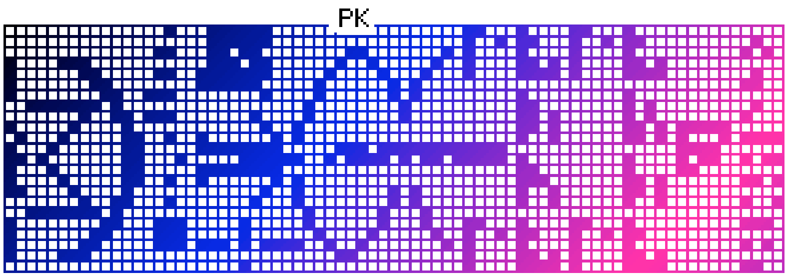
"Expanding the Human Economy through Off-Planet Resources"

MOON MINERS' MANIFESTO

MMM Classics
The First Ten Years

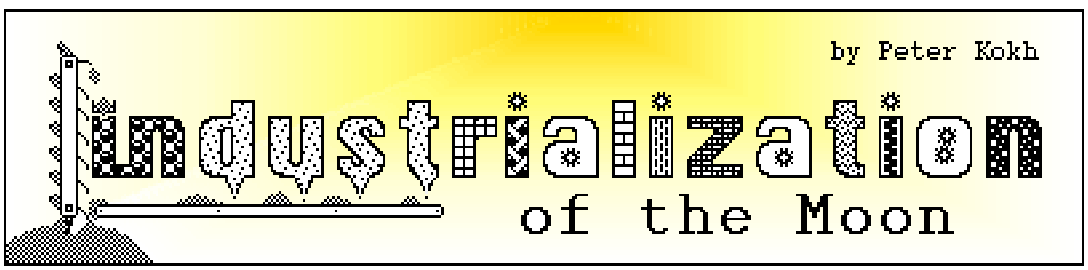
Year 7: MMM #s 61-70
December 1992 - November 1993

This year, as usual, we touched on many topics. But among the major themes was S.E.T.I., the search for extra-terrestrial intelligence. [below, the pictorial "telegram" sent out "to anyone who might be listening" by the Arecibo Radio



Telescope in Arecibo, Puerto Rico.] Articles included, all from MMM #61: "Are We Alone?"; "What is a Humanoid?"; "Galactic Topography 101"; "The Heliades Cluster"; "Sending Interstellar Signals"; and "Cheshire Messages."

But how the Moon would be industrialized was our major topic this year, with a series of articles spanning several issues.



In MMM #63: "Beneficiation of poor lunar ores"; "Sintered Iron from powder"; "Alloys & Lunar-appropriate Metallurgy," "GLAX: glass-glass composites"; "Glass"; "Ceramics"; "Color the Moon anything but 'gray'"

In MMM #65: "The Substitution Game"; "Silicone Alchemy"; "Sulfur-based construction stuffs"; "Moonwood: Fiberglass-Sulfur Composites"; " 'MUS/cle' Substitutions"; "Stowaway Imports."

In MMM #66: "Utilities Infrastructure"; "Superconductivity';. "Wiring the Moon"; "Let There be Light: Lunar-appropriate solutions"; "TELECOMCO: on the Moon, a telecommunications company must do more"; "ENCYCLOBIN: making full use of byproducts and waste products."

In MMM #67: "Water and Hydrogen on the Moon"; "A Hydro-Luna Company in charge of developing on Luna and off Luna supplies of water"; "Reservoirs: putting settlement water reserves to work"; "The Settlement Water Utility"; "Xero-processing: weaning industry of water."

In MMM #68: "Cornucopia Crops"; "A George W. Carver type agriculture-based organic chemical industrial complex: Saproculture, Bioextraction, Arboriculture.

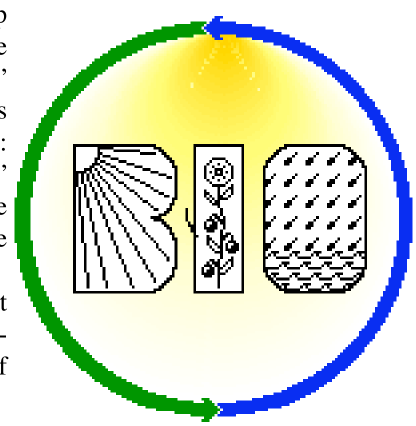
In MMM #69: "Exports: Bacon and Brass"; "¢OIN$ of the Realm"; "Cosmotive, Inc."; "Tourist Earnings."

These articles take up individual industrial options as well as the strategies we need to adopt in bringing them to realization. Export-Import policy, recycling practice, Usage of byproducts and scrap materials, development of markets, etc. must all be pursued as part of an overall plan to beat the odds against reaching an economic break-even point.

Previous treatment of this topic can be found in MMM #32, "The Import-Export Equation" and "Diversification vs. Subsidies." Both of these are reprinted in MMM Classics Volume 4, pp. 11-14. There will be no one magic formula for reaching economic viability and import-export break-even. We must pursue every trick in the book!

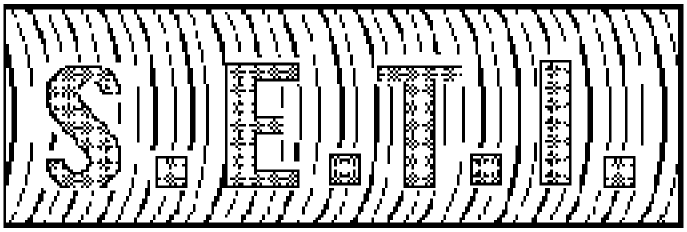
Another topic of interest was Biospherics, in the wake of the "mixed results" from the undeniably ambitious ground-breaking Biosphere II experiment near Tucson, Arizona. In MMM #64 three articles took up the subject:

David A. Dunlop contributed "Biosphere II: Potential & Problems" while Michael Thomas wrote "Biosphere II: New World or Disaster?" "Towards a Biosphere 'Mark III' " was the Editor's contribution.



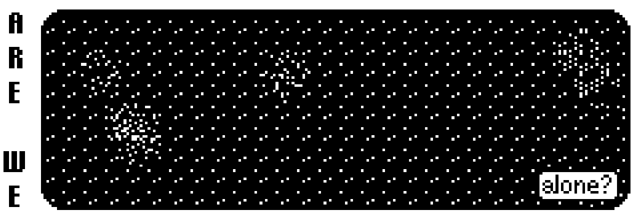
Our current efforts center about developing the concept of "Modular Biospherics."

MMM #61 - DEC 1992



<u>S</u>earching for <u>E</u>xtra<u>T</u>errestrial <u>I</u>ntelligence.

People despairing of making sense out of the chaos of life, or those who'd be their priests, have looked to the heavens for messages from time immemorial. Astrology still blooms. But today a new search, previewed in 1960, seeks messages not from gods but from alien peers. MMM looks at the odds.



By Peter Kokh

What nature does once, it can do again. To say we are alone hints at an emotional need to so believe. In the face of the vastness of the universe at any snapshot moment, even vaster through time, such views seem ill attempts at dogma.

First: the chances for "Earth-like" Planets

The famed "Drake equation" for estimating the likely number of current technological civilizations in our galaxy yielded an early back-of-envelope guess of some 280,000,000. Without going into the details of the equation which can be found in any book about Intelligent Life in the Galaxy or about the Search for it, it has become clear that the early estimates were wildly optimistic.

For one thing, the estimated size of the "eco-zones" around stars wherein planets would be neither too hot nor too cold turned out to be much too generous - for one simple reason. We have to look at the host star's whole life cycle and it has become clear that the old idea that "main sequence" stars burned with the same luminosity throughout their lives was wrong. Stars gradually get brighter and hotter, at a pace characteristic of their spectral type. Looked at that way, the solar eco-zone does not extend all the way from the orbit of Venus to the orbit of Mars as commonly thought but is much, much narrower. Had Earth's orbit been only a little bit larger or a little bit smaller, at some time in the past 4+ billion years either runaway glaciation or a runaway greenhouse would have ended the Sisyphusian rise of life up until that point.

Put another way, the chances of a planet having accreted precisely in the eco-zone instead of somewhere outside it are much smaller. Michael Hart's model gives a 28% chance for F5 stars (brighter yellow-whites like Procyon), an 18% chance for GO yellows like Alpha Centauri A, a 13% chance for G2 stars like the Sun, an 8% for G5 stars like Tau Ceti, only 0.3% for a K0 star vanishing to no chance at all for stars K5 or redder. A planet far enough from a K star (e.g. Epsilon Eridani) to avoid an early runaway greenhouse would slip into runaway glaciation about the time early life started producing an oxygen atmosphere. On the other end, stars brighter than F5 would come to the end of their stable lifetime just as life there was maturing. [see MMM # 45 MAY '91 pp 5-7 "Welcome Mat Stars".]

Somehow, some read these sobering facts to hint that Earth may be unique. Such a precipitous conclusion is inexcusably dishonest and unwarranted for these considerations only reduce the chances by an order of magnitude, dropping the BOE estimate to 28 million, still very appreciable.

But not just any rocky silicate planet in an eco-zone will do. It must be endowed with a water blanket not too stingy and not too deep, and massive enough to generate and sustain hydro-lubricated plate tectonics, inaccurately called continental drift. [see MMM # 36 JUN '90 pp 6-7 "Hydro-Tectonic Planets"] If one estimates that this requirement cuts the chances of a suitable womb world by an additional 2/3, that would still leave some 9 million more than our 1. *With a typical spacing 250 light years apart*, life-matured Earth-like planets with contemporary technical civilizations may not be common. Neither should they be rare. [Planets at an earlier stage of evolution that will remain inhabitable for long enough to make colonization worthwhile, even if not so long as to allow any indigenous life to mature, should be vastly more plentiful and more closely spaced.]

Second: the odds for the rise of Intelligence

There is another strain of pessimism that holds that intelligence is not an evolutionary value but something we can not expect on just any world where there is abundant life and a benign climate. Some hold this view because they want to protect the belief that intelligence arose by divine intervention, others because they cynically think intelligence is a cruel joke of nature. Even if you hold the former view, it should become clear upon honest examination that at least the precursors of intelligence, as manifested in the primates, do in fact confer survival benefits. While lower manifestations of life will cling on so long as there remain niches for them to exploit, there is a many-forking road of pyramiding advantages that keeps building towards a crescendo. Many a species has become fatally comfortable exploiting a temporary niche through dead-end specialization. It is successful - for a while. Yet there always remain less specialized populations capable of "making it" in a wider range of situations. This push to generalization, leads through omnivorousness and a climactic lowest common denominator nakedness allowing exploitation of all possible habitats without sorting into specialized species, to tool using adaptability to all hunting-foraging conditions and eventually even to agriculture. It is through generalization that a species transcends mastery of a specific niche to custodial dominance of a global complex of ecosystems. Wherever the maze of life has grown rich in its diversity, the opportunity to not just fit in but master an ever-widening and *indeterminate* set of conditions becomes the supreme selective survival value. The whole process of evolution must come to a boil in a global "caretaker species". Where there are planets lavish with life, the eventual rise of intelligence should not be unexpected. The path may be quite diverse in specifics and in its pacing, yet widely similar in its generic sequence.

Carl Sagan, overwhelmed by the vast complexity of the human genetic endowment, is one of many who regards humanity as highly improbable. But the rise of intelligence elsewhere hardly demands the exact duplication of the human genotype or the exact successions of choices on which it has been built. The genetic pathway to "humanoid" intelligence - different genetic makeup, same techno-custodial function [see the next article] - is forgivingly broad.

Evolution is precisely *a mechanism* that step by step works inexorably *to reduce* astronomical initial *improbability* until the light of day is seen. With the successive appearance of multi-cellular creatures, vertebrates, mammals and primates, a "humanoid" climax species became ever *less* improbable.

It is the overspecialized species that are nature's jokes, not culminatingly generalized species like ourselves! MMM

The MacPaint title art above suggests an eyes-in-head viviparous (belly button) mammalian (teats) dexterous (arms, hands) biped living on the land of an ocean-shored planet with at least occasional clear nighttime glimpses of star-filled skies. Such a sentient would have enough in common with us in both structure and environment to merit the name "humanoid".

A Science Fiction term, "humanoid" has never been carefully defined. But its use is something 'everyone' seems to understand. We exclude such creatures that (for example) don't have their eyes in their head, eat by suction, have tentacles for arms, are radially structured like octopi - or have some other really "alien" trait. How having fur, feathers, or scales, or how height and build, or respiration, nourishment, or reproduction patterns affect the classification seems less agreed upon.

Our purpose is not to define "humanoid" in contrast to "alien". Instead we propose rather to look at how wide a range of possibilities within which the "generalizing" (vs. specializing) selective workings of evolution can work - and still produce an intelligent population with technical aptitude.

Our suspicion is that what we mean in our gut by "alien" will invariably turn out to be something nature can't produce in the first place. In our well-intended resolve to free our speculations of stubborn chauvinisms, our Sci-Fi writers and artists have perhaps gone to the opposite extreme and preferentially conjured up an ever expanding exo-zoo-full of *gratuitously* alien chimeras that don't, and can't, make evolutionary sense. Between unexamined chauvinism and undisciplined fancy, there must be a middle ground. Let's find it.

"Life as we know it." Yes, we must be wary lest the singular planetful of life-forms we've been able to investigate so far may, in its shared characteristics, blind us to other possibilities, other pathways. Yet the chemical and geological processes that must *universally* underlie *all* biological possibilities are well enough known and understood for us to exclude with unhesitant confidence many of the wild-minded "why not" suggestions of how "life as we *don't* know it" might look.

Life on Earth is dependent on photosynthesis, using sunlight-power to run metabolical conversions at the bottom of the food chain via oxygen-carbon dioxide respiration. We've known for some time of methanogen bacteria that survive in anaerobic conditions. But we were all surprised at the sea bottom vent-side ecosystems that have been discovered in recent years in which the local food chain is based on bacteria that feed instead on dissolved hydrogen sulfide. But in both these cases, the creatures involved are clearly evolved from the photosynthesis-dependent mainstream. If it could be demonstrated that life could originate alongside submarine hot sulfur vents, it would not change the geological reality that such energy supplies are invariably extremely localized and would be hard-pressed to give rise to an emergent worldwide biota.

No, we know *enough* about biochemical possibilities to be fairly confident that wherever planet-transforming life has arisen, an original CO_2-N_2 atmosphere will be converted into a N_2-O_2 one. We won't find chlorine-breathers anywhere.

Our culture is a shore-based one. That is, we live on the land of an ocean-endowed world. Can it be otherwise? Surely there can be some range in the ratio of sea to land, but unless sea is dominant (one interconnected ocean, several unconnected continents) rather than land (one interconnected continent, several disconnected seas), a sustainably benign climate through the eons is unlikely, and the global spread of life might take far longer.

The "glass ceiling" for technological intelligence in sea-dwelling creatures is probably much higher than admitted. The octopus is *unnecessarily* held back by two *factitious* evolutionary choices which *could have* gone the other way: copper-based instead of iron-based blood; and a radially-symetrical nervous system that seems to resist centralization. Had these choices have been other, we might today have "wisefeet" - without fire or metal, but *with* a 'stone age' capacity to make and use artifacts, restructuring *their* environment *as we do ours*.

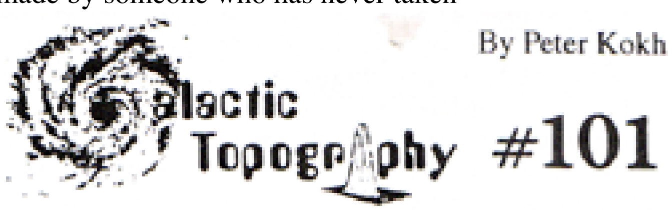
Invertebrate intelligence outside the sea is unlikely. The frequently suggested pathway of collective-mind social insect intelligence would seem to require the fanciful magic of ESP. Intelligence is supple, adaptable, self-reprogrammable - and the exoskeletal insectoid path scarcely lends itself to this.

It is no accident that we are naked skinned. This is a choice that leaves us capable of exploiting diverse niches in all climates, promotes personalizing bonding sexuality, and aids in producing young that are parent-dependent long-enough to allow education (passing accumulated technological experience and acquired know-how between generations) to supplant the paternalistic crutch of instinct. Within this general "humanoid" framework, much variation would seem to be possible.

Bearing the young live seems a more favorable choice than egg-laying, but is probably not the only path. Suckling the infant is likewise a non-exclusive preferred option. Warm-bloodedness, almost certainly necessary, has other ways to express itself than the mammalian. But "mammaloids" should be expected to more common. Could warm-blooded "saurians" have given rise to intelligence had not some uninvited killer asteroid mindlessly interfered? If so, it would likely have been a scaleless, featherless, naked erect hand-equiped biped with a paedo-morphic head (baby-faced, as we are, probably due to selection by maternal favoritism). Despite its interestingly different ancestry, we'd be hard put to find an excuse not to call it "humanoid". Saurians and mammals *do* have a certain deep underlying genetic kinship - *if you go back far enough*.

Among mammals, are *tree*-dwelling brachiated (arm-using) prehensile "primates" the only possible stock? Perhaps this is the most promising line, but can an otter-like pathway be ruled out? Finally, all sapient species must share what we call the "human condition" - struggling from birth to death in a "vale of tears". *They must look like kin, act like kin*. Our common "mother" is the Cosmos, our common "father" the path of generalization towards a capacity to be technology-using custodians of our host global ecosystem. When it comes down to it, we will find *no* honest "aliens", *only* genetically diverse ways to express being "humanoid". MMM

The conclusion that √ *either* our Galaxy must be already thoroughly colonized √ *or else* we are alone, can only be made by someone who has never taken



Enrico Fermi posed the question now known as "Fermi's Paradox". If the galaxy is full of inhabited planets, why aren't "they" already *here*? The question completely discounts anecdotal "evidence" of UFO's, ancient astronauts and the like, and we have no big quarrel with that. Our quarrel is rather with Fermi's assumption that the first intelligent spacefaring civilization to emerge must inevitably colonize the entire galaxy in something on the order of a few million years.

First of all, such a statement assumes that interstellar travel will eventually become routine and easy, or that some other means of life- and civilization-propagation will be found such as uncrewed arks containing seed and germ plasm banks with incubators and robot nannies ready to swing into action upon arrival at some virgin stellar system, hundreds or thousands of years after departure. While most of us hope that interstellar travel or propagation of our civilization is some-how possible, there are little grounds for confidence that it will be so easy that "any" intelligent civilization must inevitably *master* it.

Nor, given our own adolescent troubles as a techno-"custodial" civilization responsible not only for our own future but that of our home planet and of Earth-life in general, can we be optimistic that intelligent species are *invariably* long-lived. Many a civilization may get off to a promising start, as we have done, only to get irretrievably bogged down in nest-fouling pollution, undisciplined population growth, and tribal warfare - as we show signs of doing.

Surely some few inhabited worlds must survive their coming of age in good shape, and go on to homestead the rest of their native solar systems. And surely some further fraction of those will take the first bold steps to the stars. But unless they find such migration unexpectedly easy, and unless their civilization finds a way to ever *renew* its youthful vigor, is it not much more likely that having spread out a few dozen light years or so they will choose to rest content?

Even the vast majority of "space opera" science fiction yarns dare speak only of *regional* galactic empires. Suddenly, invoking population pressure, as if that were a transcendental given, Fermi proposes that any species that can launch a sputnik is bound to reach every star in the galaxy!

Yet the real problem with Fermi's assumption is that the galaxy is not an evenly spaced population of stars, much less one with no reefs to break the waves of expansion. Let's take a look at the galaxy's terrain.

SOME BACKGROUND FACTS: 1) It is about 29,000 light years (ly) from the Sun's position to the center of our Milky Way galaxy, and 22,000 ly to the near edge of the galaxy's central nuclear bulge which is itself some 14000 ly in diameter; 2) In our part of the galaxy, there is about one star per 275 cu ly which translates to an average separation of 6.5 ly between neighbors (we appear blessed to have four neighbors closer than that, three of them in the Proxima-Alpha Centauri system); 3) The visually prominent spiral arms are in fact only 5% denser with stars and gas. Their most definitive character is the scattering of hot short-lived O, B, A stars, not serving us as spectacular destinations but rather as handy spatial landmarks; 4) the galaxy's disk, containing the arms, where we reside, is relatively thin, a couple thousand light years thick, in comparison to its 100,000 ly diameter.

This 1:50 aspect means that *non-locally*, a wave of wholesale expansion will proceed 2-dimensionally. And once the wave front extends from the nuclear bulge to the rim, further expansion will be only 1-dimensional. Thus not all newly colonized worlds will be poised to continue the wave and *the early exponential rate of colonization will dissipate*.

Further, there be reefs! Peppering galactic space every few hundred light years or so (especially in the arms) are "superluminous" stars 10,000 to 60,000 times as brilliant as the Sun, such as Rigel, Canopus, and Deneb, the three nearest us. These monsters are very short-lived and will eventually produce cosmic supernova explosions. It will be of dubious wisdom to establish colonies around seemingly peaceful stars that happen to be neighbors of such giants. If an expanding galactic civilization steers clear of these "zones of avoidance", some backwater pockets of stars are bound to be by-passed.

There are many comparatively nondescript F5-G5 stars with planets blessed with mercifully prosaic nighttime skies like our own. These systems are likely to present enough of a terraforming and acculturation challenge to totally absorb all available settler energies long-term, leaving those with stellar wanderlust without the means to scratch the itch. Most of these virgin worlds will not be so rich and fertile that settle-ment there will soon thrive and overflow, even over centuries.

Possibly some forms of interstellar travel will work best in dust free areas, others through gas clouds. The galaxy has its versions of plains, steppes, and marshes. Can we just assume whatever means are foundd will take us everywhere?

Nearer the star dense nuclear bulge of the galaxy's hub the greater incidence of supernovas, and greater background radiation may make these regions unsuitable. Perhaps it is chauvinistic to think that because ours is a disk civilization that the disks of spiral galaxies are the only setting in which planetary systems can arise and be stable long enough to support the long term rise of life. But it now seems logical.

Finally, this prediction: "Interstellar ranges of spacefaring populations will come to interpenetrate to some depth before 'first contact' between the populations involved". The rationale here is that one species will *prefer* one type of star system to colonize, another species another kind, and that they will pass into one another's range without mutual notice. This is especially likely if their interstellar broadcasts are narrow band tight beam coded messages on arbitrarily chosen frequencies aimed at "keeping in touch", rather than omnidirectional anticryptographic beaconcasts on cosmically "obvious" wavelengths seeking to establish contact. First contact by accidental eavesdropping should be a very hit and miss affair.

Fermi's Paradox deserves little respect! MMM

IN SEARCH OF A LONG-VANISHED STAR CLUSTER

The HELIADES

DOES THE SUN HAVE LOST SIBLINGS?
If so, does Earth-Gaia have Cousins?

By Peter Kokh

Look up at a clear dark night sky, with your naked eye, through a pair of binoculars, or through a telescope - it does not matter - and ponder that more than half the "stars" you see do not live single lives, as does our domestic star, the Sun. In fact the clear majority of stars, to judge by a careful examination of the population in our own neighborhood out to 20 parsecs or 65 light years, are formed in pairs or triples, even pairs of pairs sometimes. It has been suggested that along the single road, planets are the happy consolation prize. But our current state-of-the-art detective capacities do not really allow us to yet test that proposition.

