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TERRAFORMING
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Conversion Hubs

How a Martian Settlement Makes Almost Everything From Five Raw Materials

Inner Planets Terraforming Foundation

A public report · July 2026

Written for the technically literate non-chemist

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Contents

1. What this document is

This document explains a single idea — the conversion hub — and uses it to answer a concrete question: how might a settlement on Mars manufacture almost everything its people need, starting from the very short list of raw materials the planet actually provides? The answer has a definite shape, and that shape is the subject of what follows.

It is written for a reader who is comfortable with technical argument but is not a chemist. No prior knowledge of industrial chemistry is assumed, every term of art is defined where it first appears, and a glossary at the end collects them in one place.

Section 2 sets out the problem and Section 3 defines the idea and the vocabulary used to describe it. Section 4 describes the five raw materials Mars offers. Sections 5 to 9 take each of the five hubs in turn — what it makes, what it is good at, and where it is most likely to fail. Sections 10 to 13 draw the five back together: how they depend on one another, what deliberately falls outside the scheme, the difficulties they all share, and how they compare.

2. The problem the idea solves

A settlement on Mars needs an enormous variety of stuff. Not merely oxygen and water and food, but the ten thousand unglamorous things that make a place habitable rather than survivable: soap, clothing, gaskets, glue, ink, containers, fertilizer, antiseptic, lubricant, window glass, wire, brick.

Two facts make this hard. The first is that shipping is ruinous. At a planning cost of roughly two thousand dollars per kilogram delivered to the Martian surface, a tonne of anything costs about two million dollars to send, and the things on that list are consumed continuously — soap runs out, filters clog, gaskets perish. Anything the settlement must import forever is a permanent tax on its existence.

The second fact is that Mars is chemically poor in a very specific way. It offers a short list of raw materials, and that list contains almost none of the things on the list above in usable form. There is no rubber tree, no petroleum, no chlor-alkali plant, no forest. There is rock, air, ice, dry ice, and sunlight.

So the question is not "what does the settlement need?" — that list is easy to write. The question is: **by what path does a short list of raw materials become a long list of finished goods, and where along that path is limited research effort best concentrated?** The conversion-hub idea is an answer to the second half of that question.

3. Definitions

3.1 What a conversion hub is

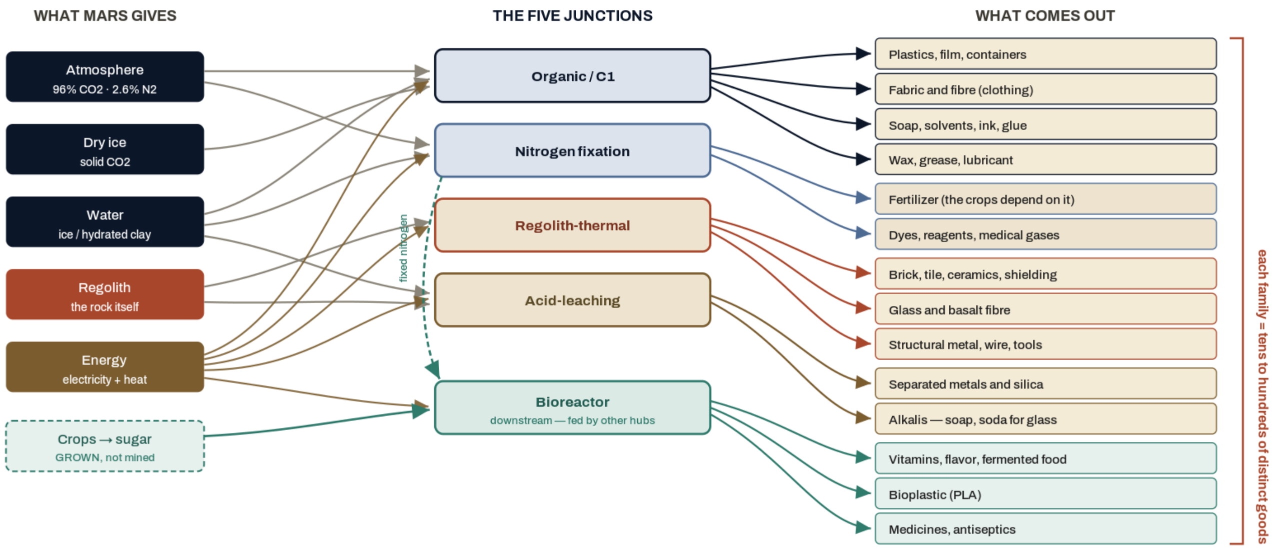
A **feedstock** is a raw material a process starts from. An **intermediate** is a substance that is not itself useful to a settler but is the necessary stepping-stone to things that are. A **conversion hub** is a small cluster of chemistry that takes one or two feedstocks and produces a handful of intermediates from which a whole column of finished goods can be reached.

