Question 1:

Dear Cheap Astronomy – Is in situ resource utilization really worth the trouble?

Here at Cheap Astronomy we tend to say disparaging things about in-situ resource utilization, but usually in response to suggestions that if we want to land on Mars all we have to do is make rocket fuel out of in situ resources to take off again. While ostensibly true, a substantial amount of infrastructure would be needed to both source and refine the ingredients to make that fuel and you'd probably want to experiment with a few different methods, expect a few false starts and have a few trial runs before you'd actually put people on your launch vehicle. It's also the case that if your plan is to electrolyze water into hydrogen and oxygen, you'll then need to cool those gases down into their denser liquid phase to be useful as fuel, so there's a separate set of cryogenic storage issues to deal with there. All this might become cost-effective once you have a booming space economy, with landings and launches every other day, but for now it's vastly easier to just fly and land a tank of hypergolic launch fuel, so it's sitting there waiting when the astronauts arrive. It would be hypergolic fuel because of the long shelf life plus there's no fussing about with cryogenics.

Nonetheless, there is real opportunity for in situ resource utilization within this scenario. Any opportunity to establish fuel depots that separate your fuel from your spacecraft is a good opportunity. To date most space missions have involved taking all the fuel with you, and hence travelling with all the burden of the rocket equation where you burn fuel just to carry the fuel you will need later on. It would ideal if you could instead position refueling depots at various spots along the journey and your spacecraft could fly faster by keeping its mass lower. You could initially keep the depots stocked up with huge slower moving tankers, but in the longer term there is a business opportunity to keep them stocked with fuel made from in situ resources.

As we'd discussed before on this podcast, living on Mars doesn't have a lot going for it. On the Moon at least the skies are clear and it's only three days home, but on the much more distant Mars there will be an orange haze everywhere and there's only so many red rocks you can look at until the novelty wears off. But if you've got a lucrative business going, with well-paid jobs to be had then a three to six month stint on the red planet, might not be so bad and there'd be a reason for your employer to make the habitation pleasing and attractive and that might bring in a few tourists who have yet to realize there's only so many red rocks you can look at. The key ingredient for rocket fuel is water to give hydrogen, as well as oxygen and you might need to source that from the poles, though Mars' atmospheric CO2 can also help make methane.

Once have a reason to host people on another celestial body, water is a great in situ resource to keep them alive, not to mention some oxygen and food producing plants, which also thrive on that other great in situ resource sunlight. You can also use in situ resources to accommodate workers, the tourists and the plants – initially just piling up regolith over a prefabricated structures for radiation shielding but later maybe fabricating something from scratch with carved blocks and mortar from local rocks and regolith and eventually you could go real high-tech by 3d printing a regolith derived paste that sets hard in whatever shape you choose to extrude it into. From lunar soil and maybe other extraterrestrial soils you can also extract silicon and aluminum

for glass windows and solar panels. There's are just theoretical ideas and remain to be properly feasibility-tested, but they are ideas.

But there is one area that's achieved more than just talk. Moxie, the Mars Oxygen In Situ Resource Utilization Experiment – apparently an acronym with a silent S, R and U, is on board The Perseverance Mars rover. Since landing in February 2021 MOXIE has been run successfully seven times now, each time producing 6 grams of O2 within an hour – which is about what you'd expect from a small tree on Earth apparently. So, that's one small step for an electrolytic conversion unit, one giant leap for robot kind.

Question 2:

Dear Cheap Astronomy – What exactly is the space economy?

The Space Economy is defined by the OECD as the full range of activities that create value and benefits to human beings in the course of exploring, researching, understanding, managing, and utilising space. As we've previously discussed both on this and the fabulous Science on the ISS podcast, exploring, researching and understanding space are important activities– but if we are really going to move forward, more of the managing and utilizing space need to come into play. It's said the space industry is now worth over $400 billion, which was the amount of revenue generated in 2020, although that includes revenue from government investment. So, it's not a measure of profit, but it does capture money that pays salaries and builds infrastructure so it's a good reflection of an industries' benefit to the global economy. Most of the revenue that does look like genuine profit comes from satellites, most of which is about broadcast TV, although internet services are a growing part of the picture.

OK, this is a science podcast, we're just making the point that's it's great to invest money in things and to employ people, but if you're not doing something that also makes money then you don't really have a sustainable economy. Space Economy enthusiasts talk about space for Earth and space for space activities, where space for Earth activities are things like broadcast TV satellites, as well as weather and GPS satellites, while space for space activities are about finding new economic opportunities out there, like asteroid mining and space tourism. So, with space-for-Earth activities most of the upfront investment is now paying off big time. With space for space activities we are still in the upfront investment phase – with any realization of that investment looking as far away as GPS satellites did back when Sputnik One orbited the Earth. But, that was less than fifty years. The future always seems a long way off until you're in it.

That said, fifty years has passed since anyone was last on the Moon. Apparently, footprints, flags and science experiments aren't enough to inspire progress. A degree of political rivalry and FOMO, fear of missing out, seem to be working better. So, the moment someone says they're going to the Moon, then everyone else wants to as well. Hopefully this time round someone's going to build a base, because then everyone else will want to as well. And after

governments break the ice, then private enterprise might follow suit, if there is a buck to be made.

To encourage risky investments in space for space activities we need to establish a set of rules. The Outer Space Treaty signed in 1967 was and is great in many ways, banning the use of space for military purposes and blocking governments from claiming sovereignty over a celestial body like the Moon. But, at the same time blocking anyone from ownership of anything is a disincentive to exploring and prospecting – since if you find something, but can't stake a claim, then someone else can just move in and grab whatever you found. The Artemis Accords had tried to modify some of the feel-good space is for all stuff by stating that the extraction and utilization of space resources should be conducted in a manner that complies with the Outer Space Treaty, but is not inherently national appropriation. So, as long as you're not a government you can lay a claim. The Artemis Accords haven't been signed by Russia or China, nor India – though India is thinking about. Critics argue it's just American capitalism taking over. But the counterview is that a free market is never really a free market, you want governments to govern it, creating a set of rules and regulations that private interests can operate within, but then get out of the way. So, space could become an almost free market, with a bit of regulatory restraint and a hope that most people will do the right thing. But while people do often do the right thing, you'll still need courts to rule on things that look a bit dodgy and eventually you'd need space police for things that are clearly dodgy. Then someone will need to sell coffee and donuts – and before you know it we'll have ourselves a space economy, that is really in space. Here's hoping.