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Sustaining Resources for *Homo Martis*: The Potential Application of Synthetic Biology for the Settlement of Mars

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Abstract:
The recent success of the Mars 2020 project and the high quality images relayed back to Earth have provided further impetus and expectations for human missions to Mars. To support space agency and private enterprise plans to establish a sustainable colony on Mars in the 2030s, synthetic biology may play a vital role to enable astronaut self-sufficiency. In this review, we describe some aspects of where synthetic biology may inform and guide *in situ* resource utilisation strategies. We address the nature of Martian regolith and describe methods by which it may be rendered fit for purpose to support growth and yield of bioengineered crops. Lastly, we illustrate some examples of innate human adaptation which may confer characteristics desirable in the selection of colonists and with a future looking lens, offer potential targets for human enhancement.

Keywords: Mars colonisation, *in situ* resource utilisation, synthetic biology, bioengineered crops, human enhancement.

1. Introduction

The concept of establishing semi-permanent or permanent colonies on Mars is receiving much attention. Private enterprise and space agencies have plans to establish a sustainable colony on Mars in the late 2020s or 2030s [1] – [3] and much will be learnt from both past and future unmanned missions to Mars and terrestrial analogue studies of confinement and self-sufficiency. Advances for the conservation of resources on Earth necessary to support an increasing global population will have positive collateral effects on space exploration. It is recognised that there are many challenges for human travel to Mars let alone permanent colonisation and the establishment of '*Homo martis'*. A recent crowd-sourcing study illustrated physiological and psychological obstacles which must be overcome [4]. The study used socio-technical systems models which included cognitive work analysis methodology [5] which was employed to build a nine step abstraction hierarchy supporting a work domain analysis [6]. The top-ranking sub-category from the 387 responders who provided input was the provision of an adequate food and water supply chain [4].

It is possible to estimate how much food may be required for a mission to Mars. We will assume that a return mission would include a 9 month travel period to Mars, a residence time of 18 months and a 9 month return trip. We will also assume that the amount of food, and packaging required for each of six astronauts is equivalent to the amount currently allowed for on the International Space Station (ISS) which is 1.8 kg per day [7], [8]. A 9 month journey requires an upfront cargo weight of approximately 3,000 kilograms (kg) which potentially could be catered for. An 18 month stay and 9 month return trip adds approximately an additional 9,000 kg. Launch windows are timed to coincide with the closest distance between Earth and Mars and are typically every 2-3 years where the inter-planetary distance at opposition is between 58 – 92 million kilometres (km) [9], [10] although the actually journey follows a least energy Hohmann transfer orbit, which is an elliptical orbit used to transfer between the two circular planet orbits using the lowest possible amount of propellant [11]. In the Hohmann transfer the spacecraft uses an elliptical orbit to transfer between two circular orbits of different radii around a central body in the same plane. The overall distance travelled is much further than the direct distance, for example the Mars 2020 mission has travelled over 234 million km from Earth to Mars. Transporting a large weight of food this distance would be logistically very challenging using technology available today.

The cost of space launch has been dramatically reduced over the years [12] and it is possible to estimate the costs involved for carrying the cargo alone [13]. Assuming that a medium-lift vehicle would be required (a cargo range of 2,000 – 20,000 kg), we can estimate a cost of between \$1700 and \$15,000 to launch 1 kg of material into low Earth orbit. Costs do not stop there and using current technology, transport to Mars requires approximately 9 times the weight of propellant per kg of cargo for launch, so it would appear that regular launches from Earth may not be financially viable to transport large masses of food such a great distance, especially given that inter-planetary launch windows are every 2-3 years. Therefore, it seems a reasonable planning assumption that as human beings begin to look further to living and existing as an interplanetary species, we cannot simply rely on Earth to supply the whole of the Martian population and as this population expands there will be an increasing demand for food and resources to be produced *in situ.*

This situation provides scientists and engineers with technical challenges and opportunities and drives the current set of planning assumptions that laying the foundations to rapidly develop sustainable agriculture ahead of any permanent human presence on Mars will be critical to the success of inhabitation and the future build of a colony. We propose the use of synthetic biology to provide solutions to some of these tasks. First, we will address the problem statements.

2. Problem Statements

The challenges we will address in the review have applications not only for the colonisation of Mars but for the optimisation, reclamation and utilisation of resources and land on Earth. With the population of Earth expected to reach 10 billion (bn) people by the mid to late 2050s [14], an increase of 20-25% from today, it is clear that radical changes in farming practice, sustainability of both food stuffs and drinkable water and conservation of the Earth's ecosystems will be required to meet the demand of an expanding population. Three problem statements may be defined which will be addressed in the next sections.

- the composition of the Martian regolith *in situ* may not support crop growth
- the conditions on the surface of Mars are inhospitable to life
- expansion of Earth's population requires further inventive ways to sustain all inhabitants with an acceptable quality of life.

3. Surface Martian Conditions

Mars is generally an arid, frigid, lifeless, desert receiving approximately half the level of sunlight on the surface when compared with Earth. The common average temperature reported is −63 °C (210 K; −81 °F) [15]. Surface temperatures may reach a high of approximately 20 °C (293 K; 68 °F) at noon at the equator and a low of about −153 °C (120 K; −243 °F) at the poles [16], [17]. The radiation environment at the Martian surface is, apart from occasional solar energetic particle events, dominated by galactic cosmic radiation (GCR), secondary particles produced in their interaction with the Martian atmosphere and albedo particles from the Martian soil, termed regolith. The highly energetic primary cosmic radiation consists mainly of fully ionized nuclei creating a complex radiation field at the Martian surface [18], [19]. Mitigating the risk of exposure to harmful levels of GCR will likely require the construction of one or more underground shelters and candidates could include modification of existing lava tubes which are located in low lying regions of the planet and which receive reduced levels of GCR. This is important as a previous study of analogue lava tubes on Earth showed that the amount of radiation in the interior of the tubes is 82% lower than on the surface of the planet [20]. These surface conditions set the scene for where synthetic biology may be able to help, which is likely in a sub-terranean environment using Martian regolith.

4. Nature of Soils

An average composition of Earth soil and Martian regolith is shown in Figure 1.

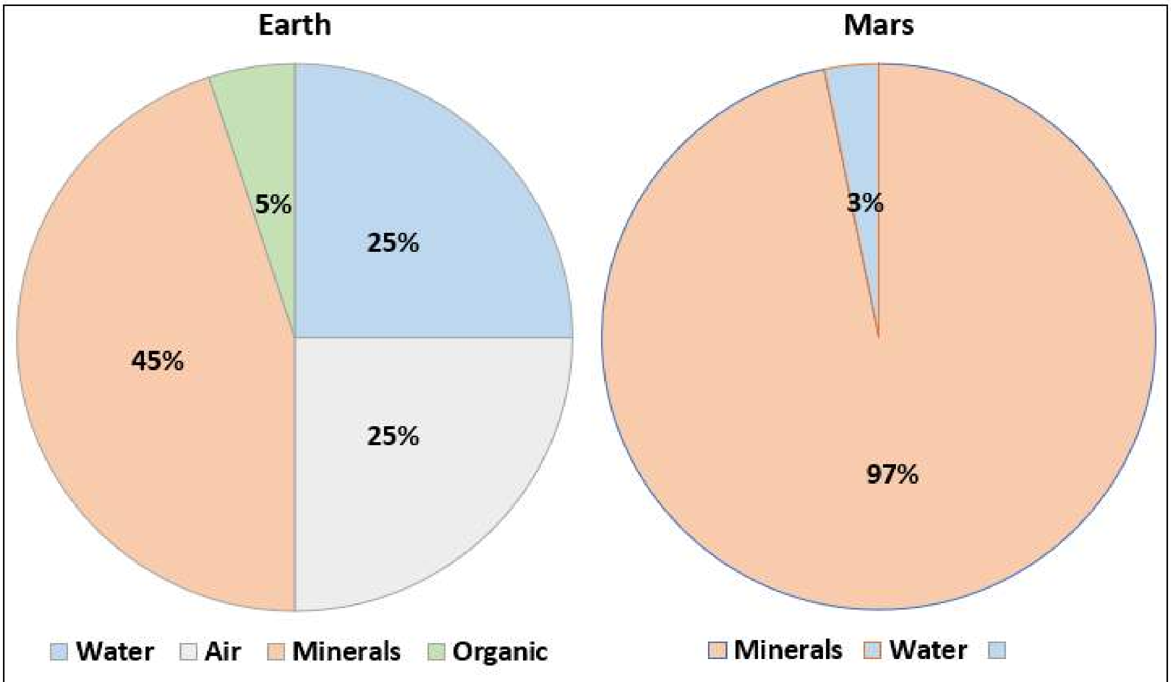


Figure 1. Approximate composition of Earth soil and Martian regolith [21 – 23].

As of May 2021, the composition of Martian regolith is believed to be devoid of organic matter due to the absence of either living or extant carbon-based lifeforms and the recent Mars 2020 mission will seek astro-biological signatures of life at sites within the Jezero crater. Unlike Martian regolith, soils on Earth comprise approximately 25% water, 25% air, 45% minerals of varying compositions and textures and 5% of organic matter derived from living or dead organisms [21] – [23].

Martian regolith is a dusty, pulverised rock layer which has been produced by the impact of asteroid and meteorite collisions with the planet's surface together with the erosion of iron-rich igneous rock by physical weathering over billions of years. The mineral matter in Martian soil is derived from weathered volcanic rock [24]. It has clay and silt-sized particles, a thin surface layer of very small sized dust particles and a reddish colour due to the presence of iron oxides. Overall, Martian regolith is of a sandy texture [25], [26] and has evolved over time [27]. Previous expeditions to Mars such as the Viking, Pathfinder, Spirit, Opportunity and Curiosity landers have analysed the chemical composition of regolith and found it to be made up mainly of silicon, iron, aluminium, magnesium and calcium oxides and these studies have permitted the sourcing of Mars regolith simulants (MRS) [28], [29] with a comparable elemental composition.

However, MRS have not included the presence of perchlorate which is present in Martian regolith as a salt of both magnesium, sodium and calcium. NASA's Phoenix Lander discovered the presence of perchlorate anions at a concentration of 0.4–0.6 weight % [30], [31] which was confirmed by the Sample Analysis at Mars instrument onboard the Curiosity rover [32]. In September 2015, the Mars Reconnaissance Orbiter detected hydrated salts of $NaClO_4$, $Mg(ClO_4)_2$ and $Mg(ClO_3)_2$ in locations thought to be brine seeps.

Perchlorates are powerful oxidising agents and toxic to both humans [33] and to plant growth [34] and a study showed that perchlorates, at concentrations similar to those detected in Martian surface regolith, become bacteriocidal when irradiated with a simulated Martian UV flux which caused vegetative cells of *Bacillus subtilis* to rapidly lose viability within minutes [35]. Moreover, two additional components of the Martian surface, iron oxides and hydrogen peroxide, were shown to act in synergy with irradiated perchlorates to cause a 10.8-fold increase in cell death when compared with cells exposed to UV radiation for 60 seconds. Interestingly, the distribution of perchlorates in the Martian regolith may be driven by the distribution of chlorine and the photocatalytic ability of silicon dioxide and other metal oxides, suggesting that areas may exist where the perchlorate concentration may vary [36].

5. Addressing the Problem Statements with Synthetic Biology

Synthetic biology, popularly known as SynBio is a multi-disciplinary area of research which aims to create new biological entities or to re-engineer systems existing in the natural world. It is a cross-disciplinary science which integrates multiple specialities including biology, systems biology and bioinformatics, biotechnology, machine-based learning, engineering, manufacturing and safety assessment. The scientific and ethical potential of synthetic biology for space exploration has been extensively reviewed [8], [37] – [41] and may in some instances be able to ameliorate the risks perceived for travelling to and living on Mars [42].