The essential observation is one of shape. If the raw materials are drawn on the left of a page and the finished goods on the right, and every real chemical dependency between them is traced, the picture is a fan. A few materials enter, pass through a small number of junctions, and from those junctions an enormous variety of products spreads out. Figure 1 shows the map.

The asymmetry is what matters. The junctions stay few while the product list grows without bound: a settlement making ten thousand different things is still, chemically, operating only five conversion routes. That asymmetry — few junctions, unbounded products — is the basis of the argument that follows.

Figure 1 — Few materials, few junctions, an explosion of goods

Every line is a real dependency. Minor flows are omitted for clarity.



The shape is a fan. Five materials enter. They pass through five junctions. Everything a settler ever touches comes out of the right-hand side. The junctions are the only narrow part of the picture, and so the place where effort repays itself.

The bioreactor sits downstream of the others: it runs on sugar the settlement grows and on nitrogen the nitrogen hub fixes.

Figure 1. The five feedstocks, the five junctions, and the product families that depend on them. Every line is a real dependency: the atmosphere supplies carbon to the organic hub and nitrogen to the nitrogen hub; water supplies hydrogen to both and the water for sulfuric acid; regolith feeds only the two mineral hubs. Note the bioreactor, which no raw material reaches directly — it runs on sugar the settlement must grow and on nitrogen another hub must fix.

Three tests decide whether a piece of chemistry deserves to be called a hub rather than merely a process. First, convergence: several different feedstocks, or several different paths, funnel into it. Second, divergence: many distinct product families depend on its output, so that solving it once unlocks them all. Third, shared apparatus: the various things it makes are made with substantially the same equipment, so building the capability once serves many ends. A process that fails all three tests is a product line. A process that passes all three is a hub, and is worth disproportionate attention.

Why the distinction matters. Suppose a laboratory of modest size can pursue one thing. It could develop a process for making polyester fabric — and it would end up with polyester fabric. Or it could develop the organic hub that produces the building block from which polyester, polyethylene, solvents, adhesives, waxes, and inks all descend — and it would end up with a claim on every one of them. The hub framing is, in the end, an argument about leverage: the same effort yields a column of products rather than a single product.

The idea has a long terrestrial pedigree. Industry has organized itself this way for a century. Petrochemistry is built on a handful of platform molecules — ethylene, propylene, benzene — from which the plastics industry descends; the field of C1 chemistry is named for the single-carbon building blocks at its root. What differs on Mars is which platforms are reachable from the available feedstocks under the available conditions. That question has a definite answer, and the answer is five.

3.2 How maturity is described in this document

Claims about how far a piece of chemistry has actually been proven recur throughout this primer, and the words used for them are precise. They form a ladder, and each rung answers a single question: what, exactly, has somebody already done?

Rung	What it means
Paper	The reaction is understood, and is very often run at industrial scale on Earth — but nobody has built or operated it for Martian conditions or on Martian feedstocks. The chemistry is not in doubt; the engineering is simply unattempted. Paper is therefore not an accusation of speculation. It locates the uncertainty: in the plumbing, not in the science.
Lab-demonstrated	The step has been run at the bench under deliberately Mars-like conditions — typically a simulated Martian atmosphere at Martian pressure — usually producing grams. The principle is shown; the scale and the durability are not.
Simulant-demonstrated	The step has been run on Mars simulant: manufactured soil formulated to match the composition of real Martian regolith. This tests the awkward, impure feedstock — but it does so on Earth, at Earth's pressure and Earth's gravity, both of which matter.
Flight-proven	The process has actually been operated off Earth, in orbit or aboard the International Space Station. Few things in this document have reached this rung.
Demonstrated on Mars	Operated on the Martian surface itself. Exactly one process in this document has reached this rung: making oxygen from atmospheric carbon dioxide.

Two cautions about the ladder. First, it measures evidence, not difficulty: a process may sit at the paper rung because it is unglamorous and nobody has bothered, rather than because it is hard. Second, the rungs are not a schedule. Climbing from simulant-demonstrated to demonstrated-on-Mars is a matter of launching hardware, not of doing more chemistry, and the two can be separated by decades.

4. The five raw materials

Everything the settlement makes must come from this list. It is worth being precise about what each item actually is, because the limitations of the list explain most of the difficulties later in this document.

