Question 1:

Dear Cheap Astronomy – Can life arise in a hydrogen atmosphere?

There's a lot of current interest in this following a recent demonstrations that a range of microorganisms can survive in a 100% hydrogen atmosphere. But surviving is only part of the story. Life as we know it requires energy to build and sustain its structural integrity in the face of various environmental challenges and to also reproduce.

If life is to arise anywhere from inorganic sources, it will initially be autotrophic – that is, able to create its own energy and structural integrity and to reproduce independent of other organisms. This excludes the animals and the fungi and most plants, which depend on animal mediated pollination or on soil nutrients derived from other biological sources. So, you can cut the list right down to some algae, cyanobacteria and archaea that survive on photo or chemosysnthesis.

Surviving in a hydrogen atmosphere is probably feasible for most non-aerobic organisms, that is ones that don't need oxygen – which again means some algae, cyanobacteria or archaea. But it's not enough just to survive – if you just have an environment of hydrogen and nothing else, you're not going to be able to build a body – and although molecular hydrogen is a good basis for metabolism, you can't do much with it if you just have the hydrogen and nothing else.

The metabolic energy production pathways that we know about mostly involve redox reactions, that is reduction and oxygenation reactions – where reduction means you gains an electron and oxidation means you lose one. Metabolic energy production pathways involve electron transport chains – where an electron donor, perhaps light-energized chlorophyll passes an electron through a chain of redox reactions to an ultimate electron acceptor – which is NADP is standard photosynthesis – the energy acquired from that then being used to make carbohydrate out of CO2, where carbohydrate is a good energy storage material which can be metabolized later (day or night) releasing energy as needed. Animals then exploit that system by eating plants to get the carbohydrate without having to synthesise it themselves. And then there's other animals that eat those animals without ever bothering the plants.

Chemosynthetic organisms use various chemicals as electron donors to make their carbohydrates, hydrogen sulfide being the main source for communities living around deep ocean hydrothermal vents – and there are some bacteria that use molecular hydrogen, h2 – which is currently our best hope for finding life under the ice on Europa or Enceladus.

In all these examples, water is needed as a universal solvent as well as having a direct role in some metabolic pathways – and of course CO2 is needed as a carbon source. Furthermore, there's a whole mechanical side to all Earth-based energy production, mediated by structures which include protein-based enzymes and phospholipid membranes. Consider that if you spill some petrol on the ground and light it – sure, it will burn and release energy, but if you want to use that energy to drive a car you need fuel injectors and pistons to usefully direct that energy towards a drive shaft. Much of the mechanical side of life is built from amino acids – which probably arise inorganically from high energy collisions between icy comets and carbonaceous asteroids – those collisions mushing frozen CO2 and H2O together with nitrogen-rich clay minerals, where nitrogen makes up the amine part of amino

acids. Phospholipid membranes probably arose around the time that inorganic chemistry became biochemistry on Earth, where phospholipids are a combination of an organic carbohydrate-based fat and an inorganic phosphate salt, things that can only really come together in liquid water.

So, yes, life can survive in a hydrogen atmosphere and also use that hydrogen as an energy source, but you'd probably need a whole bunch of other stuff for an organism to persist and to reproduce. It's unknown whether reproduction is a fundamental requirement of all life in the Universe, but it is the only way it happens here.

Question 2:

Dear Cheap Astronomy – What other forms of life are possible?

It is quite difficult to imagine a different form of life than what we see about us since what we see about us is the only example we have. So on Earth, there are various ways to capture energy, build a body and reproduce – so we tend to assume that is the standard model for life. The drive to reproduce is somewhat illusionary, much like the drive to eat. If you don't have a drive to eat you die and you don't contribute to the gene pool and if you don't have a drive to reproduce you don't contribute to the gene pool either. So, the gene pool inevitably fills up with things that do have a drives to eat and to reproduce. Having a drive doesn't mean you have a purpose, although people will tend assume there is a purpose or otherwise have to deal with being alive for no particular reason. If you do manage to resist the drive to reproduce or even to eat, that doesn't make you a bad person, it just means you will never influence the gene pool.

But, although reproduction is the only way life happens here, it's not clear if this is a defining characteristic. To be alive, with respect to capturing energy, building a body and sustaining that over time, you need some kind of renewal process to deal with wear and tear, but potentially that could just be about building replacement parts from raw materials. If we are envisioning life spontaneously arising from inorganics, then it's unlikely the ability to plan to replacing worn-out parts would be there from the start, but there might be some kind of underlying template that degraded materials eventually fall out of to be replaced by new materials that are naturally attracted to any gaps in that template. Of course the template itself might degrade – but our experience on Earth is that a mutable template is actually a good thing – like DNA with its occasional tendency for reproduction errors leading to mutations. Most mutants die, but some have quirks that let them exploit new areas of the environment, or the same areas of the environment in more efficient ways and so the mutants start to influence the gene pool – not through any innate desire to do so, they just do.

So, perhaps reproduction is not a necessary aspect of life across the Universe, but evolution is. It is hard to see how something could persist over time without also changing over time. And if we are looking out for intelligent technology users, it seems necessary that they be the result of an evolutionary process. It's unlikely any life form is going to spontaneously arise with the ability to build a radio transmitter.

Although, not so fast, this is after all a podcast about what other forms of life are possible. It's not that hard to broadcast electromagnetic radiation, which is mostly about the acceleration and deceleration of electrons around atoms. An early life form whose success depended on communalism might have used low energy radio transmissions to enable mutually beneficial cooperation. Such a strategy may never have been useful for Earth's early life since it was mostly immersed in water, which quickly absorbs radio waves.

And while we're on the subject, is water really mandatory? We'll maybe not, but some kind of chemical solvent might be necessary to provide a medium within which various chemical interactions can evolve from the inorganic to the organic. A solvent is really just the dominant part of a solution – and it doesn't have to be a liquid. So for example, nitrogen is technically the solvent for Earth's atmosphere, being the dominant part of a solution that contains oxygen and argon and carbon dioxide a few trace materials and also water.

Going further, sure carbon seems an ideal platform for the building of living bodies, given its high affinity for bonding with other elements, including most of the Universe's ubiquitous ones, like hydrogen, oxygen and nitrogen. But silicon might work nearly as well.

So, there are always possibilities. Given carbon-based life has done so well in a liquid water medium, it seems likely this same foundation may be found elsewhere in the Universe, we just shouldn't assume it's the only option.