Appendix 2

Terraforming the Underground

The Earth contains species capable of living in extreme conditions. We need only convert these adaptations to the transhuman genome to ensure our survival at depths never before possible in the history of man.

—Atticus Masimovian, 168 AR

The following is the transcript of Supreme Scientist Jeremiah Selendia's guest lecture to a Harpoon class in 233 AR. Though its central topic was underground terraforming and engineering, the lecture also covered subjects such as the Reassortment Atmospheric Anomaly, the Death Wave, the Reassortment Strain, Livelle city-state, the Beimeni zone, and the Age of Masimovian, among others. It was required reading for Harpoon candidates and knowledge of the points covered in the lecture was tested during the first half multiple choice section of the exams until Jeremiah's demotion from Project Reassortment in 283 AR. The transcript is stored in Marstone's Database and is considered classified government property.

To thoroughly understand the process by which we terraformed the Beimeni zone of the underground, a brief overview of the circumstances that led to its necessity is required. The Reassortment Atmospheric Anomaly and resultant Death Wave concluded the Second Hundred Years' War fought between the Eastern and Western Hegemonies. The paucity of data that survived in Livelle Laboratory after the zeropoint attack at the end of the war suggests the Reassortment Strain may have escaped containment from Hengill Laboratory, built 200 meters below the surface of Iceland. From there we suspect it mutated in unexpected ways, transforming into the modern killer of transhumans. We also believe the end must have been swift, and terrifying, based on our own experience with it: no transhuman has survived exposure to it.

The lone survivors of the extinction event organized a civilization within the contained and sustained Livelle Laboratory some 50 meters below Antelope Canyon. Noriel Livelle, the chief administrator for the lab, proposed the formation of a new government, consisting of a democratically-elected chancellor and 10 ministers (for 10 districts) to rule over a new city-state. The city-state would include the centrally located laboratory and its surrounding village with a population of about 15,000—the presumed last of the transhuman race.

Noriel Livelle was elected the first chancellor in a landslide victory; with the approval of the ministry, he named the new city-state after himself. He and the ministry requested a group of scientists known as the Elders—transhumans highly skilled with the zeropoint field—to formulate a strategy to protect Livellans from structural collapses and Reassortment breaches. The Elders created strategic expedition (strike) teams with a separate mission from the Livelle Guard, which protected the central government apparatus and provided security throughout the city-state.

The strike teams were instead given complete autonomy under a designated strike team commander, with the understanding their sole mission was to respond to structural collapses and Reassortment breaches in Livelle. The Elders suspected either the strain was designed to diffuse into the Earth—presumably to disrupt or kill scientists who worked in subterranean synbio labs—or did so by other means because they'd lost contact with the Western Hegemony, including the underground facilities. So the first volunteers for the strike teams understood their mission was a suicidal one; no biomat suit could then protect transhumans from Reassortment exposure in the shallower parts of the underground or upon the surface.

Concurrent with the creation of the strike teams, the chancellor called on his confidant, Ruslan Masimovian, to form the Reassortment research team to focus on developing Reassortment-resistant biomats and a cure. Masimo, as Ruslan was known, first sought to unfreeze the League of Scientists—the 340 scientists frozen near absolute zero as required by the initiation of Operation Preservation—who many believed could hold the key to immunity to the Reassortment Strain. (Some even suspected they could have Reassortment-resistant genes.)

Masimo killed five scientists before he realized the methodologies outlined by the league for awakenings would not work; neither he, nor anyone else, could find a way to repair the cells fast enough to revive the scientists held in stasis. Chancellor Livelle ordered the remaining 335 scientists be stored in a special containment chamber called the Cryo Room within the city-state's Science District, at the lowermost level of the laboratory, which lay beneath the village.

Existing synbio labs merged and new labs formed, combining with new and existing consortiums (including mechanical, nuclear, biological, civil, materials, computer, electrical, and zeropoint field engineers, among others) focused on obtaining energy and producing synisms, raw materials, and sustenance to ensure humanity's survival in the underground. Livelle's sophisticated power plant had been built prior to the extinction event, and became the basis for the design of power plants used throughout the Great Commonwealth of Beimeni.

All power plants, with the exception of solar panels, hydroelectric, and wind turbines, are the same: water is converted to steam in a boiler (or pressure vessel), the steam is used to spin a turbine, the turbine spins a generator that produces electricity, and the waste steam is condensed back into water before being redirected back into the boiler. The only difference between various types of power plants is the fuel that heats the boiler, which includes nuclear, coal, oil, or natural gas, among other sources.

Engineers designed a pressure vessel that sat in a pool of magma. The magma transferred its heat to the vessel, which boiled the water. As a result, the magma cooled and became denser than the hotter magma beneath it. The cool magma sank, was warmed by the Earth, then rose and was cooled by the boiler, and the process repeated. The idea was to create a current within the magma called *natural convection*; it was the driving force behind Livelle's power plant design. The problem: magma didn't exist naturally near Livelle Laboratory.