Feedstock	What it actually is, and what it is good for
Water	Buried ice, or water chemically bound inside clay minerals. It is the settlement's only significant source of hydrogen. Hydrogen is the currency of chemistry: nearly every step that turns a mineral or a gas into something useful involves adding hydrogen or taking oxygen away, and water is where the hydrogen comes from.
Atmosphere	About 95% carbon dioxide, 2.6% nitrogen, 1.9% argon — and extremely thin, roughly six thousandths of Earth's sea-level pressure. It is a source of carbon (for anything organic) — the other being the dry-ice deposits described below — and it is the only source of nitrogen (for fertilizer). The thinness matters enormously: to get a useful quantity of nitrogen the settlement must process a very large volume of very dilute gas, and compression is a precondition for almost all of the chemistry.
Dry ice	Solid carbon dioxide — deposited as seasonal frost and persisting as ice at the poles. Chemically it is identical to the CO_2 in the air, but it arrives already concentrated and already solid, which sidesteps the compression problem entirely. It is the settlement's second source of carbon, and the cheaper of the two to gather. Wherever this document speaks of carbon coming from carbon dioxide, either source will serve.
Regolith	The broken rock and dust covering the planet. Basaltic: dominated by oxides of iron, silicon, magnesium, aluminum and calcium, with 15–25% clay minerals, sulfate salts, roughly 0.5–1% perchlorate salts, and about 0.8% phosphate. It is the source of every metal, every mineral, all the silica, the sulfur, the phosphorus and — from localized alkali-rich rocks — the sodium and potassium.

Feedstock	What it actually is, and what it is good for
Energy	Two distinct kinds, and the distinction is not pedantic. Electricity (from a fission reactor or solar panels) is what drives electrochemistry — splitting water, splitting CO_2, running a plasma. Concentrated heat (from a solar furnace or mirror) is what melts and sinters rock. Melting glass wants heat; splitting carbon dioxide wants electrons. A settlement rich in one and poor in the other will make very different choices.

A note on what is absent. There is no biomass to start from, no concentrated ore body of the kind Earth's industry was built on, no liquid water in quantity, and no free oxygen. The chemistry that follows is shaped as much by these absences as by the five presences.

5. Hub one: the organic hub

Also called the C1 hub, because its building blocks carry a single carbon atom. It is the keystone of the whole scheme: if a settlement could establish only one hub, this is the one to establish.

5.1 What it does

It takes carbon dioxide — drawn either from the thin atmosphere or, more cheaply, from dry-ice deposits — together with water from the ice, and turns them into a gas mixture from which nearly every organic material can be built. "Organic" here is the chemist's meaning: a compound built on a backbone of carbon atoms. Plastics, fabrics, solvents, lubricants, dyes, medicines and adhesives are all organic in this sense.

The chain runs in three stages. In the first, electricity is used to prise the molecules apart: water is split into hydrogen and oxygen, and carbon dioxide is stripped of one oxygen atom to make carbon monoxide. The resulting mixture of carbon monoxide and hydrogen is called synthesis gas, or syngas, and it is the single most important substance in this document.

$$2\,H_2O \rightarrow 2\,H_2 + O_2 \qquad \text{(splitting water with electricity)}$$

$$CO_2 + H_2 \rightarrow CO + H_2O \qquad \text{(stripping an oxygen from carbon dioxide)}$$

Syngas is the narrow point of the fan. In the second stage it is assembled into a small set of simple building blocks — principally methane, methanol, and ethylene. In the third stage those blocks are strung together into long chains (polymers) or decorated with other atoms to make everything else. Ethylene strung into a chain is polyethylene, the commonest plastic on Earth. Methanol is the gateway to solvents, adhesives, formaldehyde and — through a further step — to the ring-shaped molecules that aspirin and polyester need.

$$n\,C_2H_4 \rightarrow [\text{–CH2–CH2–}]n \qquad \text{(ethylene molecules linked into polyethylene)}$$

