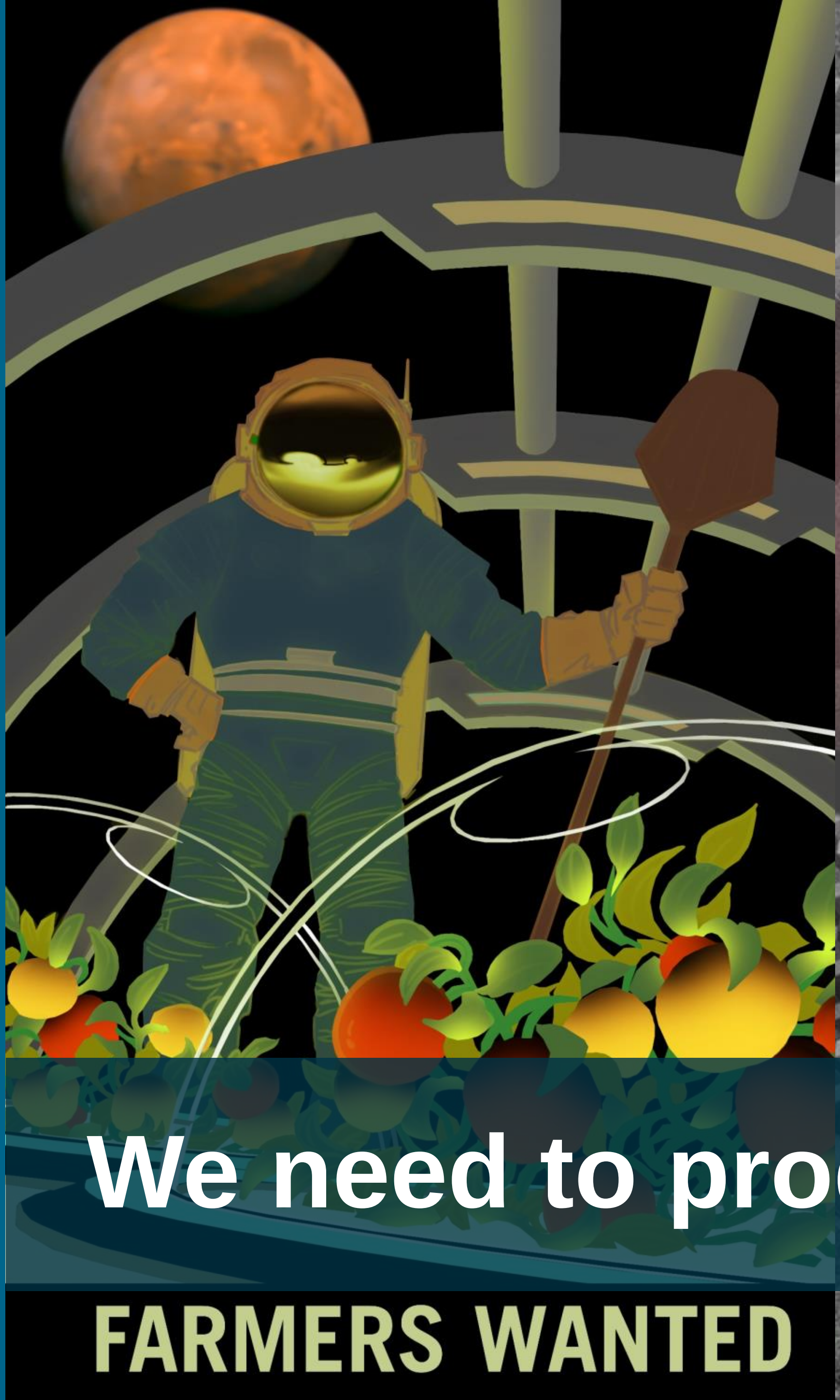
Nutrition Beyond Earth:
A Vital Imperative