The Western Hegemony had to devise a methodology to create magma based on the understanding of the way heat is spread inside the Earth. To wit, the flow of heat (i.e., heat flux with units of W/m^2 or watts per square meter) out of the Earth is roughly 87 milliwatts (mW) per square meter (m^2), averaged over the entire surface. It is driven by the fact that deep Earth is hot, and it becomes hotter with increasing depth. The change of temperature with depth is sometimes called the *geothermal gradient*, or *geotherm*. It differs for the oceanic and continental regions. (Livellans had concluded to burrow beneath the oceans would prove too difficult, logistically, biologically, and technologically, so the discussion that follows is concerned solely with the continental region.)

There are three sources of heat inside the Earth. One is "primordial" heat, or the heat left over from accretion and core formation; another is heating caused by the decay of long-lived radioactive isotopes. The relative contributions from the two sources are uncertain, but the latter probably predominates and may contribute as much as 75 percent of the total heat. The third source is tidal friction resulting from the gravitational attraction of the moon. As the moon and Earth orbit each other, both bodies bulge out slightly toward their near and opposite sides. This gives rise to the ocean tides, but there are similar, albeit barely discernible, tides in the solid part of Earth. This constant "breathing" causes friction in solid Earth and may contribute up to 10 percent of the planet's internal heat.

Radioactive heat comes mostly from decay of the elements uranium, thorium, and potassium. These elements are highly concentrated in the granitic part of the continental crust, which is why granites generate much more heat than other rocks. Despite its comparatively high radioactivity, the continental crust produces only a small fraction of Earth's total heat, simply because it constitutes only a small fraction of the mass of Earth. Rather, about 80 percent of the heat comes from the mantle and core, and this heat emerges along the midocean ridges, transported there by the convective upwelling of the mantle. The deeper a rock is within the Earth, the hotter and

denser it is. A general, though not uniformly applicable, rule for geotherm is that for each kilometer (km) in depth, the temperature increases by about 25 degrees Celsius (C).

Understanding these concepts, Western Hegemony engineers had built heat vents from where the continental crust meets the mantle to a pressure vessel 4,000 meters beneath the surface of the Earth. The vents concentrated the heat generated by the deep Earth, and connected to a pool of minerals surrounding the pressure vessel; the heat vents kept the minerals melted at 1200 degrees C.

The vessel was similar in design to a boiling water reactor (BWR), which is a type of nuclear reactor. A BWR design was chosen because nuclear reactors undergo more extreme conditions than a typical boiler at a fossil fuel plant. Livelle's vessel was shaped like a pill, a long cylinder capped by domes at either end made of an alloy with a melting point of 1480 degrees C; one half sat in the magma and the other half did not. The height (h) and radius (r) of the vessel were found by calculating the required surface area for the magma to contact the vessel in order to boil the water at the proper rate to sustain the operation of the plant; in this case, the height was 200 m and the radius was 70.4 m.

The submerged half of the vessel required insulation. The thermal conductivity (k) of the insulation and the thickness (L) of the pressure vessel required a simple heat transfer analysis. For six inches of insulation, the thermal conductivity was k = 3.76 W/(mK) where W equals watts and mK equals meters x Kelvin; thus, the maximum allowable thickness of the vessel was L = 0.562 meters.

Using a safety factor of three (standard for engineering), the maximum allowable pressure (P) within the vessel (a plane stress analysis problem) was determined to be P = 526 kPa where kPa equals kilopascals. This is relative pressure, meaning it was 526 kPa more than the pressure in the nearby earth.

The power plant included four turbines, which spun a main shaft that led directly to an electric generator. Leftover steam entered a container with a pipe of cold water, obtained from a nearby lake upon the surface, and ran through a condenser (i.e., a heat exchanger). The steam condensed upon contact with the colder pipe and collected at the bottom of the container, leaving via a pipe to return to the boiler. (A pump was used in Livelle's power plant to get the water from the condenser to the boiler, but later iterations of this power plant design in the Great Commonwealth used gravity.) The resulting power plant generated 1300 megawatts of

electricity, enough to supply Livelle, its laboratory and village of 15,000 transhumans, with energy they required to survive.

Chancellor Livelle's first priority was to ensure the power plant could continue its operation without access to the Western Hegemony's infrastructure, including nonrenewable resources supplied by its asteroid mines. Reassortment risk was, of course, also a concern. He wanted to be sure the water used from the nearby lake could be treated with liquid ethanol and radiation *before* it neared the city-state. Once he confirmed the power plant could, in fact, proceed with normal operations including radiation treatment for 250 years without resupply (based on modest population growth estimates), he quickly focused the scientists in the laboratory on production of raw materials via synbio tech.

The chancellor understood that every synthetic organism (or synism) requires a source of two things: (1) carbon (to make stuff); and (2) energy (need energy to make stuff). The first requirement was technically negotiable if the synism was trained to make molecules out of silicon or sulfur or possibly, at high enough temperatures, metal oxides, but the second one was not. Energy is necessary to change molecules, a consequence of the first law of thermodynamics.

