

31 – Growing Food

SUMMARY

We can't ship food forever. Eventually we'll need to grow our own food. This chapter goes into detail about greenhouse designs and the choices that our Working Group (AgWG) made when designing the lunar greenhouses. In a nutshell, they would be very large, multi-floor, shielded inflatables using optimized LED lighting and a hybrid, gravel hydroponic approach completing avoiding the lunar dust.

To have a sustainable base, it needs to be able to grow its own food. Growing some food is fairly straight forward. Growing all one's food is another matter. We take so much for granted every time we run down to the store. But imagine if you had to grow your own wheat to make your own flour to make your own bread. Imagine making your own oil. How about the simple ingredient, cinnamon? How would you grow that? Then, imagine making everything that you eat. It is doable but a daunting task.

THE AGRICULTURE WORKING GROUP (AgWG)

In the Space Development Network, we have established an Agriculture Working Group which met weekly via video teleconference. Space advocates with a "green thumb" have joined together in this working group to discuss and develop the Agriculture Plan. Our ultimate goal is demonstrating a greenhouse demonstrating the production of full nutrition.

Our Agriculture Plan is designed to be consistent with the Network's Innovative Plan for Space Development. As such we start with the context of an Initial Base with a crew of eight on the Moon. Our goal is not only to meet all the nutritional needs of the Initial Crew of eight but to do so with a good amount of variety while recognizing that it is not practical to grow certain foods from the beginning (e.g. a coconut tree).

The AgWG has discussed the many aspects of a lunar greenhouse and have, as a group, come to several conclusions about what approach is most practical to start with. But it is a work in progress and could change

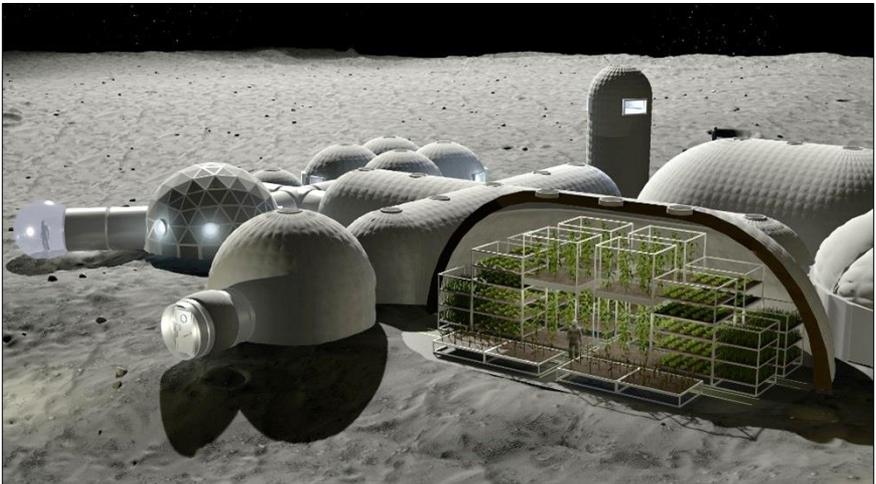
with more discussion and input from others. But this chapter describes our current thinking. If you, the Reader think that you can contribute to this effort we invite you to join us by joining the Space Development Network (for free) and then indicating your interest in agriculture.

GREENHOUSE DESIGN

Greenhouse Versus the Ecologic Approach

For starters we need to make the fundamental decision as to whether the food grown in the StarHab or InstaBase will be a greenhouse or use the ecological approach. The greenhouse approach is pretty straight forward. You just grow different plants, harvest them, and use them as ingredients.

The ecological approach is more complex in which one is attempting (at some level) to recreate Earth's biosphere by having different species being in a balanced ecological relationship with other species. The Biosphere 2 Project in Tucson, AZ attempted this approach whereas the Prototype Lunar Greenhouse Project at the University of Arizona (also in Tucson) uses the greenhouse approach.



Artistic image of the intensive GreenHab in the InstaBase.

Many people are aware of the initial Biosphere 2 Project in which eight "biospherians" moved into a huge, hermetically-sealed, \$150 million dollar facility with five different biomes for two years. The general view is it was a failed experiment with oxygen needing to be pumped into

the facility, collapse or overrun of certain species populations, conflict with the crew, and their near starvation. All of that is true even though the experiment yielded useful results and the facility continues to be used to understand agricultural and ecological systems to this day. Unfortunately, this experience has led some to claim that space settlement was shown to be impossible because the Biosphere 2 Project failed.