This section will review some selected candidates, provide an update on their status and illustrate examples under the most relevant category proposed [38], namely resource utilisation to permit life support. The mind map in Figure 2 illustrates the areas under consideration for this review. Other themes such as medicine, manufacturing, cybernetics and terra-formation are out of scope here and have been covered elsewhere, e.g. [8] and will be the subject of an additional future review when more data becomes available over the next several years.

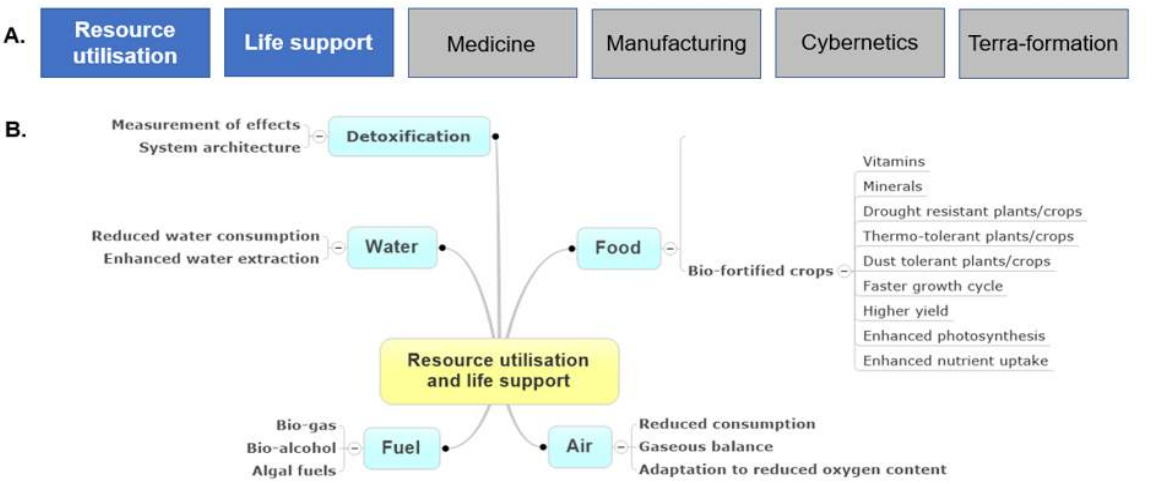


Figure 2. Mind-map of some potential targets for synthetic biology. A. Themes are denoted and those in blue colour B. form the subject of review.

a) Detoxification

The presence of perchlorate on Mars presents one immediate challenge which must be overcome to permit the growth of crops if Martian regolith is to be a substrate for establishment of a food supply chain. A terrestrial study with four wetland plants showed plant growth in soil in the presence of 0.5% perchlorate was associated with a decline in leaf chlorophyll content, a reduction in the oxidising power of root systems, a reduction in plant size above and below ground, and an accumulation of perchlorates in the leaves [34]. This study illustrates that for plants to grow in Martian regolith, the regolith needs to be processed to remove perchlorate and other toxic impurities. Moreover, findings suggest that the combined effects of irradiated perchlorates, iron oxide and hydrogen peroxide on the Martian surface, may demonstrate the low probability of survival of organisms introduced to Mars not adapted or engineered to grow in such conditions [35].

Perchlorate contamination on Earth is an issue of increasing global concern as it has a deleterious effect on ecosystems, with a concomitant loss of environmental quality and diversity [43]. Perchlorate is a ubiquitous contaminant produced from both natural and anthropogenic sources [44] and is present in areas associated with the use and manufacture of rockets and ammunition. In humans, perchlorate is a potent endocrine hormone attenuator affecting iodine fixation by the thyroid gland which is responsible for regulating metabolism, growth, and development [45] and may be considered harmful to the development of infants and children throughout their growing period [46]. Acute, short-term exposure has been shown to affect the nervous, respiratory, immune, and reproductive systems [47], [48] and it has also been related to thyroid cancer and teratogenesis during the first trimester of pregnancy [49]. The main direct routes of exposure of astronauts to perchlorate on Mars would be through direct inhalation of dust into the lungs, ingestion of contaminated water and ingestion of foods grown in the presence of perchlorate. Exposure to perchlorate through inhalation is not a general serious problem on Earth and concentrations are typically low in drinking water [50]. Most naturally occurring sources of perchlorate of potential health concern appear to be geographically limited to arid environments where deposits tend to be low in concentration, except for the relatively high natural concentrations found in Chilean caliches and some potash ore deposits containing perchlorate ranging from 0.03 to 0.1% [43]. Potash ore is mined and milled in Saskatchewan, Canada (silvite mineral), United States (New Mexico, hankite mineral from California), and Playa crusts from Bolivia [51]. The potassium chloride in these deposits originated in briny sea beds, similar to those of Chilean deposits where the concentrations of perchlorate range from 0.0025 to 0.27 %.

Given that perchlorate poses a threat to human health in some regions on Earth, various approaches have been identified which have both terrestrial utility and may be transferable to Mars, albeit in a limited environment in the first instance. It has been known since the 1920s that bacteria exist which can use chlorate and perchlorate as a terminal electron acceptor for anaerobic energy production and dissimilatory perchlorate reducing bacteria (DPRB) use a highly conserved perchlorate reductase (PcrABC), to reduce perchlorate to chlorate and subsequently chlorite. Chlorite is then rapidly removed by another highly conserved enzyme, chlorite dismutase (Cld), to produce molecular oxygen and chloride. One recent study described DPRB isolated from soil samples from hypersaline deposits in the Colombian Caribbean [45]. Capable of growing in salt concentration of 30% sodium chloride, bacteria related to *Vibrio, Bacillus, Staphylococcus* and *Nesiotobacter genera* were shown to reduce perchlorate concentrations from between 10 – 25% when grown in culture medium containing potassium perchlorate at various concentrations between 100 and 10,000 mg/L. DRPB may also have a secondary effect, particularly relevant to the concept of a closed biosphere, which is a unique ability to generate molecular oxygen as a transient intermediate of the central pathway of perchlorate respiration [52]. Constructing an ecosystem with such a population of bacteria may both protect colonists from serious health problems while also bolstering their breathable air supply.

Wherein lies the opportunity for synthetic biology? One proposition is that proposed by NASA [53] which is the construction of a synthetic biology system architecture capable of detoxifying perchlorate and enrichment Martian regolith in *one* entity. This is an example of using synthetic biology towards building organisms with a repertoire of individual functions [54]. In this case, the two system processes of perchlorate reduction and nitrogen fixation are proposed to be *combined* and be permissive for regolith-based agriculture on Mars. Research is underway to investigate two strains of a diverse clade of *Pseudomonas* organisms, which are technically more amenable to laboratory experimentation and include a perchlorate reducer and a nitrogen fixer. The concept is part of a broader field of study which includes the design, incorporation of engineered organisms and operationalisation of the Crucible open source bioreactor to emulate the Martian environment [55].

b) Engineered Plants

i) Drought Resistant Plants

Over the last decade it is now become clear that not only did water exist on the surface of Mars in the past to shape the landscape, but that it exists on the planet today in both liquid and frozen forms [56] – [59]. All plants require water, even if grown hydroponically and as of the time of writing, it is believed that considerable effort and energy will be required to abstract water and establish a supply chain even on a small scale. Water storage and retention in a form that can be made available to support plant and crop growth on demand is a significant hurdle which needs to be overcome. We should, therefore, regard water as a valuable commodity. Indeed, the predicted need to produce more terrestrial based food for human consumption and the demand for additional water to support crop irrigation and growth [60], [61], has warranted research efforts which have recently been reviewed [62]. In brief, synthetic biology has demonstrated that the amount of water lost through plant stomata can be reduced by modulation of Photosystem II (PSII). In 2018, a study investigated the effects of increased expression of PSII subunit S (*PsbS*), a chloroplast-derived signal for stomatal opening in response to light [63]. Transgenic tobacco plants were generated with a range of *PsbS* expression up to approximately 4 times that of the wild-type plant. Plants with increased *PsbS* expression showed reduced stomatal opening in response to light which resulted in a 25% reduction in water loss per CO_2 molecule imported. This study may have widespread benefit if findings can be transferred to higher plant species and food crops given that PsbS is a protein universally expressed amongst plants which photosynthesise.

A second example of the application of synthetic biology illustrates the reprogramming of plants to consume less water when they are exposed to an agrochemical [64]. In dry conditions, plants naturally produce abscisic acid (ABA), which is a stress hormone that slows plant growth and reduces water consumption by closing stomata. Using the model plant *Arabidopsis* and the tomato plant, ABA receptors were re-engineered to be activated by the much lower cost mandipropamid instead of the more expensive ABA. When the reengineered plants were exposed to mandipropamid, the plants survived drought conditions by activating the abscisic acid pathway, which subsequently closed the leaf stomata and reduced water loss.

Any plants which currently grow in a dry arid climate or could grow in such an environment may benefit if their water loss was reduced and in turn they would consume less water. Moreover, crops on the verge of viability in dry climates may become a better value proposition if their water consumption was more closely aligned with the regional supply chain. In addition to modulation of the stomatal opening and the potential application to higher plants and arable crops on Earth, these advances may offer an opportunity for growing crops on other planets such as Mars and perhaps over time, drive plant evolution to regulate stomatal opening in synchronicity with conditions. Further studies will be required to understand the extent to which these findings can be replicated in other plants and to explore any potential deleterious effects on plant growth including germination, flower and seed production and overall biomass and in the case of mandipropamid, the potential environmental risk posed by this agrochemical.

ii) Thermo-tolerant Plants

The next example concerns the bio-engineering of crops to withstand temperature extremes. As discussed above the surface of Mars experiences extremes of temperature [15-17], and today it does not appear possible that plants could be engineered to withstand such temperature extremes. However, any incremental level of tolerance, for example to cold, may reduce the need for heating and permit the constraints of temperature regulation to be more flexible. This is important as at low temperatures, ice crystals are formed in the extracellular matrix which ultimately causes dehydration in cytoplasm, shrinkage of the cell membrane and cellular rupture on elevated temperature. Engineering cold stress tolerance in crop plants and cold hardiness in trees has been reviewed elsewhere [65-67] and for heat tolerance via heat shock proteins [68]. In the case of low temperatures, our understanding of the biochemical pathways suggests that common pathways are involved in regulating both cold hardiness and plant growth, where inducer of CBF expression (ICE) and C-repeat binding factor (CBF) transcription factors play a key role in determining cold-induced gene expression [69], [70]. Molecular targets where modulation of gene expression may have utility in generation of transgenic crops tolerant to cold have been previously described [65], and one example is the production of frost tolerant tomatoes using the gene for an anti-freeze protein (AFP) isolated from carrots. Expression of AFP under the control of constitutive cauliflower mosaic virus (CaMV) 35S promoter when transformed into tomato var. PKM1, showed a significant decrease in membrane injury index upon exposure to chilling stress (4 °C) in the AFP transgenic tomato plants when compared with the wild type [71].

In summary, synthetic biology has the potential to meet increasing global food demand in the first instance and as a consequence, a collateral benefit is that our better understanding may benefit space exploration and push the envelope of genetic engineering to produce plants capable of surviving extremes. CRISPR gene editing technology, which will be referred to in a later section opens new opportunities to engineer thermo-tolerant and also disease resistance traits; current knowledge gaps and potential concerns have been reviewed elsewhere [72]. Although not addressed in detail here, the potential for plants to be engineered to dust tolerance and to photosynthesise using restricted wavelengths of light is also an area of current research.

iii) Bio-fortification of Food Stuffs

As with the previous sections on drought resistant and thermotolerant plants, the concept of bio-fortification is directed at alleviating a shortage of high quality food on Earth [73] and the first example is that of engineered rice [74]. Golden rice is a variety of rice (*Oryza sativa*) designed to produce β-carotene, a precursor of vitamin A, in the edible parts of the crop [75]. Primarily intended as a food for consumption by children in areas of the world where dietary insufficiency is prevalent, it is a product of synthetic biology which may provide an effective route to ensure a healthy complement of this vitamin in space settlers. The bio-engineered variety differs from the parental strain as it harbours three additional β-carotene genes capable of producing β-carotene in the endosperm and a further improved strain termed Golden Rice 2, was able to produce approximately 20 fold greater levels of β-carotene when compared with the original golden rice [76]. Golden rice has been demonstrated to be an effective source of vitamin A for humans [77], [78] and has received regulatory approval as a food in Australia, New Zealand, Canada and the United States [79], [80].