Look more carefully, and you'll find that many stars exist in clusters containing hundreds, thousands, even millions of members, all formed in one birthing spot at one point in time, and still closely associated. Naked eye examples are the Big Dipper, the Hyades (Aldebaran), and the beautiful Pleiades. Such clusters all seem to be relatively young (the still infant Pleiades are only about 150 million years old for example), and there is plenty of evidence to show that they are very slowly drifting away from one another, diffusing into the general star swarms of the Milky Way.

So the question arises, though the Sun was formed as a single star, was it yet born with dozens, hundreds, or thousands of others in a cluster that has since dissipated over the 4.6 billion years since? Does the Sun have unknown and undetected siblings born at the same time and place?

Not all stars born in a cluster are of the same mass. And mass is what determines how fast they will burn their hydrogen fuel, how brightly they well shine, what will be their spectral color, and how quickly they will consume themselves and die out with a bang or a whimper. So if the Sun indeed has cluster-mates, many of them might be quite unlike it, being heavier and brighter, or lighter and dimmer. All those brighter than spectral class F3 or 4 will have already come to the end of the road. Any big brothers of the Vega or Sirius type, for example, will now be little more than cooling "white dwarf" cinders. But they don't interest us anyway.

What is intriguing about the possibility of littermate stars to *Helios* (Greek for the Sun) i.e. of a vanished cluster me might aptly dub "the Heliades" [HEE-lee-a-deez), is that amongst its members might be a number (4-15%) that are in a size, brightness, and spectral range to sport a "temperate" ecozone in which some "hydro-tectonic planet"* not too unlike Earth may find eons-long hospitable conditions for life to prosper and reach evolutionary maturity. Here the long odds against finding other intelligent species should be a bit shorter.

The Sun is only about a third as old as the Milky Way itself, so there are untold billions of stars out there that are much older, around which life may have arisen, prospered, and long since vanished. There are also many billions of stars, potential planet-boasting suns, that are much younger than the Sun, around which any life that has formed must be at proportionately earlier stages of emergence.

Does that mean that if we could somehow identify far drifting birthmates of the Sun, that we might find some around which life is at a generally equivalent state of achievement? It has become clear of late that evolution is not a steady smooth process, that it tends to settle down in stable equilibriums. It is only because of not-too-frequent catastrophic interruptions via asteroid impact that these stable ecosystems are destroyed, creating a new set of conditions for hitherto submissive species populations to exploit - some of them to succeed to dominance. The average pace of those slate-smearing strikes has a lot to say about how long it has taken to reach our present situation. If they occurred with only half the average frequency, Gaia (Earth-Life) might yet be locked in some earlier stage of vertebrate or pre-vertebrate achievement. If they occurred with twice the frequency, beings like us might have come and gone hundreds of millions of years earlier - *or* the pace of rut-breaking catastrophe might have been too fast to allow interim stable ecosystems to mature, thus knocking us back to "start", time and time again. Is the pace of needed interruptive chaos we have experienced on Earth about average? We've no way of knowing that. Lacking other examples to investigate, we can only make a weak assumption that it is so.

Now all else being equal, any sampling of Solar kin stars ought to prove significantly more rewarding than a random search of the Solar neighborhood. The kicker is that it may be more difficult to identify lost siblings of the Sun than to search the general swarm of stars at large for systems on which life has emerged and matured to an equivalent stage, and on some few of which intelligence may be struggling against the same odds of survival we face. In theory, we need only examine all the stars we see, filtering out those with transverse "proper motion" across the sky, searching the remainder for small radial motions receding from our current location.

In reality, most of our conjectured cluster mates must have wandered too far away by now to still be found hanging around in the observable neighborhood. Further, most neighboring stars in the general age bracket as the Sun, have probably drifted into range from elsewhere. After all, the Sun has already made some 18-23 orbital trips around the nucleus of the Galaxy. Over this span of "galactic years" 200-250 million years long, a lot of scattering has to have occurred.

If there ever was a "Heliades Cluster", that may be of no help at all to us in our search for galactic companionship. Nothing, however, can stop us from wondering. Does Earth have "cousins" out there?

Finally, *if* Earth *does* indeed have cousins, this says *nothing* for the similarity or dissimilarity to what we find on Earth of any life biota that may have arisen there - unless, of course, and this is unlikely, the cousin worlds were all "seeded" from some common source (if they were "seeded" at all). Intriguing as the possibility may be, looking for other members of the hypothetical "Heliades" does not seem to be an especially promising line of effort.

We can't receive, unless *someone* "out there" is sending

By Peter Kokh

Our attempts at S.E.T.I., Searching for and hopefully receiving messages from a separately evolved intelligent population, assume another race's attempt at C.E.T.I., broadcasting and hopefully Communicating-to. Granted some appreciable number of comparable civilizations scattered throughout the Galaxy, the "big question" remains. Is *anyon*e sending - or is *everyone* just listening. The answer *could* be disappointing.

It is enormously easier to listen than to send. It takes many orders of magnitude less time and energy. *Our* standard search strategy is to aim an antenna at any given star for just a fraction of a second. *We trustingly assume that the sender is immeasurably more patient and dedicated, broadcasting a "hello there!" signal constantly, without intermission, for a very very long time.* To have more than a nano-chance of successful contact, the sender must be prepared to beam the message towards selected or general targets, not for a few minutes, nor a few hours, nor a few days, nor a few weeks - or years or centuries - but perhaps for millennia! If the message sent were unrepeated or non-continuing, the chances against its arrival here precisely when we just happen to tune in, are staggeringly astronomical. This places the real "burden of contact" squarely on the presumptively broad shoulders of some understanding and perhaps heroically motivated sender.

In contrast, the famed "Arecibo message" beamed toward the distant, star-rich but likely planet-barren globular cluster Messier 13 in Hercules on 11/16/74 was but a fleeting whisper that has no real chance of ever being heard. It was nothing more than a *dishonestly misleading* PR gimmick.

In contrast to the level of civilization needed either to beam sufficiently energetic tight-beam messages in a particular direction for a long enough time, or to send out an all-points beacon for a shorter time, that level of technology needed to indulge a puppy-like search of star faces for an adoptive smile, is rather crude. Those first able to listen, and with the greatest emotional need to hear something, anything, can hardly presume to be peers of those advanced enough to be able to send, and culturally mature enough to continue sending, with no more than blind hope that someone somewhere will hear.

We can only guess at the level of motivation needed to sustain such a sending effort. It could be a cheap-enough penny for a rich-enough society to toss our way without much further thought as if to some hapless sidewalk beggar. Or it could require sustained religious dedication of more than cathedral-building resolve, if not messianic insanity. That our hopes of receiving seems to require so much greater a need to send on the part of the other guy out there should sober our expectations. UPSHOT: an honest non-self-deceptive estimate would be that *only a small fraction of those civilizations technologically capable of a determined broadcasting project, actually engage in such activity in more than a playful way.*

A civilization may not be able to broadcast interstellar signals effectively much before it has an effective circumsolar presence about its home system, and is able to erect giant antenna in space or on a moon's farside, or in some other quiet noise-shielded location. Perhaps it might even require learning to modulate the very light or other radiation of one's sun itself in order to piggyback a message on an existing energetic source that can run continuously for the thousands of years it may take to earn even odds that some other civilization out there will happen to turn an ear.

The typical sending civilization must not only be technically far advanced of the typical listening one, but also more "mature" having had to successfully survive the self-imposed threats to survival (runaway population, uncontrolled pollution, undisciplined military adventurism with dangerous toys) of its own cultural coming of age. To expect that a civilization at our current stage of history should be able to mount a successful S.E.T.I. search, requires a leap of faith - that "adult" civilizations would have any interest at all in talking to "adolescent" ones like ours. [see next article.]

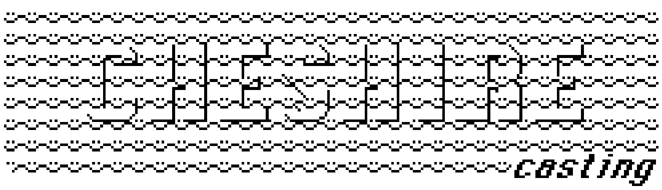
One preferentially communicates with/to one's peers. Must we not expect that preference to be universal? The upshot is that if a sending civilization wishes to improve the odds its message won't be picked up by immature civilizations like ours, there should be several self-suggesting ways to arrange this, whether in choice of carrier frequency, frequency combinations, or message encryption.

One could, for example, choose a frequency or combination of frequencies (e.g. one carrying the x-value, another the y-value of a pixel interpretation grid) beyond the range of the Cosmic Background and Galactic Background noise BUT well in middle of expected atmospheric and telecommunications background interference. Then the successful receiver would have to be not merely above the atmosphere (very high balloon, or in orbit) but also in planet shadow (e.g. lunar farside). If a pair of frequencies is chosen for encryption, one might be in radio window maximum of telecom interference (AM, FM, VHF, UHF, etc.) and the other might be one in the molecular atmospheric absorption zone or in the photochemical atmospheric absorption zone (on either side of the visual window). That any likely civilization must grow up on a world with a similar oxygen-enriched atmosphere with abundant water vapor and some carbon dioxide and methane and ozone makes this strategy workable and obvious.

The UPSHOT is that if anyone is sending messages our way, we are not likely to be able to intercept them until we expand further into space and presumably grow up a little in the process. That's a hard notion to accept, an affront to our pride. We have come far, baby, but not yet far enough. The affront need not be taken personally by the scientists involved and supportive citizens. The affront, if that is what it is, is to the well-presumed immaturity of our civilization.

"The Prime Directive" of Star Trek notoriety is not some quaint Sci-Fi notion, but, by whatever other name, a norm of behavior for more advanced peoples towards those less advanced, one that MUST inevitably powerfully suggest itself universally. If so, nothing we are now able to receive may be beamed our way. We might have to wait, and grow.

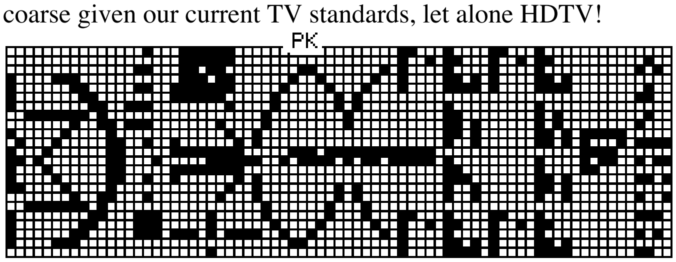
WHAT TO SAY TO UNKNOWN ALIEN LISTENERS??



Cheshire-casting

By Peter Kokh

The famed Arecibo Message sent 11/16/74 towards the M-13 globular cluster (well-known to amateur astronomy buffs) had a stingy 1679 data bits. The idea was that as this number is a product of two prime numbers, 23 and 73, the receiver would realize that the message was to be decoded by arraying the data bits, a series if 0s and 1s as full/empty pixels on a 73x23 grid. That gives a display which is surprisingly coarse given our current TV standards, let alone HDTV!



The message above intends (right to left) to set up a numbering convention, then tell that we are made of hydrogen, carbon, nitrogen, oxygen, and phosphorus; show the nucleotide and sugar phosphate backbone of our DNA and the number of nucleotides in our genes; show our biped shape and average adult height, our global population, the number and arrangement of planets in our system, and that ours is the third from our sun; finally the shape and size of the sending antenna. Given the limitations of the single 73x23 picture, that *is* a lot of supposedly 'interesting' information. But anyone receiving it is likely to find nothing surprising or out of the ordinary in it, and wonder why we even bothered to go through the effort.

There is already a considerable body of work setting up anticryptographic encoding procedures for radio messages, demonstrating the rationale behind the S.E.T.I. effort, namely that it IS possible for one civilization to convey significant information to another it has never met or knows anything about. Granted that, there are two questions: √ What does the listening civilization hope to learn? and √ What does the broadcasting civilization want to say? Counter-intuitively, the one question is *not* the flip side of the other.

The listening civilization expects to be the technological inferior and may even grudgingly grant that it may be the cultural, if not the moral, inferior as well. In addition to its basic curiosity ("Is there, in fact, anyone else out there?") there is genuine intellectual curiosity ("Are they biologically like us or are there significant differences?" "Where?" "How far away?" "How many?" "What is their diverse animal and plant life like?" "What is their home world like?" etc. etc. etc.)

But there are other questions not so purely motivated. *And lets bluntly and honestly frame these questions!* "Are there any scientific and technological insights we can garner which will give us shortcuts to the future *so that* we can slack off earning our place among the stars?" "Who's right and who's wrong on this philosophical or theological or economic point?" (We want to know so in stead of argument we can use ET endorsement as ammunition in our doctrinaire feuding.)

Some simply seek to know or be reassured that there *is* a way to overcome the problems threatening our survival as a species. Indeed even a simple electronic "hello" from a people that *has, evidently,* "made it" through its own troubled adolescence, would be telltale enough. And perhaps this is all we have the right, or need to know. Certainly it is the simplest possible message, one that needs no special coding and decoding, and one which in its utter brevity is supremely resistant to static and noise degradation. Once we know that success is possible, we should be more strongly motivated to find the way ourselves without our hands being held. Everything else is idle curiosity. Fun but unnecessary information.

The viewpoint of the sending civilization must be quite different. They may want to reach only those who have "made it" on their own to become spacefaring (not merely orbit-faring) civilizations. They will have realized the "prime directive" and be wary of giving insights that can be misused.

But affecting the shaping of the message may be a more pertinent, totally practical consideration. Is it the better strategy to send the same message to all points, diluting available power over the whole sky in the hopes of catching someone listening relatively nearby? Or is it the better strategy to use available power in a tight beam aimed at a more distant clustering of a probably greater number of listening civilizations? In the first choice, one would cover the neighboring few thousand light years of the sender's region of the galaxy. In the second, knowing full well that the probable proximity of even the nearest contemporary technical civilization might yet be far enough out to make reply meaningless and unlikely (e.g. 250 light years + 250, - 100), the sender, engaged in what can now only be a thoroughly altruistic exercise, realizes that distance and time mean nothing. The message then might be more effectively aimed at a neighboring galaxy with far more potential listening civilizations in much less angular space.

Suppose a civilization well beyond our current state of advance already some 2 million years ago, but located in the great Andromeda galaxy (M-31, floating some 2 million light years away) so reasoned, and decided to put all its effort into a millenia-long broadcast that covered our entire Milky Way galaxy. We might just now be getting a call, while our callers may have long passed from the scene. In that light it would seem a silly self-occupied aberration for them to be talking about themselves and their world. Especially when there is an excitingly more elegant opportunity.

Instead of local geological, biological, and cultural trivia, they might chose to give us *a real present*, something we could never obtain for ourselves but would dearly love to have. Imagine someone in M-31 sending us a portrait of our own galaxy taken from their vantage point! Just one photograph in visual light *or* a whole multi-spectral album - either way it would show us what we had looked like 4 million years earlier when the light they recorded left the Milky Way.

If and when we do get a message, the contents may be the ultimate gift one intelligent civilization can give another, insight into themselves. Of the senders, all we'd have is their unmistakable "Cheshire" grin. MMM

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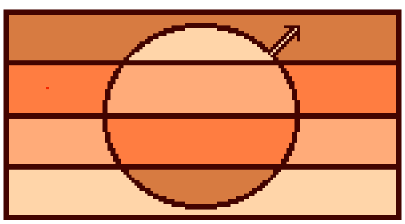


A Flag concept for a Future Mars Territory

In the draft at right, the astronomical (and astrological) symbol of Mars (and masculinity), the sphere with upper left arrow, is placed against a color-reversed background with four color bands from a Mars landscape palette: (from light to dark) salmon, peach, burnt orange, and ocher - the arrow in orange-red. - Earth and Mars were at closest mutual approach January 3rd with *Mars Observer* launched last September 16th to arrive on scene next Fall. MMM's 6th annual Mars' theme issue! .

Picking Town Sites on Mars: Climate Considerations

By Peter Kokh

Our first exploration beachhead outpost on Mars is likely to be chosen for purely scientific reasons. What site would would be most conveniently central to the areas of Mars that most pique our geological, geochemical, and archeo-biological interests? Mission planners at NASA, and their purse-string-holding second-guessers in Washington and other participating capitals are unlikely to give a nanosecond's consideration to the needs of the follow-up "permanent settlement" which is the quite different fountain of interest for the great majority of avid Mars supporters.

Not that these two separate lists of attractions don't overlap. They do. Many of the top attractions for prospective Mars geologists (areologists) must also be prominent on any list of must-see tourist attractions. And proximity to certain tourist draws is a strong economic plus for a townsite.

Tourism, however, must be secondary to considerations of economic geography. √ Where are the most easily accessible resources necessary to support earliest possible self-manufacture of the greatest bulk of the settlement's material needs? √ What regions offer easiest early-method access to sources of fresh potable water, either from permafrost reserves or "by canal" from the polar ice caps or simply from atmospheric extraction? √ Where, if anywhere on the planet, do potential prime settlement sites "cluster", affording the least difficult mutual commerce? √ Are there easily negotiable surface routes to and from an otherwise promising site?

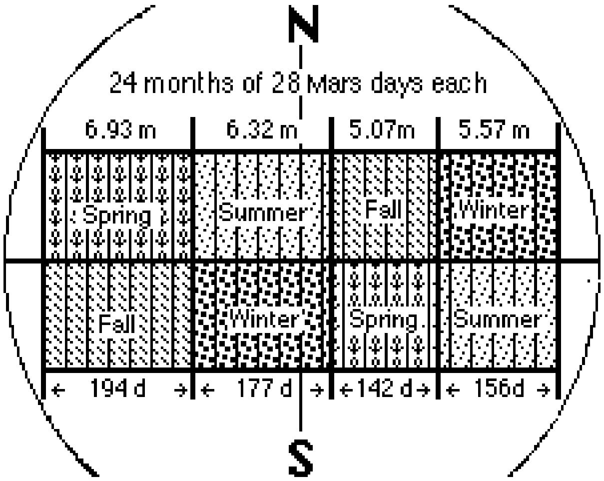
By our read, these considerations ought to be primary if and when a multi-governmental (or para-governmental?) decision is made to follow up human exploration of Mars with its opening as a settlement frontier. Later on, once a number of townsites are established, two considerations will come into play when it comes to the competition between the early Martian Towns for prospective new settlers. √ Where is the economy booming? √ Where is the local climate least hostile?

The consideration of climate will become even more important *once* consensus is reached, either before, or after, the opening of Mars to settlement, on the wisest goals and most attractive means to the "terraforming" or "rejuvenaissance" of the planet. While current climate differences between prospective sites may be moot (you can't go outside in shirtsleeves and/or without a mask to bask in the sun *anywhere*) when and if the climate is made to improve some locations might quickly emerge as the "Floridas" and "Hawaiis" of Mars.

To give us some clues to where these future balmy regions may lie, we need first to consider Mars' Season Cycle. The Fourth Planet is tilted on its axis by some 23° 59' relative to the plane of its orbit around the Sun, amazingly similar to Earth's own 23° 27'. Consequently its "temperate" zones have marked seasons, a succession of Winter, Spring, Summer, Fall etc., just as ours do. However the range of temperatures more closely follows that on our own Antarctic Continent, that is, from well under a hundred below Fahrenheit during midwinter nights to a few midsummer early afternoon very localized flirtations with the thaw point.

So just hug the equator, you suggest? Its not as simple as that. While Earth's orbit is mildly eccentric, taking us in as close as 91.4 million miles to the Sun in early January ("perihelion") and out as far as 94.6 million miles from the Sun in early July ("aphelion"), a difference of only 2.8%, Mars' orbit is much more elliptical so that it ranges from 128.5 to 155 million miles out, a difference of near 21%.

Further, neither Mars' winter or summer solstices, nor its vernal (spring) or autumnal equinoxes line up neatly with its perihelion or aphelion dates. The consequence is that the four seasons differ dramatically in length.



MARS' UNEVEN SEASONS: Mars' orbit is very eccentric, swinging out further from the Sun (traveling slower) during Northern Spring and Summer (Southern Fall and Winter) and in closer to the Sun (traveling faster) in Northern Fall and Winter (Southern Spring and Summer). The results are a TRADEOFF. There's more time (13.25 months) to enjoy a cooler Spring and Summer north of the equator, less time (10.64 m) to enjoy a warmer Spring and Summer in the southern hemisphere.

How would these curious facts affect local climates, *and future climatic potential*, of various potential settlement sites? While the terrain may be both more interesting and easier to negotiate from the Martian equator northwards, the warmest midsummer days are likely to occur at low elevation sites (well below Martian "sea level") from the Equator southwards to middle southern latitudes.

Post-Mariner or post-Viking maps of Mars show a large deep impact basin named Hellas Planitia stretching from 29° S to 58° S and from 273° to 312° longitude. Its ramparts lie a couple of kilometers above mean Martian altitude, but the northwest central part of the basin lies as much as 4 kilometers below that mean level. Here, about 38° S lies Mars' equivalent of our "Death Valley". And here, as the atmosphere thickens via human intervention, will it first become possible to bask in the sun outdoors on midsummer afternoons. Hellas is Greek for Greece. The former sea basin *could* live up to its name and host the first "flowering" of "Martian" civilization.

By sheer coincidence, Edgar Rice Burroughs placed his "capital of Barsoom", Greater Helium, in the area. MMM

Frontier Republic of MARS

"Fast Track" to "Federal" Autonomy

By Peter Kokh

The "Umbilical" Paradigm Won't Work

Mars ranges 150 to a thousand times as far away from Earth as does the Moon. Launch windows to the Red Planet open every 25 months, rather than daily as with the Moon. Replacements and resupplies must be planned well ahead and generously cachéd on the frontier itself, not in some near-Earth warehouse. In effect, "umbilical cords" connecting the Martian frontier with the home world will not work since they cannot be in continuous service. Instead, a "yolk sack" system of strategic reserve supplies and anticipated next-step development needs to "nurse" the settlements through the long periods of interrupted access will be the approach that works.

As for rescue and relief, much as in that cinema cliff-hanger standby, the suddenly pilotless airplane, "talk through" assistance will be all that Earth, or the equally remote Moon, can routinely offer. Not only day to day decisions, but week to week and month to month ones will have to be made locally without the hollow threat of any veto power from 9 to 34 enforcement-months away.

The upshot is that the demand for effective levels of local settlement autonomy will present itself at a much earlier stage on Mars than on the Moon. This demand will not be merely one of exercising political will. It will be a logical consequence of the remoteness of the frontier. Any sane Earth authority involved in the Opening of Mars will grant such autonomy even *before* the settlers on the scene are quite ready to petition for it, much like a mother bird insistently pushes its hesitant fledglings out of the nest. In this respect, the history of the Mars Colony *should not* follow closely the precedents of previous waves of Earth-bound colonization.

Prerequisites for Autonomy

For the Moon, where logistics allows the "umbilical" approach, it may be possible to simply draw up a list of prerequisites for phase by phase realization of increasing degrees of home rule leading to eventual full sovereignty. These levels may or may not be reached. For Mars, in contrast, it will behoove the authorities on Earth both to relax any "requirements schedule" and work single-mindedly to see that it is met in full as soon as possible.