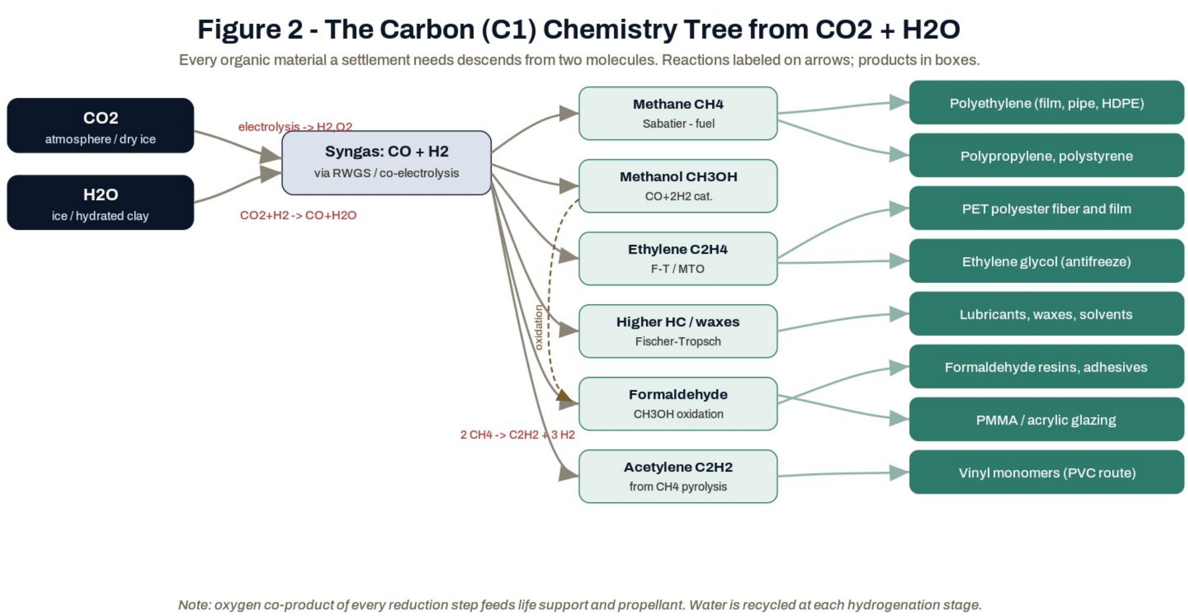


Figure 2. The organic hub as a tree. Two feed molecules at the root; syngas at the trunk; the entire slate of organic materials in the branches. Everything on the right-hand side shares the first two stages — which is precisely the argument for building the trunk first.

5.2 Merits

Its reach is unmatched. Every product in the right-hand column of Figure 2 depends on the same two opening moves. A laboratory that gets syngas generation right, and gets one flexible step for turning syngas into building blocks, has bought a claim on the entire organic economy — packaging, clothing, soap, ink, glue, wax, and the feedstocks for medicine. No other hub has this breadth.

It also closes a loop the settlement needs closed anyway. A sealed habitat accumulates carbon dioxide from the people breathing in it. The organic hub consumes carbon dioxide. The same plant that makes the plastic can be part of the life-support system, which means its value is not purely economic.

5.3 Difficulties

The catalysts. A catalyst is a substance that makes a reaction go — faster, or at a lower temperature, or toward the product wanted rather than a useless mixture — without being consumed itself. Almost every step in this hub needs one, and the catalysts industry uses are themselves highly engineered materials: specific metals, in specific crystal forms, with promoter elements present at fractions of a percent. Nobody knows how to make them on Mars. The usual assumption is that they are imported, which is defensible — they are light and long-lived — but it means any claim of "self-sufficiency" carries an asterisk, and the asterisk is load-bearing.

Nothing has been run end to end. Every individual reaction in this chain is textbook chemistry, run at industrial scale on Earth for decades. But no one has ever operated the integrated train on Martian feedstocks — that is, on gas and water carrying the impurity signature of real Martian processing, at Martian pressure, with Martian dust in the works. The honest maturity rating for the chain as a whole is: paper.

It is dual-use by nature. The same reactor train that produces plastics and waxes also produces fuels. This is a governance matter rather than a technical one, but it is a real one, and it recurs in the nitrogen hub.

6. Hub two: the nitrogen hub

6.1 What it does

It pulls nitrogen out of the thin Martian air and converts it into a chemically usable form — a process called fixation. The distinction is critical and is the whole reason this hub exists. Nitrogen gas is two nitrogen atoms bound to each other by one of the strongest bonds in chemistry. In that form it is inert: a plant sitting in an atmosphere of it will starve. To be useful to a crop, nitrogen must be broken out of that bond and attached to something else — typically as nitrate or as ammonia. That breaking is fixation, and it is expensive.

The established route is a plasma: an electrical discharge violent enough to tear the nitrogen molecule apart, allowing it to recombine with oxygen into nitric oxide, and from there into nitric acid and finally into ammonium nitrate — fertilizer.

$$N2 + O_2 \rightarrow 2\,NO \rightarrow \dots \rightarrow HNO_3 \quad \text{(fixation in a plasma, then absorption into acid)}$$

$$NH_3 + HNO_3 \rightarrow NH_4NO_3 \quad \text{(ammonium nitrate — fertilizer)}$$

6.2 Merits

It is survival-critical and it has no substitute. Crops cannot grow without fixed nitrogen, and unlike almost everything else in this document it cannot be improvised from another feedstock: there is no clever workaround, no second source. If the settlement is to feed itself, this hub must work. That is a different kind of argument from the organic hub's — nitrogen earns its place through criticality rather than through breadth.

It also produces more than fertilizer. Nitric acid is a reagent the rest of the chemistry wants; nitrous oxide is a medical gas; nitrogen compounds are the basis of dyes and of explosives useful for mining.

6.3 Difficulties

The arithmetic of a thin atmosphere. Nitrogen is only 2.6% of an atmosphere that is itself a hundred and fifty times thinner than Earth's. To collect a tonne of fixed nitrogen the settlement must move an enormous volume of gas. The hard problem is not the chemistry — that is well understood — but the concentration and the energy.

Plasma is a glutton. Tearing apart the nitrogen triple bond by brute electrical force is notoriously power-hungry, and on a settlement short of power this hub competes directly with the oxygen plant for the same kilowatts. This is the most contested trade-off in the whole scheme.

There may be a much cheaper route, and nobody has compared them. Certain bacteria fix nitrogen at room temperature, using sunlight rather than an electrical bus, and they have been grown on Mars-simulant soil. Biology may simply be better at this than plasma — slower and needing more area, but far less power. Remarkably, no one has ever published a head-to-head comparison of the two routes for Mars; the plasma community and the biology community publish in different journals. That comparison is among the most valuable pieces of work anyone could do in this field.