Other crops synthetically bio-engineered to produce increased β-carotene content include potato, canola, tomato, carrot, and cauliflower [81], [82]. Further examples of bio-fortification include tomatoes to produce a higher level of the B-vitamin folate, producing up to a 25-fold increase when compared with wildtype [83], rice and field-grown cassava to produce a higher iron content by over-expression of the iron storage protein ferritin from French bean and soybean [84].

iv) Bio-fuels

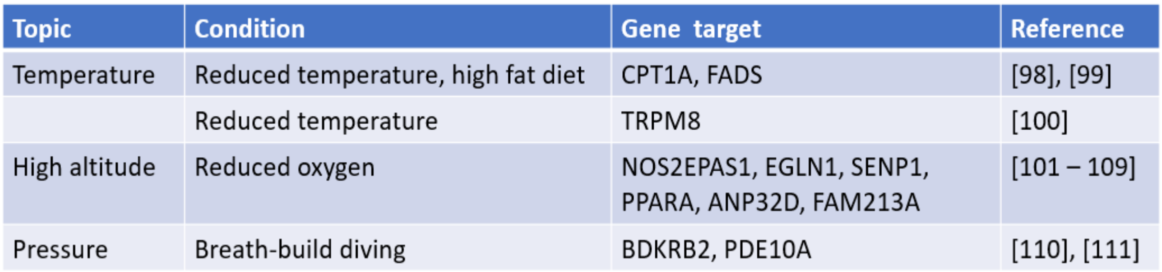
There has been great interest in the generation of bio-fuels for example, bio-gas, bio-alcohol and algal fuels over recent years, largely based on the desire and increasing requirement to develop alternative replacements for fossil fuels for terrestrial use, with a secondary consideration for provision of fuel on other worlds, e.g. [8], [85] – [89]. One of the major limiting factors for travel to and return from Mars is the limitation of propellant mass and the ability to produce propellant *in situ* rather than transporting it from Earth would dramatically reduce one of the largest contributors towards the cost of space missions. There are numerous methods for producing bio-fuels on Earth such as ethanol, hydrogen, methane, butanol and hydrazine and the production of bio-fuel on Mars would have utilisation for colony maintenance in addition to providing fuel to return spacecraft to Earth. Of particular note is a recent study [89] which aims to test the hypothesis whether cyanobacteria supported from Martian regolith and atmosphere could serve as a basis for biological life-support systems reliant purely on local materials. The investigators developed a low-pressure photobioreactor providing regulated atmospheric conditions to cultivation chambers to study the growth of cyanobacteria. The study concluded that growth of the cyanobacteria *Anabaena* was supported from the Martian regolith Mars Global Simulant-1 (MGS-1) and that cyanobacterial biomass could be used for feeding the secondary bacterium, *Escherichia coli*. This study, albeit using unmodified bacterial strains is important, because it suggests that a simulated atmospheric complement of gases at a pressure of approximately one tenth that of the Earth at sea level, may be capable of supporting photobioreactor constructs of cyanobacteria-based life support systems. It proposes the concept for future research that energy production may be made more effective by a combination of individual strain attributes in an architecture-based design system.

c) Next Steps: SynBio to SynEnhancement (SynEnh)

In the same way that synthetic biology has been popularised as SynBio, we may wish to coin the term ‘SynEnhancement’ or ‘SynEnh’, which conceptually starts to explore the potential of human synthetic biology to adapt performance to environment. The potential for SynEnh may come from many areas and one area to consider are those innate adaptations which have been identified in extremophiles. Extremophiles are organisms, generally bacteria which can live and propagate in environmental extremes including temperature, pressure, salinity, alkalinity/acidity and high radiation levels, e.g. [90], [91]. The ability of organisms to withstand such extremes may support the concept of panspermia where primitive life forms have migrated between worlds [90], [92]. A previous study has demonstrated that the *Bacillus subtilis* strain MW01 can tolerate exposure to low-earth orbit and simulated Martian conditions [93] and more recently an investigation conducted on the ISS studied the survival of three different bacteria; *Sphingomonas desiccabilis, Bacillus subtilis, and Cupriavidus metallidurans* placed in an environment which simulated the gravity of Mars [94]. The study found no significant differences in final cell count after experiencing Martian gravity. This suggested that the effects of reduced gravity change on the bacteria was overcome by the end of the experiment which may support the notion that microbial-supported bio-production and life support systems can be effectively constructed on Mars. A logical extension of this observation is that synthetic biology can be used to harness the characteristics of extremophiles harbouring pre-designed modifications as described previously in section a).

A further extension relates to the possibility of SynEnh for human enhancement [95] which proposes that the genetic component of a healthy human individual, in this case an astronaut or new-world colonist, may be modified by gene editing to confer adaptation to such an environment. Further research is needed to identify potential target genes and to ensure that the technology is both reliable and safe and this topic is out of scope for further discussion in this review. However, understanding the potential to engineer accommodation of extreme environments may be greatly assisted by understanding innate adaptation to, for example, temperature, altitude and atmospheric pressure [96], [97].

Table 1 summarises some examples of human adaptation to extreme environments which include high fat diet and cold, high altitude and reduced oxygen and increased atmospheric pressure. Human adaptation to high fat diet in populations is indicative of strong selection of the *CPT1A* allele in natives of Northeast Siberia [98] and a similar finding was made in the FADS genes in the Inuit population from Greenland [99]. Positive selection may have influenced cold adaptation where allele frequency variant increase in the TRMP8 gene may have played a role in thermoregulation [100].



Topic	Condition	Gene target	Reference
Temperature	Reduced temperature, high fat diet	CPT1A, FADS	[98], [99]
	Reduced temperature	TRPM8	[100]
High altitude	Reduced oxygen	NOS2EPAS1, EGLN1, SENP1, PPARA, ANP32D, FAM213A	[101 – 109]
Pressure	Breath-build diving	BDKRB2, PDE10A	[110], [111]

Table 1. Selected examples of gene targets implicated in human adaptation to extreme environments.

There are numerous examples of human extremophiles showing adaptation to reduced oxygen levels, such that are present at high altitude which is generally defined as greater than 2,500 m on Earth. Some Tibetans, Andeans and Ethiopians possess genetic determinants that have evolved at different times and which confer advantages for gaseous exchange in the respiratory system. Genes harbouring mutations in NOS2, EPAS1, EGLN1, SENP1, PPARA, ANP32D and FAM213A [101-109] have all been shown to play roles in adaptation to high altitude.

Lastly, some studies have shown that members of the Bajua Indonesian population have acquired adaptations to hypoxia by developing large spleens, possibly as a result of the practice of breath-hold diving performed for several minutes permitting dives to a depth of 30 m or greater [110], [111]. The study identified physiological and genetic adaptations to diving where the development of larger spleens in individuals were associated with a gene involved in regulating thyroid hormone levels which enables additional storage for oxygenated red blood cells.

These examples illustrate two things. First, it may be possible to include in astronaut or colonist selection criteria innate genetic predisposition to adaptation to extreme environments where the genotype confers a phenotypic advantage to, for example atmospheric conditions which may require less energy to maintain. Secondly, an understanding of genetic adaptation may profer candidates for gene editing strategies supporting the concept of SynEnhanced humans, specifically engineered to cope better with the Martian environment than their wild type counterparts.

In summary, Figure 3 presents an overview of the inter-disciplinary components contributing to both SynBio and SynEnh. At the heart of the principal disciplines, manipulation of DNA is a core activity which may lead to the generation of modified plants and other organisms or the construction of multi-architecture pathways within an organism.

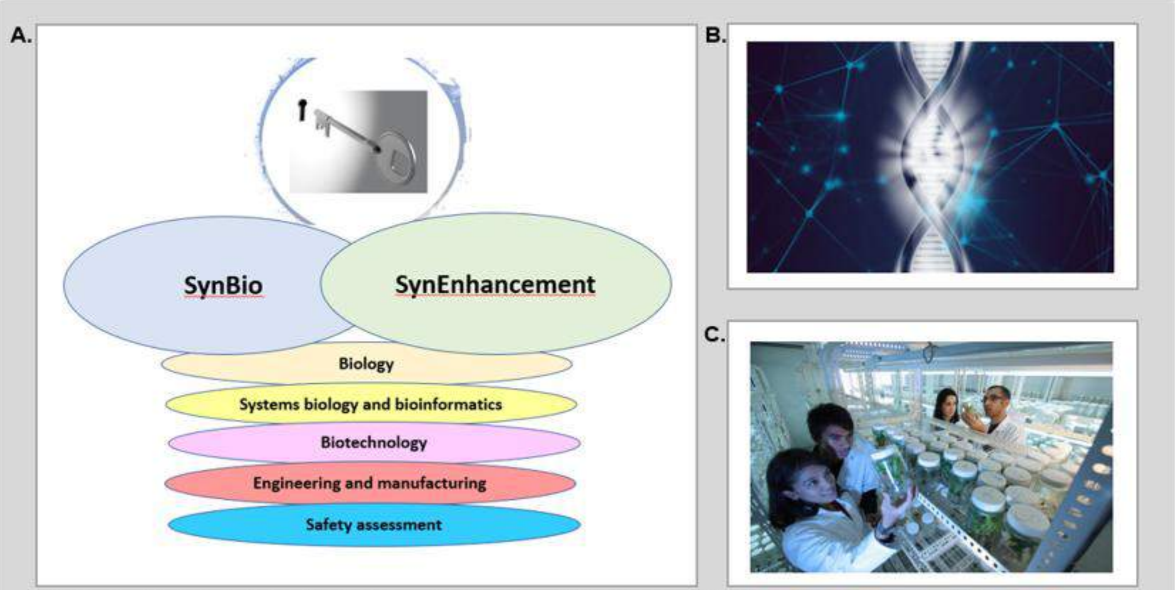


Figure 3. A. Some key disciplines supporting SynBio and SynEnhancement, B. DNA manipulation is integral and C. scientists study potential SynBio engineered plants (Images credit PIXABAY).

6. Conclusion

In this review we defined three problem statements where synthetic biology may play a role to better the future of mankind for life on Earth and to permit the exploration of space and other worlds. The first relates to the nature of Martian regolith; the requirement to detoxify perchlorates and the need to bio-augment with bacteria which fix nitrogen.

The second challenge refers to the conditions on Mars where extremes of surface temperature, the lack of flowing liquid water, the propensity for dust storms and the presence of GCR will prevent anything but short term residence of human beings and the growth of colonies. Clearly humans will need to be sheltered in a biosphere which may either be on the surface, semi or completely subterranean and the atmosphere in the biosphere must be conducive to supporting life. Thus the application of synthetic biology is as appropriate to supporting life in a closed environment on Mars in much the same way that it may support life on Earth, except on a much smaller scale and where the interdependencies of feedback control systems are absolute and where there may be little margin for error.

The third problem statement is illustrative of where developments in synthetic biology may greatly benefit life on Earth. Figure 4 shows the actual and projected increase in the total global population of the human species over the decades and sets both a challenge and an opportunity for humanity. In meeting the needs of a population which appears to be increasing linearly by approximately 0.5 to 1 bn people per decade, with no apparent sign of the rate decreasing and predicted to reach 10 bn by 2050 [112], it appears obvious that a food and supply chain will need to ever increase in efficiency while reducing the carbon footprint needed for maintenance and future growth. Crop modifications such that have been described in this review include biofortification, reduced use of water to produce faster life-cycle times and higher yield in more extreme environments. These are some prime targets for the development and deployment of synthetic biology strategies.