A plurality of towns offering some measure of economic diversity with interdependence as well as effective occupation of an appreciable sector of the planet with the real opportunity to expand both presence and self-reliance through the combined capacity of the settlements to self-manufacture the bulk of their physical needs should be Aim One. Achieved goals that will enhance settler prospects for a thriving if small "planetization", such as the establishment of a full University, running up a multiyear trade surplus (or yolk-endowment handicap), meeting set population size milestones, successful rearing of a healthy second native-born generation, etc. might be relaxed or waived. Rather, once the infant colony is moving securely on the right track on all fronts, achievement of desired phases can be anticipated and political autonomy granted. This is a real gamble, but it is a gamble that must be taken.

Early Federalism

One settlement a "World" does not make! We have already mentioned the need to have our eggs in several baskets and the need for cultivating the roots of a diversifying interdependent economy. Even if the Mars Republic begins with only one functioning local state or province, it will do well to have a federal structure in place. This will help curb later inter-regional territorial disputes, establish a federally administrated regime for yet-to-be-settled areas outside functioning regional economies, and set up patterns by which new areas of the planet can be opened by those seeking to start out fresh, not under the thumb of existing states or provinces.

Isolation of individual towns, even clusters of towns, could be significant. A federal pattern will encourage variety in social, institutional, cultural, infrastructure, and construction lingoes. At the same time state or provincial sovereignty will be limited from the outset and the terrestrial pattern of warring jealously "independent" nation states avoided.

Federal structure will need a regime of federal lands: planetary scenic and geological parks, especially strategic mineral and resource reserves (the ice caps, at least) some of which must be transferred to local state or provincial authority upon the setting up of same, others which would remain federal preserves. The federal government would control off-planet trade, at least, and have title to the moonlets Phobos and Deimos.

To avoid sure conflicts, the establishment of state or provincial boundaries ought to follow some preset guidelines. One, looking forward to a future epoch of terraforming or of the "rejuvenaissance" of Mars, might be the following of clear-cut "divide" lines between potential drainage watersheds. This would establish logical commonalities of future ecological responsibility. [Contemplate how different the political map of Earth would be if on all continents frontiers were those of the great river basins. There would be countries large and small as now, but they'd look quite different from the arbitrarily drawn nation-states we have today.]

Mars should be opened with a chartered Mars Settlement Company already in place. Prospective settlers could buy shares in the Company beforehand, giving them voting rights. A constitution and federal framework covering most of the anticipated pitfall efforts could be agreed upon by all shareholders before the first band of settlers leaves Earth. The alternative is to trust that through on-the-spot conflict resolution, sensible arrangements will spontaneously spring up, with no loss of life, derailment of effort, or resistant residue of ill feeling sure to cause trouble for generations to come. Other things that can be agreed upon by the Company beforehand are official language, frontier legal code, etc.

There is no point beginning settlement if we are not prepared to go all the way. And thus a sensible, well-considered and deliberately pursued plan is *the* way to go.

CANALS

On Mars: from self-deception to reality

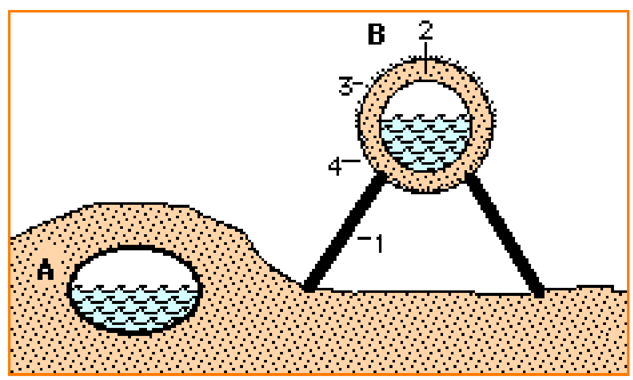
by Peter Kokh

The *"canali"* or 'channels' 'discovered' on Mars during the opposition of 1877, by the Italian astronomer Schiaparelli, and subsequently embraced and promoted as sapient-made watercourse canals by Percival Lowell, were never more than wishful thinking grounded in optical illusion. Supporting evidence of "seasonal" color changes (darkening and thickening "irrigated vegetation" strips between the polar caps and the equator were shown by Carl Sagan to be seasonal redepositions of darker and lighter dust or sand by the prevailing trade winds. The Mariner and Viking probes showed the canals themselves did not exist and that climactic conditions on Mars have been too extreme to allow liquid surface water for a billion years or more. Further, surface-drenching solar ultraviolet made the vegetation allegedly hugging the canal routes quite impossible.

At the same time a taunting picture emerged of a once water-rich Mars with an ocean, some small seas, great rivers, islands and shorelines. Some of this once generous endowment must remain: in the polar caps, in permafrost, and in possible subterranean reserves. If the canals never existed, the rationale of transporting water equatorwards from the polar caps, now known to be mostly water ice, remains intact: a tempting goal for a future *human* Martian Army Corps of Engineers.

Actual and proposed terrestrial models exist. Water has been rechanneled on Earth by canal and aqueduct for many millennia. And there have been grandiose schemes to do even more on unprecedented scales: Wally Hickel's fresh water pipeline from Alaska to California; proposals to divert Great Lakes water to the arid Southwest; abandoned Soviet schemes to reverse the flow of 3 great Siberian rivers (Ob-Irtysh, Lena, Yenisei) currently emptying into the Arctic Ocean (a scheme sure to trigger a real ice age by increasing the ocean's salinity).

Any logical canal route on Mars would have to follow land contours - valley routes with pump portages over frequent sills in Mars' immature drainage topography. We do not yet possess an adequate topographical map of the planet with accurate elevations. Hopefully, Mars Observer will improve our knowledge here to the point where some candidate routes can be sketched out, for later survey confirmation.

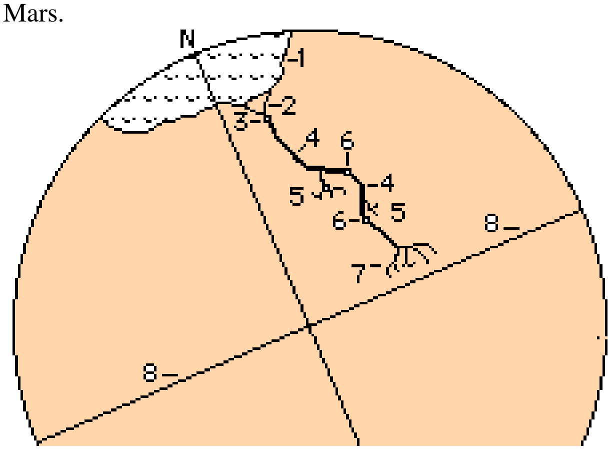


ALTERNATE THERMAL STRATEGIES: In (A), the sealed canal aqueduct is placed in a trench and covered over with shielding soil. But this will only tend to keep it as warm as the surrounding permafrozen soil. In (B), as with the Alaska oil pipeline, the aqueduct is raised over the permafrost from which it is thermally insulated by special nonconductive stilts (1). It is then jacketed by some sort of eutectic thermal mass (2) with its upper surface (3) coated IR-black to passively soak up what little solar heat is available, and its lower surface (4) silvered inward to help retain heat and prevent its radiation toward the cold ground. Here the goal is to use passive solar to keep the jacketing thermal mass just over the freezing point.

While we might romantically choose to call them canals in deference to the shattered dreams of yore, the proposed aqueducts will almost certainly be enclosed to help meet the daunting thermal challenge of keeping the water liquid. It must flow over very long stretches throughout which Antarctic-like temperatures prevail.

The thermal mass could be some ceramic or concrete solid. It could also be some eutectic compound, if a suitable one can be processed from Martian soils, that stores surplus daytime heat by changing phase from solid to liquid, resolidifying as it surrenders that heat when needed at night.

The atmospheric pressurization within the enclosed pipeline could use the available CO2 ambient atmosphere as is, or with additive gasses that help retain heat. The inner surface of the pipe could be coated to be ice-repelling. The freezing point of the water in transit could be lowered by anti-freeze additives if some can be formulated for local manufacture *that can be easily removed* at outflow points to render the water potable again. Could percussion sound waves or microwaves help keep sub-freezing-point water liquid? All the options must be investigated to zero in on those that are workable under Martian conditions, and for which the raw materials needed are locally available, and the components locally producible: Made on Mars.



CANAL ROUTING ON MARS: A number of feeds (2) from the edges of the North Polar Ice Cap (1) could feed into a main pumping station (3). From there, an arterial canal (4) would follow logical land contours on its route southward feeding into a number of mid-course delta diversion areas (5), and crossing passes and divides via pumping stations (6) to a final delta dispersal area (7) in the equatorial regions (8).

Considering that Mars' celestial north pole lies in the constellation Cygnus, the Swan, a few degrees from Deneb, the principal pumping station near the polar cap edge might be colorfully named "Swan Lake". Here the water ballet begins.

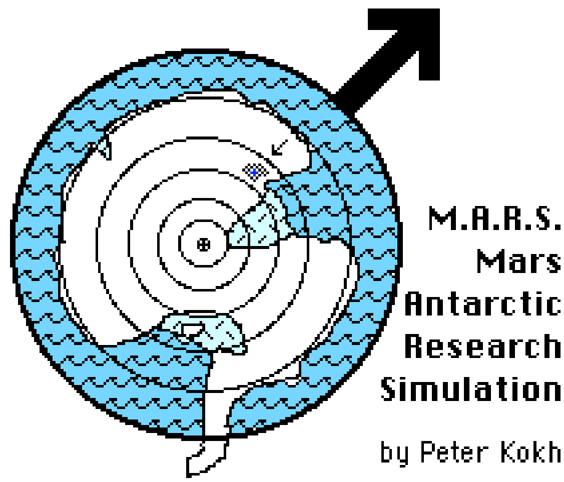
Manufacturing plants (Schiaparelli Manufacturing and Construction Company?) to produce the components needed (pipeline sections of varying diameters and couplings, thermal jacketing material, IR-black coatings, 'silvering', stilts, pump station machinery, etc.) might be best located at some midpoint along the route (5). Settlements would preferentially cluster at (3), (5), (6), and (7). Permafrost water extraction along the arterial (4) could serve as a supplement to usage at mid-course diversion areas (5) with surplus fed into the canal for use 'downstream' (i.e. a cogeneration scheme).

Will more than one such canal be built? That depends on the number of feasible routes and the number of economically attractive townsites each would serve.

Prosaic names could be chosen: the Trans-Utopia Canal, the Chryse-Marineris Canal, etc. There are many who would prefer a fresh start that makes no allusion to the tainted past of runaway Mars speculations. But *why not* dip into the available pool of names from Lowellian canal mythology? Unfounded early public daydreaming aside, Mars will need all the 'romance' we can give it. MMM

SomeLowellian MartianCanal Names:
Indus, Oxus, Euphrates [also on Earth], Nilosyrtis, Chryse, Phison, Hiddekel, Gehon, Candor, Antæus, Deuteronilus, etc.

Some LowellianNames forCanal-linked "Oases":
Lacus Solis, Phoenicis Lacus, Nuba Lacus, Lunae Lacus, Charontis, Læstygon, Zea Lacus), Ismenius Lacus, etc.



The comparison of Antarctica and Mars has long been made. The ice-bound continent is as close to "another world", one other than our everyday experience, and well off the tracks of common tourist travel, that most humans can ever hope to visit. Beyond its isolation and "difference" are the further similarities of very similar temperature ranges, abundant frozen water, constant winds, and breathtaking trackless scenery.

Beyond that the comparison gets stretched. Antarctic shores are washed by a cold nutrient-rich ocean dense with life. Its shores team with penguins, skuas and seals and occasional other wildlife visitors. And above all, the cold brisk ever-blowing air above the ice is thick, sweet, and breathable.

While there are water-ice sheets on Mars as well - at both poles (the belief that they are composed mostly of carbon dioxide snows and frosts has been long disproved), most of the planet's surface is bone dry, presumably with large expanses of subsurface permafrost of unknown thickness, moisture content, and salinity. Yet here too Antarctica offers a strikingly Mars-similar area in the "Dry Valleys" of the TransAntarctic Mountains west of McMurdo Sound, site of the largest human community (if you can call an ever changing collection of single adults a community) in this Southern World.

The Dry Valleys exist because, amidst all this ice, Antarctica, in terms of annual precipitation, is the driest place on Earth. Precipitation has to come from occasional incursions of winds off the ocean, but here the prevailing winds blow everywhere northward from the downdrafts at the pole. In the Dry Valleys there is seldom any precipitation, the march of the ice sheet and glaciers are blocked by mountain ramparts, and the eternal winds are extremely desiccating, enough so to quickly and enduringly mummify any seals, penguins, or skuas unfortunate to wander into the foodless area and die.

Taylor Valley, 2-3 miles wide and 20 miles long is the most accessible, as it reaches down to the Sound. About forty miles inland to the east is 3x6 mile Beacon Valley. To the north of Taylor but approaching no closer than 15 miles to the Sound lies the largest ice free expanse: Wright Valley, connected by dry Bull Pass to 10x18 mi. Victoria Valley. Taylor, Wright, and Victoria all have small frozen lakes and ponds (something the thin air pressure on Mars won't allow).

In these areas - inside surface rocks! and on the beds of the permanently ice covered lakes - lie the most extreme surface or near-surface environments for living creatures on Earth, and amazingly life, be it only microbial, *has* established a stable if shallow and lethargic foothold. Some Mars-Life enthusiasts have been cheered by this and cling to the belief that we might find similar pockets of microbial life on Mars. But that requires a leap of faith, for just because life has encroached there from neighboring areas teeming with it, offers no comfort to those who would think that life could therefore originate in such areas. Nonetheless, the Dry Valleys are a unique natural laboratory in which we can both experiment with techniques to search for life hiding and holding out on Mars, and at the same time gradually develop "Mars-hardy" plants and other creatures from terrestrial stock by a combination of breeding and genetic engineering.

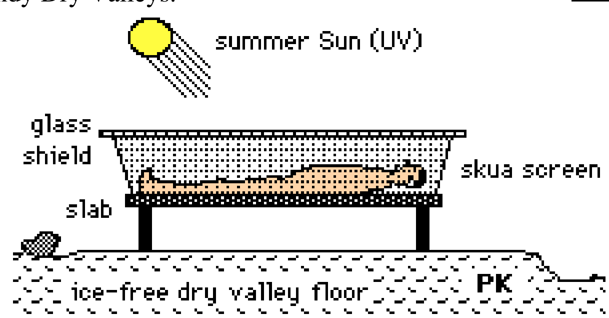
Beyond this immensely useful biological work, some of it no doubt leading to the enrichment of life on Antarctica itself, lie other areas of endeavor by which we can prepare ourselves for the opening of Mars. "Little Mars", if established here, would be the most Marssimilar area on Earth in which to experiment with Mars-appropriate exploration, construction resource-extraction, processing, and manufacturing methods and technologies, allowing us to test concepts for shielding and thermal management as well as debug vehicles that can handle the dry cold. Plans for single habitat outposts as well as more ambitious base-town complexes can be tested.

At "Little Mars", we could test out the "yolk" caché system as a logistics substitution for the "umbilical" support system. Actually we have a head start on this for we currently build up stockpiles of needed provisions and replacement parts in order to allow our various Antarctic bases to get through the winter when the near daily inbound flights from New Zealand and elsewhere are cut off for several long months.

The concept of a "Mars Spring Training Camp" on Antarctica is already beyond the talking stages with strong support from the Planetary Society and the biannual Case for Mars Conference people as well as real, if budget-hamstrung, interest from NASA and the National Science Foundation, the agency running the U.S. Antarctic Program. NSF interest is in improved waste processing and energy production technologies as well as telescience capabilities that may help reduce the number of people needed to run scientific experiments. A pilot program with a teleoperated cable-tethered rover probing the bottom of *Lake Hoare* was set for October-December 1992.

While the concept of commercial enterprise involvement continues to receive no more than the most hypocritical of lip service from NASA - giving the lie to their occasional noises about the desirability of following up initial human Mars exploration with real, committed "for keeps" settlement, "Little Mars" could also serve as an "incubator" for future Martian enterprises. If processing and manufacturing experiments are made, some trial products could be in the form of salable arts and crafts. This would help illustrate the concept of Martian settlers providing for their own needs and developing a uniquely Martian consumer culture of their own. In the process it would help deepen and widen spotty public (and commercial!) support for opening Mars. In time perhaps an appreciable part of the continuing operating costs of "Little Mars" could be defrayed in this manner, and this would help to make the base less vulnerable to fickle ever-shifting budgetary whims.

The "Little Mars" concept is worth serious support. While much equipment destined for a Mars effort might better be tested on the Moon, *some* of it will find a more adequate - and much cheaper - testbed in a test site in one of Antarctica's handy Dry Valleys.



ETERNAL REST IN ANTARCTICA?: One unusual idea for a cost-defraying enterprise that could be run our of a Little Mars base in an Antarctic dry valley (perhaps accessible Taylor) is a "Desiccatorium", a place where people could be laid to rest in the open dry frigid air facing the brilliant winter starscapes above and naturally mummify. Faces and other exposed skin would need to be sun-shielded by UV-opaque glass least the flesh blacken from UV exposure. Screening to ward off scavenger skua birds would have to cover all exposures to the open air. If people are willing in enough numbers to have their cremated remains placed in an orbital mausoleum-satellite, they would go for this too.

[Inventors Wanted: "Wheeled Walker" vehicles for Mars]

WHEELS vs. LEGS

for Extraterrestrial Transport

by P. Douglas Reeder, Oregon L5

(also submitted to StarSeed)

Comparison of existing models leads one to the conclusion that mechanical legged vehicles are not worth serious consideration for land transport on other worlds. However, consideration of the fundamental mechanics and energetics of locomotion and the capabilities of legged animals leads to a different conclusion.

Although existing legged robots are slow, it should be noted that horses can carry a human at dozens of kilometers per hour for long periods, using one horsepower. Automobile engines generate hundreds of horsepower, plenty for a car sized vehicle if it has adequate energy efficiency, about which see below. As to control at high speed, cheetahs travel up to 120 km/hr over broken terrain. Mechanical legged vehicles with electronic control should be able to do at least as well.

All vehicles expend energy to raise the weight of the vehicle against gravity when ascending large terrain features. Properly designed vehicles can recover some of this energy when they descend. However, regenerative braking systems are still experimental for wheeled vehicles and research has barely begun on downhill walking.

Both wheeled and legged vehicles expend energy to accelerate the vehicle body. A rough ride, aside from being hard on passengers and cargo, wastes the energy that is used to accelerate the body in directions other than the direction of travel. Legged vehicles have the potential for a smoother ride at all velocities, but it is not clear whether this produces a significant energy saving. A wheeled vehicle must climb over an obstacle all at once, requiring high peak power. Legged vehicles can move one leg at a time, if necessary, using a smaller, lighter power plant.

Wheeled vehicles use energy to angularly accelerate their drive train and wheels, which uses little energy for usual designs. (The rover designs that are mostly wheel use much more.) Legged vehicles must accelerate their legs. On level ground, the legs oscillate in regular patterns and a properly designed mobile (such as most mammals) expends little energy to keep the oscillations going, but much more than comparable wheeled vehicles. Current mechanical walkers dissipate the leg kinetic energy at each stroke, and much more research needs to be done in this area. On rough ground, the irregular patterns of leg motion increase the energy loss significantly at high speeds, so picking one's way across a boulder field is not just safer, it is more efficient as well. Energy dissipated in leg/wheel motion is the area where wheeled vehicles do significantly better.

Soil interaction is where legs do much better. On soft ground, wheels compact the soil *ahead* of the wheel, expending energy to dig a rut in the ground. Wheeled vehicles are continually climbing out of their own rut (on soft soil), *reducing* their traction. As a leg pushes back, the soil *behind* the foot is compacted, *increasing* traction. Hard ground reduces the penalty to wheels, but this usually requires prior paving or rail-laying, at great expense, and is only economic for high traffic corridors - common on Earth and nonexistent elsewhere.

In summary, properly-designed legged vehicles can offer efficiencies within an order of magnitude of wheeled vehicles on smooth, paved surfaces and do better than wheels on rough terrain.

Where are these properly-designed legged vehicles? They don't exist (yet). Serious research on mechanical legged vehicles is less than two decades old, while the automobile has been in development for almost a century, and wheeled vehicles for millennia. Animals demonstrate excellent mobility and good efficiency for their materials. With higher-strength material, higher energy densities, and the speed of electronics, we should be able to do at least as well, if not better, than protoplasm technology. In addition, mechanical walkers do not need to be fed when not working, can run all day and all night, and do not have desires of their own.

The most efficient and practical legged vehicle so far is the Ohio State Adaptive Suspension Vehicle (ASV) which masses 1700 kg and carries a 220 kg payload at up to 13 km/hr. It is powered by a modified motorcycle engine.

Outlook for Legged Vehicles

On Earth, legged vehicles will find a niche, but will not replace wheels and roads and rails. We have a great investment in wheel technology and our society is set up around it. In addition, population is high and transportation routes are heavily used.

On the Moon, Mars, and other bodies, the reverse is true: we have no infrastructure of roads and rails, and travel densities will be low for a long time. If suitable legged vehicles are available by the time colonization is starting, colonies can be *designed* around the use of legs instead of wheels.

What would be different? Primarily, you don't need to pave anything. No unsightly and expensive roads and parking lots. Trails need only be cleared of the largest boulders and can ascend steeper slopes than are practical for roads.

Wheeled *off-road* vehicles and rovers also eliminate the need for roads, but offer a much rougher ride which is hard on people (reducing the amount of work they can do) and on delicate scientific gear. Legged machines still need bridges for gaps larger than a few meters. (Ohio State's ASV can cross trenches up to 2.7 meters and climb cliffs up to 2.1 meters, capabilities far beyond that of any wheeled vehicle.)

A legged vehicles can carry heavy equipment right up to its final location whether that is in a canyon or on top of a mountain, *and hold it level!* You don't need to drive a road to a site before you develop it. Boulders falling on a trail for legged vehicles don't block the trail, but merely it to the side.

Legged vehicles are mechanically more complex, and probably will require more maintenance than wheeled vehicles. You won't have two lanes of traffic going opposite directions within a meter of each other, almost eliminating vehicle collisions. An interesting visual effect is that a large expedition would resemble a stampede with diesel engine sounds. A good thing there isn't any local fauna to terrify!

Legged vehicle travel will follow natural routes across mountains (valleys, ridges, passes) but on the plains travelers will head straight for their destination, instead of along the road grid we use on Earth. Putting up a fence and saying NO TRESPASSING might be considered downright hostile.

You could drive your legged truck right into the middle of the greenhouse to load it, with it carefully stepping on the walkways, Feet do far less damage to soft ground and vegetation than wheels, reducing erosion, and kick up less dust in dry soils. If terraforming ever covers the dead sea bottoms of Mars with ocher moss, feet will be kinder to the plants introduced with great effort.