Bacteria typically get energy from the sun in the form of electromagnetic (EM) radiation (light) on a certain part of the EM spectrum. They use it to boost electrons to higher energy states, then transmit them along a series of reactions that allow the organism to reduce low-energy molecules (ADP) to high-energy-carrying molecules (ATP). In Livelle, scientists used thermal radiation (heat) instead of light, procured from the heat loops surrounding the power plant. They used a ratcheting system whereby multiple photosystems each contributed a small boost, drawing lots of heat extracted from inside the Earth to create small amounts of biological molecules they called "thermotrophs." (The reason the amounts were small was because thermal radiation is longer wavelength (less energy) than light, and thus it took a lot of it to boost electrons the necessary amounts.) Keep in mind that these structures were modified from photosystems, and have analogous function, but were entirely different; the new thermosystem was modified from the photosystems that were used by photosynthetic bacteria.

While the thermotrophs constructed in Livelle's synism vats created amino acids and proteins transhumans required to live, and removed transhuman waste, they could not make iron without a source of iron; they couldn't rearrange protons and electrons to construct elements. This is a nuclear process, and can only be achieved at monstrously high pressure and temperatures

associated with nuclear reactors, or the insides of stars. The same is true for copper, nickel, iron, aluminum, diamond, and gold, among other metals and minerals. (For instance, nickel and iron are made up of nickel and iron atoms, which, at the time, could not be manufactured.)

Plastics are different, because they are polymers, constructed of large hydrocarbon molecules that can be arranged by bacteria; they are made of carbon, hydrogen, and oxygen. But the bacteria cannot simply synthesize these elements on their own. Even the carbon and hydrogen and oxygen in plastics have to come from somewhere (e.g., whatever the bacteria are eating).

Some types of organisms (e.g., chemolithotrophs) are capable of obtaining electrons (reductive power) by stripping them of certain metals. For instance, in the case of ferrous iron, the process assumes that (1) bacteria obtain energy to live; and (2) the ferrous iron was oxidized to ferric iron (a different compound) that in turn oxidized insoluble metal sulfides, turning them into a form that could be extracted by transhumans. The bacteria weren't creating metals, but rather moving metal-containing compounds from a state where they were not usable by man to a state where they were.

Bacterial mining had been performed within the Earth for centuries prior to the Death Wave and led to large swaths of the crust being hollowed for nonrenewable resources. The Western and Eastern Hegemonies devised two-part names for materials based on the organisms used to produce them, including *Ferrous coli*, or *F. coli* for short, (just like bacterial nomenclature, except in this case the name of the organism was also used to describe the metal that is obtained from it). In this case, it was a genetic variant of *E. coli* but used to precipitate iron ions out of solutions (dissolved in underground seas and from the vast reserves in the Earth's crust). The name of the bacterium reflected the metal it was used to produce, like *Ferrous coli* (a gram negative gamma proteobacteria similar to *E. coli*, but producing iron) or *Cobaltous subtilis* (gram positive firmicute similar to *Bacillus subtilis* but producing cobalt); other examples include stibium (antimony), cuprum (copper), aurum (gold), ferrum (iron), plumbum (lead), hydragyrum (mercury), kalium (potassium), argentum (silver), natrium (sodium), stannum (tin), wolfram (tungsten).

When the Eastern and Western Hegemonies exhausted the capabilities of bacterial mining, they turned to celestial bodies in the solar system. Accordingly, Livellans could not dig around the city-state and obtain raw materials necessary for long-term survival; additionally, they lacked the resources required for space travel and space mining.

Another option was to train bacteria to undergo a form of nuclear fusion to create minerals and metals. Pressure stability would come from the reaction taking place in super small molecular "reactors" made of tightly packed lattices of molecules (like buckeyballs but with many layers), which would exist only for microseconds before degrading, but long enough to make a few atoms of nickel, iron, even diamond.

High enough temps would only exist in tiny enclosed locations, and only for very small amounts of time, not long enough to lyse the cell but long enough to smash a few atomic nuclei together and make a nickel atom, for instance. Energy would come from a chain reaction, initiated by manipulating the zeropoint field.

The bacteria would need to be "seeded" with radioactive isotopes. The good part about this would be that the process would still be regulated by which metabolic pathways the bacteria were using, which enzymes were present, and which types/numbers of biofusion reactors they were making, all a product of information stored in DNA. The bacteria would require a source of radioactive material to take into their cytoplasm (endocytosis) and encapsulate in their mini reactors. While promising in theory—and implemented without success during the Second Hundred Years' War—Livellan scientists couldn't devise a workable methodology to synthesize minerals and metals from bacteria.