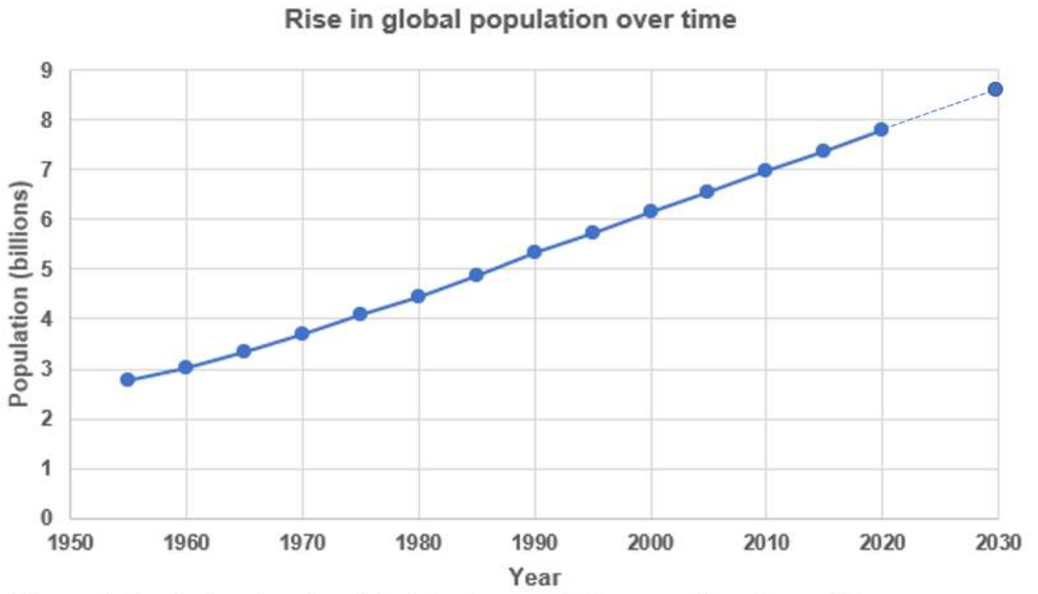


Figure 4. Graph showing the global rise in population over time. Dotted line represents the extrapolation to 2030. Redrawn from data table [14].

The potential implications of these studies are clear for sustaining an expanding human population on Earth. Likely driven out of necessity and in part to meet the challenges of climate change, the application of any discoveries provide realizable benefit for human settlements living in isolated environments on Earth, during prolonged space travel, or in the establishment and maintenance of colonies on other worlds. Synthetic biology has already changed how humans live today, e.g. [113], [114] and may have a role to play in the preservation of biodiversity, e.g. [115] and in a new generation of biosensors, e.g. [116]. There would seem to be no limit on how synthetic biology can be developed and exploited and the duty falls on us as human beings to ensure ethical and responsible use for the whole of humankind [117] – [119].

It would appear that today in 2021, that the potential benefits of synthetic biology outweigh the perceived and known risks and with the judicious and considered use of our knowledge in molecular biology, engineering science and agriculture, our species may not only be able to live and thrive on Earth, but also to expand our presence within our solar system. With the stated aim of Mars colonization by the early 2030s timeframe, this promises to be an exciting decade ahead!

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Back to the Future: The Rise of Human Enhancement and Potential Applications for Space Missions

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Abstract:
Rapid advances in biology, electronics, computer and data science have turned invention into products, changing the lives and lifestyles of millions of people around the world. This mini-review will describe some remarkable progress made over the last 10 years which serves both healthy individuals and patients alike. With a forward looking lens towards long term space missions and the potential colonisation of the Moon and Mars, we discuss three technologies under development. We conclude with a distant looking perspective on the prospect of gene mediated human enhancement and highlight the importance of aligning benefit for people on Earth with goals for future space missions and the need to establish regulatory and ethical guidelines.

Keywords: uman enhancement, gene therapy, gene editing, smart skin, brain-computer interface, prosthetic limbs, wearable devices, exoskeleton.

1. Introduction

As defined by the SIENNA project, human enhancement is: “the process of positively augmenting our abilities, permanently or temporarily. It includes any technology that expands or positively alters our capabilities or appearance: drugs, hormones, implants, genetic engineering or some surgeries" [1], [2].

In the early and middle 2000s, many concepts were progressed to products; some to restore function such as prosthetic limbs, cochlear implants, pharmaceutical [3] and gene mediated interventions [4], and others to augment human performance such as wearable devices [5]. More recently, advances have been made to support the restoration of sight and mobility, co-ordination and life-style convenience with the development of retinal implants – the bionic eye [6], brain-computer interface modalities [7] and smart skin using implanted radio frequency identification tags [8]. Selected examples of biological, cognitive and mechanical enhancements and overlaps in the underlying scientific disciplines are illustrated in Figure 1, with those highlighted in green text further depicted in Figures 2 and 3. It is widely believed that artificial intelligence (AI) has a central role to play in a post-human future [9].

Prior to 2011, prosthetic limbs tended to be clumsy, unsightly and provided sub-optimal co-ordination and mobility. Since the development of the modular prosthetic limb by the Defense Advanced Research Projects Association (DARPA) for Johns Hopkins University [10], proto-typing and evaluation [11] – [12] and the availability of life-like covers from companies such as Dorset Orthopaedica, performance and acceptability for the end user has been revolutionised. The development of virtual reality (VR) headsets which create an immersive experience can help educate and entertain consumers, has optimal uptake in technologically adept people [13] and may be associated with health concerns when used excessively [14]. Finally, development of smart watches, in particular the Apple Watch has many applications for positive monitoring of human health [15], is continuously under evaluation [16] and may inform the user of their current health status and whether intervention is required.

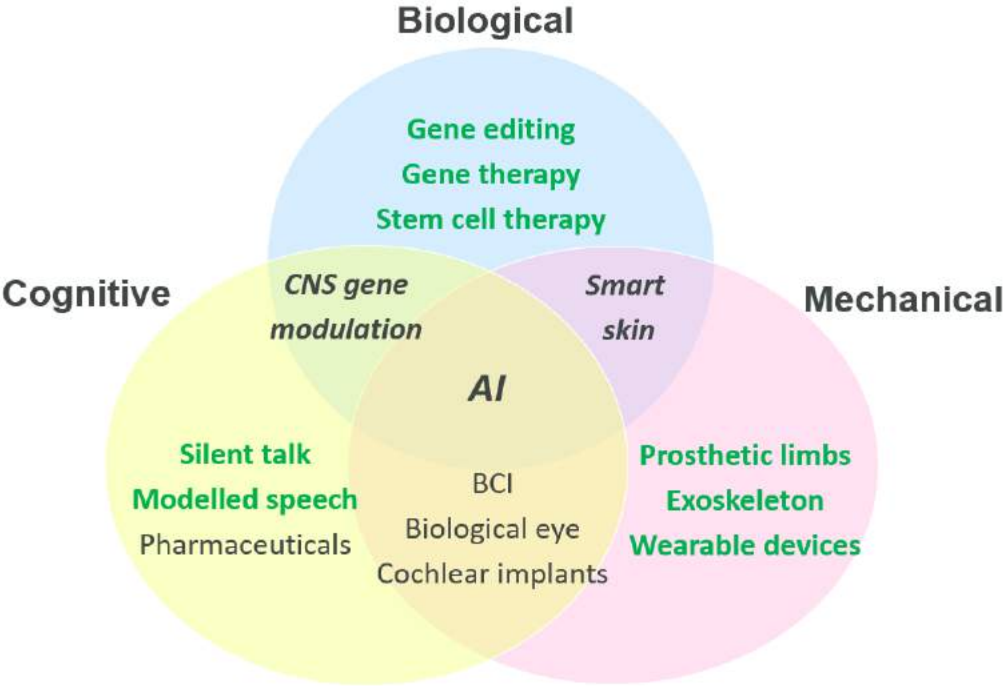

Figure 1. Venn diagram illustrating selected modalities and products and the overlap of supporting scientific disciplines. CNS: central nervous system, BCI: brain-computer interface, AI: artificial intelligence.

With a view to future developments, DARPA is developing an enhancement which may lead to the possibilities of non-vocal communication [17]. Through analysis of neural signals, brain activity is mapped using an electroencephalogram (EEG), with the aim of aligning specific EEG patterns to thoughts and given enough commonality between people, transmitting the signals to a receiver. This application may have utility in military campaigns and in extreme environments, for example in space where a synthesis of thoughts from multiple participants may be required to rapidly assess a situation and instigate an action.

The oldest prosthetic device first – a false toe dates to ~1,000 BCE. Since 2011 the Modular Prosthetic Limb has revolutionised the accuracy and control for the end user

First prototyped in 2012 and launched in 2015, the Occulus virtual reality headset allows users to experience life –like events

First launched in 2015, with health and fitness at the core, the 2020 series 6 Apple Watch is the most popular smart watch on Earth

Figure 2. Selected advances in human enhancements between 2011 and 2015. Images: credit DARPA, Dorset Orthopaedica and PIXABAY.

A further example of a communication enhancement is that being developed by Braided Communications who offer a tool for seamless and meaningful communication in contexts where there are large signal latencies, such as deep space exploration with, for example, up to a 22 min delay in receipt of a transmitted signal from Earth to Mars [18].

DARPA is developing 'silent talk' a non-vocalised communication technology using EEG signals aligned to speech patterns transmitted to one or more receivers

Braided Communications is developing a method to manage the signal delay between Earth and Mars imposed by laws of physics

NASA is developing a robotic exoskeleton which may help astronauts and paraplegics on Earth keep healthy and increase mobility

Figure 3. Selected future looking enhancements which benefit astronauts. EEG: electroencephalogram. Images: credit PIXABAY, Braided Communications and NASA.

This system may optimise communication supporting operational effectiveness for safety, medical and social exchanges with mission control, friends and family. Further details of the technology are expected in late 2021. Finally, the development of lower limb exoskeletons has received much attention since the early 2000s. In particular, this has been of benefit to people with disabilities especially since the metabolic barrier has been overcome reducing the metabolic cost of walking and running versus without a device [19], although design considerations need to be taken into account, potentially via a regulatory framework [20]. Within the context of space travel, National Aeronautics and Space Association (NASA) has developed the X1 robotic exoskeleton [21] which in addition to maintaining astronaut health in microgravity, may provide strength augmentation for astronauts during extra-vehicular activities and incorporate connectivity to record and transmit data in real-time to mission controllers on Earth. This may further inform on any remedial steps to be taken to maintain astronaut health.

2. Conclusion

Astonishing progress has been made over the last decade in products which may restore or augment human function. Advances in gene editing technology spurred on by numerous human clinical trials [22] may make it possible to genetically enhance human beings. With the stated aim of Mars colonization by the early 2030s, it is essential to progress the science for all modalities of human enhancement with both enthusiasm and caution. Society has a duty to ensure the need for compliance to and adherence with strict regulatory and ethical guidance, and to recognise both the challenges posed and the potential good for mankind if acceptable solutions can be found and enacted [1] – [3], [20], [23], [24]. With the oldest prosthetic dating back to ~1,000 BCE and stereoscopic images in the late 1830s as precursors for modern VR, we can look back to the future and a very exciting time awaits us all on Earth and in space.

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Predictions and Possible Solutions for the Sustainability of Mars Settlement

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Abstract:
With the end of the Cold War, political and ideological competition has decreased as a stated reason for space exploration. The possibility of establishing a settlement on Mars is being seriously evaluated by state and commercial space agencies, which includes objectives to expand human civilization and ensure the continuity of the human species. The technological challenges associated with space settlement continue to receive significant attention, but the success of space settlement will also depend on other human factors. This study presents a high-level overview of some potential issues that could arise with the development of a permanent populationand a space economyon Mars. This study highlights some of the anticipated problems of overnance, trade, production, and proliferation that will need pragmatic solutions to ensure the sustainability of a martian settlement. This paper is intended to instigate further discussion and research regarding human and economic factors that could enable or constrain future settlements on Mars.

Keywords: space exploration, mars settlement, mars economy, futures studies.