Legged vehicles offer the potential to significantly impact the way other planets are explored and developed. **DR**

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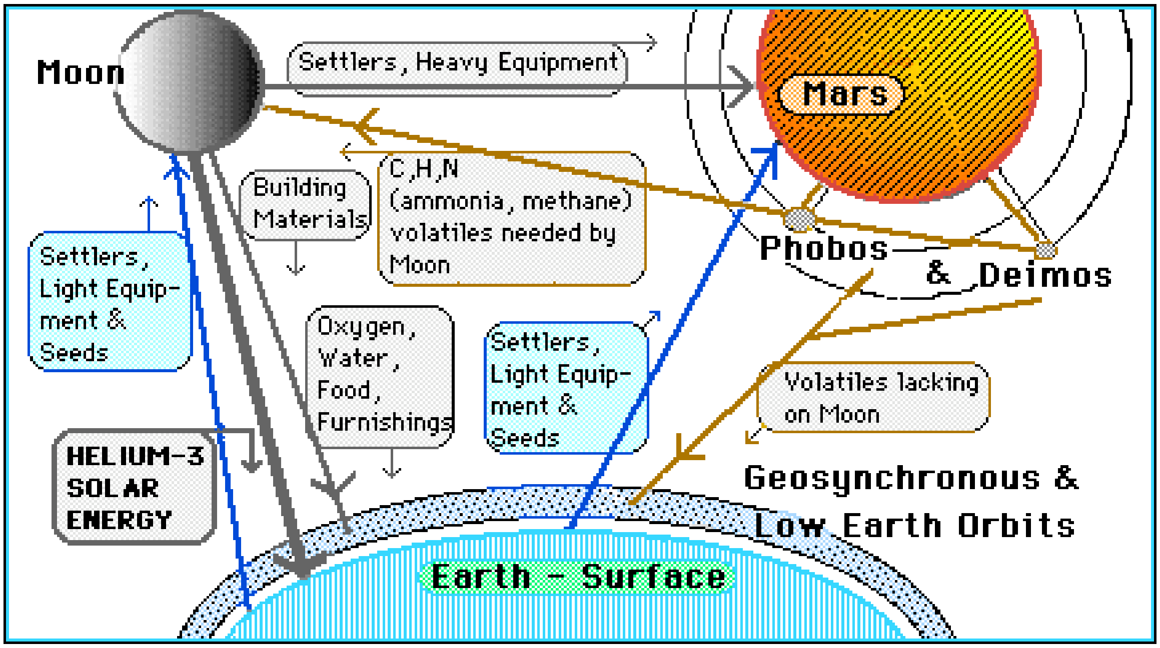
D. J. TODD, *Walking Machines: an Introduction to Legged Robotics*, Chapman & Hall, New York

Shin-Min Song & Kenneth J. Waldron, *Machines that Walk: The Adaptive Suspension Vehicle*, The MIT Press, Cambridge, MA

Inner Solar System Trade Routes

by Peter Kokh



One plausible scenario showing the development of trade traffic between Earth, Earth orbit (LEO, Geosynchronous, L4 & L5), the Moon, and Mars and its moons during the early decades after the opening of the space frontier.

Asteroids are not explicitly included in this schema. Asteroidal resources stand to cut into raw materials sales from the Moon, but may hurt sales of volatiles from Phobos and Deimos even more, leaving "Greater Mars" with that much less purchasing power.

The scenario begins with the investment of settlers, capital equipment to process lunar materials and fabricate needed items for local use and export, and seeds. The payback is in building materials, oxygen, water (lunar oxygen probably with terrestrial or PhD hydrogen), and food which can be shipped to LEO and other space outposts more cheaply from the Moon than from Earth because of its high lunar oxygen content. Helium-3 is a potential export of great importance if fusion power is realized.

Lunar raw materials are used in space construction for LEO facilities (space stations, orbital factories to make micro-G products for Earthside markets, and orbiting tourist resorts) and for construction of Solar Power Satellites and the space habitats needed for their construction crews.

The Moon is seriously deficient in hydrogen, carbon, and nitrogen. These elements can be imported to the Moon and to space construction sites more cheaply from Phobos and Deimos than from the deep gravity well of nearby Earth. *If* Phobos and Deimos ("PhD") are relied on rather than Earth-approaching asteroids for this supply, and *if* PhD is regarded as an integral part of the Mars economic area, *then* any profits realized at PhD from this volatile trade can be used to help finance activities on the Martian surface, paying the way for settlers and needed equipment. Lighter capital equipment might come from Earth, heavier items, once they are available "made on Luna", are more cheaply shipped from the Moon.

Every part of this scenario is a current plausibility, given what we now know about the Moon, Mars, Phobos, and Deimos. At the same time, every part of this scenario needs work. We are a long way from listing, let alone designing, the most efficient, lightweight, yet capable complex of capital equipment needed on the Moon to make the best, quickest use of local resources with the least human labor. We only have general ideas how to process lunar materials and what we can make from them. We have yet to plan the best paths of diversification of lunar industry.

We do not know what sort of factories using lunar raw materials can make what sort of marketable micro-G products for Earthside consumption. We have not yet identified the best means either for capturing solar power with cells made of lunar materials or for beaming it down to Earth's surface. Our ideas on how to build things in space like SPS or settlements are sketchy and vague and full of pitfalls.

Nor do we know how we will process PhD materials. Most space supporters think it is NASA's job to put all these pieces of the puzzle together. But guess what? In short, we must collectively get off our butts. **PK**

ICE ⟺ WATER CYCLE ENGINES

Possible engines for Mars Rovers?

by Francis Graham, Editor of <u>*Selenology*</u>

(Quarterly of the American Lunar Society)

The nature of Mars differs markedly from Earth in its having no free oxygen in its atmosphere and shade temperatures which are extremely low. As we begin to explore Mars, it is natural that we should select those electromechanical components with which we are familiar on Earth and which can be adapted for Mars. However, in developing space economies, it would not be unusual to develop mechanisms that would be poorly functional on Earth (if at all) but could well be functional on the planet Mars or elsewhere, where the nonterrestrial conditions can be best used. Reflecting on this possibility, one is led to a variety of Mars-specific categories. One such category is heat engines designed for Mars.

The Ice-Water Cycle Engine

In attempting to choose a design for a heat engine for Mars, the conditions of electrical power from the sun and low temperatures (-75° C, -103° F) were the major ambient factors. The lack of oxygen made internal combustion engines impossible [unless the oxygen is provided from an onboard tank]. A steam engine is possible, with a large solar concentrator providing the heat. But on Mars, it is possible to go over to the other phase transition, water⇐⇒ice, with a weight saving over steam pressure fittings and only a small loss of efficiency. A heat engine cycle across the liquidus⇐⇒solidus line using H_2O as a working fluid, i.e., an Ice-Water Cycle Engine, offers advantages.

The Ice-Water Cycle Engine is a cylinder filled with water and a piston. When the water freezes, it expands, and work is done against the piston. The solid is then returned to the liquid phase by joule resistance heating. Energy is thus transferred from the solar panels to the atmosphere through a phase transition which also produces work. The greatest advantage is the large force on a piston of modest area; the slope of the equilibrium curve is so sharp (dP/dT= -130 atm/K) that enormous forces can be generated by the expanding ice. The limit is reached when higher phases of ice with a specific gravity greater than 1 are produced. Operating between -17° C and 0° C [1.4° to 32° F], 2100 atmospheres (2.1 x 10^8 pa) can be generated on the piston. This makes the ice-water cycle engine ideal for situations on Mars where crushing, pulverizing and heavy lifting are desired. It also has a weight saving over electro-inductive/hydraulic systems, especially valuable on automated Mars rovers which must be lifted up from Earth.

A small operating ice-water cycle engine was constructed and tested at the Allegheny OIC[1] technical school in McKeesport, PA during the winters of 1978-79. Piston return was facilitated by a simple oblique spring after melting was performed by an external coil connected to an automobile battery. Cycle times were about 90 minutes[2] depending on the external temperature and the battery was drained rather rapidly. These test were not rigorously scientific but were simply designed to see if the concept worked at all.[3]

Calculation of Engine Efficiency: heat into the engine is -79.9 cal/g = 333.1 j/g. The work function is generally

$$W = f\ V(PT)\ P\ dE(P,T)$$

Considering the upper pressure limit of 2100 atm (2.1 x 10^8 pa) and the volume change of

$$\Delta V = 0.093 \text{ cc/g} = 9.3 \times 10\text{-}8 \text{ m}^3\text{/g}$$

Then

$$f\ PdV = P\ f\ dV = 19.53 \text{ joules/g}$$

For which the thermal efficiency is

$$\eta = \frac{W_{out}}{Q_{in}} = \frac{19.53}{333.1} = 5.8\%$$

This is comparable to the actual efficiency of a steam engine. Due to thermal gradients, the actual efficiency of an operating ice-water cycle engine will be somewhat lower. Additional controlled experiments are required.

In conclusion, solid/liquid phase heat engines may well become part of a menu of technology useful to applications in space economies. Undoubtedly, many other possibilities on that menu specific to extraterrestrial conditions remain to be discovered.[4] **FG**

Footnotes:

1 Opportunities Industrialization Center.

2 In a phone conversation 1/15/93, Graham suggested that this long cycle time could be brought down at least to a few minutes by using an internal heat source, perhaps a laser, in combination with a very heat conductive outer cylinder. The idea of his experiment was just to see if it worked at all, not to optimize the engineering.

3 A rather thorough patent search showed no prior work on this type of device. Graham welcomes hearing from anyone else who has thought or tinkered along similar lines. Write him c/o MMM.

4 Graham also reports on solid-liquid Bismuth engines suitable for use on Mercury. MMM will publish that article separately.

Acknowledgements: The author wished to thank Dale Amon, Hans Moravec, and Norman Wackenhut for fruitful discussions, and the Allegheny OIC for many kindnesses.

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(1) Kennedy, G.C. and LaMori, F., in Gray, D.E., ed., **American Institute of Physics Handbook**, McGraw-Hill, NY: 1963

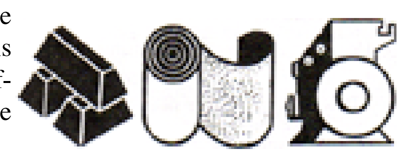
(2) Loebel, R. in Weast, R.C. **Handbook of Physics and Chemistry**, CRC, Boca Raton: 1980, p. B-253.

MMM #63 - MAR 1993

The Industrial Roots of Lunar Settlement Self-Sufficiency

A lunar settlement based *solely* on the twin foundations of Science (geology, mineralogy, astronomy etc.) and Exploration can, like bases in Antarctica, survive as long as the political and military will needed to secure public funding is high enough. That approach would make it a fragile under-taking, perennially threatened by the twin axes of back home budget priorities and fickle public support. But let civilians (people *with* families) take over and start doing something to *pay their own way*, and begin turning a *profit*, and the lunar frontier will soon take on an un-threatened life of its own.

In this issue we explore the industrial basis necessary to secure self-sufficiency and true permanence.



From "dust in" to products out:

to get the most for the least, in the shortest order, we need to preplan.

Industrialization of the Moon

by Peter Kokh

NOTE to the Reader: This will be an especially "heavy" issue of MMM. We hope the title topics will not discourage you from reading it through, however. We have tried to make the treatment as non-technical as possible while still getting across information *essential* for a *less naive* understanding of humanity's chances of building a "spacefaring civilization" based on the use of non-terrestrial, or off-planet, resources. Note too, that our topics are as relevant to Space Settlements *built of* lunar materials as they are to lunar surface settlements.

Timely Rereads from MMM #s Past

[contained in MMM C #2]
16 "Glass Glass Composites", P. Kokh
18 "MUS/cle for Lunar Industry", P. Kokh
20 "Update: Glass Glass Composites", P. Kokh

[contained in MMM C #3]
22 "Lunar Ores", Stephen L. Gillett
23 "Gas Scavenging", P. Kokh; "Tailings", P. Kokh
29 "Possible Lunar Ores", Stephen L. Gillette

[contained in MMM C #4]
38 "Regolith Primage: Key to Industrial and Agricultural Success", P. Kokh
39 "Moon Mining and Common Eco-Sense", P. Kokh
39 "Moon Mining and Engineering Reality", P. Kokh

Cons, and Pros, of a Planned Lunar Economy

In our subtitle above, we pointedly used a dirty word for some (it should be so for all): "preplan"[ed economy]. The trouble with strong-handed centralized economic guidance is that it cannot respond easily to unforeseen opportunities and needs, nor abandon nonproductive directions in timely fashion.

That being said, and emphatically recognized, it must also be admitted that industrialization of the Moon, and of near space as a whole insofar as it initially may rest on the use of lunar materials, is a whole new ball game, one in which a **different suite of raw materials** and **different conditions** affecting their production and use in manufacturing will leave "out in the cold and dark" those would-be industrialists and entrepreneurs unaware of these differences, or unprepared to anticipate how they might be addressed.

To go to the Moon with vague ideas of following up initial production of liquid oxygen with some sort of resource processing - we'll scratch our heads and think of what to do next once we get to that point - can only lead to decades of delays, *if not to abandonment* of the whole idea. While the eventual unfolding of lunar industrialization and the actual sequence and timing of diversification of products made for local use as well as export will to some extent surely be affected by unanticipated realities and developments, it will be foolish not to have approached lunar industrialization with the best Game Plan that intelligent brainstorming and exploratory research can provide. If we are not to grope around aimlessly, we need to think things through. At least some of this homework is bound to stand us in good stead, telescoping the years (and shrinking the outlays) it will take to reach a viable level of self-sufficiency. It is crucial that we all realize that until this "first ledge" is reached, our fledgling spacefaring civilization, best intents aside, can only be considered tentative.

"A Different Suite of Raw Materials"

To advance towards any level of self-sufficiency, settlers will need the capital equipment and methodology to produce materials with which to "self-manufacture" *not* "the greatest number" but "the greatest total weight" of their material needs for housing, utilities and other infrastructure, surface transportation, furnishings, food production equipment, and so on. The reason for this is that *even if* the cost of getting things from Earth's surface into space comes down dramatically, transportation costs will still make "necessity imports" onerously expensive *on a per weight basis*.

To produce on site a suitable stable of materials will be especially challenging, for many of the elements we will need will be much harder to isolate and produce on the Moon and several others that we wouldn't care to dream about being without, we must so dream, because they simply aren't there. This issue of MMM is meant to serve as a reality check. It is intended not to discourage us, but to get [at least some of] us off our ever fattening duffs.

Minus the smug complacency of naive expectations, the cobwebs that creep into brains too long idle swept aside, those space-interested souls who already work in materials processing or chemical engineering, or are poised to make a career jump into those fields, have the unique and very special chance to do the footwork that will make them the real, if ever unsung, heroes of the dawn of space civilization.

In this issue we look at the principal lines of materials we believe we can process from lunar regolith soils.

In issues to come, we will take a look at Lunar Utilities, at the "Substitution Game" - how we might make do when we can't provide locally, at pathways of Industrial Diversification, and at the contributions to both the domestic lunar economy and to export sales of Lunar agricultural products.

At the end of this series, we hope the MMM reader will have both a deeper appreciation of the challenges we face and a greater enthusiasm for seeing to it that something is done to face those challenges in anticipation. MMM

Industry is constrained by "*available*" raw materials

BENEFICIATION

Making rich "ores" out of very poor ones

ben e fi ci <u>A</u> tion: to treat ore for smelting by enriching the percentage of the desired element(s), reducing that of undesired elements found with the ore in the natural state.

ore: 1. a metal-bearing mineral or rock, or a native metal, *considered valuable enough to be mined*. **2**. a mineral source of some nonmetallic substance.

TAIL ings: the residue of a mining process.
slag: the residue of a smelting process.

By Peter Kokh

Before we can conjure up tasty recipes in our "Lunar Industrial Kitchens" for metals, glass, concrete and other Made-on-Luna building products and fabrication materials, we need to stock our "Lunar Industrial *Pantry*" with an ample diversity of ingredients including "herbs and spices". This primal chore is a lot easier said than done.

On Earth, our job has been considerably easier - we have been spoiled by the assistance of eons of geological pre-processing of a once much more homogenized mineral endowment. These processes, often with the help of water, have worked to precipitate out and otherwise concentrate into lodes and ore veins many of the elements we want to use in the refined state. These cachés are relatively easy to mine and without them, the onset of civilization as we know it could have been delayed by thousands of years, if not indefinitely.

The Moon's mineral wealth is both everywhere and nowhere. Except where we might find atypical concentrations of metals intruded into the general stony soup thanks to the impact of some large, rich asteroid chunk (like the nickel-rich Sudbury astrobleme in Ontario north of Lake Huron) any one spot is as good, or poor, a place to "mine" as any other.

Four Distinct Soil Types

That's a generalization, of course. Major differences in the percentages of the most abundant Lunar elements (oxygen, silicon, iron, aluminum, calcium, magnesium, and titanium) distinguish HIGHLAND soils from those in the MARIA, and a "coastal" site that gives easy access to both will take advantage of this. Some mare soils are relatively titanium-rich, others not. And here and there we find literally "splashes" of KREEP deposits in which potassium [and sodium], rare earth elements, and phosphorus are to be found in much greater percentages than in the host soils. Finally, VOLCANIC soils may be richer in some desirable elements.

So there are logical places to start, at least. But then the head-scratching begins. For even the modest enrichments that a thorough geochemical mapping of the Moon may turn up are unlikely to yield ores as pre-enriched as those that have spoiled several hundred generations of mining engineers, chemical engineers, and metallurgists on our home planet.

That's the rub. The "industry" considers the Moon's "poor" ores unmineable. If the job is to be done, potential Young Turks in the field, not yet addicted to 'the good stuff', must be identified and turned on to the immense challenge.

Thanks largely to Space Studies Institute and the general enthusiasm for using lunar materials whipped up by the Space Settlement visions of Gerard O'Neill († 1992), some toe-wetting work has already been done. For example, we now have an idea how to process ilmenite, $FeTiO_3$, (an iron-titanium ore) in a suite of processes yielding oxygen, iron, and titanium or titanium dioxide. Happily, we are able to determine by spectral clues from orbit, those areas of the lunar surface in which ilmenite is especially abundant.

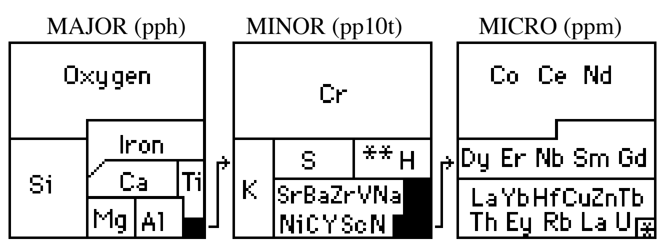
Processing Suites & Beneficiation Cascades

We can hardly build a viable lunar industrial complex solely on the three elements found in ilmenite. We need to find ways to produce other metallic and nonmetallic elements as well. Yet ilmenite does give us a model, for the proposed processing operation yields not just one element, oxygen, but by a suite or cascade of processes, refines also each of the other elements present.

While the actual goal will always be unattainable, we need to adopt a **"zero tailings, zero slag philosophy"**. If we start with highland soil, for example, processing it to sift out say the minerals with highest aluminum content, the tailings will as a corollary be enriched relative to the general soils in the area in calcium and magnesium. Beneficiation for one element, co-beneficiates the tailings and/or slag (after actual smelting) for other elements. So it behooves us to see if we can help our cause by piggybacking the production of one refined element on that of another.

Given this general philosophy, some mineral suites will prove to be better starting points than others. We might be able to identify easily separable minerals which don't dead-end so quickly as ilmenite, but produce in a cascade of processes a whole slew of useful metals and nonmetals. The start of such a beneficiation suite may be an economic source of just one, two, or three elements present in double digit percentages. By the end of the suite, we will have produced successions of tailings and/or slag that are economical sources of elements given in the starter soil in single digit percentages down to those present in mere parts per million. As we will see from the articles that follow, if we want to be able to produce useful variety of metal alloys and a serviceable stable of glasses, ceramics, and composites, we will need to pursue just this sort of mining philosophy.

Abundances of Various Elements in Lunar SOILS



* NANO (ppb): Ir Re Au Sb Ge Se Te Ag In Cd Bi Tl Br

** Lunar regolith contains significant gas reserves from the Solar Wind: H, C, N and He_4, Ne, Ar, Kr, Ze, He_3

Anhydrous (waterless) **Processing**

Beginning the final leg of its circuitous route to Jupiter, the *Galileo* probe made its second swingby of its home port planet December 7th, 1992. As planned, it passed over the Moon's north polar region, turning its eyes and other sensors to that area from its unique vantage point. Significantly, in addition to some great photographs, *Galileo* noticed no *Lyman alpha emissions*. The inference is that there was no hydrogen below, thus no water-ice lying in permashade cachés in polar craters and crevices, dashing the optimistic hopes of many advocates of lunar resource development.

Those of us who did not count our chickens before they hatched are not discouraged, never having based our scenarios for settlement on such fantasized assets. Now, we hope, the rest of the pro-development community will begin to take seriously the importance of anhydrous processing. We cannot rely on water to help refine ores and carry off tailings. Any water, or hydrogen, found to be absolutely necessary for the chemical processing involved in isolating the various elements, must be vigorously recovered in a closed cycle loop, to be used again, and again, and again - any losses made up dearly by expensive upports of water-making hydrogen from Earth, or carefully harvested (in the process of general mining, road construction, and other regolith-moving activities) gram by gram from the micro-concentrations of protons in the soil introduced there by over eons of solar wind buffeting.

Thus in most instances, we must start with a clean slate and develop new previously untried chemical engineering routes to produce lunar metals and alloying ingredients and other elements needed to build a diversified lunar economy, starting with the minimal pre-differentiation the four major soil groups allow. This is a tall order, one that will discourage *most* chemical engineers spoiled not only by the availability of richer ores to start with but also by the abundance of water on Earth. Those not daunted by the challenge will be the real architects of the economic breakout from our cradle world.

Graduating from Lunar Visitors to Lunar Settlers

We have collectively only begun the enormous backlog of homework that must be completed with and A+ grade in order for us to graduate from Lunar visitors to Lunar settlers in any meaningful sense of the term. Nothing can exempt us from this homework, not all the cheap, even free access in the world. Yes the rocket engineers who pioneer and perfect such vehicles as the single stage to orbit Delta Clipper and the National AeroSpace Plane are and will be heroes. Yet their work can only unlock "the storm door" to the Moon.

The real door will remain locked and jimmy-resistant. The true heroes of the space frontier are yet to emerge, and if they do (no thanks to the encouragements of a pro-space community interested only in quick fixes, lights, and mirrors) they may remain forever unsung. These real heroes will be the mining and chemical process engineers who find practical ways to get the "undoable" job done.

An Appeal - Room for *Your* Foot in the Door

If you are young and looking for a technical career in space pioneering, or older and considering a career change, we urge you to look beyond the glitter and glamor of "rocket science" and take up metallurgy, industrial glass and ceramics, or, most importantly, chemical engineering with a mindset creatively open to challenges to conventional methods that would discourage most of your peers. MMM

SINTERED IRON from powder

the earliest and simplest settler made metal

A good place to start, but not a laurel to rust on

By Peter Kokh

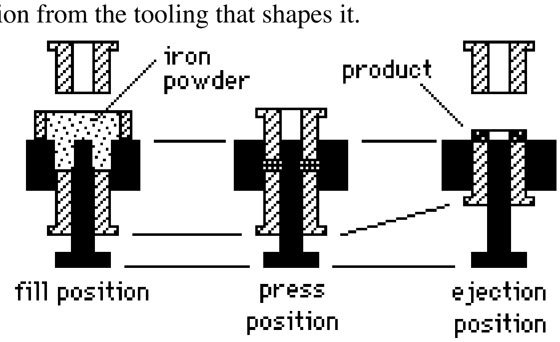
The Lunar crust is about 44% oxygen by weight, yet surprisingly, it is still appreciably *under*oxidized. Every available atom of oxygen is chemically bound up in the minerals of the crust and regolith soils derived from it without exhausting the opportunities for oxidation. The evidence is unmistakable. There is an abundance of pure iron fines or powder in the soil, something unheard of on Earth where such deposits would quickly turn to rust. Further, the iron oxides or rusts we do find are ferrous (one atom of iron to one of oxygen) instead of ferric (two atoms of iron to three of oxygen).

