SPACE INDUSTRY ON THE EXAMPLE OF IDEACITY PROJECT

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ABSTRACT

Taking into consideration a permanent Mars colony, it is extremely important to ensure proper production of goods. We can not base human life on the continuous supply of elements from the Earth, we should aim at the self-sufficiency of the inhabitants. To do this, we should plan the base properly, including the industrial part. At the same time, we can not take the time of people in the colony to perform simple, monotonous production work. The industry has to be highly automated. The publication will present the concept of the Mars industry developed for the Ideacity colony, the finalist of the "Mars Colony Prize" competition. In our paper, industry components will be discussed. The production of fuel for return flights and energy for supplying the base will be shown. The technologies of processing raw materials will be presented as well as their path from obtaining, through processing to production of the finished element. Automation and robotization of industry using artificial intelligence will be discussed.

KEY WORDS

Mars base, Mars exploration, Mars industry

INTRODUCTION

People have long been trying to get off our planet. In 1969, human set foot on the moon for the first time (1). Since then, people have stood on our natural satellite several times. Wernher Magnus Maximilian Freiherr von Braun did not want to stop at the moon, but to aim to land a manned mission on Mars (2). However, with the end of the Apollo program, plans to create an interplanetary civilization have slowed down significantly. There was an era of space shuttles, and astronauts were not as far away from Earth as they were in the 1970s. With the beginning of SpaceX and their first successes, the hopes of sending man to Mars were revived again.

People will have to face various threats to survive on Mars. At the beginning you need to build a shelter that protects the human body from radiation on Mars and large daily temperature amplitudes. On Mars, the atmosphere is more than 100 times thinner than on Earth (3). It consists mainly of carbon dioxide (4). Mars also has no magnetosphere, which on Earth protects people from cosmic rays and stops the degradation of the atmosphere (5).

The first base can be built autonomously by robots sent to Mars. The problem to be dealt with at the beginning is to provide astronauts with access to oxygen and water. Oxygen on Mars can be produced in several ways, but at the very beginning, the source of oxygen will be the process of water electrolysis. Under the influence of voltage applied to the cathode and anode, H_2O breaks down into O_2 and H_2. As a result, is obtained hydrogen and oxygen of high purity (6). NASA intends to send a device that can produce oxygen called Mars Oxygen ISRU Experiment on the Mars 2020 rover. It is an experiment converting CO_2 to CO and O_2 operating on the basis of electrolysis, the version sent in the Mars 2020 rover is 100 times smaller than the final device (7).

In 2017, Elon Musk presented the vision of "Making Humans a Multi-Planetary Species" using the Starship rocket (8). The construction of the orbital prototype is underway, and the first jumps using new engines have been successful. One of the key elements of the Elon plan is the use of methane and liquid oxygen as fuel. Both of these raw materials can be produced in-situ on Mars (8). However, tons of equipment will be needed, that will allow the production of fuel, but also to generate energy or provide basic raw materials for residents such as air, water and food. For this purpose, an industrial zone should be created in the Martian settlement.

IDEACITY

In our city, drinking water, as well as water used for electrolysis, will be obtained from underground ice water sources. This source will probably be distant from our location, however, autonomous vehicles will be used for transport. Rail transport will be built at the start of metal production in-situ.

Water and air, as well as other materials that can be recycled, will be reused. Water and air after purification and supplementing their composition with the missing components will be introduced into the system and the materials after processing may go to the warehouse.

Energy production is another important aspect in manned missions. The use of solar farms on Mars is inefficient, because Mars is further away from the Sun than Earth, which means that less sunlight reaches it. In Poland, solar cells with 20% efficiency produce approximately 155 W/m^2 (8). On Mars it is from 20 W/m^2 to 120 W/m^2 depending on the month (10). Another issue is dust storms, the formation of which depends on the season and location. However, occasionally there is a global dust storm that covers the entire planet (11). In addition to blocking access to sunlight, dust that floats during a storm settles on panels, further reducing their performance. Despite this, in our city we decided to use solar panels with an area of about 10,000 m^2. This will generate an average of 250 kWh of energy. This amount of energy allows to sustain life in the base, in the event of a failure of the main power source, or when it is necessary to carry out service.