1. Introduction

Recently, space activities have been a stage for radical transformations. Globalization and advancing technology have influenced space activities which have been a strategic monopoly for certain countries ever since the dawn of space age [1], [2]. SpaceX, Deep Space Industries, Planetary Resources, and other private companies are developing their own capabilities for utilizing space resources, while state agencies like NASA, ESA, JAXA, IRSO, RFSA and CNSA have ongoing and emerging plans for Mars exploration and eventual human settlement. Perseverance is extracting the first oxygen from the Red Planet while looking for an answer to the question "was there life?" on Mars [3]. NASA's Ingenuity helicopter completed its second flight on Mars [4]. Many state institutions and private institutions have been working on a series of plans to visit Mars or asteroids, which are intended to support both financial profit and scientific transformation. It is also hoped that starting from the mid-21th century, the cost of entering an orbit will greatly decrease in accessing the near-Earth area, the Moon, Mars and beyond. SpaceX plans to use Starship for missions to the Moon as early as 2022 [5]. The company plans to fly four ships with two cargoes and two crew members in 2024 [6], [7].

Despite the discussions on the challenges brought by the radiation level on Mars, the infertile soil and low gravity; having a settlement on Mars is no longer a mere curiosity or a science fiction due to the increase in commercial interests as well as the possibility of reducing the risk of extinction on our planet.

The presence of a settlement on Mars would also enhance scientific and technologic advancement. Despite the costs and risks, such a mission would also have some ethical considerations such as providing a refuge to ensure humanity's survival in case a global catastrophe happens on Earth. Settling Mars might be a more long-term ambition than current agencies are planning, as humans are social beings and such a settlement will have biological and social challenges [8].

Nevertheless, scientists such as Carl Sagan have suggested that an extra-terrestrial settlement would be the only way to prevent the extinction of humanity [9]. The idea of building universal shelters to protect humanity from a series of global disasters has recently gained increasing attention. Such authors as Isaac Asimov, John Lesli, Martin Rees and Nick Bostrom have argued that humanity is under the threat of a series of global disasters [10]. Therefore, it is necessary to build shelters to ensure the re-establishment of civilization and the survival of humanity [11]. Accordingly, it is of utmost significance to secure a copy of our vital materials in those shelters [12]. Undoubtedly, the most important challenge for having a settlement on Mars is the high level of radiation [13]. Mars has a weak magnetic field and a thin atmosphere. As a result, the surface is not protected from radiation like it does on Earth. There are three types of radiation on Mars that we should be worried about. The first is solar winds, which consist of charged particles that are constantly coming out of stars. The second is cosmic rays and the third is solar flares. Covering the entire habitable area with about a meter of regolith might be sufficient to protect the settlers from the first and second types of radiation [14]. Addressing the radiation risks of Mars settlement remains an ongoing challenge and active area of research.

Several countries have already started to conduct robotic missions on Mars, which support immediate science goals but are part of a longer series of missions that are intended to develop a permanent settlement.

NASA launched the Perseverance explorer on 30 July 2020, which will land at the Jezero crater of Mars to collect evidence of ancient life and samples of rock and soil for possible return to Earth [15]. The United Arab Emirates became just the fifth nation to successfully send a spacecraft to Mars when its robotic probe, named Hope, began orbiting the red plant [16]. The orbiter of the Tianwen-1 Mars mission, China, successfully launched towards Mars on 23 July 2020. China's mission to Mars is to study the geological structure of Mars, surface features and climate [17]. The ESA ExoMars Trace Gas Orbiter mission launched in 2016 and detected new gas signatures on Mars. This discovery helps to unlock new secrets about Mars' atmosphere, as well as to determine whether the atmosphere of Mars contains methane, a gas associated with biological and geological activity [18]. These missions are all part of a longer program of scientific exploration on Mars by these space agencies, which all have plans to eventually send astronauts to Mars.

This paper provides various predictions and possible solutions regarding some of the issues that are expected to emerge during the settlement of Mars. This paper is not intended to be an exhaustive presentation of all such issues that might occur, but instead this paper is intended to highlight some of the human challenges for developing a sustainable martian settlement. The high-level discussion presented in this paper could serve to motivate further research on specific issues or could also be used to developo a more extensive research agenda for studying Mars settlement. In general, this type of analysis of the sustainability of humans in space can also be useful for future studies, such as by informing activitites in scenario development or future projections.

2. Why Should Humans Live on Mars?

The Red Planet has always been a source of mystery and challenge for everyone. Settling Mars is a popular topic today, but it also has a controversial side [19]. People have many reasons for wanting to travel to Mars and to settle there. In one sense, curiosity and exploration has been innate to humans, and aspiration of going to another planet provide a continuation of this human desire to travel beyond the boundaries of our home [20].

If humans are to live on Mars in permanent settlements, then the use of local resources will be essential for long-term sustainability. The atmosphere of Mars is composed of 95% carbon dioxide, 3% nitrogen, 1.6% argon, small amounts of oxygen and water vapour. There is also a source of methane in Mars. A large portion of Martian surface is covered with a talc powder like material. Small hematite spheres has been found in the rock samples collected from the Meridian Plain on Mars. Since 2003, sulphur, iron, bromine and other minerals have been discovered on Mars by the high resolution stereo camera located in Mars orbit. Sojourner Rover of Pathfinder measured the elements on Mars rocks with Alfa Proton X-ray spectrometer by NASA. Several discoveries by the Mars rovers have shown that the Red Planet has many of the natural resources needed to sustain human life. Solar wind sources available on Mars might be a practical solution for generating energy. The abundance of volcanic features combined with widespread craters also suggests the possibility of various ores on Mars. Further prospecting would be needed to determine the economic potential of Mars, but sufficient evidence exists to suggest that commercial agencies may take interest in a variety of mineral resources available on Mars [21].

SpaceX founder Elon Musk has stated this his goals for settling on Mars is for the survival of mankind. In terms of survival arguments, authors such as Carl Sagan, Ray Bradbury, Stephen Hawking and Paul Davies have articulated views that overlap with some of Musk’s ideas [22], [11]. Various authors have discussed reasons for traveling into space and develping a permanent settlement on Mars. Many of these views have been widely represented in popular discussions of Mars settlement, such as [23], [19]:

1. Extending the sustainability of the human species
2. Searching for extraterrestrial life
3. Find new solution to problems that can improve life on Earth
4. Transforming our civilization
5. Demonstrating economic and political leadership

So far, researchers have not only discovered evidence of trace of water in the form of ice beneath its poles, but underground lava tubes are also suspected to provide potential underground habitats to future settlers. The exploration of such sites on Mars provides scientific information about the origin and the future of Earth that can also assist with planning for eventual human settlement [24].

First, reaching other planets can increase our chances of survival by providing a refuge for withstanding global catastrophes. Secondly, the purpose of Mars settlement is not just about survival but also about the contribution to sustainable growth through using the natural resources of Mars.

The third item is about improving the life quality of those people living on earth through the development of space technology. The process of technology transfer has resulted in many useful inventions in our lives today that originated as space technology. For example, weather forecasting satellites save thousands of lives each year by providing public storm warnings. Likewise, satellite communication abilities affect every aspect of civilization. Satellite technologies have made banking and finance, navigation, international and long-distance phone calls in daily communication, satellite TV and radio completely routine [25]. Fourth, space settlement provide an opportunity for the transformation of humanity as a species by challenging explorers to venture even greater distances from home. For example, the thematic epics of the long geographical discoveries of Western civilization, such as the long ships that colonized Greenland, serve as an inspiration for spaceships being designed for sending to Mars in the near future. In fact, in a way, exploring the interplanetary ocean of space is like a repeat of such old times. The curiosity about the existence of humanity, its origins and where it came from is perhaps an evolutionary drive [26]. Fifth, the state and private agencies that develop settlements on Mears will gain recognition as economic and political leaders in the emerging space sector [27].

The first settlers on Mars might be representatives of state or private agencies that are driven by mission requirements with rigid guidelines. However, as the settler population begins to grow to include a larger staff, tourists, and others, such a rigid system is less likely to be sustained. For this reason, a new governance order would likely emerge as a permanent and self-sustaining population develops on Mars.

3. Predictions

This section raises some questions and offers some predictions on the future of Mars settlement as well as the solutions for some possible challenges. These predictions are qualitative and speculative, but they are intended to help frame the discussion about Mars settlement and promote further analysis.

3.1. Who Will Go Fırst?

In terms of ethnicity, religion, terminology, and personal characteristics; the identity of Martian settlers is unknown. Personal values, political beliefs or other "psychographic" factors with which people identify themselves can become quite significant in the process. Besides, in case the private organizations offer guidance to the Mars settlement; the culture of this organization may also play a role.

The initial small group of settlers might consist of altruistic, distinguished and technologically strong individuals [19]. By sending robots to Mars first, a field station could be built on the Martian surface. Using propulsion systems similar to Deep Space Transport, the spacecraft could transport and land supplies, habitats, equipment for in-situ resource use (ISRU) and other equipment using robotic flights [28]. If a Mars settlemet is actually able to develop to the point at which it can sustain an excess population beyond those required to manage it, then Mars may attract a wide population of tourists and other visitors. Mars could be a shelter for those feeling overwhelmed by overcrowding; or it could be an attractive place for to those who want to abandon Earth. One can even imagine extreme cases in which forced labor could occur in space settlements that lack sufficient oversight. However, such futuristic space settlements might also include a mixture of different social classes in addition to lower classes. Such a broad range of possibilities is a ripe opportunity for developing different scenarios for the emergence of a Mars population [29]. In such a distant future, if Mars were to become a self-sufficient independent planetary state, then it could even be a place where people might willingly and easily travel to, which conceivably could include monitored travel that requires an international passport or a visa, similar to international travel on Earth today.

3.2. Who Will Lead the Development of Mars Settlements?

Both state and commercial space agences are seeking to eventually send humans to Mars, but it is not yet clear who will suceed first. State agencies might tend to prioritize scientific missions that also support political objectives. Commercial space agencies may priotitize missions that generate profit, which may make the partnerships between the government and the industry quite complicated [30].

Several private companies, including SpaceX and Blue Origin, have announced their intention to continue developing space touring opportunities in the coming years. Such ventures may ultimately enable tourist travel to Mars. Successful or not, such efforts show increased public interest in space settlement and suggest the possibility that private companies may be the first to arrive on Mars, rather than state space agencies.

3.3. How Will Trade be Economıcal?

Just as nation-states on Earth need to trade so that they can financially improve themselves; so will the future planetary civilizations. While it is possible to send food or other basic necessities to settlers on Mars, an important possible export could be patents and other forms of intellectual property. The settlers on the Red Planet will need to innovate to meet their own needs. And there is no doubt that they will be capable of making several technological inventions in a space without boundaries thanks to their bright, wise, and skilled nature. For instance, they will need to grow their crops in greenhouses, which certainly requires optimization for plantation area within the greenhouses. As a result, they will have a strong incentive to resort to genetic engineering to boost crop yields. An advanced technology to recycle wasted yet valuable materials. Such inventions will also prove themselves to be significant for life on Earth and patents licensed on Earth will thus create a flow of sustainable income for the Red Planet [31]. Zubrin, favours the idea to license intellectual property for the profitability of the Mars settlement. He says that interplanetary trade will have three outlines in the future. His first suggestion for export business in interplanetary trade is helium-3, a rare isotope of considerable value that does not exist on Earth and can be used for second-generation thermonuclear fusion reactors if extracted on the Moon. Mars does not yet have a known helium-3 resource, although helium-3 deposits have been detected on the Moon. On the other hand, because of its complex geological history, Mars currently possesses a considerable amount of concentrated mineral ores with precious metal ore concentration since men have intensely scanned terrestrial ores for the last five years. The second suggestion is deuterium. Deuterium is more expensive than other elements, even with cheap power. Its current market value is 25% more valuable than silver (27 dollars per ounce) or gold (1200 dollar per ounce). Zubrin suggests that a Mars settlement could profit from selling deuterium. Zubrin also suggests asteroid mining. When the Mars settlement starts living on the Red Planet, the settlement will have a crucial role in supplying ore to the asteroid belt. Zubrin also considers Phobos and Deimos as valuable preparation spots on the way to the asteroid belt. He combines all these suggestions under a concept of “triangular trading activity” in which our planet sends high technology finished goods to Mars; Mars sends low technology finished goods to the asteroid belt and possibly food staples to the Moon, and metals are sent over the asteroids [32]. Until the moment Mars settlers transform into a self-sustaining community, they will be dependent on Earth. Hence, its financial independence will be based on technological inventions that do not exist on Earth, products that cannot be acquired on Earth, and other activities.