So? So these iron fines can be harvested from the loose regolith for the price of a magnet. Seattle Lunar Group Studies (SLuGS) has estimated that in the regolith volume excavated for a lunar habitat, there will be enough free loose iron fines out of which to build that habitat.

While steelmaking will require a settlement of some size already possessing a considerable and modestly sophisticated industrial infrastructure, the simpler and humbler route of ferrous powdered metal technology, long practiced on Earth, can be used instead to meet a number of settlement needs. So goes the hype. But let's get beyond this initial enthusiasm and look at this possibility realistically.

The basic process

First of all, as commercially practiced today, powdered iron is not without other, also powdered, additions. Typical of these are 2% copper and 1% graphite, not easily available on the Moon. These ingredients affect sinter size and other properties of the finished product. For ease of manufacturing, an internal lubricant such as zinc stearate, a fatty salt, is added in amounts around 1%. The batch, from hundreds to tens of thousands of pounds or kilos is then carefully blended before it is flowed into the dies of the desired end products. Bear in mind that the green body is restricted to a geometry that allows ejection from the tooling that shapes it.



Basic steps in powdered metal compaction in rigid die.

The next step is the application of pressure in the range of 35 tons per square inch (c. 5 metric tons per square centimeter). Next the compact "green" part is sintered by subjecting it to temperatures of 1120° C (2050° F) or so in the presence of an endothermic gas or bulk nitrogen. This provides the final strength to the material.

Effect of particle shape

Even under controlled processing conditions on Earth, spheroidal particles are the exception. On the Moon they will be even more so. As particle shapes increase in irregularity, the batch mixes and flows with more difficulty and abrasiveness. On the other hand this increases the "green strength". It can also promote contamination by any present atmospheric gasses or water vapor, resulting in reduced compaction and strength. Obviously, the designer of a Moon-appropriate operation will experiment with vacuum and/or neutral gas atmospheres. Grinding to reduce average particle size may or may not be needed to increase strength in the compacted material.

Sintering bonds the particles together and decreases porosity with pores becoming smoother and more spherical. Grain growth can occur. Strength increases with higher temperatures and longer sintering times

Markets for Powdered Metal Products

On Earth, 70% of the total volume of ferrous powder metal parts is in the automotive and off-road and construction equipment areas which use P/M reduction and differential gears, sprockets, clutch plates, gear pumps, hubs, pinions, pulleys, bearing races, and other stamped parts. In the aerospace industry P/M products include compressor rotors, turbine wheels, and turbine engine shafts where near net shapes reduce the amount of subsequent machining. In all markets, to meet high standards, the batches are mixed to produce alloy steels.

P/M alloys

The simplest P/M alloy is P/M iron F-0000 with 0.3 max. carbon. P/M steels F-0005-0008 have a C content up to 1%. P/M copper-iron and copper-steel FC-0200-1000 have 1.5-10.5% copper as well as carbon. And P/M iron-nickel and nickel steels FN-0200-0708 have 1-8% nickel along with 2-2.5% copper. We will only be able to make the simpler P/M iron or P/M steel on the Moon. While carbon can be had by careful harvesting during regolith-moving operations, nickel will be harder to produce, and copper will be more precious than gold and platinum on Earth. We may be able to make iron-phosphorous P/M alloy magnets for various uses, although this requires full density or zero remaining porosity, a more difficult standard for an early settlement technology.

Sintered Iron on the space frontier

Raw no-alloy sintered iron products will perhaps be useful only for low-performance needs. In general, the P/M process is not at all as versatile as casting. The very nature of the compaction process involved seems to severely limit the product types that can be produced - even if the strength of the material would be suitable for a much broader range of objects. For P/M technology to be of greater help, some innovative groundbreaking production research will have to come first, aiming at producing compaction in new sizes and shapes. Roads not yet taken must now be explored. MMM

Al Fe Mg Ti ALLOYS

Doing Lunar-Appropriate Metallurgy NOW!

By Peter Kokh

AL loy: a substance composed of two or more metals with superior performance and service properties than either alone for machining, workability, durability, impact or corrosion resistance, hardness, or other manufacturing or service needs.

Weaknesses of pure unalloyed metals

Purity is not always better! In metals, the individual atoms tend to link up in crystal lattices. When the metal is pure, the crystal grains are relatively large, and with all the atoms in a grain lining up in planes, the material easily sheers - it is relatively brittle and soft, both at the same time.

When metallic atoms of different sizes (the heavier ones are smaller since the greater atomic forces in their nuclei compact them more) are combined, the crystal lattices that result are uneven, crystal grain sizes are much smaller, and the end product alloy material is harder to fracture.

The superior performance of alloys in which the strengths of two metals reinforce one another and their individual weaknesses are suppressed, is an early discovery, one that had much to do with the rise of civilization. Bronze, an alloy of copper and tin, was the first alloy discovered, and the art of making it spread like wildfire through the ancient world, marking the end of the Stone Age. The next to be invented was Brass, an alloy of copper and zinc. (Pewter is tin and lead.)

All the production metals we now use to manufacture the products and components we need, are made of alloys. And for each major metal many different alloy formulations have been experimented with, and a number have tested well enough to be produced regularly.

The Moon's crust, and the meteorite-pulverized regolith blanket derived from it, is made of many minerals mostly composed of these seven elements: oxygen, silicon, iron, aluminum, calcium, magnesium, and titanium. It may surprise some that this list and the relative abundances is no different from what we find on Earth. Again surprisingly, except for volatile elements easily boiled off at high temperatures, most other elements exist on the Moon in percentages not unlike those in Earth's crust. So "no problem", right?

The hitch is that on Earth, civilization has had a lot of help from the eons of hydro-lubricated tectonic geophysical processes that have worked to leech out and concentrate many otherwise "trace" elements into pre-enriched "ores" that it is relatively economical to mine. In comparison, the Moon has been geophysically dead practically since birth, and many of the elements we are accustomed to using in our alloy formulations will be much harder for us to produce on the Moon.

Which secondary ingredients are most often used in making alloys**?** And of these, which will be easier, harder, or practically impossible to isolate economically on the Moon**?** The answers will determine which alloys it *may* be practical to produce on the Moon, and *that* will affect **the direction and extent to which Lunar Industry can diversify** to support its own needs and those of its export markets.

1. Fe - Iron and Steel

Iron, as it was been produced until relatively recent times, is something of an inadvertent alloy, the coal or coke used in heating the ore introduces a large amount of carbon, 2-4.5% or so, into the produced metal. Yet cast and wrought "pig" iron has and continues to serve us well for some uses.

Steel is the vastly superior alloy that results from intentional, controlled alloying processes. It also contains carbon, but in more measured amounts, appropriate to producing such desired effects as hardness and temper. There are many families of steel alloy, and many currently produced variations within each. For our purposes it is enough to mention and consider the alloying ingredients most used.

Carbon is absolutely necessary to steel production. Yet it is not a constituent of the lunar crust. Fortunately there is an appreciable amount of it adsorbed to the fine particles of the upper layers of the lunar regolith soil, a gift of the Solar Wind. If settlers customarily and religiously practice "gas scavenging" as part of all 'lith-moving operations in construction, road building, and mining, they should have a steady supply. However, this precious endowment will more dearly be needed for incorporation into living plant and animal tissues to provide the settlement with a biosphere, food, fiber, and other essentials. This deficit can be eased in three principal ways: a) imports from Mars' moons, Earth-approaching asteroids, or comets, instead of from Earth, at a 2/3rds or so fuel savings; b) theoretically possible (don't hold your breath) discovery of CO carbon monoxide gas pockets trapped in the less fractured depths of the lunar crust; c) a relatively abundant byproduct of large-scale Helium-3 mining operations producing fusion fuel.

Silicon and titanium are very abundant on the Moon. **Chromium, manganese, molybdenum, nickel, phosphorus, sulfur, and vanadium,** exist in enough abundance to be produced by a second generation lunar processing industry. Designing beneficiation suites to yield them *must* be a **priority goal**. All of them are needed for other purposes as well, such as in glass production and in oxide colorants.

Two types of alloy-ingredient-rich soils that *should* exist on the Moon but are almost never mentioned because they were not found at any of the sampled Apollo or Lunakhod sites (to no one's surprise) are: (1) soils derived from upthrusts of heavier mantle material (the stuff of mascons) on and around the central peaks of some of the larger craters. (2) soils derived from the debris of nickel-iron asteroid impacts such as we have on Earth around Sudbury, Ontario in Canada north of Lake Huron. Prospecting for such areas should be a high priority.

Tungsten steels will be out, as there are only nano-traces of W tungsten in the regolith. This is more of a problem for would-be makers of incandescent light bulbs.

Al - Aluminum

Aluminum is the most abundant metal in the lunar crust just as in Earth's crust and it is second in production after steel. Aluminum is produced in a virtually pure (99.6%) state for use as an electric (wire) and thermal conductor (cookware). But for most other purposes it is alloyed with various ingredients. Of 60 alloys in common production by Alcoa, all have silicon (57 below 1.2%, 3 in the 4.5-13.5% range). All sixty also have iron in the 0.3-1.3% range. And distressingly, all sixty incorporate some **copper**, although in only 10 aircraft-quality alloys such as duralumin™ does this range over 1.9%, up to 6.8%. Copper is not something we have found in appreciable traces on the Moon. Baring an unexpected strike of an asteroid-impact-donated lode, we will not be producing such alloys on the Moon, unless the needed copper is imported. Few lunar deficiencies will be felt as much and place as great a distinguishing and restraining mark on Lunar industrialization.

Some 52 aluminum alloys have up to 5.2% magnesium and 51 up to 1.5% manganese, both lunar sourceable. But 51 of the 60 also include **zinc**, though in only 7 - again aerospace grades - does this exceed 0.4% ranging from 2.4-8%. This is another problem, for zinc, like copper, may need to be imported if aluminum metallurgists can't learn to work their trade without it. Some 38 of these 60 aluminum alloys have up to 0.4% chromium, 30 up to 0.2% titanium, and 4 up to 2.3% nickel. These ingredients we should be able to produce.

The Big Question: can metallurgists produce good aluminum alloys without copper and zinc inclusions? If all the shuttle external tanks had been brought to orbit and cachéd, we would have a 50% cheaper lunar import source of copper now rapidly approaching 100 tons! Someday NASA's path-of-least-resistance ET-throwaway habit may be judged to have been an historic crime right up there with the burning of the library at ancient Alexandria. Meanwhile there is urgent homework that needs to be done in aluminum metallurgy. Any volunteers?

Ma - Magnesium

Magnesium is the third most abundant "engineering metal" in both the terrestrial and lunar crusts. Cast and wrought magnesium alloys use three principal secondary ingre-dients: aluminum, manganese, and zinc. Zinc is the catch and only 6 of eleven standard Ma alloys do not include from 0.5-3% of it. If Ma metallurgists cannot do without it, the use of magnesium as a structural material on the Moon may be limited, and that will hurt. Again, lots of homework to be done; and to our knowledge no one is doing it.

Ti - Titanium

Titanium is the 4th most abundant engineering metal in the lunar crust just as on Earth. There are four alloy types in common use: ferrocarbon titanium (Fe, C, Si), carbon-free ferrotitanium (Fe, Al, Si, P, S), manganotitanium (Mn), and cuprotitanium (Cu). We should be able to eventually produce all but the last on the Moon, starting with ferrotitanium from the relatively abundant ilmenite. Cuprotitanium is used as a deoxidizer in making brass and bronze which we won't be making on the Moon anyway. We are in good shape here.

BOTTOM LINE: To provide a truly useful choice of alloys, future lunar processors must go beyond the "easy" tasks of isolating oxygen, silicon, iron, aluminum, titanium, and magnesium. We must also be able to produce carbon, chromium, manganese, molybdenum, nickel, phosphorus, sulfur, vanadium, etc. Without these essential elemental herbs and spices, the bland low-performance metals with which we will be left to make do, will give us a lunar civilization just a notch or two above that of the Flintstones. If we don't do our homework, we will by default justify the argument of those "Moon critics" who claim that all we will ever make on our companion world are "brittle bricks". **PK**

GLAX

glass-glass composites

By Peter Kokh

As important a long term goal for lunar development as is the production of truly serviceable metal alloys, it will take a sizable settlement and diversified processing industry to bring it to realization. *We have to start more humbly*.

Glass glass composites, fiberglass in a glass matrix on the analogy of fiberglass reinforced plastics, offers us the hope of producing serviceable building components with a much lower investment in capital equipment and in required man-power. Still a laboratory curiosity, GGC tests out as strong as or stronger than steel in several parameters.

Space Studies Institute with the help of Goldsworthy Alcoa Engineering and McDonnell Douglas Huntington Beach has been exploring this brave new world. It seems quite feasible at this juncture to build a highly automated plant to turn lunar regolith into glass fibers using a solar furnace.

The problem is that these glass fibers must be used with a glass matrix formulation having a substantially lower melting point, if they are not to be weakened beyond use. About as big a temperature spread as we can arrange with raw unprocessed regolith is the approximately 200° C between the melting points of highland (higher) and maria soils (lower). So the brainstormers has been leaning toward importing a doping agent from Earth to lower the melting temperature of the matrix batch. Lead, exotic to the Moon, is mentioned.

This is folly. What needs to be done is to take a third soil type, splashout KREEP deposits (potassium, rare earth elements, phosphorus), and beneficiate them to enrich the sodium and potassium content and use that as a lunar-sourced dopant. A mix of 65% Sodium Disilicate $Na_2O{\cdot}2SiO_2$ with a melting point of 878° C and 35% Phosphorus Pent-oxide P_2O_5 with a melting point of 580° C will match the 774° C melting point of Lead Diborate $PbO{\cdot}2B_2O_8$. *Thus we* ***need to plan how to isolate the KREEP component and to beneficiate it for Na and P.***

Once we've learned how to make GGC or Glax on the Moon without a self-defeating heavy import burden, and then *validated our expectation* that we can fashion GGC products by much the same methods as we fabricate items from fiber-glass reinforced plastics, we will be poised to "self-manufac-ture" a good portion of settlement needs. Habitat hulls, interior walls and doors, window frames and window safety glass (*provided* we learn how to formulate GGC that is optically clear!), furniture items, vehicle body and frame parts, tanks for storing volatiles, utility pipes, conduits, and drains, etc. No other candidate processed lunar material promises to be so versatile and so appropriate for a small early settlement.

Glax technology can be predeveloped and predebugged right here on Earth e.g. for the upscale furniture market. ["Glass Glass Composites" MMM # 16 JUN '88 >>MMM C2]

TM TM TM TM TM TM TM
Possible TradeMarks:
Glass-glass Composites

GLASS

by Peter Kokh

glass: a hard, brittle noncrystalline more or less transparent solid produced by fusion of mutually dissolved silica and silicates usually containing soda Na_2O and lime CaO.

It is an inexact commonplace that glass is no more than fused sand, silica, silicon dioxide SiO_2. In fact while silica is almost always the major component, most commer-cial glasses contain, besides soda and lime, other dissolved oxides that give the product desirable properties. Alumina Al_2O_3 improves weathering and minimizes devitrification or crystalli-zation. Borate B_2O_3 make the glass easier to work and lowers its rate of thermal expansion. Arsenic and antimony oxides help remove bubbles. Lead (PbO) contributes a high refractive index, easier working, and greater density.

Of the secondary and lesser ingredients commonly or sometimes used in modern glass making, Boron, Lead, Tin, Arsenic, Antimony, Selenium, Tellurium, Bismuth, Indium, Lithium, and Tungsten may not be economically producible on the Moon. Of these, we will most miss Boron and Lead.

Soda Borosilicate glass (Corning 7050) used for sealing is 76% silica, soda, and alumina - all producible in abundance. But it is 24% B_20_3 which gives it an exotic Boron content of 7.44% or 1 part in 13.5.

Alkali lead glass (Corning 0010) used in lamp tubing is 92% silica, lime, soda, and potash but has a PbO content of 8% giving it an exotic lead content of 7.4% or 1 part in 13.5.

Pyrex (Corning 7740) is 85% silica and soda, but 13% B_20_3 for an exotic Boron content of 4% or 1 part in 25.

Alkaline earth aluminosilicate high temperature glass (Corning 1720) is 95.5% silica, alumina, lime, soda, potash, and magnesia, but also 4.5% B_20_3 for an exotic Boron content of 1.4% or 1 part in 72.

The most important formulation of all in terms of volume of production on Earth is everyday soda lime glass (Corning 0080) used for windows and lamps. It is 99.2% silica, soda, potash, lime, magnesia, and alumina - all readily produ-cible on the Moon. It does, however, include 0.8% B_20_3 which gives it an exotic Boron content of 0.25% or 1 part in 403. It is fortunate that the kind of glass we will need to make the most of, is also the one requiring the least foreign content.

We *do* have ready *all*-lunar choices.

Three such are:

A) SiO_2 69%, Na_20 15.2%, CaO 7.4%, Al_2O_3 4.4%, K_20 3.6%, Fe_2O_3 0.4%, MgO 0.4%.
B) SiO_2 66.7%, Na_2O 16.3%, Al_2O_3 13.2%, TiO_2 3.8%
C) SiO_2 69%, Na_2O 27%, Al_2O_3 4%.

The challenge for lunar glass makers is to make **a serviceable stable** of all-lunar glass formulations.

BOTTOM LINE: As far as the needs of glassmakers go, **sodium and potassium** are the most important secon-dary ingredients that regolith processing must produce (in addition to the abundant oxygen, silicon, calcium, aluminum, iron, magnesium, and titanium).

CERAMICS

By Peter Kokh

ce RAM ics: [Greek κεραμοσ - *burn stuff*]
Traditional: the **skill** of making things from **baked clay**.
Modern: the **science** of making things of **inorganic** and **nonmetallic** compounds.

On Earth we have long used ceramics for abrasives, for refractory liners and crucibles, for construction bricks, for floor and wall tiles, for architectural ornament, for tableware and storage urns, for flower pots, vases, and planters, for sinks and toilets, for knobs, handles, and giftware, for electrical insulators, and for many other uses. Lately Iranian-born Nadir Khalili [see MMM # 20 NOV '88 "Ceramic City"] has been experimenting with firing whole ceramic house modules, retaining walls, and other macro items. Quality manufactured ceramic raw materials such as alumina Al_2O_3 (carborundum), silica SiO_2, and zirconia ZrO_2 have opened the industrial use of ceramics: wear guides, valves, cutting tools, ball bearings, seals, gaskets, insulators, capacitors, memory cores, etc. Add to that new high-tech developments like non-oxide ceramics (carbides, nitrides, borides, and silicides), glass ceramics (e.g. correlle™), and ceramic metals or cermets for automotive and aerospace uses like turbine rotor blades and rocket nozzles.

It would be helpful to space pioneers if we could learn to make a similar range of products using lunar materials as a starting point. If so, we might even expand the traditional product lines, for example using ceramics to substitute as room trim "tilework" in place of "woodwork".

It might seem that the ancient potter's trade could not translate well to the Moon, a world without natural clays. Yet clays are but the water-weathered transformation products of virgin aluminosilicate feldspars in which the Moon is rich. We actually only need to add water to the proper powders in a coarse to fine ratio of 70:30.

One might think that any water-dependent technology would be an inappropriate choice for a water-parched world. But this too is no problem. The water of suspension from slip casting and the interparticle water from 'plastic' forming are quickly lost in the shrinkage of the shaped 'green body'. Pore water between the particles and physically bound water is removed as soon as the firing temperature passes 100° C. Above 600° C any lattice water trapped within the crystal structure is baked out. And finally, chemically bound hydrate water is purged above 1000° C. The end product is totally dry. The initial 'capital' endowment of H_2O is totally recoverable.

Available "Lunar" Formulations

For most low performance uses, the ceramic "raw" materials hardly need be refined. Alkaline (sodium, potassium) or alkaline earth (calcium or magnesium) aluminum silicates with widely varying formulae and structures will do nicely for bricks and tiles and planter trays and early tableware etc. As we become better able to control and select the ingredients we can make products that perform better, and look better. The production of alumina Al_2O_3, Silica SiO_2, Magnesia MgO, Titania TiO_2, and Zirconia ZrO_2 will be major goals in support of a more sophisticated ceramics industry. Once regolith gas scavenging is practiced, even carbides and nitrides should be within reach.

There are, however, some secondary ceramic ingredients that won't be economic options on the Moon. Arsenic, antimony, boron, lead, lithium, and zinc oxides find some application in ceramics and are not likely to be produced on the Moon. There unavailability will be felt, but not fatal.

Ceramic glasses deserve attention too. These are glass formulations allowed to partially crystallize (devitrify). This process proceeds around uniformly distributed crystallization nuclei, ordinarily small amounts of copper, silver, or gold - all apparently unobtainable on the Moon. However some metallic phosphates as well as Titania TiO_2 will serve as lunar-producible nucleation catalysts. Correlle™ tableware is a ceramic glass. Greatly improved impact resistance is its trademark. It should be possible to manufacture something crudely similar in a maturing lunar settlement.

Practicing Lunar Arts and Crafts

Decorative ceramics will play a major role in lunar arts and crafts from the very beginning. Even at the outset, regolith batches gathered from diverse locations will produce products with distinctive features. Glazed ceramic items will provide welcome splashes of color - traditionally formulated 'paints' will be unavailable. Tile can replace woodwork and paneling and vinyl flooring. Given the unavailability of traditional jewelry metals, ceramic baubles will play a larger role in personal adornment. Given the likely taboo on withdrawing wood from the biosphere cycle, ceramics are likely to be part of a wood-substitution strategy for furniture. Ceramic toys will be considerably less expensive than plastic ones.

Industrial ceramicists have turned to dry powdered raw materials some time ago, while hobbyist and artisan potters and ceramicists continue to rely on clays. Those who wish to lay the foundations of lunar ceramics art and crafts cottage industries can start by turning to regolith-like powders.

[MMM #22 FEB '89 "First Souvenirs" >> MMM C3] MMM

Color the Moon
"anything but gray"

By Peter Kokh

"Blue moons" aside, the Moon is a very gray place. So much so that when Apollo astronauts stumbled on a small patch of regolith with a faint orange tint to it, there was a great deal of excitement on two worlds. If future lunar outpost crews and the settlers that eventually succeed them are to have any chance of keeping up their morale, they will need to see to it that their cozy pressurized safe havens against the magnificent gray desolation "outlocks" are literally alive with color.

For the initial outposts staffed by small scientific garrisons, the task will be easy. Their Made-on-Earth habitats will come vividly pre-decorated. But as settlement begins, based on the availability of shelter Made-on-Luna of lunar raw materials, colorization will have to be arranged locally using coloring agents derived from on site materials. This will take a great deal of forethought and prior experimentation.

The principal avenues for introducing color on the Moon as in Space Settlements built mostly of lunar materials are these: **1)** luxuriant green vegetation and colored foliage and flowers; **2)** naturally colored cotton and natural organic fabric dyes that do not stress water recycling systems; **3)** vitreous stains for coloring glass and glazing ceramics; **4)** inorganic "paints" that do not tie up precious carbon or nitrogen; finally **5)** colored "neon" lighting using noble gases scavenged from regolith-moving activities.