Chancellor Livelle understood that to get this system to work would require numerous, unprecedented breakthroughs in the fields of biology, nanotechnology, physics, and nuclear engineering. He instead insisted that scientists focus on molecules they could create with existing resources, rather than wasting time and energy on biologically mediated nuclear processes. Accordingly, Livellan scientists trained bacteria to produce weaving composite materials made primarily from carbon structures. (What I mean by "weaving" is simply taking carbon-containing monomers and arranging them into polymers like starch, peptidoglycan, lignin, cellulose, or even graphene and carbyne.)

In general, composite carbon-based materials are superior to pure metals and even alloys because (1) they can be produced microbially with relative ease; (2) are made from carbon (which implies that human remains could provide raw materials); (3) are incredibly strong, durable, and flexible (i.e., they don't melt); (4) can be used as a semiconductor; and (5) can be used to make flexible screens. In simple terms, graphene is a thin layer of pure carbon; it is a single, tightly packed layer of carbon atoms that are bonded together in a hexagonal honeycomb

lattice. It is among the thinnest and lightest compounds known to man at one atom thick, with one square meter coming in at around 0.77 milligrams. It is between 100 to 300 times stronger than steel with a tensile stiffness of 150,000,000 psi. Carbyne is also a chain of single atoms, but has twice the tensile strength of graphene and three times the tensile stiffness of diamond.

The consortiums used the composite materials to expand and fortify Livelle, and by the year 55 AR, while Chancellor Livelle had perished of old age, his legacy would influence humanity for centuries. (Note: Noriel Livelle had served as chancellor of the Livelle city-state from 2 AR to 12 AR.) Livelle's population had increased to 23,573, and the city-state was ruled by its fifth chancellor, Sora Lubourne. Early in her rule, she received a request from the chief engineering officer of the Bashkirian Consortium to allow construction of villages beyond Livelle. The chancellor, sensitive to the needs of a growing population, granted the consortium's request, and the Underground Realm was born.

The Bashkirian Consortium discovered thousands of underground streams and rivers, which connected to more caves and caverns. Very soon, numerous villages formed beyond the jurisdiction of Livelle, governed instead by local magistrates and executives. But unexplained, instantaneous deaths in shallower villages surrounding Livelle in 72 AR provided the first proof of concept of *Reassortment seepage*, the unexplained osmotic, diffusive process by which the strain passes through solids, including the Earth's bedrock.

Scientists formulated a number of hypotheses regarding seepage including: (1) known imperfections in the Earth's crust could've enabled the strain to descend, including faults, hydrothermal vents, volcanic hotspots, among others; (2) for many centuries, humans exploited the Earth through deep drilling for resources, which provided man-made features for the strain to descend; (3) even structures that seem impermeable, like bedrock, have small fissures and imperfections and over time, Reassortment, which is metabolically diverse, metabolizing organic molecules (heterotrophy) as well as extracting carbon from CO2 (autotrophy), could survive at greater and greater depths; (4) as it was suspected that Reassortment could use nitrogen/ammonia as an energy source (which would've enabled it to spread rapidly over the Earth's atmosphere), it could also possibly use sulfur/sulfides, as well as hydrogen, methane, etc., which could allow it to thrive at even greater depths; and (5) a less likely scenario was that perhaps it was sentient, perhaps it was simply seeking out pockets of transhumans. (Note: we still don't understand how Reassortment passes through gases, liquids, and solids.)

Though Reassortment seepage was an unfortunate occurrence, it wasn't wholly unexpected, given the loss of contact with the Western Hegemony's underground laboratories and bunkers located elsewhere in North America and around the world. But that the Reassortment Strain mysteriously descended so far underground presented a new and dangerous stage in the history of Livelle.

The recently elected chancellor, Abdiel Marlour, issued a travel and trade ban to and from Livelle, even as the ministry and Science District objected. Their concern was that if the Reassortment research team could not study the strain underground or upon the surface, Livelle had no hope of long-term survival. Hence, not all of them viewed Reassortment's seepage as a terrible event, primarily because it would force Livellans—who hoped the strain would somehow disappear, or perhaps mutate into a benign organism—to face the truth and focus their time, energy, and resources on finding a cure, rather than bickering over expansion plans and barter trade. (Note: Noriel Livelle didn't believe in a traditional monetary system, preferring instead a transfer of wealth based on a sophisticated, complex barter system, a system in place until the Age of Masimovian.)

Under pressure from the electorate, the ministry convinced Chancellor Marlour to allow the transhumans who lived beyond Livelle's borders a one-time return to the city-state, primarily to aid as employees to the engineering consortiums tasked with establishing a new Livelle at a greater depth. The consortiums constructed a new, somewhat larger Livelle about 100 meters deep. At that depth, Livelle's ground temperature was about 15 degrees C, but heat generated within the city-state would raise it closer to 30 degrees C. Transhumans could then survive for long periods of time at temperatures near 40 degrees C, but the chancellor required horizontal heat loops be constructed, as a precaution. The difference in temperature (ΔT) versus the surrounding earth was low, so Livelle required a relatively large system to remove the heat.