In contrast, the Prototype Lunar Greenhouse Project goes directly to growing food without the complications of having to figure out ecological relationship between animals and plants. As a result, they have, on a far smaller budget and far smaller facilities, been able to demonstrate the production food for crew in the controlled setting of a greenhouse. Our Agriculture Working Group (AgWG) has compared the two approaches and have settled upon the greenhouse approach for the initial levels of a permanent base. We are open to the more complex ecological approach, but we believe that it would be so far down the line that it doesn't concern us at this time. The partial exception would be with waste management which will be described shortly.

General Design Options

Now that we've settled on the greenhouse approach, there remain several options for how this could be done. These options are not so easily chosen between, and our choices may change with more study.

Related issues have to do with how we use sunlight and the radiation environment within the GreenHab. Specifically, on the Moon, there is no atmospheric protection against either solar particle events (SPEs) or the constant rain of galactic cosmic rays (GCRs). SPEs can be detected and the crew can shelter in time. But GCRs make up most of the radiation dose over time and need to be shielded against for long-term crew.

The easiest way to protect against GCRs is to simply have telerobots cover the habitat with lunar dirt (regolith). But this blocks out the sunlight and so light would need to be transmitted into the GreenHabs in one of several ways:

- Solar drapes producing electricity which runs into the GreenHab via wires to power magenta LEDs optimized for plant growth.
- Solar collectors with fiber optics or light tubes transporting light into the GreenHab without the energy conversion losses.
- An innovative approach using berms and mirrors to block the radiation while bouncing sunlight into the sides of the GreenHab. Since these mirrors could not turn and the Moon rotates on its axis very slowly the long lunar night would be a challenge.

As we have considered the various options, we have settled upon the solar drapes & wires approach to transmitting power into a shielded habitat. It allows for the best control of growing conditions. Also, we have calculated that a 100 metric ton Starship payload could deliver enough solar drapes to power plant growth for about 300 settlers. So, we will have far more than enough electrical power using the Solar Drapes approach.

Moon Versus Mars

We don't feel compelled to have the same agricultural system on Mars as we do on the Moon. If the relevant factors are different so they could lead to different GreenHab designs.

Mars probably has enough of an atmosphere to prevent plants from dying in the setting of an SPE. The great advantage here is that one can consider just having clear walls and ceilings and let the natural sunlight power plant growth without needing the photovoltaic production of electricity. One downside is that plants could not be grown in 3D like they could with interspersed LEDs. As for the radiation issue, we have calculated that, if the agriculture workers are over about age 50 then the radiation levels are low enough such that they can remain within their career limits.

HYDROPONIC OR SOIL-BASED?

Hydroponics is a good way to grow food and there are a wide variety of plants that have been grown hydroponically. But the AgWG feels as though there is an advantage to growing plants in soil due to the favorable microbial environment that soil provides. But using regolith for soil is probably a bad idea. Lunar regolith is a health hazard because it is essentially finely ground glass. Inhaling it is a particular concern, so we'd like to not let any of it into the habs.

But there are a couple of other ways of using lunar material to make soil. Lunar rocks could be crushed down to make particles of the right size. Alternately, telerobots could simply sift the lunar regolith and separate out particles of the right size.

Now, soil is not just bare dirt. A high percentage of soil is organic matter of which lunar regolith has none. So, how could our manufactured lunar dirt be turned into soil? We could simply start with growing plants hydroponically. The inedible waste portion could be further processed using mushrooms and/or biodigestion. The rich organic material can be added to the dirt thereby making it soil.

SOURCING NUTRIENTS FOR PLANTS

The LCROSS results show that carbon and nitrogen are present in appreciable amounts in the lunar polar ice. (See page 200). These can be converted using well-known chemical processes into the CO₂ and ammonia or nitrates that plants need.