In this article we will deal with **3)** and **4)** above: inorganic chemical agents for decorating interior surfaces and to support a vigorous arts and crafts enterprise. The critical importance for keeping up settler spirits so that the populace can sustain overall high productivity, will demand that the processing of such agents be totally integrated, on a high priority basis, into the overall lunar industrialization strategy.

The bottom line is that those planning beneficiation suites and cascades needed to "stock up" the lunar industrial "pantry" with available "processed" elements, will have to pay as much attention to the production of coloring agents as to that of elements needed for metal alloys and glass and ceramic additives. Happily our chemical engineers will find that many elements desirable for alloying can also support colorization.

Stained glass and vitreous ceramic glazes

Staining glass and applying colored glassy glazes to ceramic ware both have venerable, millennia-long histories. New coloring agents have been explored and experimented with to expand the choice of hues, tints, shades, brightness, opacity, transparency, and ease of workability.

Lunar pioneers will find many of the choices we now take for granted closed to them - those that involve chemical elements that we won't be able to produce economically on the Moon for a long time to come or must instead be expensively upported out of Earth's gravity well. Those lunar-supportable choices that remain will yield **a distinctive lunar palette**. The order in which these agents become available will clearly mark "**periods**" in lunar decor.

[*Elements not easily produced on the Moon shown in italics*]

REDS

Familiar agents that can't be produced on the Moon: *lead* chromate, *cadmium* sulfide, *cadmium* sulfo-*selenide*, and manganese *copper*. Lunar chemical engineers will be able to produce the chrome, the sulfur, and the manganese, but will not too soon nor too easily come up with the lead, cadmium, selenium or copper.

Fortunately, aluminum oxide mixed 4:1 with ferric oxide Fe_2O_3 produces an attractive red. While lunar iron is mostly ferrous, yielding FeO, the ferric oxide can be prepared by controlled rusting of native iron fines from the regolith. A spinel, FeO. Fe2O3, produces a darker red. A tomato red can be prepared from Uranium oxide which can likely be found with known Thorium deposits.

PINKS

Lead chromate and chrome *tin* pinks are out - little or no lead or tin. Chromium-zirconium is a possible substitute. A manganese-alumina pink and a chromium-alumina pinkish red are other choices. Eventually, cobalt-magnesium combinations might produce a pink to lilac range .

ORANGES

Unsupportable lunar options are Uranium-*cadmium* and chromium-iron-*zinc*. Glazers may have to blend available reds and yellows.

YELLOWS

The list of closed options is long: *lead* chromate, *lead* nitrate, *zinc* oxide, *antimony* oxide, red *lead*, potassium *antimoniate,* vanadium-*tin*. Instead colorizers will have to play with vanadium-zirconium and titanium-iron oxide preparations.

BROWNS

Unavailable will be the orange brown of *copper*-based $CuO.Al_2O_3$ and the reddish brown of *zinc*-based $ZnO.Fe_2O_3$. But in stock should be the reddish brown of iron chromate $FeO.Cr_2O_3$, the Indian red-brown of magnesium-iron oxide $MgO.Fe_2O_3$, and the red-brown manganese titanate $MnTiO_4$.

GREENS

Out are chromium-*beryllium*, *lead* chromate, *copper*, and *coppe*r-vanadium preparations now in use. A blend of yellowing vanadium and bluing zircon in the presence of sodium fluoride (if fluorine can be produced, a difficult but high industrial priority) is an option. Praseodymium (from KREEP deposits) phosphate with a calcium fluoride additive is another. The deep emerald green of chromium oxide may be the standby. This could be blended with available yellows and blues to produce neighboring tints.

BLUES

My favorite color. If we can't do blue, I ain't goin'! Many blue ceramic stains use *zinc* oxide, *barium* carbonate, *tin* oxide, and *coppe*r phosphates. Fortunately cobalt aluminate yields a matte blue, and cobalt silicates and oxides produce mazarine blue, royal blue, flow blue, and willow blue. A titania-alumina blue, $TiO_2.Al_2O_3$, with a corundum structure is a possibility but it is difficult to prepare by synthesis as opposed to starting with Ti-rich bauxite. Other choices include a vanadium-zirconia blue and a silica-zirconia-vanadia-sodium fluoride system of blues, turquoises and greens. *I can go!*

WHITES

Commonly used *tin* and *antimony* oxides will likely be unavailable. Instead, titanium dioxide, zirconium dioxide, and zirconium silicate seem the way to go.

BLACKS

Blacks have always been the most difficult stains to produce as there are few truly black inorganic agents. Instead we are left to blend semi-blacks with noticeable green, blue, or brown casts to them in hopes of neutralizing those tints and being left with apparent true black. Given the narrowed list of preparations available on the Moon for blending, coming up with a satisfying black will be especially difficult.

COMPLICATIONS

Making everything harder is the fact that the choice of flux affects the color outcome. *Lead* fluxes will be unavailable. While there has been considerable success in preparing lead-free glazes and fluxes on Earth, many of the substitute preparations rely on other elements hard to come by on the Moon such as zinc. Glazes based on feldspar (aluminosilicates of potassium, sodium, and calcium), alkalis (Na_2O, K_2O), alkaline earths (calcium and magnesium) with borax (hydrated sodium borate) will work. The trick is to find the boron. It seems absent in the crust but should be in the mantle. Central peaks of large craters may include upthrusts of mantle material and will be worth prospecting for this and other elements. Boron is a frequent major addition to many glass formulas as well.

Lead and boron make the best fluxes and if neither is available we may need to experiment with sodium, potassium, or NaK compounds. Waterglass, a hydrated sodium silicate and the only known inorganic adhesive is a possibility and it is on the must-produce list anyway.

None of the needed experimentation need wait upon our return to the Moon. Would-be contributors to a pretested distinctively lunar palette of glass-staining and ceramic color-glazing preparations need only religiously exclude at every step any of the coloring compounds based on lunar-scarce elements and concentrate on those likely to be produced in plausible beneficiation and chemical processing suites.

This is, however, a task that can occupy many people over long periods. They might establish a network and share the results of their trials and errors. Art styles that preview lunar settlement art will result, helping to promote the opening of the frontier by making its visualization more concrete and vivid. Future lunar settlers will be much in their debt for contributing greatly to their way of life.

Stained glass

As to working with stained glass, once we are able to produce it in a variety of colors, we face another problem. The individual pane-cells that go into a stained glass mosaic piece are usually held together by lead caning. We'll either need a pliable and malleable lunar-sourceable substitute (a stabilized sodium-potassium alloy?) or we will have to bypass the problem. One approach may be to cement the individual pieces on a host glass pane using a waterglass type adhesive. If we want stained art glass dividers and Tiffany type lamp shades we will have to literally get the lead out, one way or the other.

Oxide pigments for waterglass suspension "paints"

Painting, in one form or another, has been practiced from prehistoric times. Lunar paints will return the art to exclusive reliance on inorganic oxide pigments, greatly reducing the available choices and again producing a distinctively lunar palette for home decor, art and craft use, and painting in general. Forget today's vivid coal-tar derived organic pigments. Forget the alkyd, oil, acrylic, and latex suspensions. Forget the organic solvents. All of these rely almost exclusively on organic materials, and in a lunar or space settlement environment would mean permanent withdrawals of carbon and nitrogen from the biosphere cycle, demanding replacements at high cost. Until the day carbon and nitrogen can be produced locally as cheaply as inorganic substitutes, formulators of lunar paints will have to rely on something quite different.

Perhaps the best candidate for a suspension medium is the only known inorganic adhesive, waterglass, a hydrated sodium silicate ranging in formula from $Na_2O.3.75SiO_2$ to 2 $Na_2O.SiO_2$ and as white powders or viscous-to-fluid liquids. MMM suggests preparing paints which are suspensions of lunar-sourceable inorganic oxides in waterglass. Unprocessed fine-sifted regolith dust can be added for graying the hues. Flecks of aluminum can provide a silver, and particles of FeS_2, Pyrite (fools' gold), can produce a gold.

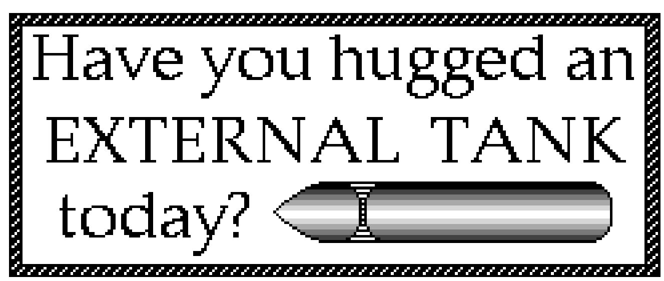
What about a canvas? That's an easy one. Try painting on glass. Flip the finished piece over or lay on another pane to present a protected face. For large expanse painting - like walls - we could try titanium dioxide or calcium oxide (lime) waterglass based naturally flat whitewashes. While experimentation with lunar-repeatable glass staining or ceramic color glazing will beyond those without access to a good chemical lab and considerable experience, trying out lunar type paints should be something quite a few of us could try.

We hope one or more readers will be inspired to take the plunge and thus advance us one big notch further towards a livable lunar frontier. Pioneers in lunar appropriate colorization, whether they ever set foot on the Moon or not, will have a special place in Lunar Settlement Prehistory.

BOTTOM LINE: to supply those who would add a healthy dash of color to lunar existence, processors, in addition to supplying elements present in abundance, must also isolate **chromium**, **cobalt**, **potassium**, **sodium**, **sulfur, vanadium**, and **zirconium**.

postscript: Beneficiation

Processing of "poor" lunar "ores", whether on the Moon's surface *or* at space settlement and construction sites, will be the keystone to an off-planet economy. It is not enough to brainstorm how to produce oxygen, silicon, iron, and aluminum, all present in parts per hundred! Unless we can devise ways to isolate and produce the elements present in parts per ten thousand, even in parts per million, the idea of building a self-sufficient community on the Moon, *or* in space, is innocently naive. Without much more serious homework, the dream of a spacefaring civilization is DOA. **PK**



ORBB - "Orbital Resources Bootstrap Bank"

The forever lost opportunity to caché in orbit the raw materials incorporated in the External Tanks of just the first fifty successful Shuttle missions now amounts to a loss of:

3,300 tons of aircraft quality aluminum
high-Cu alloy that can't be made from lunar material

86 tons of copper which does not exist at all
in mineable concentrations on the Moon

150 tons of cryogenic hydrogen & **oxygen**

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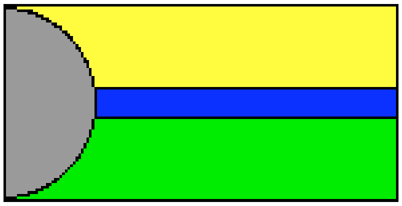
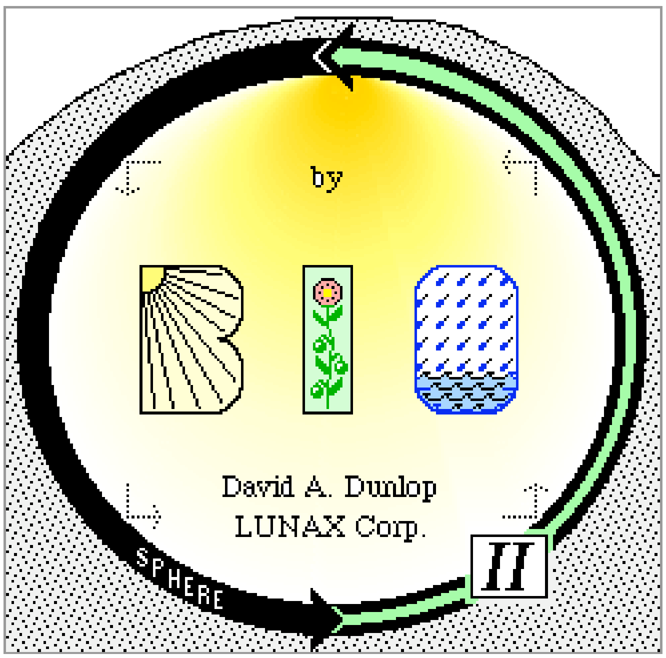
Flag Concept for a Future Lunar FRONTIER REPUBLIC



In this proposal, the half moon is shown to the left in regolith **gray**. The three stripes to the right, top to bottom, are **yellow** (sunshine), **blue** (water) - or preciously harvested or expensively imported hydrogen with which to make it, and **green** (farms and gardens) of transplanted Earth species -- creating the mini-Biospheres that must cradle enduring settle-ments. Such a flag would help bring home to the Earthbound that the Lunar Settlement is Gaia-friendly.

More on Biosphere II, and where we go from here, below.



"The National Commission on Space has reported that a highly reliable Controlled Ecological Life Support System is mandatory for extended space travel."

Maurice M. Averner -- NASA HQ

While it is often said that man cannot live by bread alone, it is also a truism that in space as everywhere else, bread is indeed a necessity. The Biosphere II project has a much more sophisticated goal than to merely produce a high degree of self sufficiency in food for long duration space flight. The Book "Biosphere II: The Human Experiment" by John Allen, Director of Research & Development at Biosphere II, provides a beautifully illustrated history of the project. I have abstracted much of the Biosphere II history and description from this volume.

The word biosphere was introduced in 1875 by the Austrian geologist Eduard Suess to describe the "envelope around the planet which was inhabited by life". In 1926 Russian geochemist Vladimir Vernadsky published a volume entitled 'The Biosphere" which offered a framework for the existence of a global ecosystem controlled by life. He argued that life was in fact a geological force shaping and changing the environment in which it evolves.

Later British Atmosphere scientist James Lovelock showed that Earth was unique in having an atmosphere with oxidizing oxygen and reducing methane at the same time - in sharp contrast to the atmospheres of Mars and Venus oxidized to over 95% CO_2, while that of Jupiter was reducing. He argued that life itself working on the physical-chemical processes had created an atmosphere particularly useful to life.

Lynn Margulis, an American microbiologist, worked with Lovelock to demonstrate the mechanisms by which the atmosphere regulates itself. They described the biosphere as a cybernetics system which is self-regulating by means of rapid microbial response to small changes in the composition of the atmosphere. They also showed how the atmosphere, through these biological feedback mechanisms, had evolved from one comprised largely of CO_2 with only trace nitrogen and no free oxygen, through the processing of anaerobic bacteria using hydrogen sulfide and releasing sulfur as waste, to an atmos-phere with 16% free oxygen and 80% nitrogen with bacteria using water as their source of hydrogen releasing oxygen as they used the Sun's energy to combine hydrogen with the carbon from atmospheric CO_2.

The 'whole systems' modeling of Earth was discussed by Buckminster Fuller and many others during the 1960's and 1970's and planetary exploration provided more examples of planetary atmospheres in sharp contrast to that of the only planet with life. In 1961 Russian scientist Evgenii Shepelev began designing 'closed loop' biological systems to support cosmonauts in space.

American Claire Folsome created a closed glass sphere with seawater and a natural diverse community of the microbes that live indefinitely within the closed marine environment with only the input of solar energy. By the early 1970' the Soviets had developed larger closed system environ-ments with higher plants, as well as algae tanks. By 1984 the Bios 3 exper-iment was the size of a small space station 315 cubic meters in size with a human crew tending its garden and algae, harves-ting crops, and preparing the food they had grown.

The Russian experiments had shown that soil-less agricultural systems provided too few habitats for the microbes so vital in the natural environment of Earth. In Bios 3, gases emitted by the algae tanks proved toxic to the plants and trace organic gases built up over time. Essential trace elements were lost by the removal of solid human waste and plant material.

This theoretical and experimental history then was the foundation for the design of the Biosphere II which would attempt to seal several varied biomes into one enclosure. The closed system would include "designer" analogs of different natural biomes as well as a carefully designed horticulture and animal food production system. The environment would carefully monitor a variety of atmospheric gases and would be highly engineered to maintain a tight seal with a goal of 1% leakage per year and other sophisticated environmental controls maintaining temperature, humidity, and pressure.

The challenge was to establish and maintain the different biomes in close proximity to one another, and to supply the range of functional microbial suites necessary. It was also argued that small quarters for travel in space were not adequate to the requirement of a self sustaining space habitat. Quantifying the volume of biomass necessary to use up all the carbon dioxide and make adequate oxygen from human crew consumption was attempted. To design adequate soil beds, a volume of "ocean", and the "right" communities of plants to provide a stable system sustaining not only the human crew, but also the plant, animal, and microbiology communities is the challenge of Biosphere II.

Departing from the Biosphere II project for a moment, I have quoted NASA researcher Maurice Averner in an article on Controlled Ecological Life Support System research. NASA's program dates to 1978 with the goal of supporting extended duration missions beyond the capability of the life support technology then existing. The CELSS concept is based upon the integration of biological and physico-chemical processes relying heavily on green plant photosynthesis to construct a system that will produce food, potable water, and a breathable atmosphere from metabolic and other wastes in a stable and reliable manner.

NASA research on CELSS is conducted at the Kennedy Space Center, Johnson Space Center and Ames Research Center. Other NASA funded CELSS research is funded at universities such as UW-Madison, Purdue, and previously the University of Florida at Gainesville, and Utah State University. In 1985 the CELSS Breadboard Facility was initiated at Kennedy Space Center. Comprised of a Plant Growth Unit, a Food Processing Subsystem, and a Waste Processing Subsystem. Each component was to be tested independently, and then integrated, to demonstrate the basic techniques and processes for a larger ground based system of practical size.

Simulation models try to define the parameters of air and water reclamation, moisture condensation and vapor-liquid equilibrium, contaminant control, and O_2 removal. Mathematical models of materials flow for monitoring CELSS performance, and related research, is intended to determine the effects of plant-microbe interaction on plant health, growth, food production, and regeneration of atmospheric gases.

The future thrust of NASA research will continue engineering and development. After the Breadboard Project will be a ground based unmanned CELSS. A gravitational biology research program will be conducted. The Space station will provide a vehicle for testing specific CELSS issues and hard-ware components. Subsequently a Manned CELSS prototype would be deployed. The development of of a fully integrated bioregenerative life support system will be enabling of long duration missions such as a permanent Lunar base or Mars missions.which need to be both secure and autonomous.

February 16th, 1993, Biosphere II's scientific panel dissolved. Earlier the project had suffered when early participation of the University of Arizona was terminated. The program has also suffered from bad publicity which has tended to raise questions about the integrity of the project and which has conveyed the impression that the project has 'tampered' with its results by breaking its seal and pumping in some outside air. Containment of the seal has also been questioned as no where near reaching the !% goal initially set. Some press coverage has reported a significant percentage die off of the 3800 odd species of plants, animals, insects placed into the enclosure.

It is difficult for this observer to determine from the popular press what other scientific and technical problems may have been encountered. In large part this difficulty is inherent in the nature of a proprietary project which is attempting to developed a "trade secret" technology base which can then be marketed to recover the estimated 150 million dollar investment put into Biosphere II thus far. Having toured the facility several times during its construction, I was struck by the limited nature of the technical information available about the project. This secrecy in and of itself is understandable from the standpoint of the development of a trade secret technology base and is indeed common for much proprietary research. This same secrecy, however, does not invite peer review or permit open reply to disgruntled ex-employees, who I understand, are in legal jeopardy as a result of agreements signed at the initiation of employment at Biosphere II.

It is clearly too soon to write off the Biosphere II project as a fraud or a scientifically invalid effort. Its goals largely parallel those articulated by NASA. However the NASA approach, present and future, involves a smaller scale sequen-tial approach to the complexities inherent in CELSS develop-ment. NASA seems perhaps less grandiose in setting a narrow focus on food production and bioregeneration of wastes. NASA does not talk grandly about biome system development and maintenance, much less try to build the large scale test bed that Biosphere has constructed with a variety of biomes.

Biosphere II engineering is exotic and wonderful to see with the spaceframe structure set against the magnificent mountain background of Sunspace Ranch. It is questionable as to why anyone with the goal of a 1% leakage rate would resort to a glass pane system with thousands of feet of glass panes edges to seal against the daily expansion and contraction of the desert temperature extremes. Would not the use of a series of extensive metal tanks (perhaps on the order of the space shuttle external tank) interconnected in a manner feasible for lunar or Martian base construction been much less challenging in terms of gas seal? The energy cost of lighting such a complex may have been a financial reason for the green house strategy as opposed to the type of "ecology in a can" approach that seems inevitable for rocket-launched "biosphere" systems.

Neither the Lunar or Martian environment would permit anything like Biosphere II to be constructed given the extreme temperature ranges and the high radiation environments. Martian and Lunar habitations will need to be buried under a minimum of two meters of regolith and perhaps twice as deep to survive solar flare storm radiation.

On the other hand it is not without merit to do trial and error research. This approach may in fact lead us more quickly to a better understanding of the critical variables at work and the design deficiencies of the current Biosphere II. In the long run it does seem important to look broadly at the biomes that man must take with him as opposed to "bread" and regeneration alone". Perhaps it is not bad science to try to design complex biomes, look carefully at the "failures" of various communities of plant and animals to sustain, and to work incrementally on increasing the survival rate of, increasing numbers of plant, animal, insect, and microbiology communities. With so many potential feedback loops to map mathematically between 3800 species it may be best to inform our mathematical models with the repeated trial runs of complex systems. Smaller, more tightly controlled variable research might never yield the same understanding of a few large scale systems "flops" at Biosphere II. Even if the system crashes down to a small percentage of the starting species it would be worthwhile to see if the "crash" was consistently repeated. Chaos theory might challenge the ability to reliably model the future functioning of so complex a system. The system itself might not "know" this and exhibit some surpri-sing regularities in performance. Something novel might be learned by such experiments.

I am not therefore disheartened by criticism of former scientists disgruntled by legal "gag" contracts and under threat of lawsuits. Nor am I disheartened by initial problems with hardware performance, and operations performance different from initial expectations. Complex experiments encounter these human and technical problems all the time. Only time and repeated results will be convincing that anything useful has been learned from Biosphere II.

I am more troubled that Biosphere does not realistically model equipment, operational conditions, or the schedule of operation that are directly analogous to Lunar, Martian, or space station prototype models. Lunar and/or Martian soil simulants used as the basis for evolving soil beds might have been used to demonstrate the evolution of a mature productive soil with a diverse and effective microbiology community. They haven't been. The limited reports to date of significant species reduction might suggest that Biosphere II adapt as its theme song "Yes, We Have no Bananas". Reports of mite infestations of potato crops might mean a slight change of lyrics and a loss of "fries" potential for the first round crew.

Such failures may also be a reflection of poor technical execution of plant and species selection and horticultural technique. Perhaps a "C" team or a "D" team might do better than the first round of consultants. It may also be that the management and funding components of the program are compromising the professional efforts and operational judgement of the horticulturalists and botanists, dooming them to failure. For that judgment we may have to wait for the volume "Biosphere II the Biopsy" to be written.

Since no taxpayer dollars are involved in this project the public is not being defrauded no matter what happens. Mr. Bass and other investors in Space Biosphere Ventures Inc. might well worry that the poor analogy to lunar and/or Martian equipment and environmental conditions is a waste of their risk capital in developing a technology that can be sold to the spacefaring nations at a price that will recoup the initial investment and operating expenses of the project.