7. Hub three: the bioreactor hub

7.1 What it does

This hub differs from the other four in kind: it is biological. A bioreactor is simply a vessel in which living cells — yeast, bacteria, or cultured cells — are kept alive and fed so that they manufacture something. Brewing is the oldest example. The cells do the synthesis, and they do it at body temperature and ordinary pressure, using machinery evolution spent three billion years debugging.

The hub takes sugar (grown by the settlement's crops) and fixed nitrogen (from hub two) and lets biology make what abiotic chemistry finds hard or impossible: vitamins, flavors, organic acids, biodegradable plastics, fermented foods, and — at the frontier — proteins and peptide drugs.

7.2 Merits

It reaches molecules the other hubs cannot. Many biologically important molecules are *chiral* — they come in left- and right-handed forms that are mirror images, and typically only one of them works in a human body while the other is useless or harmful. Ordinary industrial chemistry tends to make both at once, and separating them is difficult and wasteful. Living cells make one hand only, effortlessly. Vitamins, most drugs, and the amino acids of protein are all in this category. Without a bioreactor, a settlement can make plastic but not a vitamin.

It is, surprisingly, the most flight-proven hub on the list. NASA has already flown microbes that manufacture vitamins on the International Space Station, across several iterations of an experiment series. Microbial extraction of metals from basalt has also flown. No other hub in this document has been operated off Earth at all — with the single exception of oxygen-making, which is upstream of everything.

It is also frugal with power, which makes it the natural hedge if the settlement's reactor underperforms.

7.3 Difficulties

The problems are biological, not chemical, and that makes them unfamiliar. Keeping a strain alive and genetically stable over years, without a supply chain of fresh cultures from Earth. Preventing contamination — a sealed habitat is a perfect incubator for whatever gets loose. Feeding the cells on locally grown sugar rather than the refined laboratory media they are used to. None of these are questions a chemist is trained to answer, and all of them remain open.

It is also downstream and therefore gated: the bioreactor cannot run until the settlement is already growing sugar in quantity, which means it cannot be the first thing built.

8. Hub four: the regolith-thermal hub

8.1 What it does

The inorganic counterpart to the organic hub, and conceptually the simplest thing in this document. It applies heat to crushed rock. What comes out depends almost entirely on how hot the furnace is run — which is why it is best pictured as a ladder rather than as a process.

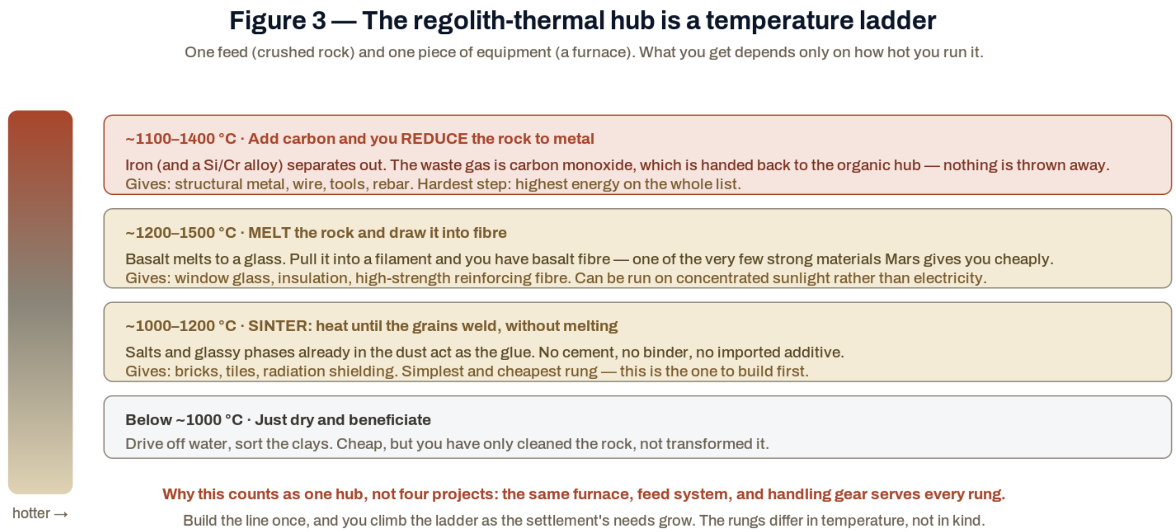


Figure 3. The regolith-thermal hub as a temperature ladder. One feed, one furnace; the product is selected by the dial.

8.2 Merits

One capital investment serves four material families. The same furnace, the same feed handling, the same crushing and sorting gear yields bricks at the bottom of the ladder, glass and structural fibre in the middle, and metal at the top. This is the shared-apparatus test from Section 3, passed as clearly as it can be.