The main source of energy in our base will be a nuclear reactor based on sodium coolant. He should use uranium-235 as fuel. Our plan assumes the possibility of further scaling of the Kilopower reactor (12). The amount of energy that should be generated to power a 1000-person Martian base is about 7 MWh. The advantage of using sodium is a much greater possibility of heat absorption, compared to water, which allows you to increase safety. Surpluses of produced energy will be stored in battery-based energy warehouses. This will cover the increased demand for energy during the day when the entire industry is in operation, and store the excess produced at night when energy is used less.

Industry

A city on Mars with 1,000 inhabitants should be as self-sufficient as possible. This will not be possible without building an industrial zone that will allow the production of necessary components for the development of settlement. The first element that has not yet been clearly defined, but we expect it to exist, is the presence of deposits of raw materials on Mars. We have now discovered the composition of the surface of Mars and found several other sources of raw materials such as berries. However, we do not know much about Mars geology. The InSight mission that was supposed to broaden our knowledge in this topic has not yet brought the expected answers. However, we found out that earthquakes occur on Mars (13). This is important because Mars was thought to be inactive.

In order for our industry to operate with adequate efficiency, it is important to find ores with a high content of needed elements. One of the most sought-after deposits are iron deposits, which will enable steel production. Other elements sought are aluminium, titanium, molybdenum, copper, cobalt, neodymium. In our base, the deposits will be obtained as in the case of water, through autonomous works, and transported to the base by rail transport. Due to the very rare atmosphere on Mars, the use of railways based on the Hyperloop idea can be extremely effective and easy to implement.

After extraction, the raw material is transported to the sorting plant (fig. 1). Ores are divided there due to the type of element and its percentage content. In the case of ore with high content, e.g. when iron deposits are found in the form of magnetite or hematite with iron content over 30% in the ore, it is transported straight to the smelter. The process of producing steel from ore is a blast furnace process in which iron is reduced by means of carbon or carbon monoxide (II) (14).

In the case of ores with a low concentration in the extracted material, e.g. copper ore, its extraction process is more complicated. On Earth, copper mines are built where the copper content is at least 0.5% and preferably 2%, it must be similar in our city so that production is as effective as possible. At first, crush the ore. Ball mills are mainly used for this purpose. After receiving the powdered ore, it binds with oil, which does not allow wetting of the ore with water. Then the ore goes to the water bath. This water contains a foaming agent and air is supplied to it. This causes that copper particles are picked up by the rising air bubbles and carried up. The foam is scraped from the surface, the resulting enriched ore is suitable for further processing. It contains about 25% copper (fig. 2). Then, at 500-700℃, roasting occurs, and its product is roasted ore, which is a mixture of oxides, sulfides and sulfates. During this process, hazardous products such as sulfur dioxide are also produced, which must be removed and can be used, e.g. for the production of sulfuric acid used in industry. Then, this time with fluxes, we heat our material to a temperature above 1200℃. Thanks to this, some impurities float to the surface, and then they can easily be removed. The last step is oxidation in an air converter, which allows obtaining blister copper with a purity of 99%. If there is a need to use copper with a higher degree of purity, an electrolytic refining process should be carried out, where 99.99% pure copper is obtained (15).

We will then melt the products thus obtained into bars, rods, plates, rods or profiles depending on the application. In addition, semi-finished products will be prepared in the casting process for further processing. In the case of unit production, which will take place in our martian base, a good way is to use models made in 3D printing technology, and then their reflection in the moulding mass, which will be used to make the casting. The disadvantage of such technology is the need to use larger technological allowances or to obtain worse structure properties than in the process of pressure casting. However, die casting requires expensive moulding form and proper equipment. It is profitable for mass production.

The prepared blanks go for further processing. The base on Mars, in addition to using modern manufacturing methods such as additive manufacturing (AM) technologies, will have to have the possibility of traditional machining of details. Our industry's Breakdown Structure system is shown in fig. 3. In our base we will use such types of machining as milling, turning, drilling, but also unconventional methods such as Electrical Discharge Machining (EDM), laser cutting or water jet cutting. All machining stations must be fully robotic. Replacement of details on machine tools or tools must be done automatically so that people only deal with the supervision of the process, and do not participate in it.

