The **Steel Seeds** Plan
to Start Human Settlement of Mars

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Introduction

There have been many more or less serious plans to colonize Mars, or just put humans on it.

The first noteworthy one was from Wernher von Braun (1948, 1953). It used a fleet of ten interplanetary spaceships to take seventy people to Mars and put them on its surface. The fleet would have been constructed in orbit around the Earth and 1000 three-stage rockets would have lifted everything up to the orbiting construction sites. Von Braun pushed for funding of a similar plan after the Apollo missions ended but was famously snubbed around Washington.

US President G.H.W. Bush ordered a plan to be written in 1989. This plan was called variously the Human Exploration Initiative, the Space Exploration Initiative (SEI) and the 90-Day Report (NASA 1989). Although this plan stated one of its goals was to get humans on Mars, it was not really a plan to go to Mars at all, but, rather, it laid out a smörgåsbord of goals and program outlines for potentially interested parties in Washington. This initiative's extremely high price tag ensured its quick demise in the US Congress and this demise consequentially set-off a long-term shift in how the National Aeronautics and Space Administration (NASA) has operated.

Spurred on by problems with the SEI, Robert Zubrin and David Baker developed an alternate plan called Mars Direct (Baker and Zubrin 1990; Zubrin 1996). Mars Direct was the first plan to feature pre-positioning of useful manufacturing assets on the surface of Mars prior to the arrival of humans on long-stay[1] missions on the Red planet. These assets would manufacture rocket propellant and oxygen using local Mars resources, which is an example of in-situ resource utilization (ISRU). Mars Direct was the first Mars plan to give detailed proposals of ISRU implementations for Mars. Mars Direct also required that a habitat unit ("hab") with a high mass (~40,000 kg) be landed on Mars in one piece. This land-a-giant-object-in-one-piece feature of Mars Direct meant it could not be implemented in the 1990s, the 2000s or now in the 2010s.

Buzz Aldrin (2008, 2013) has called for Mars settlement in which settlers should go to Mars with no intention of returning to Earth but with some capabilities to return, rather like the seventeenth century colonial settlers of the American colonies that eventually became the United States. Buzz Aldrin also had one of the most creative ideas for transport between Earth and Mars, variously called the Mars Cycler, Aldrin Cycler and Cyclic Trajectory Concept, in which a spacecraft continuously cycles back and forth between Earth and Mars and in which payloads are sent up to and dropped off from the cycling spacecraft (Aldrin 1985).

One recent Mars plan, from a NASA working group, would land the first humans on Mars not as settlers but as brief visitors (Naderi, Price and Baker 2015). This plan needs space vehicles, such as the Space Launch System (SLS), which are under development by long, established aerospace contractors.

When discussing plans to go to Mars and colonize Mars in July of 2016, there is a giant in the Mars community, Elon Musk, who is enormously influential at driving what might happen or will happen regarding the colonization of Mars. His rocket company, Spacex, has rapidly growing capabilities for sending cargo to Mars and landing cargo on Mars. Elon Musk is committed to colonizing Mars either in partnership with government agencies or, if necessary, through private efforts led by himself and Spacex (Musk 2012). In addition, the capabilities of Spacex, Tesla Motors (Mr Musk's car company) and OpenAI (an organization researching artificial intelligence (AI) that Mr Musk funds) for carrying out colonization operations on the surface of Mars are likely to grow to become very substantial. What is meant by that is that (i) Spacex, Tesla and Open AI have a wealth of hardware and programming skills and resources that can be applied to automated manufacturing and running semi-autonomous robots in digitally described environments, (ii) these technical capabilities will be key for establishing a first Mars base or seed settlement. Mr Musk has announced that he will

1 Over a year.

be presenting plans for the colonization of Mars at the International Aeronautical Congress in September 2016 (Musk 2016). His plans can have some flexibility through the array of capabilities that his companies and their partners have, or will soon have; however, he has indicated the importance of new, very large, reusable rocket boosted transporters that will, early on, transport a lot of equipment on to the surface of Mars and, as time progresses swap to transporting more people and less equipment (Musk 2012; Musk 2016).