Beyond Livelle's borders, a new Underground Realm formed, and for the next 80 years, humanity worked together to survive. Livellans used synisms to generate resources and sustenance and studied novel containment, burrowing, transhuman genome development, and research methodologies. Reassortment seepage seemed as extinct as Neanderthal Man, and Livelle's population, though restrained by population controls, increased to 47,761, the ministry grew to 14 members, 9 more chancellors came and went, and the population beyond Livelle's borders increased to 15,920.

During my own development from 135 AR to 152 AR in House Nexirenna, I formed a strong bond with my brother-in-development, Atticus Masimovian. Our parents were academics in the Education District. Their connections to the Central Government District and our hard work during the development program landed us in the prestigious Science District, where many of the high-level discussions regarding the Reassortment Strain with the central government occurred.

We formed the Selendia–Masimovian lab in 153 AR. Our team included Solstice Rupel, Carillon Decca, Charlotte Beam, Ahab Janzer, Erelah Thuddan, Turi Seaborne, Eulalie Lachaize, Nataya Mueriniti, Genevieve Sineine, and Rueben Variscan, among others. Our lab rose in prominence, particularly after Ahab Janzer developed biomat suits capable of shielding transhumans from the Reassortment Strain in 154 AR. Many brave volunteers perished at shallower depths and on the surface testing this technology, until Ahab determined it would protect a transhuman from long-term Reassortment exposure with probabilities as high as 70 percent. While three in ten with long-term exposure to the strain would die, the importance of this technological breakthrough could not be overstated: for the first time, we were able to study the deceased.

We conducted autopsies and found the Reassortment Strain exhibited traits common and uncommon to viruses. Of particular interest was its characteristic of chirality. In nature, near all biomolecules prefer one of two hands, with amino acids and proteins being designated as left-handed (or levo), and natural nucleic acids (DNA and RNA) designated right-handed (or dextro); the Reassortment Strain, with 8 nucleotides and 39 amino acids, combined the levo and dextro, something we'd never encountered before outside controlled laboratory conditions.

The strain's mirror proteins were not performing any special action; they had the same functionality of their natural counterparts, but their slight difference rendered common protease or other treatments ineffective. Proteins do nearly 100 percent of the functional things cells do (i.e., enzymes, ribosomes, etc., are all protein), while DNA is just the code for proteins. So with proteins that were fundamentally different (mirrored) from the ones we understood well, and with the code used to make these proteins always changing, it was challenging to determine what protein was doing what. Thus, the strain's chirality made learning or defeating it very difficult; it became clear to us how the strain confounded the sophisticated transhuman immune system, which at the time of the Death Wave provided protection from many cancers and 75 percent of the Earth's natural pathogens.

Air samples taken from the surface suggested the strain traveled easily through the Earth's atmosphere. It did, in fact, latch onto nitrogen gas, using it, carbon dioxide, and sunlight to synthesize energy. It reproduced at rates far faster than natural (and most synthetic) biological organisms. It's unclear whether the strain could always reproduce outside its human host, or if this ability evolved after its release into the atmosphere. We believe the strain was designed to recognize humans as human before it moved into deadly action, entering the human body in a series of waves, penetrating through the skin, eyes, ears, nose, and mouth. It rapidly reproduced within the host's neural and blood cells, killing the infected within seconds of exposure, pushing the limit on what we'd previously believed was possible biologically. Bloody discharges from the orifices and sometimes parts of the skin concluded the process. It didn't seem to have any recognizable impact on other fauna or flora on or in the Earth.

Strike Team Commander Vastar Alalia requested the new biomat, combined with existing synsuit technology, be deployed to his teams. (Previously, the strike teams wore synsuits that protected from high temperature and pressure, but not from Reassortment.) The timing was fortuitous, for the next year, during what the media called the Great Reassortment Panic of 155 AR, an entire government housing sector (holding some 10,000 Livellans including Atticus's and my parents) perished before the strike teams (who sustained massive losses) could contain the outbreak. They sealed off that part of Livelle with fortified carbyne walls, then flooded it with liquid ethanol and radiation.

Chancellor Hardington ordered an evacuation of Livelle to a newly hollowed city-state positioned 300 meters deep. The engineers recycled much of the composite materials from the legacy city-state to build the new one. At the new depth, Livelle's temperature was expected to rise to nearly 35 degrees C (which included the net impact of heat generated by the laboratory and population, offset by a new system of horizontal heat loops). With an underground ground temperature near 21 degrees C in the caverns surrounding Livelle, new villages formed along the rivers and streams outside the city-state.

Secretly, prominent scientists of the time had wished the strain would've killed more Livellans in 155 AR. They doubted the synism vats we then used could produce enough raw materials for the ever-expanding population. (Chancellor Hardington had refused to enforce the preexisting laws on population controls and instead pressured the Science District's synbio labs to produce more raw materials and sustenance.)