Another way to make parts is additive manufacturing technology. Nowadays, it is becoming more and more popular, which results in its faster development. In the future, techniques such as Selective Laser Melting (SLM) should be as popular as now Fused Deposition Modelling (FDM). Incremental techniques depends on adding consecutively layer upon layer a portion of material to produce an object. On the example of SLM, the principle of operation and benefits of use will be presented. The SLM technique is based on the selective sintering of metal powder layer by layer, so that a ready detail is created. A thin layer of powder is applied to the table, and then the laser, moving along the programmed path, melts the material together. Then the printer table is lowered and another layer of powder is applied. This process allows the production of details in which the degree of complexity does not affect the cost of production. The cost of production depends on the size of the item and the amount and type of material used (16). Thanks to this, it is possible to produce details with a complex structure, where often achieving such a shape would not be possible with conventional machining. The disadvantage of the AM technique is the unprofitability of series production, because the production time is longer than for the same detail in the conventional machining process. Another application of additive manufacturing technology is the regeneration of worn elements in the laser surfacing process. On Earth, this is used, for example, to regenerate jet engine blades. The blades are made of hard-welded and difficult-to-cut alloys, so it is economical to regenerate them in the surfacing process rather than making a new element. The advantage of this treatment is the small heat affected zone generated by the laser in the workpiece, thanks to which the chance of cracks is reduced.

The building production process is another important application of this technology. To protect man against the harmful effects of cosmic rays, the walls of our buildings in which he will be staying must have a thickness of up to 15 m. To obtain walls of this thickness, you need to use raw materials found on Mars, because importing them from Earth is unprofitable. The buildings in our base are built with the help of 3D printer robots that will use regolith as the main building material. In recent years, NASA has run a competition for printing a 3D base on a small scale (17). In our base, in addition to 3D printing, we will use ethylene tetrafluoroethylene (ETFE) and aerogel to build bases to ensure light access to the base (18).

The finished items will then be sorted, depending on where they need to go. They will be divided into 3 groups:

- ready items that will be sent to warehouses,
- ready elements that go to the assembly hall to further create larger components from them,
- ready elements that will go straight to the recipient, e.g. a specific apartment.

Such production should meet the needs of our martian town as much as possible, but it is not possible to produce everything. We will still have to import some of the elements from Earth. Such elements will be e.g. advanced electronic circuits. These elements will be transported using rockets. Rockets will arrive at the designated landing pads. Then the rocket will be unloaded, and transport from a remote landing site to our city will be by rail. These elements will be sent to the distribution. There, larger containers will be unpacked and all arriving goods sorted. Sorting will take place autonomously, vision systems will recognize objects and scan their markings to direct them to the appropriate places in the base. The entire transport will take place using a transporter system and over longer distances or in the case of larger elements using autonomous rovers moving on the surface of our base. Therefore, the roads on the surface must be larger than 5 m so that traffic on them can be conducted in two directions.

To enable the export of goods to Earth, our base will produce rocket fuel in-situ. We assume that the rocket fuel will be methane and liquid oxygen. Engine prototypes using new fuel, e.g. Raptor or BE-4 (19), are currently being tested. To produce this fuel, use the Sabatier reaction. It involves the reaction of CO_2, which is in the air along with H_2, which we obtain in the process of electrolysis at a temperature of about 400°C under pressure. This process produces methane C_4H_2 and water (20). Liquid oxygen will be obtained in the process of electrolysis. Fuel production will take place in the upper part of the base (no. 9 on fig. 4), and then, via pipelines, it will be transported to tanks located in hangars, in which we will store rockets awaiting return to Earth.

Research & Development

The first goal of the R&D department will be to adapt terrestrial technologies to Martian conditions. Due to the reduced gravity and lower pressure in the base than on Earth, processes such as welding, casting, etc. may require different parameters than their Earth counterparts. Then we will have to improve these processes. Ultimately, laboratories should work on developing new technologies that will be our export good. To this end, a complex of buildings should be built in which R&D laboratories will be located. Our base will include laboratories such as:

Biological Chemistry Lab — in this laboratory, mainly research will be carried out on genetically modified organisms to adapt plants to breeding on Mars. The impact of Martian conditions on the human body will also be studied here. In addition, Mars studies will be carried out to search for traces of life. It will be one of the largest and most important scientific centers.