The Outer Space Treaty of 1967 gives states responsibility and jurisdiction over any non-government organizations, so the laws of the host state regarding patents and intellectual property will likely also apply to private space agencies. For example, consider a group of people living on Mars. Initially, settlers will be dependent on Earth. However, the mass of the products to be supplied from the world will be very costly as the population increases in time.

As the incentives for technological development increase, financial growth will follow. The cost of importing food from Earth to Mars will result in financially high export and import rates for many products as the cost will include transportation and labour work, and as a result it will eventually be cheaper to produce food on Mars. In this context, the Martian economy will be dependent on capital initially, and over time the settlers will attempt to capitalize their products and inventions [33].

4. Can We Develop our Own Food Production on Mars?

When the first settlements reach Mars, one of the biggest challenges will be producing a food source. It will be very costly to continually procure these food resources from Earth. Over time, this will push settlers on Mars towards a self-sufficient and sustainable agriculture [34]. So what kinds of foods can we produce on Mars? Transporting large animals into space and set up the facilities necessary to house the animals as livestock is infeasible in the short term, but smaller animal protien sources such as crickets could supplement plant-based foods [35].

In the long term, Mars settlers will contribute to the manufacturing of anything varying from food and medication to breathable air, industrial chemicals and construction materials, depending on the options for on-site production. Biological manufacturing will be of utmost importance in Mars as it will help Mars settlements transform gradually from full dependence on Earthly resources to full independence. Biotechnology is one of the most urgent needs for food production on Mars. For instance, it will take about five tons of food to feed a crew of six with a daily 3.000 calories for a 500-day surface mission. For emergencies, this will vary from eight to ten tons. Traditionally, nutrient and calorie dense foods are the preferred dietary options for astronauts to minimize the workload, which does not necessarily priotize the variety and aroma of foods. Although the first missions will transport all the food needed to survive; microbial organisms might supplement the basic food supply [36].

Insects and clean meat (cultured meat) may be produced as food on Mars. As time progresses, Mars settlers may increasingly turn to different options beyond plant-based options. In a study conducted at Lunar Palace 1 in China, they created a menu of cultivated plants and insects that feed 3 people in 105 days. In such studies, microbes have been suggested as a direct or indirect food source that could be used on Mars [37]. Plants and vegetables have been successfully grown in NASA’s hydroponic greenhouses that mimic greenhouses on Earth [38]. The use of synthetic biology, which offers a new perspective on growing plants and vegetables on Mars, could also improve the potential performance of plant life on Mars [39]. Synthetic biology is ‘a new field aiming to use engineering principles to reprogram living systems’ [40]. An advanced synthetic biology facility could improve many of the features needed to ensure crops thrive on Mars, and developing such these next-generation products on Mars might even benefit people on Earth [34].

5. What Governance Structures Will Develop on Mars?

The Outer Space Treaty forbids any claim to sovereignty on celestial bodies. Yet space agencies are still developing plans to permanently settle Mars, while refraining from making explicit sovereign claims. Such an ambiguity suggests the need for new governence models to apply to the sharing of Mars.

Bruhns and Haqq-Misra suggest a large-scale planetary parks and land approach for Mars settlement to limit sovereignty over certain regions of Mars. According to this model, the international community will determine a planetary park system to exclude irregular trespassing or settlement within the park borders of Mars [41]. The model also suggests the establishment of an administrative Mars Secretariat. Intersettlement relationships and conflict resolution will be diplomatically managed as in line with international agreements by a commission of representatives for Mars settlements [41]. Once Mars settlements reach a certain size, then conflict and the need for conflict resolution may become inevitable.

The leaders of martian settlements may not always be able to resolve all conflicts with other settlements. Therefore, it could be beneficial to have a Mars Secretariat as a mediator, although it should be emphasized that such a Secretariat does not hold any formal power or claim sovereignty over other states.

Many other such possibilities exist for governing Mars; however, until a state structure is built on Mars, it is strongly possible that Mars will be run by global actors [29]. Elon Musk thinks that the Mars will have not a representative democracy but a direct democracy; so that means people will directly vote on the problems. He said that laws are made with 60% of the votes and laws are abolished with more than 40% of the votes. Direct democracy would create conditions where it's slightly harder to put laws into effect than to abolish them and where laws do not automatically just last forever [42].

Technocracy is a system in which the decision makers are technical experts. The administrative roles are taken over by the scientists, engineers and technologists with the knowledge, experience, and talent [43]. Such countries as South Korea, Singapour, Malaysia, Vietnam, India, and Thailand are the countries which practice the basic elements of technocracy really well. Their basic philosophy is "minimum government, maximum governance" [29].

Meritocracy is also suggested for Mars settlements. Meritocracy is a system in which the merits, skills, effort, and competence are considered as measurements for seniority and promotions. The term merit also includes talents, education, and experience. Meritocracy can be considered as an ideal justice principle as it ignores ethnicity, origin, and gender. A combination of competence and effort is basically the key point in meritocracy focusing on the occupational achievement [44]. Singapore is the best example country for applying meritocracy principles as the qualified people are assigned to the management positions, which could be a contributor toward Singapore's financial success as a dominant ideology within the country.

This list of suggested models is necessarily incomplete and intened to be illustrative of the types of models that are relevant to Mars. Regardless of the model, it is imporatnt that such models maintain the political freedom of Mars settlers. In other words, governance should avoid any tendency toward tyranny or the infringement of civil liberties.

6. How to Proliferate on Mars

It is questionable whether it will be possible to proliferate on Mars. However, it will also be mandatory to sustain the population on Mars. Until Mars is a self-sustaining settlement, there will be a need for migration from Earth to maintain a stable population [45].

The space environment is already physically challenging for manned flight. Ionising radiation, tissue damage, cancer risk, acute radiation syndrome, and central nervous system damage are some problems [46]. Ionising radiation will cause "either directly or indirectly an atom to lose an electron or a breakdown in the nucleus" and this is significant potential risk for space travellers. This ionising radiation can directly damage cellular structures or break down water molecules, both of which may lead to abnormal cellular function, DNA mutation and even cellular death [46]. The space environment has severe impacts on muscles, bones, blood flow and immune system and thus understanding how to treat them is of utmost importance for space missions. Genetically compared to humans, mice are easy to work with and can help us understand how the human body may operate under these circumstances [47].

Russian Bion-M 1biosatellite hosted male mice in space for 30 days. The project's objective was to understand cellular and molecular mechanisms of mice when exposed to long-term microgravity [48]. In a study conducted by Italian Space Agency, mice were exposed to 91 days of microgravity [49]. Which affected their reproduction system and fertility. In another study carried out by Japanese researchers, 12 male mice were kept for 12 days in the International Space Station. While some were exposed to microgravity, the others were exposed to artificial gravity. Upon their arrival on Earth, female mice which had never been to space were fertilized with male sperm and the babies turned out to be healthy. The fact that their parents' were exposed to radiation had no negative impact on the babies and the male genital organs did not get damaged [50]. In a study trying to find the impact of space radiation on male genitals; mice sperm were preserved in the International Space Station for 9 months. Researchers found that they have a greater amount of fractal DNA than the ones on Earth, and when they fertilized a female mouse with this sperm, the space sperm managed to create healthy embryos, healthy and fertile babies [51].

Therefore, as the studies suggest, it can be said that proliferation seems possible for space environment or in a extraterrestrial settlement. However, when it comes to human proliferation, age is a significant factor that needs to be considered. As we age, DNA damage becomes increasingly widespread on our cells. As the eggs age, our body loses its skills to fix the damaged DNAs of the sperm.

Proliferation in space may pose some risks. However, it is possible that these challenges can be overcome with the help of technological advancements as it will take decades for humanity to start a settlement on Mars. Although it will be challenging to see an embryo growing in a womb during a long space flight; it can still be possible if we manage to develop an artificial womb to do the job so that both the mother and the baby will be safe.

7. Conclusion

This study focuseds on a high-level discussion of some of issues in maintaining the sustainability of Mars settlements. Thinking broadly and critically about Mars settlement is necessary today, well in advance before any space agencies begin sending the first human explorers to Mars. New studies also need to be conducted to understand possible on-site resource use and cost. Such further studies will allow for more quantitative predictions and scenario building. A new governence structure seems likely when contemplating a distant future of an independent Mars settlement, and such models should continue to consider both technological and sociological factors that may enable or limit their success.

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On Liberty and Cruelty: A Reply to Walter Block

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Abstract:
A standard argument for ethical vegetarianism contends that factory farming – the source of nearly all animal products – is morally wrong due to its extreme cruelty, and that it is wrong to buy products produced in an extremely immoral manner. This article defends this argument against objections based on appeal to libertarian political philosophy, the supposed benefit to animals of being raised for food, and nonhuman animals' supposed lack of rights.
Keywords: vegetarianism, utilitarianism, libertarianism, slavery.

1. Introduction

Every year, human beings raise and slaughter approximately 74 billion animals on factory farms, under conditions of extreme pain and suffering. I contend that this practice is profoundly immoral and therefore that conscientious individuals should refuse to buy the products of this industry. I base my argument on the evil of suffering and the wrongness of paying others to perform grossly immoral acts. My basic argument is as follows.

1. It is wrong to cause a large amount of suffering for the sake of relatively minor benefits for oneself.
2. Factory farming causes a large amount of suffering for the sake of relatively minor benefits for humans.
3. Therefore, factory farming is wrong. (From 1, 2).
4. If doing *x* is wrong, then paying others to do *x* is also wrong.
5. Buying products from factory farms is paying others for factory farming.
6. Therefore, buying products from factory farms is wrong. (From 3, 4, 5) [11].

Economist Walter Block has suggested that my defense of ethical vegetarianism rests on a utilitarian philosophy that is incompatible with libertarian political philosophy.[1] He argues, further, that meat consumption is permissible since animals are benefitted by being raised for food and they, unlike humans, have no rights. In this article, I rebut Block's objections and conclude, again, that buying meat from factory farms is morally unacceptable.

I would like to start by thanking Walter Block for his good-humored reply to me, despite my earlier, merciless refutation of him [2]. In this reply, I will again not be responding to everything Block has said but will try to focus on a few of the more important issues. (We may disagree about what is important.) My reason for doing this can be explained using Block's own words: "One must sometimes put the 'blinders' on, and focus, narrowly, on the issue at hand. To do so in this case, one must ignore irrelevancies, however important they are for other purposes" [p. 68].

There we are in agreement; indeed, I think Block could stand to follow his own advice more often.[2] Intellectual issues are often difficult, and they often require sustained attention to make progress on. Furthermore, time and attention are limited. Thus, attempting to address every tangential or irrelevant issue that occurs to one, or to one's interlocutor, usually results in making no progress on the central issues.

I took the central issue at hand to be ethical vegetarianism. It appears that Block, however, took the central issue of interest to be whether I, Michael Huemer, am a libertarian.[3] He thinks that I am instead a utilitarian. So I shall address myself to three general topics: libertarianism, utilitarianism, and vegetarianism.

2. Libertarianism

Block has raised the issue of whether I am a libertarian. I myself think this an objectively uninteresting question. What mental states are going on in some particular individual's head is of no philosophical or scientific significance. Though Block [p. 67] rightly argues that science is often concerned with categorization, note two things that science is generally *not* concerned with. (i) Science is not normally concerned with the categorization of *specific, individual objects or people*.[4] For example, you could not publish a paper in a chemistry journal discussing the chemical composition of the stain that was on the floor in Mike Huemer's kitchen on July 3, 2015. (ii) Science is not usually concerned with semantic questions about theories. For example, you could not publish a paper in a physics journal arguing about which physical theories deserve to be called "Newtonian."