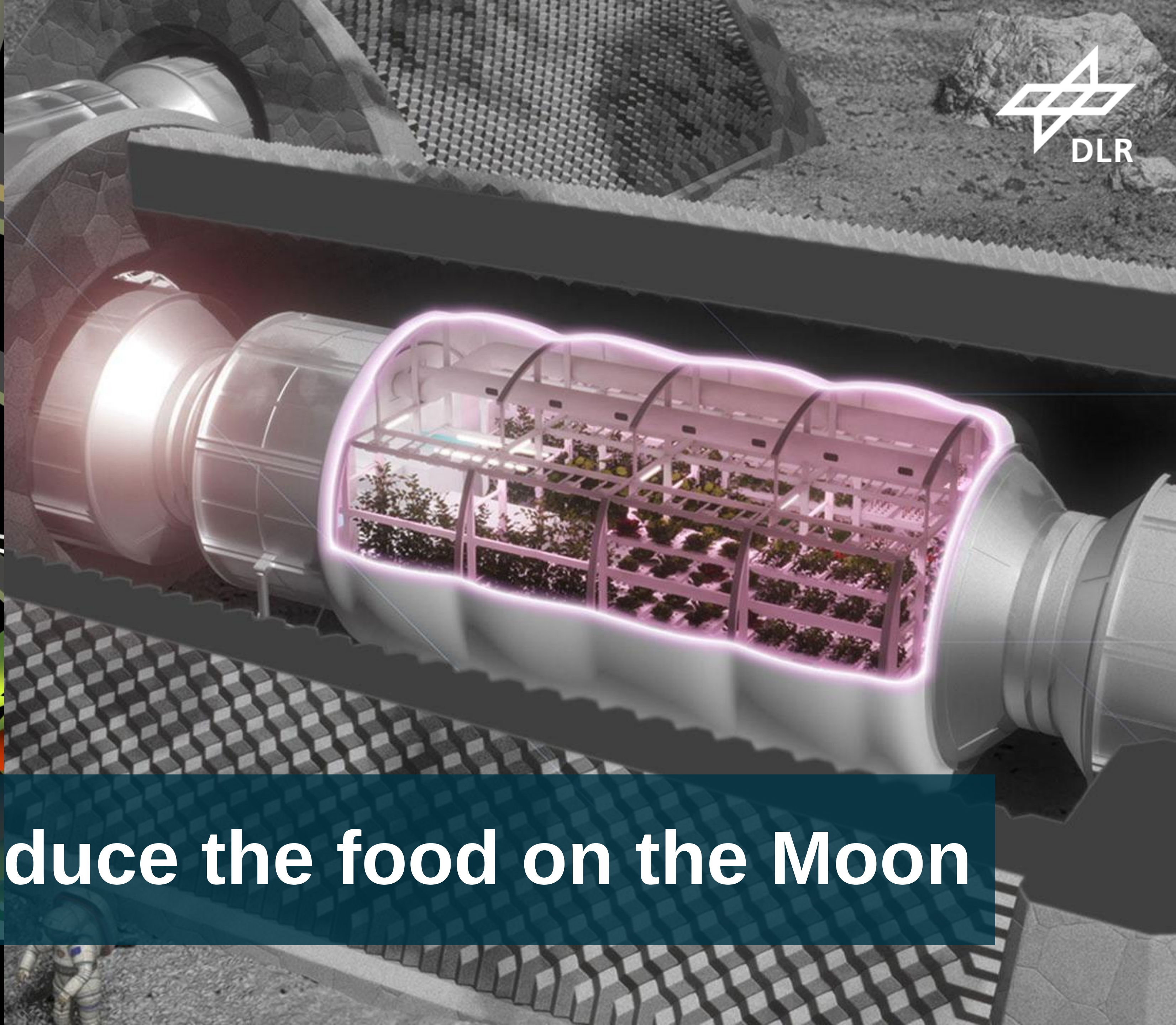
Nutrition mitigate effects from

- Radiation exposure
- The effects of microgravity

No matter how much nutrients food contains, it needs to be eaten to fulfill its purpose

Food works as a countermeasure for the psychological and physiological challenges that comes with space travel