Artificial Intelligence and Robotics Lab — the second most important laboratory. Due to the need to automate the entire base, we must constantly research and improve the algorithms controlling our base.

Electronics Lab — it will explore ways to use Martian raw materials to use them in the electronics creation process.

Material Science Lab — materials produced on Mars will be examined here to improve their properties and develop new ways of producing them,

Technician lab — a laboratory dealing with the development of manufacturing processes and their optimization.

Geological lab — this laboratory will deal with exploring the geology of Mars, seeking answers to questions such as it was created. His other task will be to search Mars for resources.

Social lab — a laboratory dealing with the social aspects of life on Mars.

Agriculture

In addition to the mining, construction and manufacturing industries, agriculture is the last important industry for the base to operate. It will allow you to produce the right amount of food to meet the needs of the Martian city. According to our calculations, we need 20 ha of crops. The diet in our base will be based on a plant diet, due to the difficulty and efficiency of meat production in Martian conditions. In our base we will grow Tomato (Solanum lycopersicum), Carrot (Daucus carotas. Sativus), Stinging nettle (Urtica dioica), Garden cress (Lepidium sativum), Potato (Solanumtuberosum), Soya (Glycine max), romaine lettuce (Lactuca sativa L var. longifolia Lam.) and other, but also it will be insect breeding (Grasshoppers) and seaweeds bioreactors (spirulina (Spirulina platensis), chlorella (Chlorella vulgaris)). Insects will be bred in order to provide protein in the daily diet and algae will be will supply and complete vitamins, micro- and macroelements. Plants will be cropped also for medical application. Plants, in addition to food purposes, will also be responsible for the production of oxygen, and in some places decorative plants will be grown to improve the aesthetic value of the base.

To make food production run optimally, we will use hydroponics and aeroponics. Plants grown in these systems grow faster and are larger compared to plants growing in soil. We also intend to conduct research on growing plants in the Martian regolith.

Appropriate conditions must be ensured in greenhouses where food production will take place. The greenhouse must be maintained at an appropriate temperature, humidity, pressure, air composition and plants should be well lit. The fertilizer fed with the plant must be adjusted to supply ingredients such as phosphorus, nitrogen and potassium in the right amounts. All this is controlled by means of an artificial intelligence system that will watch over the breeding process as well as the process of harvesting by robots (fig. 5).

Artificial intelligence and robotics

In creating a self-sufficient base that will have as many as 1,000 inhabitants, it is important to ensure the highest degree of automation. Therefore, all repetitive processes will be handled by robots. One such element is maintaining the base. Bases, walls, pipelines, life support systems should be inspected for signs of wear and maintenance. Another thing is to keep the base clean automatically. Underground corridors should be cleaned and the outer coating of our base and solar panels cleaned of dust accumulating on them by robots.

All these elements, as well as the aforementioned elements of mining, production or agricultural process automation must be controlled from the level of one artificial intelligence, but its operation should be supervised by people.

CONCLUSION

In order for the settlement to become self-sufficient in the future, it is necessary to plan the industrial part properly before the arrival of human on Mars, so that it is easily scalable and ensures that all the basic needs of the inhabitants are met, as well as allowing further development of the settlement. However, before this takes place, certain factors must be ensured. The first of these is to find appropriate ore deposits for the elements needed to develop settlement. Then the first inhabitants should be provided with access to water, air, energy and food. In addition, in-situ must produce Mars production technologies that may differ from their Earth counterparts. It is also necessary to create an industry from the beginning with a focus on complete automation of production, so that people on Mars do creative things, such as developing new technologies. It should also be remembered that such prepared industry may still not be able to meet all the needs of settlement and some elements such as advanced electronics will be necessary for importing from Earth, however, for settlement to have adequate means for trade, one of the key export goods may be Intellectual Property.

