Mining Asteroids: Why, How, Who, When, Where?

Dr Michael McEllin 1 May 2020

The Problem

Every time you buy a new smart phone you are purchasing a bundle of up to 60 chemical elements, some of them quite rare and very expensive. Their unique properties cannot be substituted by anything else without compromising some of the things you really like about your phone (such as its light weight, touch screen and so on). The "Rare Earth Elements" for example are not present in high concentrations in Earth rocks, and their recoverable ores tend to be found in a very few places. China at present has the biggest rare-earth mines, and it is starting to restrict exports because it needs the supplies for its own mobile phone manufacturing industry. Even if we open new mines, expecting them to be profitable as prices rise, there is still not going to be enough to keep the electronics industry going at its present rate: current projections suggest that they will effectively run out within your lifetime. Even precious metals such as gold are essential in modern electronics to ensure that electrical connection do not corrode and the contacts continue to function properly.

You might be wondering if we could solve some of the supply problems by more recycling. Unfortunately, although we put a lot of these materials in smartphones (there are a lot of phones made each year) each phone only contains a very little - sometimes only microgram quantities - of these rare elements. Even if you filled up the old mines with compressed phones, the new "ore" concentration would be lower than that in the original rock. Even worse, the way they are now chemically bound up into the complex materials in phones means that it is is effectively impossible to recover the valuable elements at any reasonable cost.

It is not just phones. Our renewable energy supplies depend on having super-strong permanent magnets in wind turbines, which can only be made from alloys using rare-earth elements like neodymium. We also need to move from petrol and diesel cars to electric cars to tackle climate change, but their motors also depend on the same rare-earth magnets. These cars - and your phones - depend on very high capacity batteries, which today are made mainly with lithium. Current supplies probably will not hold up as we expand electric transport. So, demand is only going to go up, while supply is going down.

One of the reasons why these element *are* rare at the Earth's surface is that during the very early history of the Earth when it was partly molten, most of the iron and nickel and anything else that easily dissolved in molten iron sank towards the core, and this included a lot of the rare-earths. So, the concentration of many valuable elements is actually much lower in Earth's surface rocks than the average concentration originally found in the nebula from which the Solar System planets formed. So, might we find these rare elements more easily accessible in asteroids?

Asteroids are most remnants of the planet forming process and with the exception of volatiles elements (such as hydrogen and helium) are on the whole probably fairly representative of the original relative concentration of elements. They are mostly not big enough to have gone through a melting and core-forming process similar to that of the Earth. Therefore in many cases their *surface* compositions will reflect the original higher abundance of the rare elements. This is what we see when we examine meteorites that fall the the Earth's surface. In fact, one of the reasons we know that a large asteroid hit the Earth 60 million years ago, wiping out the dinosaurs, is that it deposited a thin but World-wide layer of dust containing high concentrations of iridium, which is otherwise simply not present in such high concentrations in Earth rocks.

A few larger asteroids did get big enough to melt and form metallic cores. They were then completely fractured into smaller fragments during collisions with other asteroids. We know this because a small fraction of meteorites recovered at the Earths surface are almost pure metal (mostly iron, with with lots of other metallic elements). These came from the core of a shattered asteroid. The metals are not chemically bound with oxygen or sulphur, as is common with Earth ores, so if we could capture such an asteroid the refining of metallic products might be relatively straightforward.

Your challenge is to investigate the science, engineering and the economics of asteroid mining, and see if sending spacecraft to extract minerals from asteroids, and bring them back to Earth, is a realistic possibility.

Imagine that you are a consulting engineer, retained by a large multinational in order to assess whether they should invest large amounts of money in asteroid mining. From this perspective it is important that you identify not only the opportunities and possibilities but also the potential barriers and risks that would make the proposal uneconomic or unsafe.

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20 Questions

The best way to start any investigation is often listing a series of questions. These are mine:

1. What are asteroids?
2. Where are asteroids to be found? (Hint: some are closer to the Earth than you might think.)
3. How do we find asteroids? Asteroids are often cold and black, against a black background. (Hint: we look for movement against the background, and some telescopes can see in the Infrared, where asteroids may stand out against the blackness of space because even though they are cold they are slightly warmer than the background.)
4. What are asteroid made of? Are all asteroids the same? (Hint: probably not!)
5. Are only some asteroids worth mining? How would be recognise them?
6. How would we reach asteroids? Are only some of them reasonably accessible?
7. Could we bring an asteroid that is particularly rich in useful elements closer to Earth? (Look for the details of a now-cancelled NASA mission to capture an asteroid was planning to do just that.)
8. How would we actually mine them? Could it be done with robots?
9. Were would we get the energy to run mining operations? (Hint: possibly solar. What are solar panels mainly made from? Is it common in asteroids rocks? Could it be transformed in space? Could we actually make solar panels in space from stuff mined from asteroids?)
10. How would we move stuff around in space? Are there better ways than rockets which use chemical fuel? (Google “solar sails” for one possibility - is it likely to be realistic for moving large masses around? Would it work is we had stronger and lighter materials than we now have? Do we have any of these under development in labs?)
11. If we need to use rockets, could we get the fuel from asteroids? (E.g. is there a source of hydrogen and oxygen?)
12. Do we find water on asteroids? Would this be useful? (Think about electrolysis using electricity from solar panels.What does it produce, and how could it be used?)
13. Where has water recently been found on the Moon and would this be useful?
14. How do we get mining equipment into space from the Earth’s surface and how expensive would that be? (How much precious fossil fuels will we be burning to do that and is it worth it?)
15. How do we get stuff back to the Earth’s surface and how expensive would it be. Would more fuel be required. (Hint: just dropping large lumps from a great height is not likely to be welcome!)
16. Is there anything that does not work well in space? (Hint: look in the mirror.) Are electronic devices vulnerable in space?
17. What are the main hazard of working in space, both for people and machines?
18. Would a robot working in space look like a man or would another form (such as a spider) perhaps work better?
19. Could robots make other robots in space? (Would you worry about the possibility of robot self reproduction simply getting out of control - consuming everything in sight? This has been discussed as an existential threat to the human race by serious thinkers! Google “Nick Bostrum at the “Future of Humanity Institute” at Oxford University.)
20. Is 3D printing an answer to many of the requirements for flexible production techniques in space?

Earth based industries all tend to require at least five fundamental components:

- **Raw materials**. The stuff that goes in through the factory front door.
- **Energy**. Everything we do requires an input of energy. Sometimes we just want it in the form of heat (to drive chemical reactions). More commonly we need things like motive power to work machinery, which usually means electricity supplies.
- **Plant**, by which I mean the special tools and equipment to run industrial processes. For these we also need a **Supply Chain** for the parts and any chemicals required etc.
- **Intelligence**. To direct how the plant and the energy is used to transform the raw materials.
- **Capital** (i.e. money). You need to be able to buy stuff and pay people to run things before you start making a profit.

Could we put these together in space?

Earth based industries are actually part of a complex hierarchical web of connections: one factory's output are the tools and equipment used by another plant. The raw input to a car maker, includes, for example, steel, which is the output from a steel producer, who in turn takes material from miners. But the steel producers also need many types of specialist tools (such as rolling mills). These are called "supply chains". Would it be possible to create such an integrated web of economic connections in space? Could we make it more or less independent from Earth inputs?

Consider the difficulty that there is at the present time in reproducing the industrial base of the rich western countries in the third World. If we can't do this, why should we expect to build an industry in space?

The Rules of the Game

You must stay within the current laws of physics. No assumptions about magic space drives or "Star Trek" transporters.

You are allowed to assume that current cutting edge technology now in university laboratories will become mature and mainstream (even if we are not 100% certain at the moment that some will scale out of the research laboratories).

For example, *graphene* in its purest and most perfect form is know to be a super-strong material with many other wonderful properties. Unfortunately, it currently difficult to make in large quantities while still having its theoretical maximum capabilities. (We might think of building highly efficient solar sails if we could have square kilometres of the stuff - but really good samples currently tend to be about the size of a finger nail.) However, it is just possible that the best place to make it in large quantities might be in the vacuum of space.

There are also lots of exciting potential developments currently being researched in robotics labs (such as robots that can reconfigure their own structure to do different jobs - "transformers for real"). We will allow you to make a few well-justified assumptions about the progress of technology in the next two or three decades.

It is perfectly OK in engineering to speculate about "*the things we could do if only*…(insert your technology).": it gives us an incentive to do the research and development that might actually make it happen.

Put in the numbers wherever you can. Engineers need to calculate things like: How big? How strong? How heavy? How Far? How long does it take? How expensive? Try to work out how much metal of the required type there might be in, say, a 100m diameter asteroid. Look up the costs of getting stuff up into space and back down again. Compare it with the costs of extracting rare elements on Earth.

Your multinational client will ultimately want to asses how much it is likely to cost them and whether they are likely to make or loose money. They will be prepared to take risks with their investment, but probably not “betting the company” on a favourable outcome.