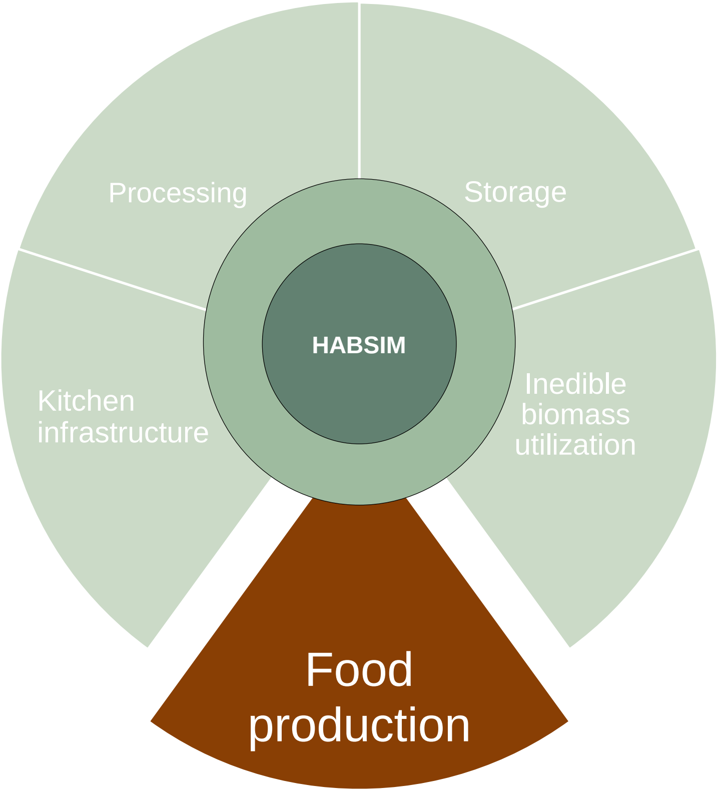


We need to produce the food on the Moon


HABSIM
EDEN MODULE
01
DLR
HAB SIM


HAB SIM

Food production



CO2 to food products

Robotic farming

Controlled environmental farming

Personilized nutrition

Insect production

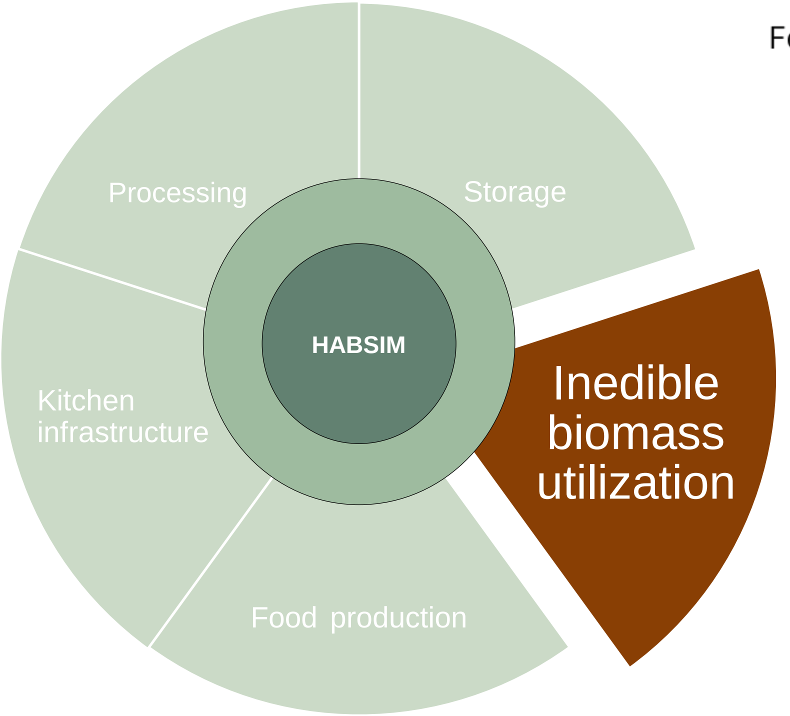
Cultured meat

Mathematical models for crop choice and production planning

3D food printing

Just a few examples

Inedible biomass utilization

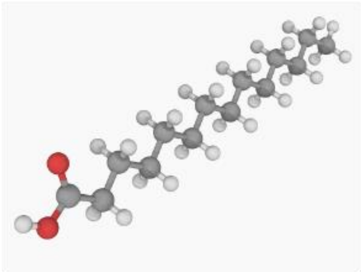


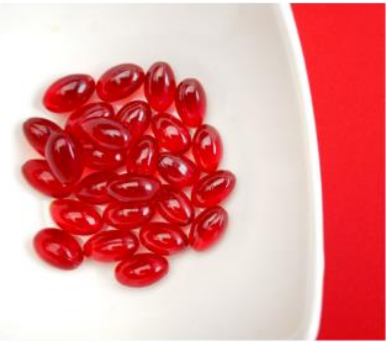

Food packaging from biomaterials


Advanced 3D printing

Bioplastics manufacturing


Fabrics and materials


Fatty acid extraction


Personilized Nutritional supplements

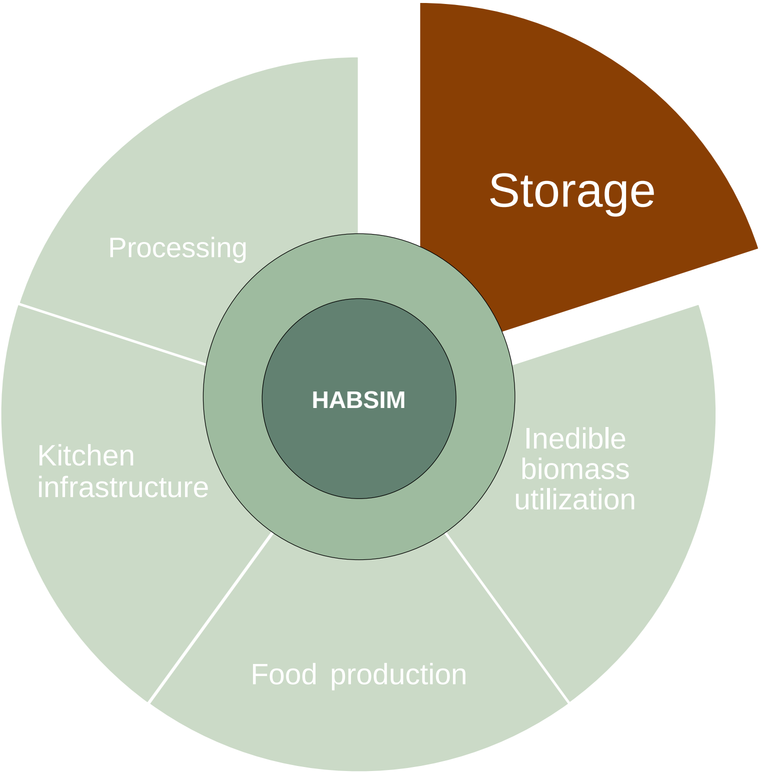

Medicine


Fertilizeer


Tableware from greenhouse side streams

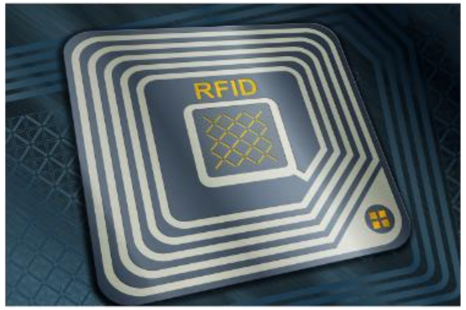
Just a few examples

Storage



Controlled environment / modified atmosphere Food storage

Dynamic and advanced Food packaging

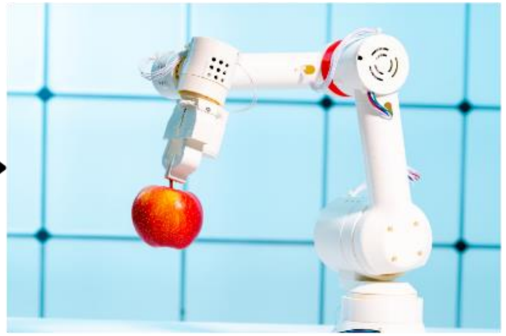


Novel sensors for quality management and inventory monitoring

Shelf life optimization

Dynamic labeling and storage

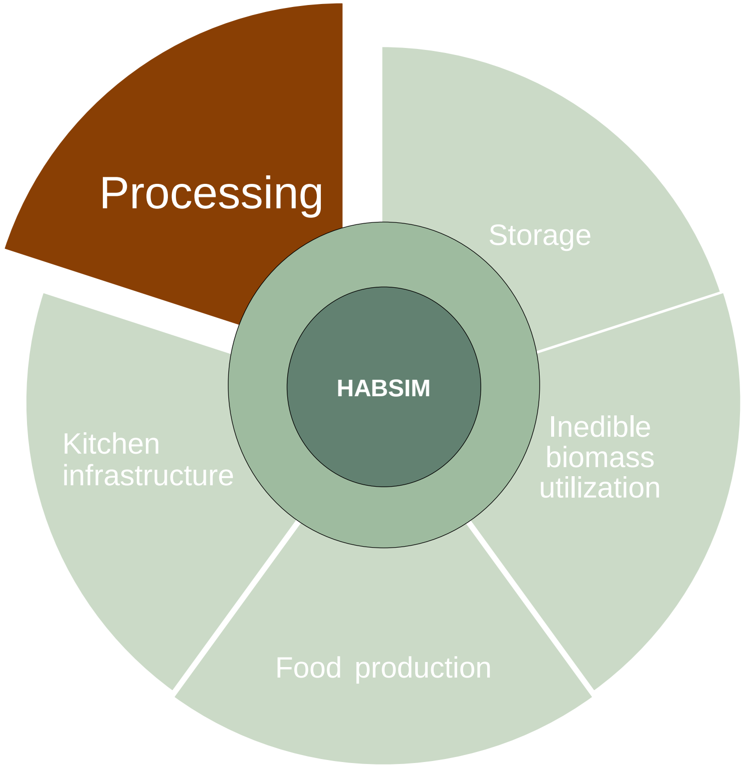
Data transfer



Robotic enhanced support systems / Automation

Just a few examples

Processing



Just a few examples

Advanced and optimized Food processing equipment

Nutrient dense processing methods

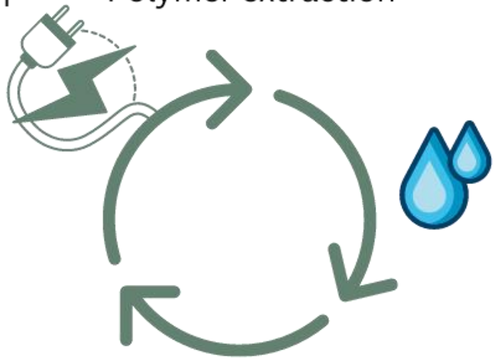
Augumented reality aid

Advanced Oil extraction

Polymer extraction