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FIGURES

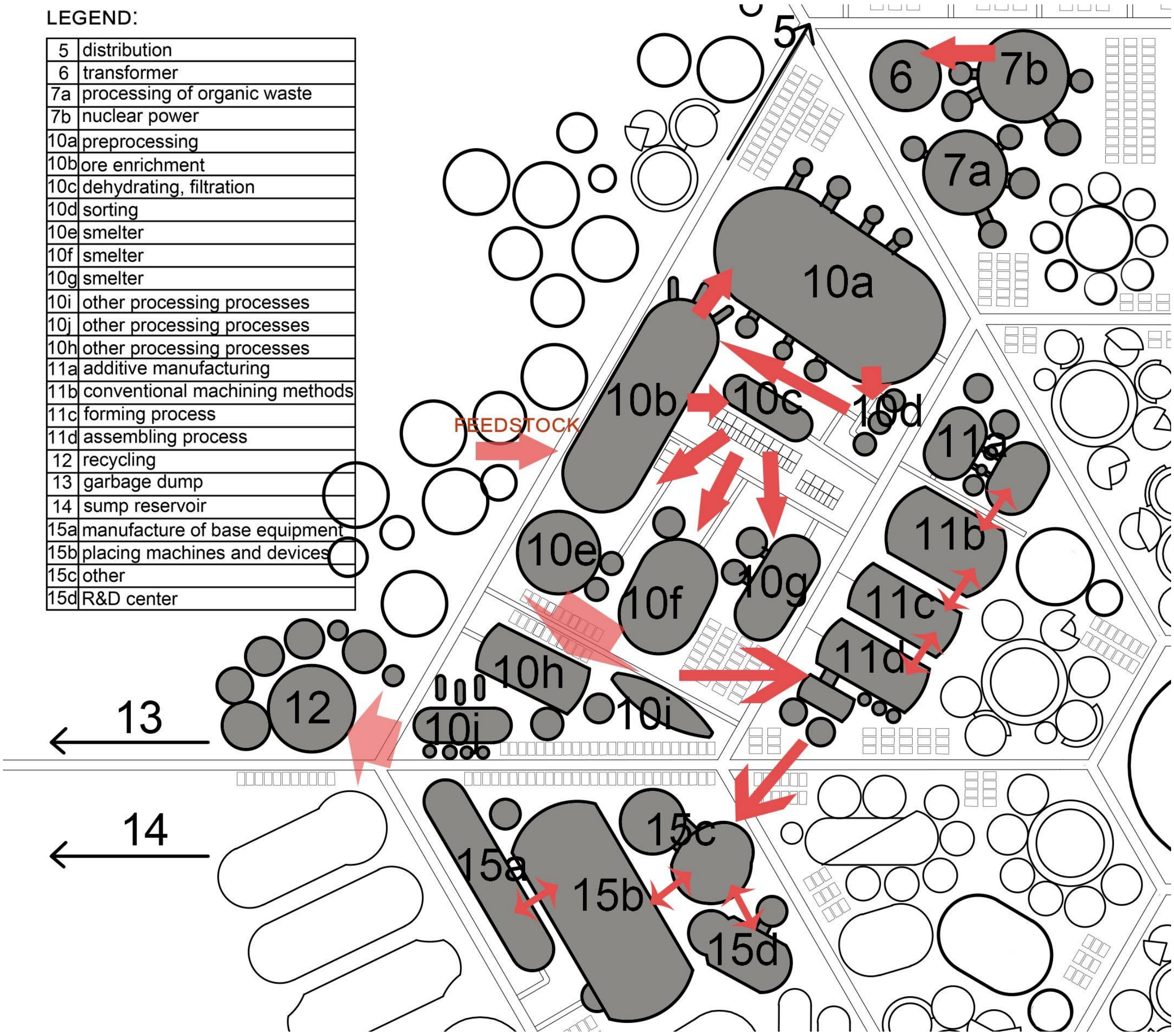