To our dismay, he was reelected twice. His popularity stemmed from his devout belief in the Twin Gods of the Cosmos and his tight control over the media. Over time, it seemed as if the people came to think of Chancellor Hardington as one of the gods, even as starvation surpassed old age as the greatest killer of transhumans in Livelle. (A positive, if morbid, side effect of Hardington's incompetence was an increased supply of carbon for composite materials supplied by dead transhumans.)

Reassortment still loomed as a threat to humanity. Tests of the bedrock above Livelle suggested the Reassortment Strain continued seeping underground, below 150 meters. My lab drew up new plans, outlining further descent, but I had this terrible feeling all we were doing was hollowing out a tomb for 90,000 transhumans. Then the disaster many scientists foresaw, happened.

The Great Reassortment Panic of 165 AR struck on the 137th day of the year and for the third time since the Death Wave at the end of the Quaternary Period, Livellans faced the real possibility of extinction. Chancellor Hardington, who grew madder by the day, declared a state of emergency in Livelle after the Reassortment Strain breached the borders of the Information District, killing 5,000 transhumans before the strike teams achieved containment. I feared for Atticus, who'd left our lab in favor of political office, and was elected Minister of the Information District the prior year. Luckily he survived the containment breach.

The chancellor and the ministry evacuated the Central Government District to the Science District, to which I'd been elected the minister of in 164 AR, located at the lowermost level of the city-state. In the meetings that followed, a boisterous Atticus Masimovian demanded the chancellor take a drastic step and move Livelle to a depth of 2,000 to 2,500 meters. He suggested that the high heat and pressure deeper inside the Earth would ensure natural safety from the Reassortment Strain. (While I agreed with my brother-in-development publicly, privately I told him that depth would also prove untenable for transhuman existence without full containment!)

Atticus knew that my team had synthesized a variant of *C. perfringens* capable of rapidly ingesting limestone and granite, among other minerals, which we called mineral crushers; they were a programmable form of lithotroph or "rock eater," far more advanced than any that existed Before Reassortment.

Lithotrophs are organisms that naturally occur in the environment, and are diverse enough to include bacteria, archaea, and fungi. Their metabolism is based on the ability of certain enzymes

to catalyze reactions where electrons are stripped from metals and inorganic ions. This energy is transferred to cofactors with reductive potential, such as NAD(P)H, which are in turn used to reduce carbon-containing molecules into useful biomolecules. The carbon dioxide may come from biological sources (heterotrophy) or from carbon dioxide in air or dissolved in water. This combination of energy and carbon allows the organism to make new cells. Moreover, lithotrophs commonly use inorganic sulphur-containing compounds for the source of electrons, then excrete the oxidized remains as sulfuric acid. Sulfuric acid readily dissolves minerals such as carbonates and can even break down other types of rock at a slower rate. This activity reveals more metal ions for sources of more electrons, as well as more carbon dioxide for cellular proliferation, and the process repeats. This process can hollow out vast sections of the Earth.

The mineral crushers my team synthesized required large-scale shifting of material (mass transfer) to be successful. Mass transfer was increased by engineering the crushers to be more mobile through an amoeboid locomotion system. They entered into miniscule cracks in rock and worked quickly; by liberating tiny sections of entrapped air in semi-permeable rock, gasses were released; by engineering these synisms to split water (using an enzyme similar to what is known as Photosystem II in photosynthetic organisms), some water from the surroundings was broken down and oxygen was released. The important part was that the crushers didn't violate conservation of mass or energy; they received the energy from their "food," in this case slightly reduced metals or other compounds, and they used it to grow, as well as cause change in their surroundings, (i.e. move the compounds in the limestone and granite to slightly different states). Put simply, the crushers, with far faster metabolisms than natural lithotrophs, enabled a rapid, controlled clearance of bedrock inside the Earth.

The descent was less the issue than the temperature and pressure measurements, which I'd assured Atticus would be ominous. My lab calculated that 2.0 km deep, the ground temperature would be about 65 degrees C, while 4.0 km deep, the temperature increased to nearly 130 degrees C. Tests of natural life indicated the highest temperature for any functional living creature was 122 degrees C, and that required at least 2.2 atmospheres (atm) of pressure to prevent boiling. (The air pressure of a shaft at 4.0 km would be about 1.6 atm.) The highest temperature for a functioning animal (not mere survival) was 80 degrees C for the deep ocean floor Pompeii worm (pressure of 400 atm).

We worked tirelessly to adapt the genetic characteristics of the Pompeii worm to the transhuman genome, while the engineering consortiums designed a closed thermosiphon loop that would reach into the nearby lake (170 meters deep), then back down into the new Livelle at 2,500 meters deep. The difference in temperatures would naturally drive fluid flow without pumps, so no energy would be required, while several loops would provide redundancy. Large-diameter loops would actually be used for transport of people and material to "stations" near the surface in sealed "pigs" similar to those used to inspect pipelines from the inside. The problem, as ever, was that in addition to liquids and gases, the Reassortment Strain could pass through solids: it would contaminate the water inside the piping, killing all the transhumans in Livelle. To avoid this scenario, we pumped liquid ethanol and radiation into the piping at shallower depths.