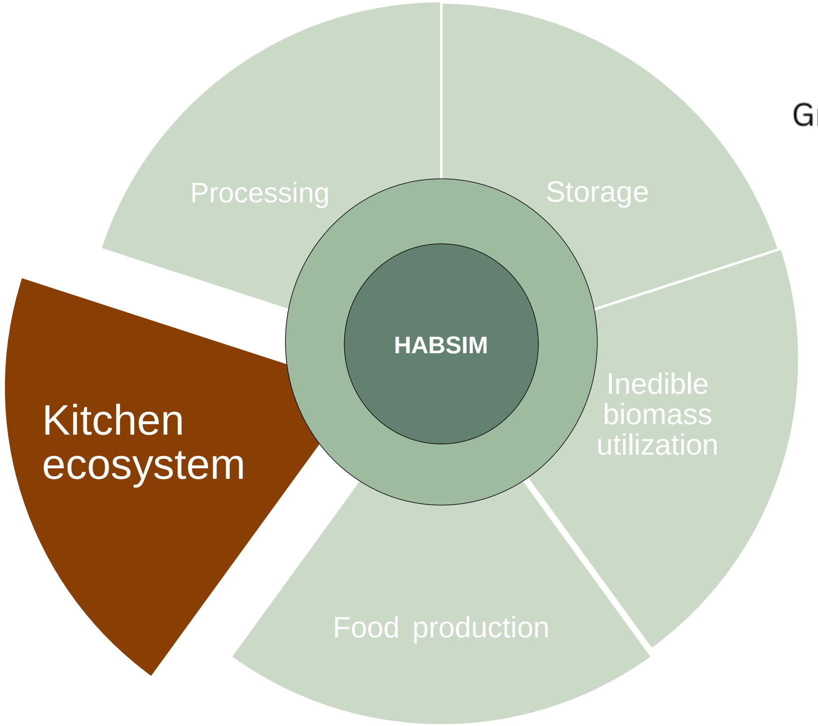
Nutritional adequacy
&
Variety

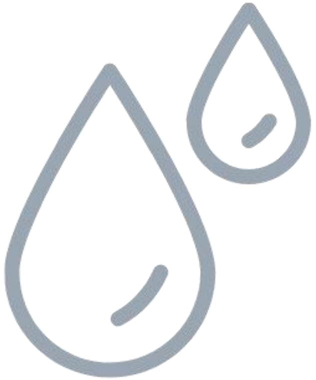
Shelf life extension



Water & energy reecovery

Kitchen ecosystem




Greywater management

Innovative kitchen systems


Human factors Investigations


Advanced & recycling ventilation system


Low energy and water free cleaning systems

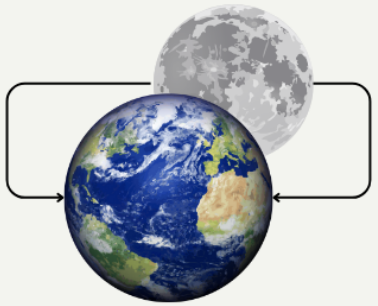

Advanced air purification systems


Digital interactions and smart cooking systems

Just a few examples

Overarching research topics

Technology Transfer



Terrestrial applications and
spin-off productions
Humanitarian projects
SME accelerator
Industry tech transfer

Nutrition

Nutritional adequacy and
dietary variability

Food quality

Improved food quality-
food saftey and
acceptability

Technological synergies

How do all technolgy and
innovations work together
and how can they benifit each
other?

Psychology

Psychological Investigations
of food provisions in extreme
environments

Water cycle

No wastewater, all is recycled
to the last drop

Food Saftey

Advanced safety and
quality addressal system
with reliable protocols
suitable for space

Human-in-the-loop

Realistic data and feasibility

BACK TO EARTH

How can we address the sutainability challenges on Earth?

DLR

In space we need to think sustainable, there are NO other options. Everything needs to be recycled, reused, every surface needs to be optimized and one needs to economize every resource.

Now change the word space to Earth.