Be that as it may, in case someone wants to know whether I am a libertarian and is having difficulty figuring it out, here are some relevant facts. I have published a book defending anarcho-capitalism and rejecting all government authority [3]. I have written articles defending the right to own a gun based on the right of self-defense [4]. I have attacked drug prohibition based on the right of self-ownership [5]. I have defended open immigration based on individual rights against coercion [6]. I have argued that taxation is theft [7]. I have rejected wealth redistribution as a violation of property rights [8]. I have criticized licensing laws and regulation in general [9, §4.3]. I scored 156 out of a possible 160 on Bryan Caplan's "Libertarian Purity Test."[5] I think Walter Block is probably the only person in the universe who thinks that I'm not a libertarian.

Why does he think that? As near as I can tell, he thinks it because my book, *Dialogues on Ethical Vegetarianism* [11], fails to endorse or argue from libertarianism. Rather than saying, "Give up meat because libertarianism is true," I say, "Give up meat because it's wrong to inflict great suffering on others for minor benefits for yourself." The latter principle isn't specifically libertarian, so I must not be a libertarian (?).

Need I explain the mistake? (Followers of Ayn Rand, incidentally, sometimes make the same error, when they deny being libertarians.) To be a libertarian is to hold certain political views. If you have libertarian political beliefs, then you're a libertarian. That's it. It is not required that those be *the only beliefs you have*. For instance, if you believe in heliocentric cosmology, that doesn't bar you from being aptly labelled "a libertarian." Even writing a whole book defending such other beliefs doesn't disqualify you; for instance, if Walter Block were to write a book devoted to arguing that Cardi B is the world's greatest artist, he would still be a libertarian.[6]

3. Utilitarianism

Walter Block may also be the only person in the universe who thinks I am a utilitarian (though he also thinks that I endorse animal *rights*; I guess he thinks I am inconsistent?). *Pace* Block, I am not a utilitarian. I know this because I have introspective access to my own beliefs, and they include the belief, "Utilitarianism is false." Outside observers can know it because I have regularly given ethical and political arguments resting on individual rights, which I understand in the standard, deontological way.[7]

What led Block astray on this matter? It appears that he was misled by my frequent insistence that one should not cause enormous suffering to others for the sake of trivial benefits to oneself. This is certainly something that a utilitarian would agree with. But *so would virtually everyone else*. Block appears to conflate the following two propositions:

(a) Utilitarians believe that only pleasure and pain matter.
(b) Only utilitarians believe that pleasure and pain matter.

(a) is true; (b) is false. *Every* moral theory that is taken seriously today holds that pleasure and pain matter and that one should not cause enormous amounts of something bad for trivial reasons. That is not unique to utilitarians. What is distinctive of utilitarians is that they add: *and nothing else matters*. *I*, however, did not add that.

Here is an analogy. Suppose I hear Block say "Murder is wrong." "Oh," I respond, "I didn't realize that you were a Christian. Christians think that murder is wrong, and *you* think that murder is wrong, so … you must be a Christian."

4. Vegetarianism

4.1. Block's Indifference

Let us now turn to the most important issue, that of ethical vegetarianism. In my earlier reply, I noted that a few years of factory farming probably causes more suffering than all the human suffering in all of history. I noted also that "to react to such a problem with indifference would be a shockingly nihilistic stance" [2, p. 43]. Block responds: "Who says that I react to this fact with indifference? Not I, not I, nor does Huemer quote me to this effect. He cannot, since I never wrote anything of the sort" [p. 68].

This is one of several times that Block complains of being misrepresented. But note three points. First, I did not say that Block reacted with indifference. I cautioned that it would be shockingly nihilistic to do so (so he ought not to do so). Now, this would have been an inapt observation to make unless there was some threat that Block might react or might have reacted with indifference.

But, second, it was in fact perfectly apt, since in his first article in this exchange, Block wrote the following words:

> A large corporation underbids a small mom and pop operation. The former earns a miniscule profit […] while the latter goes bankrupt and suffers grievously […]. Perhaps this is unethical. I don't know, *I don't care*. [12, p. 54; emphasis added]
>
> But, qua libertarians, we are simply not at all interested in what is, or is not, "perfectly alright." [12, p. 55]

Both remarks appeared in a discussion of my thesis that it is wrong (and not alright) to cause great suffering for the sake of minor benefits (apropos of factory farming). I cited both quotations in my reply, so it is not exactly true to say that I did not quote him to that effect or that he never wrote anything of the sort. These quotes, in the context, suggest that Block does not care about, or is not interested in, the question of what is morally wrong. Of course, if in fact Block *does* care about that question, I will be happy to learn it.

Third, although Block's refusal to address the problem of factory farming does not entail that he is indifferent to it, it at least suggests, in this context, that he does not care sufficiently about it. The question of the ethical response to factory farming is vastly more important than the question of whether Mike Huemer counts as a "libertarian," and it is also much more salient in a context in which one is reviewing a book about the ethical response to factory farming. In such a context, it would be decidedly odd for someone who cares about the problem of factory farming to choose to instead focus on whether I am a libertarian. Perhaps more importantly, the refusal to *do anything* regarding the problem of factory farming also evinces an inappropriately low level of concern. (More on this below, §4.3.)

Admittedly, other parts of Block's text suggest that he agrees that we ought to wish for less suffering in the world. That is why I found Block's stance puzzling and seemingly inconsistent. And that is why I did not say that he in fact reacts with indifference, but rather only cautioned that one ought not to do so.

I have written all of this (i.e., §4.1) partly to show why I can't address everything Block says. Block issues dozens of claims and arguments in rapid succession, in which I see many mistakes. In this case, the mistake I am addressing goes by in just 34 words in Block's article, yet my response to it is now approaching 600 words. This is why I cannot address every idea that appears in Block's article.

4.2. The Libertarian Slavery Advocate

In his latest piece, Block comes out in favor of slavery, a position that strikes me as somewhat more in tension with libertarianism than ethical vegetarianism is. Context: In response to Block's observation that the particular animals living on farms would not exist if not for the meat industry, I raised the example of humans who are bred to be slaves and who thus would not exist if not for the slavery industry. Block courageously bites this bullet: "Slavery would be justified under these weird conditions. And I don't mean voluntary slavery. I am now talking about the coercive variety that has occurred all too often in human history" [p. 71].

This bold move is slightly marred by the timorous insertion of "weird," meant to suggest that Block's endorsement of slavery would only apply in rare circumstances. Nice try, but I am not letting Block get away with this. This is not some weird alternative universe. In actual United States history, the importation of slaves was prohibited as of January 1, 1808. From that time on, domestic slave traders could only replenish their supplies by breeding existing slaves to produce more slaves. And that is exactly what they did [14]. All the new slaves after that point were people bred from slaves, to be slaves. So let us update Block's admission as follows: on his view, slavery *in the actual U.S. after 1808* was justified.

Block goes on to try to wriggle out of the sheer outrageousness of this position: "But there is a caveat. The alternative is death. … I claim that from the welfare point of view of Heumer's [*sic*] slaves, they would be better off alive, and enslaved, rather than dead. One 'proof' of this is that we have never had mass suicide on the part of slaves" [p. 71].

Again, I am not letting Block change the scenario or insert conditions to try to make his view seem less bad. The alternative to slavery was not "death." The alternative was to free the existing slaves, then *not create any more*. Which is exactly what America did at the end of the Civil War. Merely potential people who are never created because the slave industry ended are not *dead*. It is not the case that there are millions of *dead* would-be slaves today, namely, all the people who *would* exist today if slaves had continued to be bred in the U.S. for the last 160 years.

Why is this the correct description of the scenario? Because the scenario is an analogy for Block's argument against vegetarianism. As more people become vegetarians, the meat industry will breed fewer animals to live on factory farms. Block sees this as a problem, since he thinks it better for those animals to exist than not [p. 73]. But the result of breeding fewer (or even no) farm animals is not a scenario in which all the animals who don't get born are dead. It is a scenario in which they are never born. Exactly like the slaves who were not born after the coerced slave-breeding practice ended. (Former slaves, of course, still went on to have children, but these would not be the same children who would have been created by the slave breeders, since there would be different pairings of parents.)

Block goes on to try to explain why slavery is better than "death": "Where there is a will there is a way. Where there is life, there is hope. Life is a very precious commodity. Who knows, a slave rebellion might succeed. Perhaps the evil slave holders will repent their monstrous ways, and engage in manumission. If all the slaves are dead, this cannot occur" [p. 71].

Again, I am not letting Block change the scenario. The scenario is that the people are held as slaves for their entire lives. They do not successfully rebel, and their masters do not free them. We have to evaluate the scenario with that stipulated. Why is this the correct version of the scenario? Because, again, the scenario is an analogy for Block's view of the meat industry. There is no chance of the farm animals successfully rebelling, nor is the meat industry ever going to set them free (at least, not as long as people keep eating meat).

Moreover, there is an incoherence in Block's type of argument. One cannot argue in defense of slavery by saying that, as long as we keep holding slaves, there is a chance that we will stop. The possibility that we will stop doing A isn't a reason to do A.

Block continues: "Note that in this section we are straying from deontological libertarianism. We are not discussing rights, here. Rather, we are engaged in a utilitarian analysis. Would animals, human slaves, be better off from a pragmatic point of view, if they did not exist at all" [p. 71].

But note that we are only straying from deontological libertarianism because Block's own views are incompatible with it. Deontological libertarians are against slavery, even if the slaves were bred for the purpose.

Block has one question for me: "My only question of Huemer in this section is, why was this not already fully comprehensible?" [p. 71] In reply, I in fact had no difficulty at all understanding Block's argument. I simply disagreed with it.

4.3. The Other Problems with Block's Argument

Block claims to have addressed all of my arguments.[8] But in fact he overlooked many of them.[9] On the particular argument discussed above (§4.2), he missed at least two points. First, he did not address my point that factory farm life is so miserable that it would be better to have no such lives [2, pp. 46-7]. He did not try to offer any evidence that factory farm life is not really that bad.

Second, he overlooked my point that there are other alternatives that he was ignoring – for example, human beings have open to us the alternative of raising animals only in humane conditions, rather than in factory farms [2, p. 46]. Block claims that he opposes suffering yet buys meat (almost all of which comes from factory farms) because this is better for the animals. If this is true, I await his imminent announcement that he has decided henceforth to buy only humane certified animal products.

Here is an analogy. Suppose that Walter's reprobate nephew, Scarface Block, shows up at Walter's house one day with a big bag of money. The following dialogue ensues:

Scarface Block:	Hey, check it out, Uncle Walt. I just robbed a bank and got all this loot!
Walter:	Why did you do that? Don't you know that's wrong?

Scarface:	Oh, no. You see, when I woke up this morning, I decided that I was going to either rob a bank or murder twelve people today. I'm sure you'll agree that bank robbery is better. So it's permissible!
Walter:	Hmm, I can't see anything wrong with this logic.

What have the Blocks missed? Well, *perhaps* it is justified to harm others if doing so is better than *every* alternative (though even this is not always true). But certainly one can't justify harming others merely by the claim that doing so is better than *some* alternative. One must compare the action to the best alternative.

4.4. On Forfeiting One's Rights

It turns out that I misunderstood the slogan "rights imply responsibilities" as used by Block. It appears that Block intends the phrase to mean that, if one violates others' rights, then one loses one's own rights. This, I guess, leads to a rejection of animal rights via something like this reasoning:

1. If A violates B's rights, then A loses A's own rights.
2. Nonhuman animals do not lose any rights upon attacking other animals.
3. Therefore, those other animals do not have rights not to be attacked.

From (3), one could plausibly infer that animals in general lack rights in general.

The problem with this inference is the completely unqualified first premise. On Block's view, (1) holds regardless of whether A has free will at the time, whether A is aware of what A is doing, or whether A is even capable of understanding morality. Only by saying this can Block claim that principle (1) applies to animals.