On Mars, basic human life requirements, like breathing, will be enabled and sustained by technology, such as pressure vessels that contain interior living spaces and pressurized suits for walking around outside. Very often this technology will be vital, that is, on Mars humans will die without appropriate sustaining technology. This will also be true for the animals, plants, fungi, bacteria and other organisms that get transported from Earth to Mars. Life will be enabled and sustained by technology on Mars.

Although discussions of the settlement of life on Mars often focus on launch rockets and space ships, the settlement of life on Mars is becoming a big subject with many facets. Two of these facets might be called 'the seeding and germination of human settlement on Mars.' What is meant by this phrase is the landing on Mars of collections of equipment capable of mining, making and building useful things on Mars, along with the early operation of this equipment, to grow the capabilities of the equipment and its output to enable and sustain first human life on Mars, and, also, after the first people land on Mars, the immediate continuations to keep sustaining human life, grow the life enabling and sustaining technological infrastructure, and increase the number of people living on Mars.

A question arises, what technology should be landed on Mars for the seeding and germination of human settlement of Mars?

This draft plan proposes a specific answer: Redundant collections of equipment, and robots, capable of (i) generating electricity, (ii) mining iron ore, (iii) processing the ore to make fine steel powder, generate oxygen and liberate bound water, (iv) fabricating finished steel products, including spare parts, building structural elements and panels, as well as building fittings and fixtures and more, (v) carrying out repair and maintenance by the robots of themselves and of other pieces of equipment, (vi) making, on Mars, mostly steel, power generation sytems driven by small, solar parabolic dishes, (vii) making, with assistance from people on Mars, robotic steel trucks, with mostly steel engines, (viii) starting truck fuel/rocket propellant production to establish muscular ground transportation and abundant water collection, (ix) making, with some human assistance, additional pieces of equipment for gas compression, nitrogen and argon separation, ceramics and glass manufacture, soil improvement, fertilizer production and more. Re-phrasing the answer from describing the equipment and robots in terms of their capabilities to describing them as specific pieces of equipment, a single collection of equipment and robots would include the following (a) power units (or unit) (b) units for reducing iron and other transition metal oxides to metal and oxygen (and also liberating some bound water), (c) units for final refinement and powdering of the reduced iron and minor transition metals (collectively Martian steel powder) (d) a small, modular, gang-able Martian 3D metal powder printer, (e) a set of spare parts which are hard to make on Mars from steel, (f) a (somewhat smart) roving robot with at least two mechanical arms and multiple arm-end attachments. The plan needs multiple sets of these individual collections of equipment and robots to supply redundancy, to also supply multiple robots which can then take and make collective actions and operations (including complicated repair and maintenance actions), and to gang together several small, modular, Martian 3D metal powder printers into one printer with a large build bed.

Some practical points about such seed collections of equipment and robots include: (a) they can be made (*i.e.* they are feasible), (b) they can be operated by the robots with only occasional guidance from humans, (c) they can be made compact and light (using very little mass), (d) because of their compactness and small mass, a single collection of equipment and robots can be easily transported onto the surface of Mars in a relatively small landing craft (if necessary). This last point allows some implementations of this plan to avoid the land-a-giant-object-in-one-piece feature of several previous and current plans. This aspect of this plan is potentially very important for removing obstacles and delays that have occurred, and may well yet occur, in the development and funding of any very large systems required for landing a giant object in one piece on Mars.