Figure 1 Close-up of the industrial part in our base

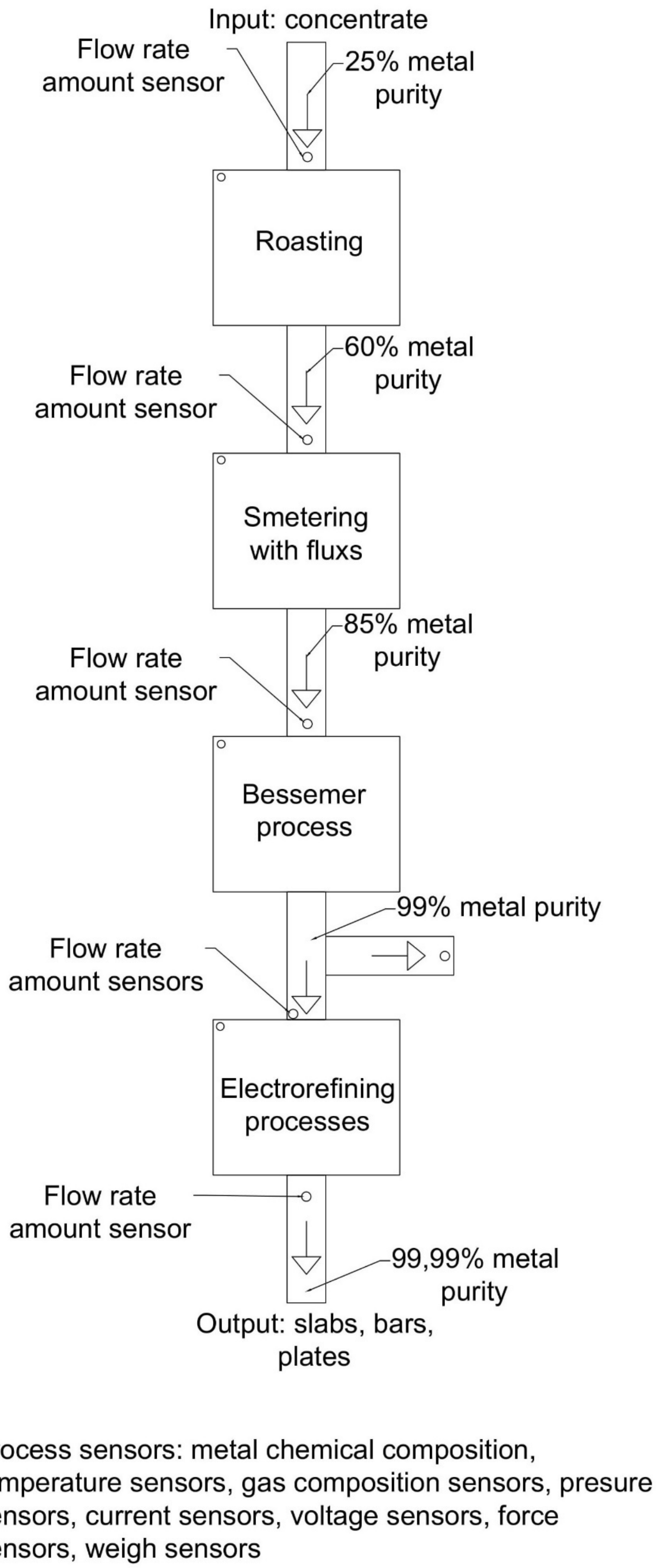

Figure 2 Copper processing proces