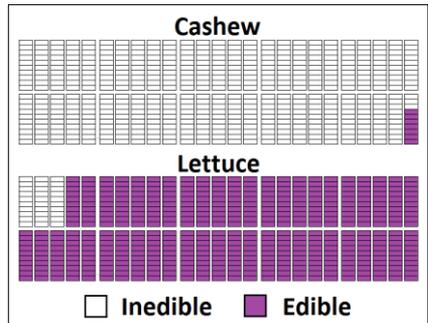
For potassium and phosphorus needed as part of the NPK nutrients that plants need, these will likely be supplied from Earth initially and recycled. These are also present in the lunar regolith but would need some processing to free them up. Longer-term, KREEP rocks located near the equator contain appreciable amounts of potassium and phosphorus and could be transported overland in electric vehicles.

As for the micronutrient elements, plants are designed with biochemical mechanisms to extract these from the dirt where they are concentrated in the plant's tissue. This is a process called phytomining. Copper is an example element that can be concentrated and extracted using this method.

WASTE MANAGEMENT

Plants are not entirely edible. There will be much plant waste that will need to be dealt with. So too with human waste. We cannot afford to let any waste product go unrecycled. It is just too precious to lose.

Plant waste can be processed in several different ways. One can simply incinerate it to make basic chemicals. One could also use one of several types of bioreactors to biologically transform the waste into more usable chemical forms. Finally, mushrooms could be grown on top of waste material and then become an ingredient in a recipe.



Human solid waste can be ground up and treated with UV radiation to sterilize it thereby making it safe for later processes. Both waste streams could then be fed back into the nutrient solution which would pass through the soil.

The AgWG has considered the options for waste management and have currently settled on some of the plant waste being used to support mushrooms but with the bulk of it processed by bioreactors with incineration of any remaining waste.

We considered attempting a fully ecologic approach to waste management including an aquaponic set but settled on the above due to the complexity and manhours of managing the aquaponic systems.

GREENHOUSE ENVIRONMENTS

Greenhouses can have their environments highly controlled to optimize production. In a 3D growing environment with magenta LEDs dispersed throughout, production per square meter can be greater than 10 times that done in fields.

Many people are aware that plant growth rates can be increased with elevated CO₂ levels. This approach could be used in sections of the GreenHab provided that the gaseous environments could be managed to allow crew to enter those sections as needed. We don't have the luxury of simply venting air with high CO₂ levels outdoors.

Lighting can also be highly controlled with some plants able to continuously grow while given light while other plants seem to need the day-night cycle.

Some plants need seasonal environments to come to full fruition. These can include length of sunlight during the day and certain temperatures such as cold snaps. For this reason, some plants would need to be grouped into the same GreenHab chamber, and the dietary menu would have to take into account how this seasonality would yield an abundance of fruit but during a limited period of time.

CHOICES OF PLANTS

We will want to grow as wide a variety of food plants as possible to make living off Earth attractive. But certain plants have a high percentage of the mass edible whereas other plants have only a small percentage edible. This table provides a general summary:

Salad Vegetables

- 90% - Salad greens
- 75% - Bulb vegetables
- 70% - Root vegetables
- 68% - Fruit veggies (tomatoes)
- 65% - Herbs
- 60% - Crucifereous vegetables
- 50% - Pod vegetables

Fruits

- 52% - Melons
- 35% - Banana
- 19% - Strawberries
- 4% - Tree fruits
- 4% - Avocados
- 3% - Olives

Beans

- 22% - Soy beans
- 18% - Black beans

Grains

- 30% - Grains

Nuts

- 12% - Peanuts
- 0.3% - Tree nuts

Oils

- 6% - Seeds
- 0.4% - Olives

Other

- 2% - Chocolate
- 1% - Coffee

So, in the early phase, the choice of plants may be something like this:

- Salad veggies
- Root vegetables (e.g. potatoes)
- Tomatoes, Broccoli, Green beans
- Herbs: Basil, Parsley, Cilantro, Oregano
- Fruits: Melons, Bananas, Strawberries
- Grains: Wheat, corn
- Nuts: Peanuts
- Beans: Soybeans & other beans
- Ship: Tree fruits, Nuts, Olives, Avocados

MEAT

Meat isn't essential for good nutrition, but many people would really want it on the menu. Since animals are not autotrophs (grow just from sunlight) there would need to be an agricultural step prior to meat production.