The descent didn't go as planned. Construction on the deeper city-state experienced delays, primarily owing to a lack of leadership. Several less severe Reassortment scares put more pressure on Hardington, who'd narrowly won reelection in 167 AR based on the assurance he was best qualified to rule Livelle during its existential crisis. But where his approval had hovered near 50 percent at the time of his reelection, by the following year it had dropped to just 20 percent, the lowest for a chancellor in Livelle's history.

He imposed Martial Law following another Reassortment scare, ceding control of the city-state to General Palomar, the leader of Livelle Guard. When demonstrators against the Hardington Administration organized in Centaurus Square, Palomar ordered the Guard to arrest anyone who gathered there and on the city's pathways. Peace returned to Livelle, for a time. The ministry urged the chancellor to address the people. On the 245th day of the year 168 AR, he gave a speech in Centaurus Square before a crowd that turned violent. Vastar Alalia ordered the strike teams to stand aside as General Palomar and the Livelle Guard were overwhelmed by the crowd. A pulse blast echoed throughout Livelle's main level, and Chancellor Hardington collapsed in a pool of blood.

Atticus Masimovian, the Information District's popular minister and heir-apparent to the chancellorship, took Hardington's place at a podium before the people. He gave his most famous speech, ending it with the words all future Beimenians knew as well as their own names: "Henceforth, there shall be thirty precepts by which thirty territories of a Great Commonwealth of Beimeni shall live." There began the Age of Masimovian and the Great Commonwealth of Beimeni.

The new chancellor, in a break from his predecessors, ordered the scientists to synthesize the biologically mediated nuclear processes abandoned by Noriel Livelle. He called the theoretical synisms part of these processes, which would produce minerals and metals, *biostars*. To accelerate research into biostars and that into transhuman genome enhancement, Chancellor Masimovian formed a Research & Development Department (RDD) to be led by the Supreme Scientific Board of Beimeni. He worked closely with the board, appointing me to be its chairman and our longtime friend Ahab Janzer to be its vice chairman. At the first board meeting, he mapped out an ambitious expansion plan—including thirty territories spread from the arctic to Central America—even as we still lacked protection from the high heat and pressure of the deep Earth and as Reassortment roamed the bedrock around Livelle. His plan received much pushback.

“The Earth contains species capable of living in extreme conditions,” Masimovian objected. “We need only convert these adaptations to the transhuman genome to ensure our survival at depths never before possible in the history of man.” Similar to his ancestors, Atticus had a way of stirring creativity, ambition, and hard work among his fellow transhumans. I’d never seen my team work so tirelessly on anything in my life. While it would take decades before transhumans discovered methodologies to transform bacteria into biostars (which relied heavily upon manipulation of the zeropoint field), we immediately recycled and transferred enough composite materials from the city-state to build Livelle City (the first capital city of the Great Commonwealth of Beimeni).

We also enhanced our genome such that our bodies could, for a period of time, withstand higher temperatures and pressure within the deep Earth. The Beimenian transhuman exhibited structural advantages as compared to the Livellan transhuman, including, but not limited to: (1) cellular nanostructures for support against physical crushing; (2) additional “aftermarket” macrostructures (i.e., bones); and (3) an alteration of the chemistry of the transhuman body through the use of enzymes engineered to maintain efficacy even when intracellular partial pressure of gases was increased.

We’d still require a system of controlling the extreme heat and pressure in an uncontained commonwealth, but it was a start. We’d need a more creative way to terraform the Beimeni zone of the underground, roughly 2,000 to 2,500 meters deep. Carbyne pipes used to release the pressure of the deep Earth would have theoretical built-in resistance to Reassortment seepage in that gases would rapidly escape through them to the surface. But the chancellor required the pressure-release piping be treated with radiation at shallower depths. Separately, while the lake near Antelope Canyon might’ve provided a means to cool Livelle City, it could not cool an entire commonwealth stretched across an entire continent.

For the coolant, the two sources we coalesced around were the Pacific Ocean to the west (at the 37th parallel) at a distance of 885 km, and an unnamed arctic bay (what was known as Hudson Bay, Before Reassortment) to the north (at the 51st parallel) at a distance of 2,575 km. Each option presented opportunities and challenges, for while the ocean was closer to the city, to build a tunnel and piping through the West was to build it through a highly seismic region of the continent. Meanwhile, the bay was nearly three times as far and would require more resources,

including time and sustenance. (Note: by this time in the Earth's history, the Great Lakes had become the Great Canyons.)

On the recommendation of Chancellor Masimovian (and against my opinion), the board approved a western expansion into a new territory called Angeles. It took three years to complete construction of the downward-sloping coolant piping from Angeles City on the coast to Livelle City deep beneath Antelope Canyon. We built the commonwealth's first coolant station at the border of the continent in Angeles City, burrowing through the bedrock into the Pacific Ocean. Tests of the salt water at a depth of 2,000 meters suggested it *wasn't* contaminated by Reassortment. Even so, we treated the salt water entering the piping with liquid ethanol and radiation, then let it flow down to Livelle City at its depth of about 2,500 meters.