The bottom rungs are also the cheapest and most certain thing in the entire program. Binderless sintering — heating dust until the grains weld together without any added cement — has been demonstrated on Mars-simulant soil with respectable strength. It needs no imported additive and no exotic catalyst, and the heat can come from concentrated sunlight rather than the electrical bus, which insulates it from a power shortage. If the settlement can do nothing else, it can make bricks.

Basalt fibre deserves a special mention: it is one of very few genuinely strong materials Mars offers without imports, and strength is otherwise in short supply.

8.3 Difficulties

The numbers come from Earth furnaces. The encouraging strength figures were measured in terrestrial laboratories on simulated Martian soil at terrestrial pressure. Mars adds a near-vacuum, which changes how bubbles escape a melt; a third of Earth's gravity, which changes how the melt convects; and perchlorate and sulfate contaminants, which may weaken the product or may flux it usefully. None of this is known. The published strength should not be assumed to survive the journey.

The top rung is brutally expensive. Reducing rock to metal is the most energy-intensive process on the whole list, and it also produces an impure iron–silicon alloy rather than separated, clean elements — which is where the fifth hub comes in.

9. Hub five: the acid-leaching hub

9.1 What it does

It dissolves rock rather than melting it. Sulfate salts, which are abundant in the Martian soil, are cooked to release sulfur trioxide, which combines with water to give sulfuric acid. That acid is then used to digest silicate rock, pulling it apart into separated components: iron metal, silica, oxygen, and a set of clean metal oxides. It is a chemical route to the same destination the top of the thermal ladder reaches by brute heat.

The same acid digestion, applied to the localized alkali-rich rocks found at places like Gusev crater, is also how the settlement obtains sodium and potassium — the first for soap and soda-based chemistry, the second for fertilizer. Ordinary Martian basalt is poor in both.

9.2 Merits

It separates. This is the crucial difference from the furnace route. Carbothermic reduction gives a lump of mixed alloy; acid leaching gives distinct, purified streams — which is what a settlement needs once it wants refined silica for glass, specific metal oxides for pigments, or clean elements for anything demanding. It runs at far lower temperature, and it produces oxygen as a byproduct.

9.3 Difficulties

It requires an entire acid economy to exist first. Before a gram of rock is dissolved, the settlement must be able to make, store, concentrate, and handle sulfuric acid at scale — and must build every vessel, pipe, and pump in the line out of something the acid will not eat. That is a large industrial precondition, and it is why this hub is generally seen as the second metals route a settlement builds, not the first.

It is also, of the five, the least demonstrated. It is a well-argued proposal at laboratory scale rather than a technology with a track record.

10. How the hubs interlock

Presented one at a time, the five hubs look like five separate factories. They are not. The strongest argument for the whole framing is that the hubs close each other's loops: the waste of one is the feedstock of another. Figure 4 traces the main connections.

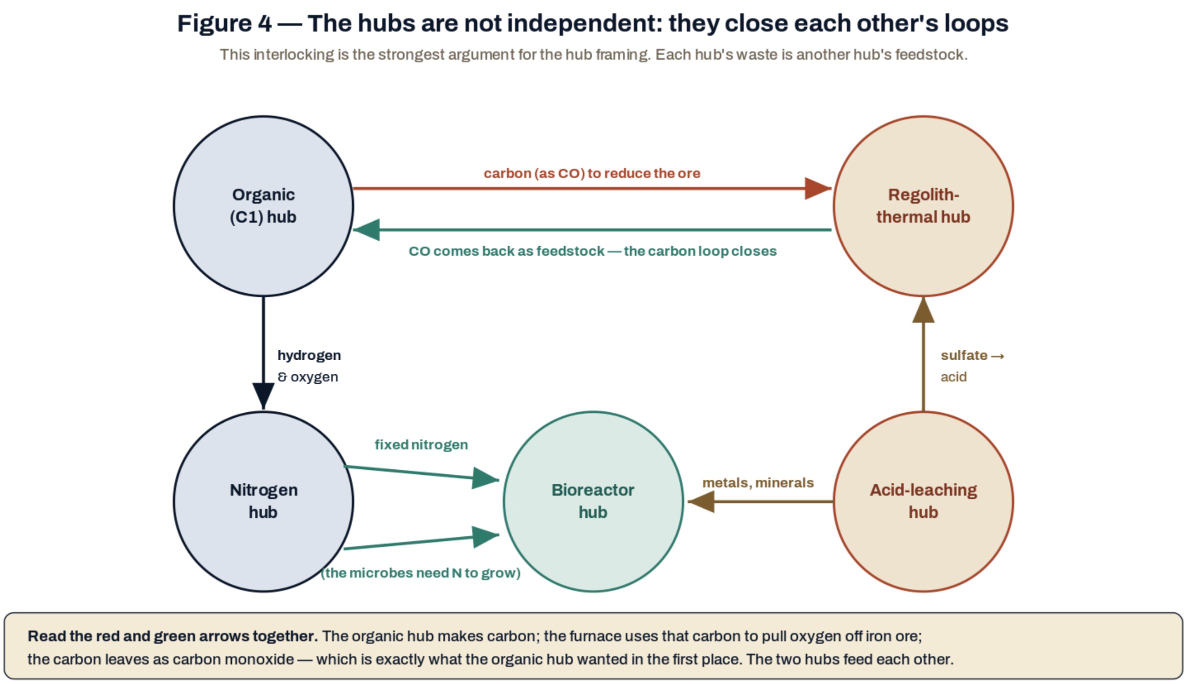


Figure 4. The five hubs, and what they hand to one another. The carbon loop between the organic and thermal hubs (red and green) is the clearest example.