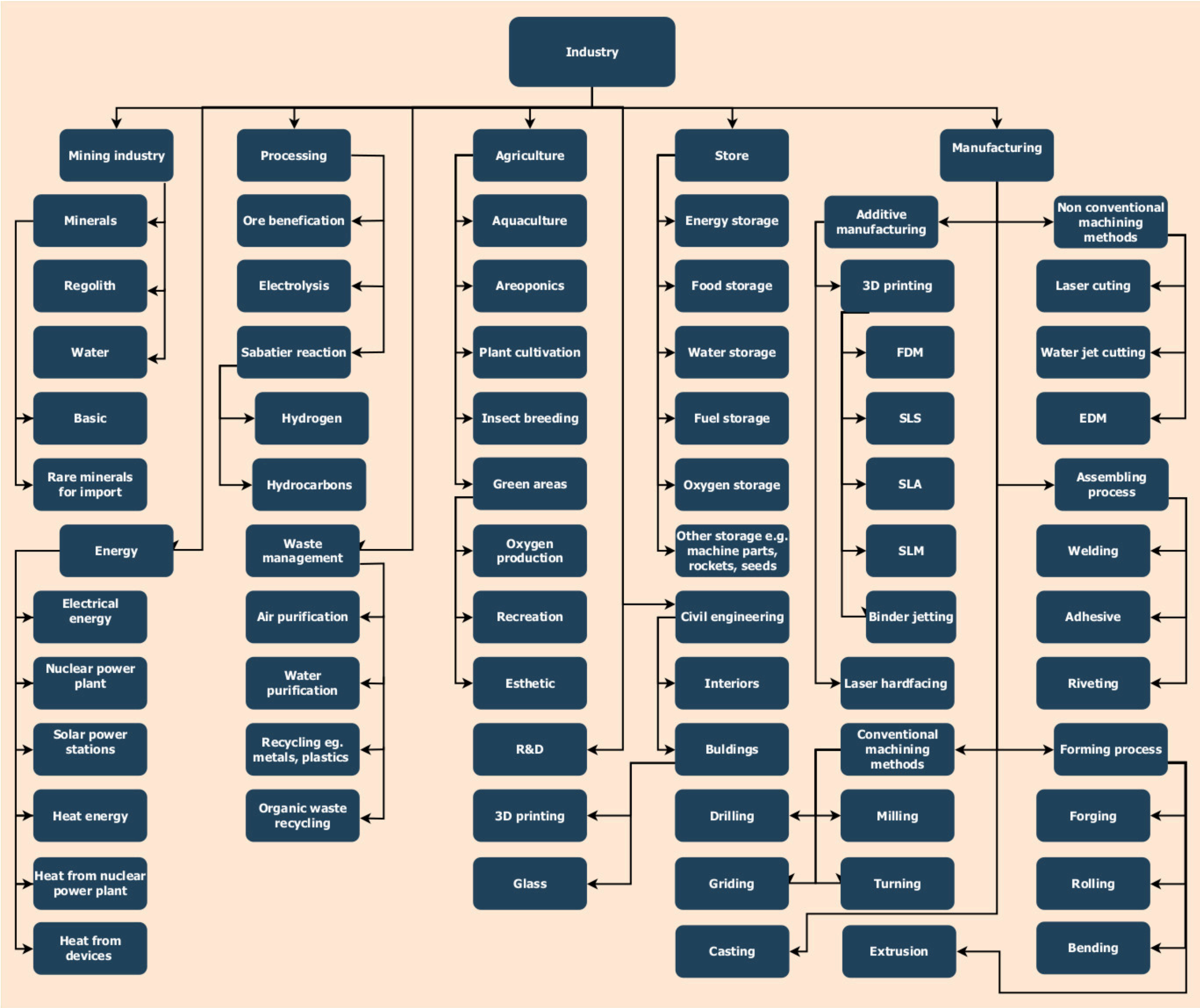

Figure 3 System Breakdown Structure

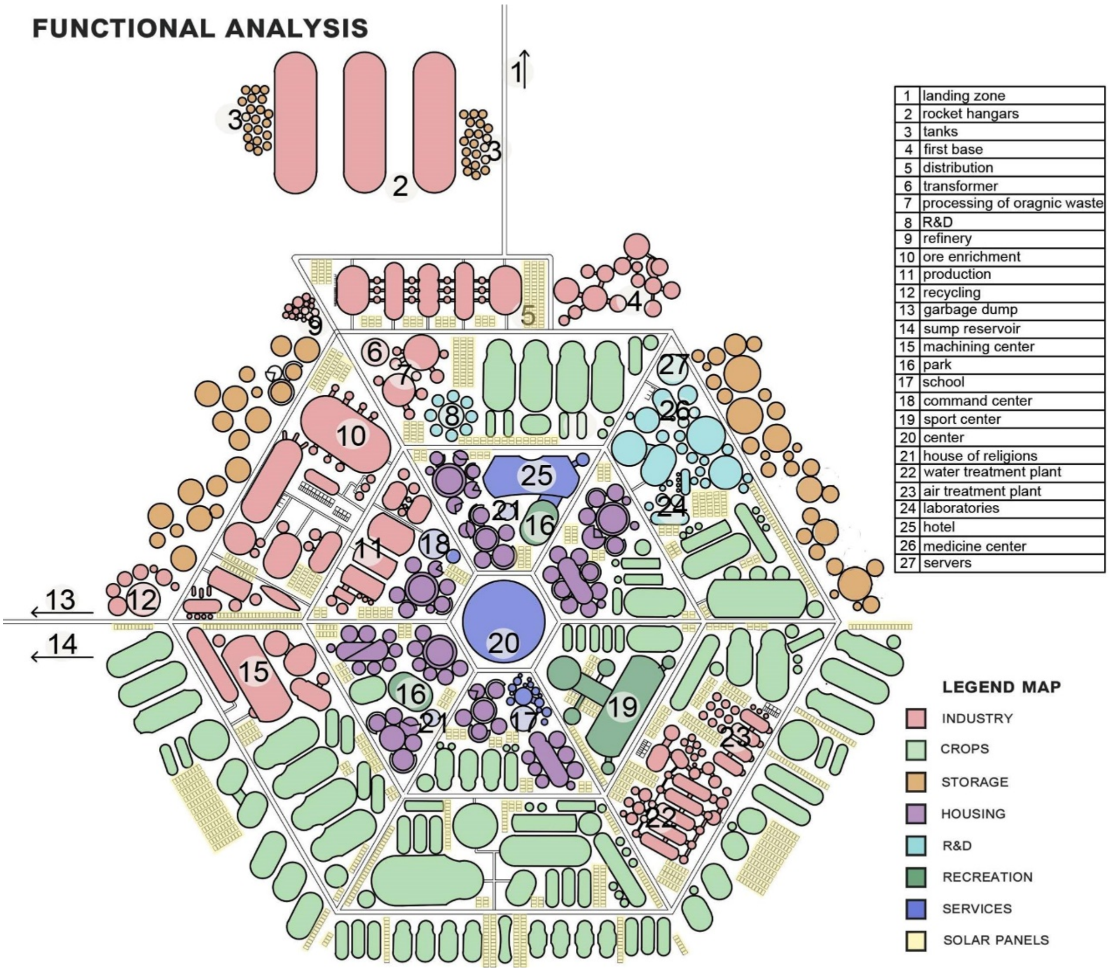