To a large measure, the Biosphere II Project has been a huge success in increasing public awareness of the significance of space horticulture and the science challenges facing the extension of humanity's operational realm to the Moon, Mars, and immediate Solar System. Its potential for public education is as great as its potential harvest of "hard" science, and as an engineering test bed for large scale CELSS.

Until much more details of this first experimental run are known, we can hope that the project will continue with a net gain in techniques applicable to space development and occupancy. These research issues remain a key missing piece of the technical capability to capture the economic potential of space-derived energy resources which must be handselled if Biosphere I, Planet Earth, is to survive with its human population having an economy. The stakes and uncertainty are high for Biosphere II but then the stakes and uncertainty are high for planet Earth as well. **DD**

Materials cited or paraphrased are from the following:

1. Biosphere II The Human Experiment, By John Allen, 1991 Penguin Books New York, New York ISBN # 014 01. 5392-6.

2.Lunar Base Agriculture: Soils for Plant Growth, Editors D.W. Ming & D.L. Henninger, 1989, American Society of Agronomy Inc. Crop Science Society of America, Inc., Soil Science Society of America, Inc., Madison, Wisconsin.

Biosphere II: Brave New World or Disaster?

What Can Space Enthusiasts Learn From This Experiment?

by Michael Thomas, Seattle L5 Society

No one can deny that Biosphere II has been a public relations disaster; but is it a scientific disaster as well? Or is it the brave new world it was meant to be? With months to go before it's two year trial run is over, Biosphere II seems to have fallen short of it's lofty and ambitious goal of being a brave new world: a self contained and (except for electricity) a self sufficient biosphere.

There have been criticisms from the scientific community and the media about lack of scientific controls, too few scientists on the staff, lack of candidness, and *cheating,* that is, filtering out carbon dioxide, and more recently, injecting oxygen. And now the panel of scientists appointed to oversee it after previous criticisms have resigned.

This is not a good sign, but is it really a scientific disaster? *I submit that the only way it could be a scientific disaster is if it provided no useful informa-tion.* There are many lessons already learned from biosphere II, and much useful information. So while it may have fallen short of its lofty goals, it is by no means a disaster. What lessons have we learned already?

• **Lesson #1: You cannot recreate the whole world in a few acres.** But recreating seven of Earth's major environments in "biomes" was as much an aesthetic, even metaphysical goal, as it was a scientific one. It is rich with symbolism and emotion, but hardly an essential element of a self-contained biosphere.

• **Lesson #2: Including "biomes" of desert, savanna, and others low in plant density, do not make for efficient life support.** Most of Earth's oxygen production and Carbon Dioxide removal occurs in the oceans and dense forests, particularly rain forests. Cacti in the desert and grasses n the savanna do not provide a very large fraction of the oxygen we breathe. Therefore, deserts and savannas do not make efficient self-contained biospheres.

• **Lesson #3: Making a biosphere very large and complex does not necessarily make it efficient.** Biospheres should be designed for efficiency,not complexity, and certainly not aesthetics. We should do what works, not what is popular, nor what looks good.

• **Lesson #4: In order to support one human being, a biosphere needs a lot of space and a lot of plant matter.** Biosphere II in its present state, is not quite adequate for the number of persons it contains. It might, however, support fewer people adequately if not too much labor is required of the smaller crew. A crew of four might be good fro a second run of the experiment.

• **Lesson #5: Biosphere experiments need to be designed to produce *quantifiable data.*** Here are some essential formulae that need to be determined. First, how many pounds of plant matter are required in a closed biosphere to supply the nutritional needs of one human being of average size? (This includes plant matter required for the nutritional needs of any animals that are t produce milk, egg and/or meat [if a non Vegan diet is to be supported.] Second, how many square meters of "leaf surface area: are required in a closed biosphere to provide the oxygen needs of one human being of average size? [Plus the amount needed for animals if included.]

Where do we go from here?

In comparison with smaller previous experiments like those conducted by NASA and in the former Soviet Union, Biosphere II is unequivocally the largest and most successful biosphere experiment ever done. Despite the negative publicity, its failings compared with its successes, are relatively few and small. It has not been kept completely self contained, but has come a lot closer to that goal than any previous experiment with humans that ran longer than a couple of weeks

So what can we space enthusiasts learn from Biosphere II? One thing is that if a space habitat is to be a completely self-contained biosphere, with all biological recycling of elements and no artificial (mechanical/chemical) recycling of elements, it will have to be large and the human population density will be low. And low population density is not an acceptable condition for space habitats, as it would render them economically infeasible. So how do we solve this problem?

There are two approaches to solving this problem, which, in some combination, can be used to produce a habitat that will be economically feasible.

1. Artificial means of recycling elements can be used if they require no import of bulk materials from outside the habitat [or host environment, i.e. the surface of the Moon or Mars]
2. Humans and plants can be housed in separate structures in space: habitat quarters for humans, ***habitats,*** and habitable quarters for plants, ***agritats.*** There are many benefits to be gained from this strategy.

Humans have more rigorous health requirements than most plants. In space, people need artificial gravity, a dense atmosphere, and radiation shielding. While more research needs to be don, it is very likely that plants can make due with less of all these things. Artificial gravity, shielding and air pressure all require increased structural strength. And increasing the strength of a structure can only be achieved by increasing its mass, and by using stronger materials: titanium. This, in turn, increases the cost of the habitat exponentially.

If structure "A" has X amount of artificial gravity, X amount of air pressure, and X amount of radiation shielding, and structure "B" has 2X amount of gravity, air pressure, and radiation shielding, it will cost much more than 2X dollars to build. because of the geometric scaling of the structure massive enough to accommodate these changes. It all adds up. Therefore, such an expensive habitat should only contain things that cannot survive in a less costly habitat.

[**Editor's note: The** author, in all his considerations that involve gravity level, has in mind space settlements or oases in free space, not on the surface of the Moon or Mars, where the gravity level is a given. However, the air pressure values are relevant for planetary surface habitats also.]

Air Pressure Constraints for humans and plants

The minimum air pressure humans can breathe is 1/10th that at sea level, or about 100 millibars, Mb. And at this level, pure oxygen is required. The atmosphere in a large habitat for humans will probably be at least 500 Mb, or half Earth-normal. But many plants can thrive in a carbon dioxide atmosphere of only 50 Mb, or 1/10th that likely to exist in a human habitat. It is likely that almost all plants will grow in an atmosphere of nitrogen,oxygen, and carbon dioxide at a pressure of 100 Mb, 1/5th that likely in a human habitat.

This would not constitute a breathable atmosphere for humans, but the 100 Mb pressure would allow humans to breath pure oxygen from a tank and work without a pressure suit within the agritats.

Gravity Constraints for humans and plants

Similarly, humans will require a certain level of gravity to maintain normal health and be capable of returning to Earth. Since it is unavoidable that humans will be living in lunar gravity , 1/6th Earth-normal, human habitats [in space] are likely to be designed to a similar level [which would require 1/6th the radius required to provide that gravity level at a given rpm, and (1/6) cubed the amount of structural mass for any given shape structure, and a correspondingly greater likelihood that such a structure will ever be built!] Yet it is likely that many plants will be able to survive a a much lower level of about 4.25% G or a quarter of the lunar level.

Shielding Constraints for humans and plants

Plants are sensitive to radiation, but still can tolerate a little more than humans [especially if the seed stock is more fully protected.] Gardeners working in the plant agritat will need some [slideaway] shielding even for short periods of a few hours. Nevertheless, I believe than an agritat could get by with about 1/3 the shielding needed for a human habitat. During high radiation episodes like solar flares, all humans could simply return to the safety of the more heavily shielded human habitat areas until the episode had passed.

Given the kilograms of plant to kilograms of human ratio required by a mostly biological CELLS system, it is very likely than an agritat (the farming areas) will have to be measurably larger than the habitat (residential) areas, perhaps 2 or 3 times as large. Therefore limiting the mass of the agritat [by lowering pressure and shielding levels, and in space habitats, by lowering gravity levels as well] will be more important than limiting the mass of the habitat areas. I believe that an agritat with .0425 G (applicable in space only), 100 Mb atmosphere, and minimal shielding could be built much larger than the human habitat without using any more mass than is used in the human habitat. The agritat areas, though comprising a majority of the volume, could account for less than half the total mass and cost of the space colony.

The most important factor in determining the efficiency of a CELLS, is that it be fully closed, not that its functions be fully biological rather than technological.

There is noting wrong with technology, so long as you don't have to import anything from outside the [space] habitat [or the host planetary surface] to use it. Because the human habitat will be as small and compact as possible to save on cost, it is likely that it will not contain many plants, other than ornamental house plants or perhaps household mini-gardens in resident's quarters. Carbon dioxide and oxygen will have to be exchanged between the habitat and agritat. And because they will exist at measurably different pressures, it cannot be accomplished by simple ventilation. That means that carbon dioxide will have to be removed from the habitat's atmosphere by machines, not plants. This will not affect the closed nature of the habitat-agritat duo.

Nothing need be imported but electricity to drive the machines. The most straightforward way to remove the carbon dioxide is by freezing it our. And I recommend the use of acoustic refrigeration devices which require no working fluid, and, except for vibrating, have no moving parts. Air could be pumped through a cold chamber, where at a temperature of -250 °F, the carbon dioxide would condense into dry ice and be removed. The waste heat from the acoustic refrigerators could then be pumped through a heat exchanger to reheat the purified air. The dry ice could then be transferred to the agritat, where it would be vaporized and used to supply the needs of the plants.

The carbon thus removed from the habitat would eventually be returned to the habitat in the form of food. The oxygen thus removed from the habitat would have to be returned artificially. The agritat would also have an acoustically refrigerated chamber that would freeze out carbon dioxide. But in this case the frozen carbon dioxide would be reheated and vaporized with the waste heat from the acoustic refrigerators, and remain in the agritat, while the oxygen rich purified air would be compressed to a pressure of 500+ Mb and pumped into the human habitat. This cryogenic separation of the air would make possible the necessary interchange of gasses between the agritat and the habitat to meet the needs of both with a system that is both biological and technological, but nevertheless closed. Only the energy to drive the system would come from outside the habitat.

Biosphere II: Looking Back

Biosphere II, while it may have been plagued with many problems, is far from being a disaster. We have already learned much from it. And if a second run of the experiment is designed to be simpler and more efficient, while eliminating elements like desert biomes that contribute little to the success of the biosphere, we can learn even more. Something is a failure only if we learn nothing from it. **MT**

Towards BIOSPHERE "Mark III"

a *Practical* step-by-step Game Plan for early Lunar and Space Settlements

by Peter Kokh

One can look at the unfolding experiment of the Biosphere II project in Arizona and say it should have been bigger or smaller, simpler or more complex, had a lower people to biomass ratio, etc. I submit the place to start is not in adjusting any of these parameters at all, but rather in altering the basic assumption. The assumption that off planet settlements should have a closed loop life support system still seems worthy of unqualified support on logistical-economic grounds. But, as Michael Thomas points out above, that this loop must be fully biologically maintained - without chemical or mechanical assist - is *not* demanded on economic grounds.

If a fully biospheric system is desirable, it *is* so for esthetic or philosophical reasons. Self-maintaining biospheres also merit support as a long term strategy, in that biological systems are capable of self-repair whereas mechanical and chemical ones are not - so far. Even here, with the advance of cybernetics, a worry-free "hands-off" chemical-mechanical component is at least not unthinkable, if still Science Fiction.

Our purpose is to establish communities in space that support the retrieval and use of off planet resources to alleviate the economic, environmental, and energy constraints plaguing the ailing Closed-Earth System in which human civilization has unfolded up to the present day. If we are to do this in a timely fashion, i.e. *as soon as the other needed elements are in place* for transportation, raw materials mining and processing and off-planet manufacturing capabilities, energy collection and delivery (perhaps including helium-3 burning fusion plants) and so on - *then* perhaps we should not be held 'hostage' to the demonstration of a fully successful biospheric system. The biosphere may prove the element most difficult to achieve.

Biosphere II has three principal areas: the habitat or "city", the food-production area or "farm", and the 'wild' and 'natural' multiple biome "biosphere" area proper. There was widespread recognition that the amount of biomass represented in a proportionately-sized farm area would not be enough to close the system. That assumption has been proven correct. I propose, however, that our response should not be to design even more elaborate setups with even more generous acreage devoted to forest, ocean, and other natural biomes.

Instead our goal should be clean and simple: self-sufficiency in food production except for luxury items and delicacies. *We need to build a working modular food-producing farm system.* Such a system will measurably "assist" in cleansing the air and water, but not do the job totally. At first we must be content with this "assist" and make up the deficit by mechanical and chemical means.

As the Lunar settlement grows, the proportion of the life-support loop that is closed "biospherically" is bound to grow. As we start adding less cramped residential quarters built from cheaper Made-on-Luna building materials, settler home-steads are likely to include a "garden space atrium with solar access" as a very popular option. Public thoroughfares and passageways are likely to be landscaped, a green answer to the sterile gray outlocks. But over and above these incremental additions to the total biomass of the settlement with the resulting increase in the biomass to people ratio, the farm unit acreage per person is itself likely to expand significantly.

This farm expansion will come not so that the settlers can eat better, but so they can help feed other pockets of humanity in space that are less equipped to grow their own food. Anything grown on the Moon will consist of 50% or more Lunar oxygen by dry weight, with 89% Lunar oxygen in all the associated water. This simple fact means that *even if* all the carbon and nitrogen and hydrogen incorporated in living tissue grown on the Moon must *still* be upported out of Earth's deep gravity well, *capital equipment costs amortized*, the cost delivered to Low Earth Orbit space stations, factories, hotels, etc. - and to anywhere else in space - of Moon grown food will be significantly lower than that of equivalent food grown on Earth and shipped up the gravity ladder.

Space settlements will surely have their own food production areas. Nonetheless, until these are well established, a lunar settlement may be producing far more food for export than for its own consumption. Not only will this food go to off Moon space markets, and to spaceships, it will also go to smaller, perhaps tentative outposts elsewhere on the Moon. All this extra biomass may come close to closing the loop.

Further, farm grown fibers may be the cheapest and *only* acceptable way to clothe space frontier folk. The farms will be called on to produce a lot more than just food. That too will boost the biomass-per-inhabitant ratio.

As settlements grow large enough, and earn enough from exports, they will surely want to establish "Nature Parks" whose flora and fauna citizenry are chosen to add delight, enjoyment, education, and relief. By the time the first settlement is large enough to do so, we *might* be better prepared to select self-maintaining stable ecosystems, collections of plants and animals that will live in fairly stable harmony with one another - at least better prepared than we are today! Only then ought we to contemplate closing the loop by biospheric means alone, phasing out chemical and mechanical systems from general service, but keeping them on standby for fallback duty in case of major crop failure or ecosystem collapse.

Towards the Biosphere in 4 Step by Step Phases

- **I:** Farms for Food Staple Production Self-Sufficiency, *sized for local* settlement *consumption*.
- **II:** Farm Expansion to serve Food Export Markets elsewhere on the Moon and in Space.
- **III:** Farm Expansion to supply fiber and other nonfood but fully biodegradable and/or recyclable uses.
- **IV:** Beyond private and common "gardens" to communal "Natural Parks", and their expansion as settlement discretionary trade surplus income allows.

We have all been captivated by the Biospheric Siren. We are coddled from birth to grave by Mother Earth. It is understandable that it should be our Goal, big G, to establish totally separate, fully self-sufficient, mini-biospheres beyond Earth's atmospheric shore within which to reencradle our lives. But for perhaps many generations to come, this ideal will be but a standard by which to measure our progress, not something we *have to* achieve before we *dare* to cast off. **PK**

MAILBOX

Growing the Economic Case for Mars

Your editorial in the February issue of MMM was very challenging. But in the very next issue [March # 63] you gave clues to what just could be a major part of an answer.

Earth is so much more "industrially fertile" a world than the Moon because billions of years of very active water-involved geological processing have concentrated many of the trace elements modern technology has grown dependent upon into ore and mineral veins from which these elements can be extracted rather "economically".

Mars represents an in between case. Full-blown plate tectonics never developed, witness the magma-hot-spot-stuck shield volcanoes, probably because the once abundant surface water reservoirs disappeared too fast or were too localized (in the northern hemisphere). Yet it is quite evident that considerable rifting has occurred.

At this stage we cannot be confident that any of the element-leaching ore-body-building processes that occurred on Earth also occurred on Mars. But if such processes did operate, even for a short time, there just may be a few scattered lodes of sundry ores of real economic value.

Not only would this be a boon to any future settlers on Mars for their own purposes, it might give them an additional cost-competitive export to the Moon, which is deficient in copper, lead, zinc, tin, gold, silver, platinum, mercury, chlorine, fluorine and the other halogens, germanium, gallium, arsenic, tungsten and other hard-to-do-without elements needed in small amounts. If such treasures could be launched cheaply in processed or crude ore form to Mars orbit, say by a launchtrack up the west slope of mighty Pavonis Mons [MMM # 18 SEP. '88] and then transshipped to the Moon at a cost break over shipments out of Earth's much deeper gravity well, future Martians may find a better way to integrate themselves more thoroughly into a Moon-anchored economy supplying Earth with space-based energy.

Until we can do a thorough orbital chemical mapping of Mars and back this up with ground truth prospecting of promising sites, we can do no more than hope that such geologically-provided mineral concentrations exist. I would prioritize the search in two areas: (1) the craters and slopes and lavatubes of the great shield volcano massifs where any crustal material further processed in the magma might be found and (2) the walls of the crisscrossing canyons of the chaotic labyrinth terrain at the head of the Valles Marineris rift-canyon. These walls might be the best place to see whatever treats lie in the exposed strata

Thomas Heidel
Milwaukee, WI

Developing "Mars-hardy" Plants

More than once you have mentioned the possibility of breeding plant varieties that could survive out in the open on Mars - once the carbon dioxide atmosphere had been thickened somewhat by incipient terraforming activity and temperatures rise seasonally high enough to allow liquid surface waters.

Some research has been done to support the belief that the physiological needs of plants in near-vacuum conditions are less rigorous than those of humans. Some cultivated plants have been known to thrive in vacuum jars with atmospheres as low as 30 Mb [3% Earth normal (1 bar), whereas Mars' atmospheric pressure varies seasonally from 7-10 millibars, 0.7-1.0% Earth normal].

Also the ease with which many plants adapt to higher UV levels at high altitudes suggests that they may be further adaptable. And some succulents and cacti can withstand higher radiation levels than exist in any natural environment on Earth. So the development of radiation-resistant crop strains should at least be possible.

The environment on Mars, even at enhanced pressure levels, will remain highly desiccating and "space-exposed" both to UV and cosmic radiation. This suggests that high altitude succulents, if there are any, may be a good place to start in any attempt to breed "Mars-hardy" vegetation.

Michael Thomas,
Seattle, WA

Lowell's Canals; Ice-Water Cycle Engines

A list of Lowell's canals form Acalandrus to Xanthus (there are 183 of them!) along with a map can be found on pp. 145-6 of Lowell, P., Mars (Longman, Green & Co., London 1896).

Many thanks for publishing my article on Ice-Water Cycle Engines. I don't personally have the resources to engineer prototype space liquid/solid cycle engines or experimental methane-hydrogen sucking jets which carry oxygen. Yet I have felt these ideas should be at least described.

Please let me know if there are any nibbles - supportive or critical on either of these ideas. If an idea has a flaw, I sure want to know that too. Perhaps one of the nibbles will lead to an opportunity to continue this line of research.

Francis Graham,
East Pittsburgh, PA

Riddle: Just before departing for the Moon, you weighed yourself at 189 pounds. One week after arrival, you have a physical at the doctor's office in Heinlein Statiion. The nurse wighs you in aat 180 pounds, not 30. What gives?

The scale used was calibrated to compensate for the lower gravity, and thus accurately measures your mass, not your lunar weight. Mass remains the same no matter where you find yourself.

MMM #65 - MAY 1993

Lunar Industrialization: Part II by Peter Kokh

the substitution game

A spectrum of stratagems will be needed to cope with "LDEs" - Lunar-Deficient Elements

One can hardly establish a self-sufficient population on the Moon, or anywhere else, on the basis of locally producible building materials alone - however good a foundation that may be! The crucial facts affecting a Lunar Balance Sheet are the hard-to-do-without non-luxury items that cannot, or cannot yet, be locally manufactured from indigenous materials. At first, the list of such needs will seem discouragingly long and "weighty". But as we succeed in producing more and more secondary elements from the Lunar regolith soils [See the March issue # 64], the list of things that must be imported will shrink both in number and in total mass (per inhabitant to be supported) to a somewhat more palatable but stubborn core. Sooner or later, the law of diminishing returns will step in to discourage further efforts.

The Operative Philosophy is a two-sided coin with which to help pay the settlement's bills:

A) Minimize imports by learning to do without or finding locally sourceable substitutions.

For example, furniture and furnishings will rely on metals, glass, and ceramics rather than wood, plastics, and fabrics. Such *substitutions* will carry us only so far, however. We must try to develop and pioneer *new* types of lunar-appropriate materials to make such restrictions less chafing. Glax, or Glass-glass composites, is one of these new families of materials. For additional ideas, see the following three articles: "Silicone Alchemy", "Sujlfur-based Building Materials", "MoonWood: Fiberglass Sulfur Composites".

B) Choose imports to best advantage

(1) Stress capital equipment over finished items on an aggressive schedule; grow the settlement population in step.

(2) Import only those components that cannot be made on the Moon, rather than whole assemblies, and redesign both Made-on-Luna products and major and frequent imports from Earth accordingly. In other words, we "count on" *substituting* Lunar made components wherever possible and plan the diversifi-cation of settlement industry in a just-in-time basis. √ See the article "MUS/CLE " below.

(3) Bend over backwards ***not-to-import*** **items made of elements in which the Moon is well-enough endowed.** Here our "No- Coals-To-Newcastle" strategy is to make well-thought-out *substi-tutions* on Earth with respect to the composition of things sent to the Moon. This policy will be against the grain to carry out, entailing extra effort and sometimes significant upfront expense. But the rewards of pursuing such a mandate faithfully will be be accumulatively rewarding for the pioneers and could very well make or break their long term mission.

(4) an aggressive effort to wrap and package import items only with cannibalizable "tare" stuffs composed of elements that cannot (or not yet) be economically produced on the Moon. We can use alternative packaging materials made of metals or alloys embodying Lunar deficient elements. We can also formulate them out of hydrocarbons and other volatiles. If we are especially determined to tilt the game, we might go much further and consider which parts of Earth-Moon vehicles *and their outfitting* could eventually be replaced item for item with things made by the settlement. The original equipment could then be made of "Lunar deficients" and be intended and designed to be cannibalized upon Moonfall. In both these categories, tare stuffs and lunar-replaceable outfittings, we are making strategic Earthside *substitutions* to provide limited endowments on the Moon of certain very critical elements. √

See the article "Stowaway Imports" below.

"The Substitution Game" will require careful and very detailed planning if the results are to approach the potential. This means that an autonomous "Settlement Authority" answerable only to settlers and settler candidates *must* be in charge. If Earthside governments call the shots in business-as-usual fashion, non-germane political considerations and budgetary myopia will result in token half-measures. The predictable result will be that the odds against timely settlement success will be heavily stacked by negligence, apathy, and competition for attention. Imagine a settlement designed and operated like NASA's shuttle fleet and you get the idea. We'd get the short-term gratification of starting human outposts on the Moon only to see the whole grand effort inevitably collapse of its own negligently unsupported weight.