IF WE CAN ESTABLISH A FULLY INDEPENDENT FOOD PRODUCTION SYSTEM IN SPACE

IT CAN BE DONE ANYWHERE ON EARTH

- Humanitarian situations
- Arid or barren lands
- Urban or remote areas
- War zones where agriculture needs to regenerate

It can be applied anywhere to help the 811 million people on Earth that doesn't have sufficient access to food

DLR

Space research is a catalyst for innovation and a playground for multidisciplinary collaborations, that have for decades provided tools for the improvement of life on Earth.

If we can create an independent and sustainable food system on the Moon, we can do it anywhere on Earth

THANK YOU

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HABSIM – Unique R&D Infrastructure for closed-loop food production in space and on Earth

UNIQUE R&I INFRASTRUCTURE FOR CLOSED-LOOP FOOD PRODUCTION

BRINGING TOGETHER THE SPACE AND TERRESTRIAL SECTORS TO ADDRESS A UNANIMOUS GOAL

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Keywords Space, Bioeconomy, Closed-loop, Food, Post-harvest management, Moon

ABSTRACT

There is a reinvigoration of human space travel and the goal is to establish a moon base with a constant human presence by 2030 to eventually bring mankind to Mars. Missions to the Moon come with a myriad of challenges and even though we may have the required technology to bring humans to the Moon, we do not have the **food system** to sustain them. Ultimately food is a **limiting factor for human space travel**. Due to resource and cost limitations and food acceptability challenges, future lunar habitats cannot rely solely on resupply missions from Earth. As a result, **in situ food production** becomes a necessity for sustained human space travel.

There is a variety of research on how to provide food for space missions, such as insect farming, cultivated meat and Controlled Environmental Agriculture (CEA) where projects such as the EDEN ISS developed by the German Aerospace Centre (DLR), have shown promise in closed-loop food production during space analog missions. However, there are still certain gaps to be addressed if food production on the moon is ever to become truly independent, variable and nutritionally adequate. For instance, certain areas such as **nutrient rich crop production**, and **post-harvest management** including food **storage** and food **processing** have been overlooked.

Food processing will not only extend shelf life and increase the nutritional qualities of certain foods, but also create new products, and introduce new crop varieties e.g., staple foods such as cereals and tubers. Similarly, alternative sources of protein such as cultivated meat and insects needs processing, preparation and storage to be acceptable. Subsequently leading to a **highly sufficient and variable diet** over the long run. Furthermore, food processing may lead to better caretaking of **side streams from the greenhouse or crew waste**, which in turn can be refined into **useful** products that promote the **circularity** of the closed-loop habitat.