With renewed hope and momentum, Chancellor Masimovian pushed for expansion in the West and South. He requested Vastar Alalia to allow his strike teams to participate in the construction and Vastar agreed. The chancellor also modified the existing system of transhuman development, instituting a round of testing (that would later be called the Harpoon Exams), followed by an auction (that would later be called the Harpoon Auction). Formal competition among the houses of development led to exponential advancement in genomic enhancement and transhuman evolution, which, in turn, led to new scientific breakthroughs.

The commonwealth rapidly expanded from Livelle City in Natura Territory to Luxor City (Luxor Territory), Zanclea City (Reanaearo Territory), Wenlock City (Jurinar Territory), Piscator City (Piscator Territory), and Yeuron City (Yeuron Territory) in the South, concurrent with expansion in the West, including Gaia City (Gaia Territory), Silkscape City (Lovereal Territory), and Dunamis City (Dunamis Territory). (The southernmost cities of Port Newland and Huatervian City in Haurachesa Territory would not be formed until 217 AR and 227 AR, respectively, while the collapse of Angeles City in 214 AR halted further construction in the designated Western Inaccessible Region of highly seismic earth. Angeles City was renamed the City of Eternal Darkness, and Angeles Territory was renamed Nyx Territory after the collapse.)

Decades before the collapse of Angeles City, I'd convinced Chancellor Masimovian to create coolant piping that would ensure his expansion plan succeeded—the pipelines to the arctic bay. I worked closely with Vastar Alalia to design primary pipelines from the 55th parallel on the western side of the arctic bay (in what would later be called Area 55) and from the 51st parallel on the southern side (in what would later be called Area 51), down to proposed cities in

Underground North, including Boreas City (Boreas Territory), Nurino City (Zereaux Territory), and Arrowhead City (Columbia Territory).

Secondary pipelines (with multiple redundancies) were designed to run from these cities to existing cities in Underground West and South, and proposed cities in Underground North including Xerean City (Xerean Territory), Farino City (Farino Territory), and Kiplorea City (Kiplorea Territory); Underground Central including Beimeni City (Phanes Territory, which became the capital city and territory of the Great Commonwealth in 197 AR), Cineris City (Cineris Territory), Ope City (Ope Territory), Portage City (Portage Territory), Vivo City (Vivo Territory), and Nexirenna City (Nexirenna Territory); and Underground Northeast including Gubertiana City (Gubertiana Territory), Northport (Gallia Territory), Palaestra City (Palaestra Territory), and Volano City (Volano Territory).

From the Northeastern cities, more pipelines would be built to the newly constructed Research & Development Department (RDD) east of Palaestra City, along with proposed cities in Underground East, including Peanowera City (Peanowera Territory), Navita City (Navita Territory), and Alpinia City (Marshlands Territory). Finally we built a smaller coolant station where the man-made Hillenthara River met the Atlantic Ocean; the pipelines from this station would serve cities and villages along the river and provide a redundancy for Gubertiana City in Underground Northeast.

From 168 AR to 227 AR, the RDD scientists, the strike teams, (and beginning around 220 AR, the Janzers), completed the most aggressive engineering project in human history. We'd burrowed through tens of thousands of kilometers of earth and built carbyne piping to release the pressure of the Beimeni zone and to transport cool salt water and freshwater to stations in cities and villages around which civilizations of transhumans would form. In all the cities and villages along the man-made rivers (which served as runoffs for the coolant system), we built carbyne pillars to fortify the structure of the newly formed Beimeni zone of the underground. We also built synbio vats to provide electricity, breathable air, food, and water, with the understanding that the ultimate responsibility for raw material production was in the RDD. (Note: following the synthesis of biostars in the early 200s, the carbyne support pillars were replaced with compressed diamond support pillars at the insistence of Chancellor Masimovian.)

During this time, advances in genomic enhancement would enable me to see the project complete, not as an old man, but transformed into my younger self, owing to breakthroughs in

aging research conducted by Turi Seaborne and Eulalie Lachaize (who would later become Turi Thuddan and Eulalie Variscan when their eternal partners formed houses of development). The Seaborne lab constructed *E. fountain*, a synism designed to adapt the genetic characteristics of the *Turritopsis nutricula* (jellyfish; age reversal) to transhuman DNA. Likewise, the Lachaize lab adapted plant DNA to transhuman DNA within *Bacillus subtilis.* These synisms were refined into the athanasia vapors released throughout Fountain Square, giving transhumans of the Great Commonwealth our theoretically infinite lifespan.

Well, it looks like I'm out of time. I hope you found the Beimeni terraforming story as exciting as I did living through it all. I wish you all much success during development and the Harpoon Exams, and afterward in the Great Commonwealth.