This makes the principle extraordinarily implausible. Suppose that a baby, a severely mentally retarded person, or a severely mentally ill person shoots you because he has no idea what a gun is, or because he can't control his own actions. On Block's view, that person now has no rights.

Block even adds another counterexample to his own view: suppose a sleepwalker kills someone while sleepwalking and unaware of what he is doing. On Block's view, the sleepwalker could be justly punished for first degree murder [p. 72]. Block tries to soften this by adding, "at the very least after the first such foray." I am again obliged to call Block on his attempt to modify the example to cover up the absurdity of his position. On Block's principle (1), the sleepwalker is guilty the *first* time, not merely the second time, he kills in his sleep. That is what Block has to say, since he does not recognize any constraints on culpability.

This is not a plausible view. The standard, plausible view is that A becomes liable to punishment to the extent that A *culpably* violates B's rights, and that there are different degrees of culpability. People sometimes lack free will or lack the ability to understand their actions, in which case they are not responsible for their actions and they continue to have rights. The same may be true of nonhuman animals.

Block goes on: "If these predatory animals really had rights not to be killed by humans, they would not pick on other chickens, zebras and deer. But they do engage in these acts. Ergo, they do not have rights" [p. 71].

Imagine that an advanced alien species arrives on Earth. The aliens shortly set to debating whether it is permissible to kill humans for sport. Among them is an economist named Alien Block, who lands in New Orleans to have a conversation with the renowned human rights expert, Walter Block …

Alien Block: Hey there, human. Just FYI, my buddies and I are shortly about to start torturing humans and chopping them up for fun, unless someone can give us a good reason not to. So far we can't think of any.
Walter: Uh, well, I think that would violate our rights.
Alien: No, that doesn't work. If humans really had rights to not be killed by aliens, they would not pick on other humans. But they do engage in these acts. Ergo, they do not have rights.
Walter: Oh, okay, that makes sense. Carry on then.

Alien Block's factual assessment is correct – humans have been torturing, enslaving, raping, and murdering each other throughout history. So what is Alien Block's mistake?

I see two ways of reading Alien Block's argument. First reading: If humans had rights, then humans would surely know that they had these rights, in which case they would respect these rights, and so they would never attack each other. Since they sometimes do attack each other, we can conclude that they have no rights. If this is what Alien Block means, he errs by confusing the *existence* of rights with their *recognition* by people, as well as by assuming that people would always behave ethically.

Second reading: When humans pick on other humans, they forfeit their rights. Since rights "go by species," it is not only the specific aggressors who lose their rights but the entire species. So the whole human species has lost its rights, if they ever had any. If this is what Alien Block means, he errs by assuming that rights accrue to species rather than individuals.

Walter Block's argument in the actual world has two parallel readings, with the same errors, depending on how we read it. Either Block is falsely assuming that animals would have the ability to recognize rights and would in fact always behave ethically, or he is falsely assuming that rights accrue to species rather than individuals.

4.5. Speciesism

This brings us to Block's "defense" of speciesism.[10] By this, I mean his view that rights accrue to species rather than individuals: once one person claims rights for himself, that somehow gives rights to the entire *species*, not just that individual. When asked to explain or justify this, Block pleads that "we all have to start somewhere" [p. 69]. Granted, we all have to start somewhere, but most of us decide to start somewhere that seems obviously true, or at least plausible, rather than somewhere arbitrary and implausible.

Block has another argument to justify his assumption: "[I]t would be an act of murder to kill a baby, or a sleeping person, or a mentally handicapped individual, none of whom can petition for their rights. Only if rights are accorded to all members of a species are we logically entitled to arrive at any such conclusion" [p. 69].

Vegetarians often accuse meat-eaters of just inventing rationalizations. Here, Block makes explicit that that is what he is doing. There is no explanation for why rights should accrue to species; that's just what you have to say to rationalize Block's claims that (i) rights are produced by petitioning or "homesteading," yet (ii) somehow babies and mentally disabled humans have rights, yet (iii) nonhuman animals don't. There was no reason for assuming (i) or (iii) to begin with, so there is no reason to embrace increasingly implausible rationalizations for those assumptions either.

As the previous section hinted, the assumption that rights accrue to species would seem also to suggest that rights *forfeiture* should occur at the species level – in which case, all humans have lost their rights. Again, Block might simply claim that acquisition and forfeiture work differently (but only for humans; animals, apparently, forfeit rights at the species level) as an ultimate, inexplicable fact, but this would be an ad hoc rationalization.

4.6. Homesteading

In my last reply, I pointed out that Block's theory of homesteading rights seems inconsistent: he claims that when an individual claims self-ownership rights for himself, that grants self-ownership rights to all members of that individual's species. Yet when an individual claims a plot of land for himself, that only gives *that individual* a property right in the land; it doesn't grant any rights at all to the rest of the species.

Block's explanation: There are two differences between land and self-ownership rights. First, self-ownership rights are prior to land rights (you must own yourself before you can come to own land). Second, land rights are alienable (you can sell your land), but some people think that self-ownership is inalienable (you can't sell yourself into slavery). That's the entire explanation. By the way, in citing the second difference, Block neglects to mention that *he himself* thinks that you *can* legitimately sell yourself into slavery.[11] So in *his* view, there *isn't* actually that second difference.

Be that as it may, the main thing to point out is that neither of these alleged differences on its face appears at all relevant, nor does Block attempt to explain how they would be relevant. In other words, say Block is right: in order to acquire land, you have to first own yourself. So what? How does that even on its face seem to suggest that self-ownership would depend on species membership but land ownership depend on your individual actions?

Resolving a tension in your theory can't be this easy. It can't be enough to say, "Well, I thought of *some difference* between those two cases (nevermind whether it's a relevant difference)." If that were enough, Block could have just said, "Well, self-ownership is different from land ownership because the former applies to a *self*, whereas the latter applies to a piece of *land*." Applying that strategy, any tension in any theory is instantly resolved.

5. Avoiding Dogmatism

I want to conclude with some methodological remarks about how to avoid dogmatism, which is perhaps the most serious and pervasive intellectual problem. A dogmatic person refuses to reconsider his controversial opinions no matter what evidence or arguments appear. We should all agree that dogmatism is a vice to be avoided. We should all agree that controversial ethical opinions are among the beliefs concerning which we should be open to counterarguments. Therefore, one should not deploy argumentative strategies that enable one to maintain one's starting position *come what may*. That is what Block and many meat-eaters do.[12] They start from the absolute axiom, "it's fine for me to continue what I'm doing," then adjust the rest of their belief system in whatever way they have to to maintain that fixed point.

What argumentative strategies do I have in mind?

i. *Biting the bullet.* When someone locates an absurd implication of your view, you can always simply embrace the implication. For instance, if someone finds that your view implies that slavery is acceptable, you can say, "That's right, slavery is fine."

ii. *The appeal to foundations*. When asked to explain or justify some seemingly odd or arbitrary assumption of yours, you can always declare, "That's an ultimate starting point."

iii. *Rationalization*. When asked why you believe A, you can cite some theoretical principle B, then say you believe B because it's the best explanation for why A is true. If someone comes up with a counter-example to B, just modify the principle ad hoc to exclude that example and justify the modification by saying that the modified principle explains A while avoiding the counterexample. E.g., humans have rights and animals don't, because (in part) rights accrue to species, which we should believe because that helps us explain why humans have rights and animals don't.

Notice that these strategies are general tools of dogmatism: *Any belief can be maintained in the face of any evidence*, as long as you're prepared to deploy these strategies whenever necessary.

For an illustration, let us imagine that Walter Block travels back in time to talk with one more member of his extended family, his great grandfather, the slave owner Jefferson Block …

Jefferson Block: It's fine to enslave black people.
Walter Block: Wow, really? Why is that?
Jefferson: Because black people have lower average IQ's than white people. IQ determines rights.
Walter: But that would imply that you can enslave low-IQ white people too.
Jefferson: No, you see, it's the average IQ of one's *race* that matters, not the IQ of the particular individual.
Walter: Why on Earth would that matter?
Jefferson: You have to start from somewhere. This is the best explanation of the self-evident fact that it's fine to enslave blacks but not whites.

Jefferson is being dogmatic. There is no way Jefferson Block will ever admit that he is wrong; he'll just make whatever arbitrary claims he has to in order to maintain that it's fine to enslave blacks.

Alternately, he might have responded to Walter's second comment as follows:

Jefferson: Yep, it's fine to enslave low-IQ white people.

Or, even more simply, he might have responded to Walter's first question as follows:

Jefferson: That's just an ultimate, foundational principle. You have to start somewhere.

And then there is no way of reasoning with him.

Granted, we cannot say that one should *never* use any of the above strategies. After all, some things are in fact foundational. If someone asks me why 2=2, I am not inclined to offer any justification or explanation; I would likely say that that is simply a fundamental, ground-level axiom. Also, some counter-intuitive claims are actually true and justified. For instance, most people find the correct solution to the Monty Hall problem counter-intuitive, but it can be demonstrated from the laws of probability. So those are examples where strategies (ii) and (i), respectively, are appropriate.

Nevertheless, they are usually not appropriate. Because these strategies are such easy tools of dogmatism, one should be very wary of them. One should think very hard before declaring that something that one's interlocutor rejects is a foundational, inexplicable, ultimate starting point. Typically, ultimate starting points are extremely obvious and non-controversial propositions, such as "2=2" and "murder is wrong." Bearing in mind such examples, you should ask yourself, when you're tempted to claim an ultimate starting point, "Do I really find this self-evident, or do I just not want to question my assumptions?" Likewise, one should reflect carefully and honestly before biting the bullet on some counter-intuitive consequence. Bearing in mind that the usual cases where we should embrace counter-intuitive conclusions are ones with very clear and almost indisputable evidence, or even mathematical proofs, one should ask oneself honestly, "Has this really been sufficiently established, or am I just being dogmatic?"

Bearing all this in mind, I find it hard to believe that any reasonable, open-minded person would really conclude that "rights accrue to species, not individuals" or "humans but not animals have rights" is self-evident.

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Notes

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1. See Block [1], responding to my [2]; unless otherwise specified, all references to Block herein are to [1].
2. See p. 66, where he defends the appropriateness of his raising tangents about insider trading, my use of the word "them," U.S.-China trade policy, etc.
3. Note, however, that for reasons that will emerge below (§4.1), I now hesitate to ascribe any beliefs to Block – for any claim that I might ascribe to him, there is a good chance that he will insist he never said anything of the kind and has no idea why I would think that.
4. Unless it is an extremely important individual object, such as the Earth.
5. See [10]. I declined to answer two questions about the Federal Reserve.
6. Cardi B is a popular singer of questionable merit. Her artistic merit is unrelated to libertarianism.
7. See [4], [5], [6], [8], [9]. For an explanation of my understanding of rights, see [9, §2.4]. For my objections to utilitarianism, see [13].
8. "I have been very thorough in my response to Heumer [*sic*]. I replied to each and every point he made in this essay of his" [p. 74].
9. Some additional points that Block did not address in his latest reply: Block's attempted refutations of expected utility calculations are confused [2, p. 45]; humans' behavior is probably worse than animals' [2, p. 47]; I did not advance hedonism, nor did I reject rights [2, pp. 47-8]; the fact that experts aren't infallible doesn't mean you shouldn't listen to them (unless *you're* infallible) [2, p. 48]; factory farming is obviously wrong [2, pp. 48-9]; most of Block's arguments are misdirection [2, p. 49]; Block is confused about masochism, pain, and suffering [2, p. 50n2]. (Note that I don't count merely saying something about the section that an argument appeared in as responding to the argument.) There are other cases in which Block sort of responds to an objection, but only with a bare denial or a repetition

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of the point the objection was directed at. I am not upbraiding Block for failing to address everything, though. I don't address everything either, but at least I don't claim to.

10. I use scare quotes because Block's discussion [pp. 69-70] is more assertion than argument; I am not sure to what extent this qualifies as a defense.

11. Block, p.c.

12. See also the case of Bryan Caplan, discussed in [15].