In current landscape of space food research, the efforts are scattered and lack a cohesive, integrated approach. A **holistic multi-factored approach** to test the **synergies** between different innovations as well as with humans in the loop, is a requisite to **accelerate current food production research** and **innovations**. Existing research initiatives and facilities often focus on isolated aspects of space food production, failing to address the critical need for a **holistic understanding** of the **synergies** between different innovations and the inclusion of **human factors**. To address this, a **centralized facility is needed** to serve as a hub,

bringing together **diverse research and innovations** under one roof. Such a facility would provide a unique opportunity to systematically test and evaluate the **interplay** between various space **food research components**, while incorporating the invaluable insights gained from **human involvement**. By bridging the existing gaps and **fostering collaboration**, this comprehensive platform would accelerate the pace of research and implementation in space food production, ultimately advancing the prospects of sustainable food systems for future space missions.
The objective of this project is to establish a **centralized facility** that integrates **post-harvest management** and **Controlled Environmental Agriculture** (CEA) systems, bolstered by state-of-the-art **laboratory** infrastructure. This facility aims to serve as **a versatile closed loop food production system**, specifically designed for future lunar habitats, allowing for **comprehensive testing** and acceleration of any related research.
The urgency behind this endeavor stems from the current **roadmaps** of international space agencies are to establish a **constant human presence** on the Moon before the **end of the decade**. By developing this **research facility**, we aim to address the **critical need** for advanced food production capabilities that will support prolonged lunar missions, laying the foundation for **sustainable food systems** in extraterrestrial and terrestrial environments. This comprehensive platform will foster collaboration, **bridge existing gaps**, and accelerate the pace of research and implementation in space food production, ultimately advancing the prospects of sustainable food systems for future **space missions** and on **Earth**.

The HABSIM project team aims to create a comprehensive concept for **a world-class research infrastructure** in the area of **sustainable closed loop food production and management**, using space as a testing ground to foster **out-of-the-box thinking**. The plan is to establish an **international incubator** that focuses on accelerating and testing the **synergies between food pre-harvest and post-harvest** technologies, as well as the utilization of **inedible biomass** and **bio-based materials** for manufacturing. This initiative aims to develop innovative food production solutions for **space infrastructures**, while also fostering **sustainable applications** for **terrestrial markets**. The HABSIM is designed with **circularity** in mind, aiming to **recycle and reuse** water, heat, and gas, and utilize side stream and **biowaste** processing for **nutrient reintroduction** and natural product extractions. The goal is to achieve **complete self-sufficiency** in consumable materials, including packaging, tableware, utensils, and nutrient components, all derived from the **closed-loop system**.

State of the art

The current roadmaps of international space agencies are to establish a human **constant presence on the Moon** by the end of the decade, to eventually bring **humans to Mars** (1). However, the lack of suitable food supplies poses a challenge, as food is a limiting factor for lunar habitats (2). Even though we may have the technology to bring humans to the Moon, we do not have the required food systems or the food technology to sustain them. Space food has evolved from toothpaste-like tubes to food similar to what we eat on Earth, emphasizing organoleptic appeal and variety to prevent menu fatigue. During longer missions, it is important to consider that food is **not only a source of nutrients** but should also ensure personal and emotional well-being. In other words, **food plays an important role as a countermeasure** to the many psychological challenges that humans experience on longer space missions (3). **Nutrition is vital** for overcoming physical challenges in deep space, as environmental conditions and reduced gravity impact the body's metabolic processes and the body's nutrient utilization ability. Furthermore, microgravity affects pharmacokinetics and since research on pharmaceuticals and potential side effects in space is scarce, food is the primary source of nutrition and the most important countermeasure for these challenges (4) (5). Developing food for long space missions requires the consideration of these factors (6). Due to resource limitations and acceptability challenges, future lunar habitats **cannot rely on Earth resupply** missions, **necessitating in situ food production** (7). Greenhouse modules as an implementation into bio-regenerative life support systems (BLSS), such as the EDEN ISS project developed by the German Aerospace Centre (DLR), have shown promise in closed-loop food production during space analog missions (8). However, current space food and crop research are focused on fast growing ready-to-eat crops, which evolved as the main focus during the International Space Station (ISS) program to meet the immediate needs of astronauts in low Earth orbit. However, prior to the ISS program, the significance of staple foods like tubers and cereals was recognized as a **vital part** of an **independent lunar food production system**. Continuing previous research on staple foods in space is crucial for achieving an independent food production system. An area that has been overlooked in space food research **is post-harvest management** such as **food storage and food processing**, which is essential for meeting the aforementioned criteria, and a truly bio-regenerative and sustainable lunar food production made possible. Food processing can also facilitate the **circularity** of closed-loop habitats by utilizing side streams and waste. Additionally, a comprehensive approach is needed for **testing synergies** between different space food research and innovations, and involving **humans in the loop** for accelerated research and implementation.