Figure 4 Functional analysis of our base

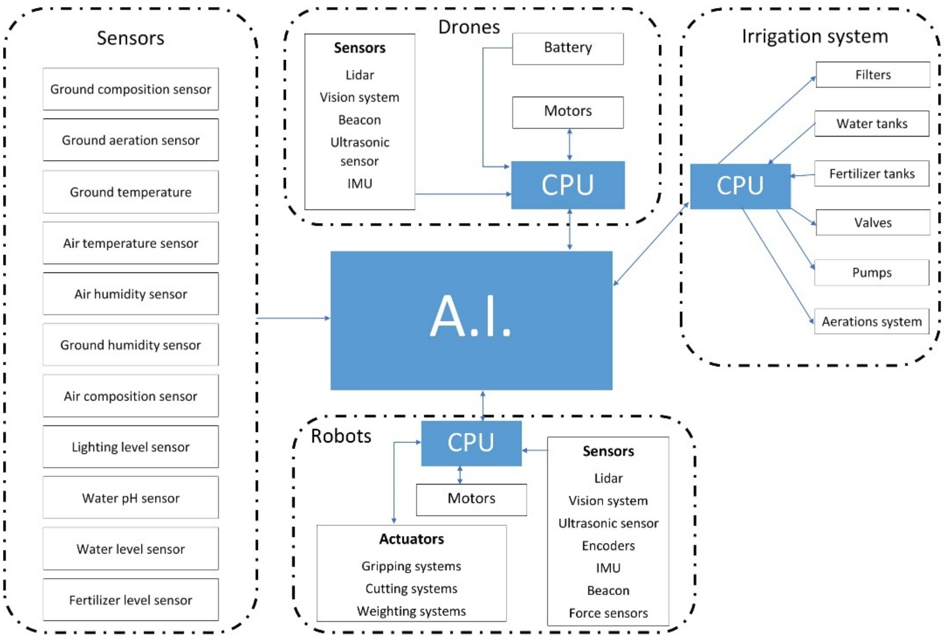

Figure 5 Agriculture AI system