The carbon loop is the elegant one. To turn iron oxide into iron, the oxygen must be pulled off, and carbon is what pulls it: carbon has a stronger appetite for oxygen than iron does. The carbon comes from the organic hub. It leaves the furnace as carbon monoxide — which is precisely the gas the organic hub wanted in the first place. The carbon therefore circulates rather than being consumed, and the two hubs feed each other. Neither is as attractive alone as the pair is together.

The other couplings are less pretty but equally load-bearing. The nitrogen hub supplies the fixed nitrogen that the bioreactor's microbes need in order to grow at all. The acid-leaching hub supplies the sulfur trioxide that the soap project needs, and the sodium that makes the soap a soap. The organic hub supplies hydrogen to nearly everything. Oxygen, liberated as a byproduct of splitting carbon dioxide, is exactly what the nitrogen plasma needs to burn nitrogen into nitric oxide.

The practical consequence is a sequencing constraint. Because the hubs depend on one another, they cannot be built in an arbitrary order, and a hub that looks cheap in isolation may be expensive once its upstream requirements are counted. It is why any serious plan must state explicitly what each stage assumes is being handed to it.

11. Why five — and what is deliberately not a hub

A taxonomy is only as good as its edges, and two things that might look like hubs are deliberately excluded. Both exclusions are instructive.

Chlorine is a chain, not a hub. Martian soil contains perchlorate salts — a notorious hazard, toxic to humans and awkward for every process that must tolerate it. It is also, viewed the other way round, the settlement's only realistic source of chlorine. Two well-developed process routes already exploit this: one makes silicone rubber for gaskets and seals by way of a chlorine loop fed from perchlorate, and another makes hypochlorite disinfectant by electrolyzing Martian brine. So chlorine is genuinely used. But it fails the hub tests: it does not converge, it fans out to only a narrow set of products, and it borrows other hubs' apparatus rather than justifying its own. It is a dependency running through the scheme rather than a junction in it, and it is at present less thoroughly mapped than any of the five hubs.

Catalysts are a dependency, not a hub. Every hub except the bioreactor leans on imported catalysts, and the ability to manufacture them on Mars would change the self-sufficiency arithmetic of the whole program. But making a catalyst is not a junction through which materials flow; it is an enabling capability sitting underneath the junctions. It is treated as an open research question, and an important one, rather than as a sixth hub.

The fifth hub is biological rather than chemical, and it belongs on the list for the same reason as the other four: it passes the three tests. It converges (sugar plus fixed nitrogen), it diverges (vitamins, organic acids, bioplastics, fermented food, medicines), and it shares apparatus (a single fermenter serves all of them). A settlement that grows crops and runs fermenters depends on it whether or not it is given a name.

12. What all five have in common

Certain difficulties are not properties of any one hub but of doing chemistry on Mars at all. They recur, and they are where a small laboratory's effort is most likely to matter.

The recurring problem	Why it bites
Impure feedstocks	Terrestrial chemistry is developed on reagents from a bottle. Martian chemistry runs on whatever the rock and the air actually contain — iron, magnesium and calcium ions, sulfate, chloride, perchlorate, residual dust. A process that works beautifully on pure feed may foul, poison, or simply stop on the real thing. Testing against deliberately dirty surrogates is, arguably, the single most useful thing an Earth-based laboratory can do for a Mars program.
No liquid water to waste	A vast amount of terrestrial chemistry is done in dilute solution and separated by washing. On Mars water is precious and does not stay liquid. Separations must be done by other means — crystallization, sublimation, absorption into a gas stream — and separation, not reaction, is usually where an industrial process actually fails.
Six millibars of pressure	Almost nothing works at Martian ambient pressure. Gases must be compressed before they can react, melts behave differently as bubbles escape, and every vessel is effectively a pressure vessel. Compression is an unglamorous, power-hungry precondition that appears in nearly every process.
Perchlorate wears two hats	It is a contaminant to be removed in most processes and a deliberate raw material in two. Both are true at once. A project team that designs perchlorate out of a feed may be starving another project that needs it.
Imported catalysts	The recurring asterisk on every claim of self-sufficiency. See Section 11.
Dual use	The chemistry that makes fertilizer also makes explosives; the chemistry that makes plastic also makes fuel. This is inherent, not incidental.