Beyond state of the art

The current foods for space missions have **limited shelf-life stability** and rely on Earth-dependent pre-packed foods, which are **not sustainable for longer interplanetary missions** (9) (7). Existing research on space food production **mainly focuses on pre-harvest technologies**, such as micronutrient focused fast-growing crops, algae, insects and lab-grown meat. Areas such as **post-harvest management has generally been overlooked**, leaving a **knowledge-gap** of how to store and process food once its produced. Insects and meat all **need processing and storage to be acceptable**, while lunar greenhouses need to expand their crop selection to include staple foods that can be processed to provide a **diverse and nutritious diet**. To achieve this, post-harvest technologies such as food processing equipment and storage solutions **must be implemented alongside greenhouse modules and other food production technologies**. Addressing the gaps in space food research, the inclusion of post-harvest modules for processing and storing food is essential. Processing technologies also enables **side stream and biowaste valorisation** by reintroducing nutrients, **producing packaging materials** and utensils made from greenhouse side streams, or **providing components** for cultivated meat production. However, food handling on the Moon presents unique challenges due to reduced gravity, which affects heat and mass transfer, fluid behaviour, and physiochemical properties of food, **necessitating the adaptation of processing methods and equipment to the space environment** (10) (11) (12) (13) (14) (15). Moreover, the lunar environment, with its elevated radiation levels, can **increase the pathogenicity** of certain bacteria as well as improving microbial tolerance to intrinsic and extrinsic stressors which impacts food shelf-life stability and processing mechanisms (16) (17) (18). Hence, **determining the requirements for storage facilities becomes crucial**.
Previous **closed-loop efforts**, such as, Lunar Palace 1, the MELiSSA initiative and DLR's ModuLES approach, are mainly concentrated on simulations of closed loops with several breadboard test facilities. However, **their integration with post-harvest management** and the incorporation of humans in the loop have been **limited**. The project described here aims to **bridge these gaps** and establish a **comprehensive framework for space food production**, encompassing both **pre-harvest and post-harvest** technologies, as well as human involvement. By combining the **post-harvest** module with Controlled Environmental Agriculture (**CEA**) technologies from the **EDEN-ISS greenhouse**, the project seeks to create **HABSIM**, a **research infrastructure** for a **multi-purpose closed-loop food production system** essential for **human survival** on the Moon. The implementation of post-harvest management within HABSIM is crucial for achieving a truly sustainable and **self-sufficient** food production system in space. This will provide a technological layout of a future post-harvest management facility as a part of the bio-regenerative life support system and closed loop habitat, to **minimize resupply missions from Earth** and to establish an **independent closed loop food production system**. HABSIM, a research infrastructure for a multi-purpose closed-loop food production system, will be essential for **human survival on the Moon**. The **implementation of post-harvest management is necessary** for the feasibility and acceleration of research and innovation in space food development, as the **HABSIM** aims to integrate **various research** into a **closed-loop system** that will enable testing of **technology synergies** and humans-in-the-loop experiments. The project has garnered interest from research institutions and international space agencies such as National Aeronautics and Space Administration (NASA) and Canada Space Agency (CSA). The module is designed with **circularity** in mind, aiming **to recycle and reuse water, heat, and gas**, and utilize **side stream** and **biowaste processing** for **nutrient reintroduction** and **natural product extractions**. The goal is to achieve **complete self-sufficiency** in consumable materials, including packaging, tableware, utensils, and nutrient components, all derived from the closed-loop system.

The closed-loop food production technology developed through this project has applications beyond space, supporting independent food production and reducing external dependencies **in challenging environments on Earth**, aiding both rural and **urban areas, and contributing to climate neutrality and humanitarian efforts**. The project promotes collaboration among scientific, engineering, and industrial teams across Europe, strengthening scientific excellence and fostering **leading-edge research of space food in** and **Europe**.

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