This plan is called the Steel Seeds Plan to Start Human Settlement of Mars, which is shortened to the Steel Seeds Plan for the remainder. Each of the individual collections of equipment and one or more robots is metaphorically like a seed in that it lands on the Martian ground in something like a seed pod, *i.e.* the landing spacecraft, then, under its own stored energy and probably also using solar energy, the robot and equipment unpacks itself from the spacecraft and then starts operating mostly autonomously to grow, wherein this growth uses ore, carbon dioxide and water like nutrients and solar power like sunlight driving photosynthesis. This is all seed-like. These metaphorical seeds are <u>steel</u> seeds in that they focus on iron ore mining, steel powder production and finished steel object fabrication; although, this early seeding activity quickly branches from just steel activities to many other activities, with the expansion of power generation capacity and output being particularly important and happening very early as the first application of the first made-on-Mars steel parts. However, the seed metaphor is not wholly appropriate in that the operation of these collections of equipment and robots will be collective in some respects, particularly repair and maintenance and steel object fabrication, so that the group of collections are capable or more than the individual collections. With this steel work these steel seeds enable the fabrication and growth of the first human settlement infrastructure on Mars. This settlement infrastructure includes, at least, steel components for pressurized buildings for humans to live and work inside, furniture, fittings and tools to put in these buildings, most of the life support equipment, water and gases needed for breathing and recycling products of human respiration, digestion, perspiration *etc.*, a reservoir of water, means for collecting more water, storage tanks for the oxygen produced during steel-making, storage tanks for nitrogen and argon, the steel parts needed to construct new pieces of equipment needed for activities such as Martian agriculture, glass and ceramic manufacture, methane/oxygen fuel/oxidizer production, eventually also basalt fiber manufacture and other manufacturing activities and also, importantly, from an early point and continuing on, the manufacture and operation of new power generation equipment made almost entirely out of Martian steel and driven by sunlight.

These redundant collections of equipment and robots would work on Mars for at least two Earth/Mars synodic periods,[2] *i.e.* a 2 x 780 days, prior to the arrival of the first humans. However, this preparatory period could be extended to as many synodic periods as needed to properly prepare for the safe arrival of the first humans. Further, each synodic period after the landing of the first collections of equipment and robots can include the landing of extra supplies, spare parts and equipment as will be necessary for settlement success. The construction needed to turn the steel building components into buildings might be done starting with the landing of the first people, or before this human landing. It may well be better from a mission story perspective to have the first Mars settlers participate in the construction of their first Martian home.

Another important point arises out of the plan's scheduling possibilities: The longer a seed collection of equipment and robots is up and running on Mars the more valuable it becomes. This is because the total mass of all the useful, finished steel objects produced by a collection increases linearly with the amount of time the collection is up and running (the same is true for the total mass of oxygen generated by the same collection). In fact, the value increases more than linearly with the amount of uptime, since some of the steel objects made by a collection will be put to uses, like making solar parabolic dishes, that themselves increase overall capacity and capability. One way to think of

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2 The main launch windows for flights from Earth to Mars are separated by an Earth/Mars synodic period, which is very close to 780 Earth days in length.

this is that a relatively, small and inexpensive (in Earth dollars) group of collections of equipment and robots will eventually produce very high value results on Mars, so long as these collections are kept operating for long enough.

It is a key idea of the Steel Seeds Plan to structure all the plan's components such that the average working life of a collection of equipment and robots is long and very useful and valuable. To this end the plan builds in (a) redundancy, (b) steel spare part manufacture on Mars, (c) occasional spare part deliveries from Earth and (c) teams of robots with the mechanical and computing abilities to perform repair and maintenance tasks.

The combination of iron ore mining, ore to steel powder processing and finished steel part manufacture can collectively be a core technological capability, quite possibly the core technological capability, for the seeding and germination of human settlement on Mars. This technological capability enables the start and growth of extra power generation, water collecting and manufacturing capabilities, which, will start an upward spiral in life-sustaining capabilities. The net output from, steel-making, oxygen generation, steel fabrication and muscular water collection can provide the large majority of the mass of all the useful technological objects, liquids and gases that will be needed to enable and sustain human life on Mars in a first habitat and workshop.

The literature on steel-making on Mars is, at the moment, quite limited. Molten metal oxide electrolysis research has been carried out, with NASA funding, for the purpose of generating oxygen on the Moon (Curreri et al. 2006; Vai et al. 2010). Such electrolysis splits metal oxides to produce both oxygen and metal, the American Iron and Steel Institute funded a feasibility study to see whether molten metal oxide electrolysis could be practically implemented to produce iron (AISI 2005). Shaun Moss (2006) reviewed steel-making methods and techniques on Earth and recommended direct reduction techniques for Mars steel-making. Some prominent people have also made brief talking points on iron and steel-making on Mars.[3]