13. Which hub to build first

The five hubs are not equals, and a settlement cannot build them all at once. Two axes govern the order in which a rational settlement would establish them.

The first is criticality: does the settlement die without it? Oxygen, water, and fixed nitrogen are in this category; window glass is not. The second is leverage: how many downstream products does solving it unlock? By this measure the organic hub dominates. Nitrogen fixation ranks high on the first axis and only moderately on the second, which is why it belongs early in the sequence despite producing a comparatively small tonnage.

Figure 5 — The five hubs compared

Maturity words (paper, lab-demonstrated, simulant-demonstrated, flight-proven) are defined in Section 3.2.

Hub	What it turns...into	How proven?	Energy appetite	The hard part
Organic / C1 the keystone	air + water → a gas mixture ("syngas") → nearly all plastics, fabric, solvents	Individual steps textbook; the whole chain: paper only	High (splitting water is the sink)	The catalysts are imported. Nobody has run the whole train on Mars-grade feed.
Nitrogen fixation survival-critical	2.6% of the air → fertilizer and nitrogen reagents	Lab-demonstrated on simulated Mars air	Very high (plasma is greedy)	Crops cannot live without it and there is no substitute. Biology may be the cheaper route.
Bioreactor the biological one	sugar + nitrogen → vitamins, flavors, bioplastic, medicine	Flight-proven — microbes have made vitamins in orbit	Low	Problems are biological, not chemical: keeping strains alive, contamination in a sealed can.
Regolith-thermal infrastructure	rock + heat → brick, glass, fibre, and metal	Simulant-demonstrated	Medium-high, but sunlight can do it	Strength figures come from Earth furnaces. Mars is near-vacuum.
Acid-leaching infrastructure	rock + acid → separated metals, silica, oxygen	Paper (some lab work)	Lower heat, but you must first make acid	Needs a whole sulfuric-acid economy, and acid-proof kit.

Figure 5. The five hubs compared on what they make, how far they have actually been proven, how much power they demand, and where each is most likely to fail.

The power question changes the answer. The usual planning assumption is that the settlement has abundant power from a fission reactor, which makes feedstock access — mining, moving, compressing — the thing that limits it. But if that reactor underperforms and power becomes the scarce resource, the ranking shifts. The two programs that suffer most are precisely the two that spend electricity most freely: nitrogen fixation and metals production. And, strikingly, those are the two for which biology offers a low-power alternative — nitrogen-fixing bacteria in place of a plasma, and metal-leaching microbes in place of a furnace. The bioreactor hub is therefore not merely a producer of vitamins. It is a settlement's insurance policy against a power shortage.

14. Glossary

Term	Meaning as used in this document
Abiotic	Not involving living organisms. Four of the five hubs are abiotic; the bioreactor hub is not.
Catalyst	A substance that makes a reaction go faster, or at lower temperature, or toward the desired product, without being consumed. Nearly every hub depends on one, and on Mars they are imported.
Chiral	Existing in left- and right-handed mirror-image forms. Most biological molecules are chiral and only one hand is useful; living cells make one hand, ordinary chemistry makes both.
Feedstock	A raw material a process starts from. Mars offers five.
Fixation	Breaking inert nitrogen gas out of its very strong bond and attaching it to something else, so that a plant can use it. Expensive, and unavoidable.
Intermediate	A substance of no direct use to a settler but necessary as a stepping-stone. Syngas is the most important one.
Organic	Built on a backbone of carbon atoms. Not a synonym for "natural" — polyethylene is organic.
Perchlorate	A chlorine-and-oxygen salt, abundant in Martian soil. Simultaneously a toxic contaminant and the settlement's only source of chlorine.
Plasma	A gas energized until its molecules break apart. Used here to tear nitrogen out of its bond. Effective and power-hungry.
Polymer	A long chain built from many identical small molecules. Polyethylene is a chain of ethylene units. Most plastics and fibres are polymers.
Reduction	Removing oxygen from a compound (or adding hydrogen). Turning iron oxide into iron is a reduction; carbon is what does the removing.
Regolith	The layer of broken rock and dust covering the planet. On Mars it is basaltic and it is the source of every mineral the settlement uses.
Sintering	Heating a powder until the grains weld together without fully melting. How Martian brick is made, with no cement required.
Syngas	Synthesis gas: a mixture of carbon monoxide and hydrogen. The single most important intermediate in this document, and the narrow point through which most organic chemistry passes.

15. Further information

This report sets out the conversion-hub framework and the reasoning behind it. It is one product of a continuing research effort by the Inner Planets Terraforming Foundation into the materials chemistry of a Martian settlement — what can be made from local feedstocks, by what routes, and at what cost in energy and imported goods.

Readers who wish to discuss the analysis, to question or correct it, or to learn more about the research behind it are invited to write to info@innerplanets.foundation, or to contact a Director of the Foundation. Correspondence from specialists in any of the five hub chemistries — and particularly from those who think a conclusion here is wrong — is welcome.