Fortunately, some animals consume plant waste and therefore don't need any special feed production system. Tilapia fish and insects are favored for this reason. Chickens also consume plant waste and provide delicious globules of protein and fat in the form of eggs.

As mentioned before, maintaining the equipment necessary for an aquaponics system was considered too much work for an Initial Crew of eight. But, by the time the base gets to about 100 residents, and with economies of scale, we feel that aquaponics make sense.

Chickens too could be introduced fairly early in a base, but we felt that it was not appropriate for the Initial Crew level due to the need for a specialty hab that could address the odors produced by cooped up chickens. Again, chickens and their eggs could be introduced when the base population reaches about 100 and there is a BarnHab that would be capable of addressing odors.

DISTRACTIONS

There are certain food items that some people are almost evangelistic about which we in the AgWG are more reserved about.

Insects

Yes, certain insects can efficiently convert plant waste into high-protein meal. But our goal is off-Earth settlement. We have to bear in mind that, if space settlement is associated in the news with eating fried crickets (and the news would jump all over such a story) that it could discourage a fair percentage of potential settlers (and spouses) if they got the impression that they would have to eat insects if they were to move to the Moon. So, for us, for that reason, insects are off the human menu. No problem if the insects are for fish though.

Marijuana

The most skilled hydroponic experts are in the cannabis industry. No surprise there. And could lunar marijuana be a high-value cash crop? Perhaps. But again, do we want lunar settlement to be all about growing marijuana with all the positive and negative emotions that would elicit. So, we're just leaving that topic alone.

Alcohol

Alcohol isn't a particularly good way to meet one's nutritional needs. But boy does it take over the conversation when it comes up. However, it is a good "social lubricant" and wine goes well with meals. So yes, alcohol is on the menu in modest amounts.

STORAGE

It's not very exciting but we've got to think about how food is going to be stored. Ideally, we would like to harvest the food just as it was to be eaten for the best taste and minimum storage needed. But:

- there will always be a mismatch between production and use,
- storage allows for a varied menu throughout the year,
- and we will want to build up a reserve to maintain food security.

So, storage must be designed into the base from the get-go.

Different foods have different storage requirements. Forms of storage include: dried, canned, refrigerated, and frozen. They have different shelf lives which a flexible menu would have to consider.

THE ROLE OF ROBOTS

Crew time is so valuable. So, every chance we can, we should shift work off to the machines. Telerobots, even with a 2.6 second time delay, could be extremely helpful. It's also most helpful that telerobots could work 24/7 being operated by shifts of crew from Earth. As such, these robots would have human-level intelligence because they would be operated by humans. And they could swap out special implements to harvest specific fruits / produce. But we are rapidly approaching the point where humanoid robots will be able to be trained on an increasing number of tasks. In that case, teleoperations will be unnecessary.

What agricultural tasks could telerobots and autonomous robots do? Could they plant, inspect, and harvest? Probably yes. Not as quickly as humans but then they can work about four to five times more hours per day than humans. Could they process produce and place them in storage? Again, probably yes. Maintain systems by disassembly and repair? That might be pushing it. But if the systems were specifically designed for easy telerobotic manipulation, perhaps even this.



iSAS

The Space Development Network is working towards having an Intensive Space Agriculture Session (iSAS) to demonstrate the full nutrition production starting with a single person and later for an Initial Permanent Crew of eight.

Our concept is for a two-month session with university students led by their faculty who is a space agriculturist. Prior to that session, a variety of food plants would be grown to fruit-bearing maturity. At the start of the session, the first thing that the students would do would be to bring in those fruit-bearing plants into a large inflatable greenhouse with semi-transparent roof allowing in the same photon flux as will be present on Mars.

Then, during the two-month session, plants will continue to grow, bear fruit according to a schedule, and the waste harvested and re-used.

An associated space nutrition group will take the produce, produce ingredients, and through a somewhat complex system of recipes, produce meals that provide for full nutrition while also not requiring a great deal of storage.

The analog Mars GreenHab will be constructed like a very large air mattress and be at a single level without the use of LEDs. According to our Agriculture Consensus Plan, we will start mostly with hydroponics but begin the process of making our own soil using crushed rocks and not toxic regolith. Optimizing the environmental conditions will be the major part of our research goals and defining the processes involved.