The rest of this plan draft is organized into sections as follows. **Capable, Slightly Smart Robots:** A description of the capabilities and specifications of the robots needed for mining ore and the operation of other pieces of equipment. **Massive Masses, Repair and Maintenance:** This section covers considerations of the mass of things, and how and why mass considerations should factor into the design of a plan for seeding and germinating the human settlement of Mars. **Mars Dust and Mars Sand:** In this section the composition of Mars dust and sand is looked at with the benefit of detailed sand and dust composition data gathered by NASA robotic rovers *Spirit*, *Opportunity* and *Curiosity*. In addition, an initial discussion is given of how this sand and dust might be very useful as a potential ore for steel-making, ceramic and glass manufacture and also for agricultural soil. **Martian Iron Ore Enrichment:** This section reviews how iron ore mining and iron ore enrichment (beneficiation) is done on Earth. This review serves to shows how very good it is to start iron ore mining and enrichment with an ore in sand or dust form. This is important for making small-scale steel-making on Mars mechanically feasible, as the small robotic rovers have only a little mechanical muscle. The section also points to fields of sand dunes on Mars which may be especially good for iron ore mining. **Steel-powder Making from Enriched Martian Iron Ore:** This section discusses the processes and equipment needed for the small-scale conversion of enriched, sand/dust iron ore into fine steel powder that is suitable to be used in three dimensional (3D) metal powder printing machines. **3D Metal Printing Machines on Mars:** This section discusses 3D metal printing machines on Earth and on Mars and the significant differences between such machines on Earth and Mars. The first 3D metal printing machine on Mars will have especially

3 Robert Zubrin was quoted saying "Iron oxide and silicon oxide are also common in Martian soil, so human pioneers would be able to make iron, steel and glass" (Wall 2013); while answering a conference question Elon Musk (2016) stated that if large numbers of people and goods were transported to Mars that this would create tremendous opportunities "for everything from creating the first iron ore refinery to the first pizza joint to something that does not exist on Earth."

low mass and low power consumption per unit printing bed area in comparison to those on Earth. Also, the first Martian machine will have a printing bed that is especially long. **Growing Power Generation:** This section discusses a developed power generation technology, *i.e.* solar parabolic dishes coupled with free piston Stirling engines/generators, that can provide electrical power on Mars that can be made almost entirely out of steel parts, that can be made at physical sizes that are small enough that (i) all the steel parts can be made-on-Mars by the first 3D metal powder printer using steel powder made from Martian iron ore and (ii) the rover robots will be able to assemble the parts into complete working systems. So that, *early human settlement of Mars can have all the electrical power it needs to grow by making the power plant on Mars*, if it starts steel-making and fabrication early. The section also points out that it would be very useful to have small-scale, parabolic dish systems that can output piped flows of hot, pressurized gas to provide thermal power to drive useful thermo-chemical processes and that, while no such hot gas dish system is close to be properly developed, that this development could be done in the coming few years. **Collecting Water, Muscular Ground Transportation:** This section discusses water sources on Mars, including the lack of certainty about abundant water sources in the most desirable, equatorial regions for living. The section also points out that large capacity trucks can be built locally on Mars from steel and also their engines and the solar powered systems needed to produce suitable fuel and oxidizers to run the truck engines. The introduction of a muscular transportation capability can then be used for all sorts of things including overcoming likely water supply problems by providing the capability to use distant water sources. **Making Other Equipment, Doing More Things:** This section gives a brief outline of other equipment that can be made on Mars using Martian steel and what this other equipment can do to make more useful things on Mars from local Martian ore resources. **Summary and the Start of Human Martian Life:** The summary gives an outline of the Steel Seeds Plan for seeding and germinating the human settlement of Mars; it re-iterates some key themes, needs, features and benefits of the plan; and, also, discusses when, during the implementation of the Steel Seeds Plan, humans should first land on Mars, and makes a few remarks about the relationship between people and the technologies used for settling Mars. An appendix to the section on Martian 3D metal printers, **Oxidation of Fine Steel Powder in the Martian Atmosphere**, is included.

This document only covers the introduction to the Steel Seeds plan. The whole plan was initially available on request from the plan's author, Rif Miles Olsen, now, for a period, it is available as a "backer reward" to a Kickstarter project done in a collaboration between Food for Mars and Two Planet Steel.