A whole spectrum of substitution gambits must be devised, *designed to work in concert like some materials ecosystem*. A number of major enabling technologies need to be developed to make this all possible. And at least here and there we'll find terrestrial applications for some of these efforts.

The ultimate payback will be making economically feasible a sizable settlement that *can* support the delivery of clean space-sourced energy to Earth. While Earthsiders may show little direct interest in the success of the Lunar endeavor, their indirect stake will be collectively enormous. **PK**

READINGS from MMM Back Issues

[included in MMM Classics #1]
MMM #4 APR 87 "Paper Chase"

[included in MMM Classics #2]
MMM #13 MAR 88 "Apparel"
MMM #18 SEP 88 "Lunar Industrial MUS/cle"

[included in MMM Classics #3]
MMM #26 JUN 89 p4 "Toy Chest"
MMM #26 JUN 89 p5 "Thermo Plastics"

[included in MMM Classics #4]
MMM #32 FEB 90 pp3-4 PRINZTON VI: Import Export Equation; A. Settlement Import Categories, Strategies to cut and/or avoid them; B. Strategies to lower import costs and increase import quantities.
MMM #32 FEB 90 p5 "Port Nimby": Unwanted Earth Wastes

silicone ALCHEMY

-Si-O-Si-O-Si-O-Si-O-Si-O-Si-O-Si-O-Si-O-Si-

Priority Need of Early Lunar Settlements to minimize Carbon Import$

Can we learn to formulate and fabricate serviceable gaskets, seals and sealants, elastic and pliable materials, lubricants, and oils from "hydro-sili¢ones" instead of hydrocarbon$??

By Peter Kokh

In general, elements are classified on the basis of the number of electrons in their outer electron shell. If the ring has a complete set of eight, the element is 'self-sufficient' or 'anti-social', so to speak, and is a "noble gas" of which there are six examples: Helium, Neon, Argon, Krypton, Xenon, Radon. These elements do not enter into chemical combination with others but we do find them in the lunar soil, adsorbed an atom at a time to the fine surface particles, a gift of the Solar Wind.

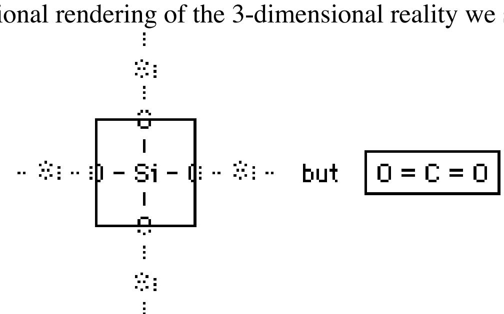
Those elements that have 1 to 3 electrons in the outer shell are metals: they 'lend' these 'extra' electrons to other atoms lacking a corresponding number, the nonmetals, thus forming chemical compounds linked by "covalent" bonds.

Then there are the fence-sitters, with four electrons in the outer shell: carbon, silicon, germanium, tin, and lead. In theory, all these elements should act either as metals or as nonmetals. In actuality, carbon acts as a nonmetal, silicon and germanium are "metalloids", and tin and lead behave as metals. Of the heavier four, silicon most behaves like carbon.

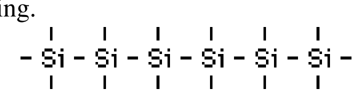
Both silicon and carbon have a tetrahedral tendency: they tend to form four chemical bonds in three dimensions oriented towards each apex of a tetrahedron with the atom at the center. Back in the nineteenth century chemists first started to wonder if they could construct a silicon-based "organic" chemistry that would parallel that of carbon, the basis of life "as we know it", and of fossil fuel derived synthetics. If that were possible, it would solve many problems for those planning development of the Moon, where silicon abounds and carbon is in very very short supply. Even if every last carbon atom cannot be replaced in "organosilicates", every Si for C substitution that can be made makes the end product that much cheaper in any market deprived of a cheap source of carbon.

Silica has been good to humankind and to civilization, giving us sand, granite, clay, pottery, vitreous enamels, glass, cement, water glass, and silicon chips and solar cells, in that order. The actual goal of the original dedicated research at GE was to see if the good qualities of Silica (high electric strength, immunity to temperature changes up to 573° C, the melting point of quartz, and resistance to chemical attack) could be married to the good qualities of hydrocarbon polymers (rubbery, water repellency, ease of molding and shaping at ordinary temperatures). These aims have been partially met.

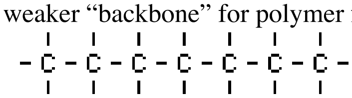
Unfortunately there are critical differences and the first clue to that should have been as obvious as night and day. Consider carbon dioxide CO_2 and silicon dioxide SiO_2. One is a gas with a very low freezing point, the other a solid (sand, quartz, glass) with a very high melting point. They could not behave more differently. The reason is that silicon fills each of its open slots one by one, whereas carbon can double up or even triple up its bonding. In silicon dioxide there are actually four oxygen atoms attached one to each available slot, but since oxygen needs to borrow two electrons, each of these oxygen atoms is also attached to another silicon atom in another direction. So the oxygen is shared and the result is a crystalline lattice. It is thus a deceptive bit of shorthand to write SiO_2 when we should be writing $Si(_{1/2}O)_4$. Looked at in a 2-dimensional rendering of the 3-dimensional reality we see:



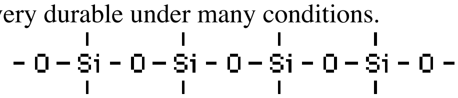
Actually, the hydrides of Silicon behave more like those of boron (with a +3 valence) than those of carbon. The two (Si, B) are similarly very reactive to oxygen, water, and the halogens (chlorine, fluorine, etc.) Even in compounds where they each (Si, C) form only single bonds there is this significant differences. Silicon bonds poorly to itself as a basis for polymer building.



makes a much weaker "backbone" for polymer formation than



On the other hand, deriving the "organic" backbone from silica or sand instead of just silicon yields a backbone which is very durable under many conditions.



This is called the "Siloxane Bridge" and is the basis of the misnamed "silicone" chemistry ["siloxane" chemistry would have been more apt.]

The combined result of carbon's peerless ability to form double and triple bonds, and silicon's need to incorporate oxygen into its polymer backbones is that truly parallel chemistries are not possible. Where we find analogous molecules with a Si for C substitution they don't behave analogously.

the "But" ... and the "Yet" ...

Nonetheless, chemists at the General Electric plant in Waterford, NY, where the foundations of silicone chemistry were laid during WWII, succeeded early in making some very interesting and useful synthetics out of silicones. In order of discovery they are resins (1938), water repellent surface films (1940), silicone oils (1942), and silicone rubber (1942).

Research involves inquiry (experimentation) into the unknown under controlled and repeatable conditions. The cold truth is that many avenues of research get nipped in the bud, largely because of two types of hazards: discouraging inherent weaknesses in the *initial* products, and the *untimely* appearance of more promising competitors. The researchers get sidetracked or the money dries up, or both. Result? "The path not taken".

Who knows what useful or marketable products have not been developed because the *paths* to their discovery were/are too discouraging or unremunerative? If the research had been done under the ax of a ban on the use of straight hydrocarbon products (the likes of which the facts of life of Earth-Moon trade economics may well impose upon lunar/space settlements), how many of these unexplored pathways would have been more thoroughly scouted in search of products that, inferior to organic synthetics already on the market or not, could be "made to serve"? Indeed, how many silicone preparations have actually been synthesized only to be abandoned because they were "2nd best" in property for property competition with hydrocarbon-based products already on the market?

Most silicones only replace the carbon in the polymer backbone, with methyl (CH_3) and phenyl (C_6H_5) serving as the attached R groups. In the former case, no more than a third of the total carbon is replaced. In the latter at best only 1/13th. Can we make Si/C substitutions in the R groups as well?

Why not try sulfur-based Thio-radicals to replace additional carbons? Sulfur-based and sulfur-added adhesives and sealants are already in widespread service. Silicone researchers ought to research "thio-silicones" much more thoroughly.

Lunar and space pioneers need an unprohibitively expensive supply of sealants, gaskets, lubricants, and other hard-to-live-without synthetics.

For the frontier, early access to hydrogen, carbon, and nitrogen "volatiles" from Phobos and Deimos, or from Earth-approaching carbonaceous asteroids or dormant comets could render the whole discussion moot by dissipating the need. So would an adequate supply of lunar carbon either as a by-product of gas-scavenging in Helium-3 mining operations or from a lucky strike of conceivable (but unlikely) carbon monoxide gas trapped in underground lunar reservoirs ("lacunae").

Yet the pro-space community ought not to count on any such butt-saving developments. At stake is the need for an unprohibitively expensive supply of sealants, gaskets, lubricants, and other hard-to-live-without synthetics. We ought to get busy hedging our bets, encouraging renewed exploration of unknown options down those silicone "paths not taken".

The problem is that it might be difficult to find "*terrestrial*" profit motive keys with which to open the files at GE, *and* attract adequate venture capital to support further exploration of abandoned avenues of silicone research. Dry holes in R&D can be very expensive. What we need is someone(s) working in the field, or willing to get into the field, with an unquenchably creative discouragement-proof mind set and a mold-breaking penchant for ferreting out hitherto unthought-of marketable terrestrial applications. Is that too much to ask? Not if we want to pride ourselves in collectively having "the right stuff". To date, indications of that are hard to find. MMM

SULFUR
S-based construction materials

The Jekyl-side of a Moon-available element

by Peter Kokh

Sulfur is to oxygen as silicon is to carbon - i.e. one notch up in the same valence column in the periodic table of elements. It comes in several allotropic forms: tetrahedral, monoclinic, and rhombic crystals, and in an amorphous quasi-plastic form as well. Sulfur is non-toxic, and non-irritating to the skin. It has many industrial, metallurgical, medicinal, and agricultural uses. There is as much as one part per thousand sulfur in the Lunar regolith as Pyrite, fool's gold FeS_2. Pyriting steel surfaces would give them a decorative brassy color.

In 1978, oil-rich Dubai began using the 100,000 tons of sulfur removed from its oil at the refineries each year to make '**sulfur-concrete**' **blocks** for housing construction. Sulfur, hot-impregnated into the block, serves as a densifying impervious binder.[1] Surprisingly, this use was nothing new.

Chapter 14: Sulfur Containing Materials, pp 308-320 in SULFUR, ENERGY, & ENVIRONMENT, by Beat Meyer, (Elsevier Scientific Publishing Co, New York, 1977. ISBN 0-444-41595-5) lists a slew of patents for sulfur-concretes, sulfur-foam, sulfur-ceramics, and S-based adhesives and sealants. Some have potential application to Lunar construction needs in lieu of organic materials or alongside other inorganics.

Sulfur Concrete: impregnated into concrete at 125°C (257°F), 8-13% sulfur addition increases tensile strength to 700 bar or more, 6-10 times original value. Sulfur concrete is used worldwide, e.g. in sewer pipes. On the Moon, sulfur concrete may complement fiberglass reinforced concrete.

Sulfur-bonded aggregates: Sulfur has been mixed with clay, glass, and quartz to make architectural ornamenta-tion that can be colored; with sand, and gravel for street pave-ment; with sand to be cast into floor slabs and side-walk blocks; with 60% Portland cement to make imitation china; and with marble dust to make artificial stone.

Sulfur foam: Sulfur has been foamed by itself, as a poly-sulfide, and as an additive to polystyrene and poly-methane foams. These have a density of from 5-60 lbs/ft^3.and have been tested as insulation boards and even as ICBM silo liners. It is the pure or almost pure sulfur foams (with little hydrocarbon content) that are of interest for lunar application.

Sulfur Ceramics Vacuum impregnation of tiles and ceramics yields products with greatly improved resis-tance to moisture, corrosion, and temperature shock.

Sulfur and sulfur-added Adhesives and Sealants bond most types of materials well. These partially-explored and test-proven uses of Sulfur-based construction materials give enterprising encouragement to would-be Lunar deve-lopers. A solid foundation for further R&D. . MMM

1 BUILDING FOR TOMORROW: Putting Waste to Work, by Martin Pawley, Sierra Club Books, San Francisco, 1982, ISBN 0-87156-324X. Page 8

MOON WOOD — fiberglass Sulfur composite

Devil Magic with Yellow Brimstone Stuff?

by Peter Kokh

Sulfur Composites and the Unexplored Frontier

Of all the work already done exploring sulfur-based construction materials, what has really grabbed our attention is the fact that sulfur is already in use[1] as a matrix for wood, paper, felt, and fabric fibers, into mats of which it is hot-impregnated. To the resulting composite sulfur brings density and imperviousness, tensile strength and durability.

⇒ *Could we not* similarly impregnate *fiberglass* fabrics and mats with hot sulfur[2]? Could such lunar-sourced and fabricated composites be a significantly cheaper option for lunar manufacturers of items traditionally made of wood or plastic? Would they fill a different end-product niche than SSI's Fiberglass-Glass Composites (Glax™)? We *suspect* that the answer to all these questions is "yes".

Yet we worry, not knowing, that all such composites might be vulnerable to corrosives or fire, and liable to produce the nauseous H_2S rotten egg gas hydrogen sulfide, or the industrially and chemically useful but otherwise unwelcome H_2SO_4 hydrosulfuric acid. That *would be* a problem. In lunar and space settlements noxious, toxic, corrosive, and flammable materials must be highly controlled if permitted at all. Sulfur composite products, then, may need some sort of stabilization or surface armor coating. Answers may already exist.

Let us assume that if such concerns are real, they are not insuperable, and that **FSC** (Fiberglass Sulfur Composite) alias **FRS** (Fiberglass-Reinforced Sulfur) alias **SIF** (Sulfur-Impregnated Fiberglass) is an appropriate Lunar-producible material that may be useful as a substitute for traditional organic materials that it would much be too expensive for the settlement to "withdraw" from its closed loop mini biosphere.

While such a composite would be rather dense, it ought to be softer than any all-glass composite. Could it be formulated to have a workability similar to wood? Sawable, drillable, shapeable, sandable, carveable? While that may be too much to ask, *any* of these qualities would be an asset. An SIF wood substitute might be given trade names like Moonwood,™, Xanthite™ [pronounce *Zanth*-ite], Xanthic™, Xanthyl™ [from Greek ξανθος - yellow], or Carpentrite™.

Plyxanth™ and its uses

We should be able to manufacture plyboards of the stuff. No glue would be needed to bond the plies. Enough heat, or a skimcoat of hot liquid sulfur, or some other sulfur-based adhesive would do the self-bonding trick.

For use as a surface material, the top finish ply could, if desired, be textured in the manufacturing process. It could also be colored with sulfur-soluble dyes *if* these were not organic coal tar derivatives which on the Moon would have to be synthesized by other routes from agriculturally produced chemical feedstocks. But their use for this purpose would involve permanent withdrawals of the involved hydrogen, nitrogen, and carbon from the biosphere (the oxygen and sulfur being no problem). But up to 5% available metal oxides have also been used successfully[3] to modify the final color from brown hues to orange. Greens and grayed yellows should also be easy to affect. So our proposed plyboard might not have to retain its natural yellow. In addition, we might subtly affect the finish hue by staining the fiberglass component [see "Color the Moon" in MMM #63]. Finally, we could give the surface other colors with paints of metal oxides in a waterglass suspension doubling as a protective armor coat.

As a substrate material, SIF plysheet could serve as a general construction 'carpentry' material as well as panel to be covered with fragile materials like foils, fiberglass fabrics, and fiberglass wall carpets used for sound-deadening. It may serve too as a suitable backerboard for ceramic tiles, even in wet area applications like showers and sink backsplashes.

Perhaps thinner corrugated sandwich SIF boards could be fabricated to serve as a lunar cardboard substitute out of which to make boxes, packing separators etc. SIF 'cardboard' might also work as a canvas for painters using metal oxide waterglass suspension paints. And *if* we can find a workable lunar-sourced paper substitute for the pages, this lower density SIF board might do as book "hard cover" material.

Other Uses of Moonwood™ or Xanthite™

SIF Moonwood™ could be a welcome new option in furniture making, for interior framewall systems (both studs and panels), for room trim (Xanthmill™? or Xanthwork™?), and for arts and crafts applications - especially if it is an easier material to work, carve, saw, drill, shape, and glue than the all-glass composites. Even if nailing and screwing are out, peg joints can be set with a cement of hot sulfur which is already in use as an anchoring cement to set iron posts in concrete.

Dense, impervious oxide-tinted formulations of this material could be fabricated as paving tiles, drain tiles, and basins, even tanks and hulls not exposed to the sun. Since it can be more easily fabricated *on site* than glass composites, SIF might be the material of choice for making very large planter beds, pools for swimming or fountains, drainage basins, and for similar large size custom-fabricated applications, either as the principal material or as a coating for a construct of other Made on Luna materials. It is perfect for on-the-spot repairs of leaking pipes and other water containers.

Where *you* come in

Perhaps this speculation is naive and simplistic, based as it is on a layman's knowledge lacking real familiarity with whatever manufacturing or performance limitations such materials may exhibit. MMM would welcome comments from those more knowledgeable. And we especially wish to encourage 'Young Turk' experiments by those who have the [access to the] equipment necessary to perform them.

Let's hear from you! MMM

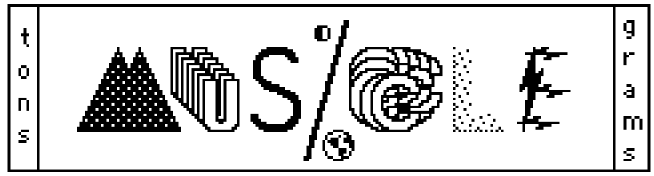
References:

1 Meyers, op. cit. [Sulfur article preceding), p. 314.

2 Pawley, op. cit. [Sulfur article preceding], p. 9. A house made of newsprint core beams and newsprint panels was coated with a thin layer of sulfur and glass fiber to retard corrosion.

3 Meyers, op. cit. p. 318.

The Fast Road to Lunar Industrial



and the "Substitution Game"

by Peter Kokh

"MUS/cle" is a mnemonic acronym we coined in a previous article on Lunar Industrialization strategy in MMM # 18, SEP '87 pp 3-4. The first syllable **MUS** endeavors to point out the type of products it is appropriate for a small lunar outpost to *try* to make in an effort to cut down on the tonnage of imports needed to support its existence. "**M**" stands for massive items and components, "**U**" for unitary items or things manufactured in large quantities, "**S**" for items that are fairly simple in design and manufacturing process. Sometimes an item will be M, U, and S all at once, sometimes not.

The "**cle**" syllable, usually in small letters to get across that this suite of items represents much less aggregate tonnage, endeavors to point out the type of things that are best left to Earthside manufacturers because they are "**c**" relatively complex in assembly and require sophisticated manufacturing from a host of parts and subassemblies supplied by a large number of diversified subcontractors, and/or "**l**" lightweight, at least by comparison, and thus much less burdensome for the settlement to upport out of Earth's gravity well. Such items often include "**e**" electronic components or assemblies.

Such a MUS/cle strategy for deciding what the young settlement should try to self-manufacture and what it should rest content to upport is absolutely necessary. Space advocates talk frequently about settlements becoming self-sufficient or able to pay their own way. But the cold fact is that while in simpler ages, now irretrievably long gone by, smaller towns could make most of what they needed, in today's increasingly technical civilization, it is estimated that a city has to have at least a quarter of a million people (250,000) to be able to support an industrial base sufficiently diversified to satisfy 95% of its own needs. Self-sufficiency is an asymptotic goal, of course, one which (like the elusive speed of light) requires exponentially more heroic effort to continue closing the gap the closer one gets to it. Thus, for example, a more modest goal of 60% self-sufficiency might be achieved by a town of only 25,000, just 10% as large (to grab a figure out of the air).

While the law of diminishing returns must eventually step in to make further efforts at self-sufficiency unrewarding, it will make an enormous difference in how we plan, or fail to plan, expansion and diversification of the lunar industrial base. "MUS/cle" gives us a serviceable rule-of-thumb guideline.

Following this guideline, we need first to look at the list of material items our settlement will need in terms of gross tonnage per item. Obviously shelter is at the top of the list. But included in the upper ranks are many other things that can be made of the same indigenous "building materials" suite needed to make shelter (metal alloys, glass, glax, ceramics, Lunacrete) namely tankage for volatiles, vehicle body parts, furniture, utility system components, etc.

Now the “Tonnage Of Imports Defrayed” [**TOID:** a Lunar Accounting Term on the same side of the Balance Sheet as our “Retained Earnings”] is not our only consideration. It is also extremely important to see that scarce lunar personpower is used as productively as possible. This will mean not only output per person (a “ton of dishes” over a “ton of computers” as a goal for self-manufacturing) but rather more significantly, **exportable output** per person. It reinforces our belief that “MUS/cle” puts us on the right track that many “MUS” items and components self-manufactured on the Moon for settler’ use are *also* high on the list of potential moneymaking exports to markets in Earth orbit, L4 & L5, expeditions to Mars and the asteroids, etc. We’ll talk more specifically about exports in the closing installment in this Lunar Industrialization series.

The “MUS/cle” paradigm will not take us too much further than this if we limit it to ‘whole’ items. “Phase II” (logically; in fact it must be implemented alongside Phase I from the very outset) is to look at *every* more complex item that the settlement needs and see if it can be broken down into “MUS” components for local manufacture (example appliance cabinets or casings) and “cle” parts for shipment from Earth.

“MUS/cle” Inspired Industrial Design

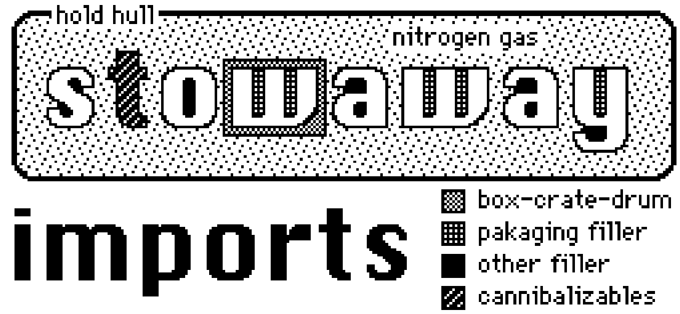
To maximize the potential, it may well be necessary to do some serious industrial redesign of the items in question to better segregate and maximize the potential “MUS” components, and to better integrate the remaining “cle” components in “works cartridges” for subsequent labor-light mating and assembly on the Moon. This may seem a costly burden for Earthside suppliers. But forces now at work are slowly forcing industrial designers to rework their products even now. In Europe, it is becoming the law that manufacturers must buy back their own products (once they are unwanted) for recycling. In order to make recycling easier, these products are being redesigned so that they can be easily disassembled into various types of recyclable components. “MUS/cle” provides a compatible and enhancing guideline for industrial designers, and is especially appropriate for today’s multinationals who manufacture components all over the globe. So “MUS/cle”-inspired Industrial Design is a promising **career choice** for one motivated to do his/her part to push the opening of space.

The “MUS/cle” Program can be 100% Retroactive

The cynic will say that there is no hurry here because the settlement will not be able to supply the potential “MUS” components for some time. So we might as well save some money and ship ready-to-use items as we now have them. Such (*any!*) cynicism per se blinds its slave to opportunities. While the above assertion is undeniable on the face of it, it is in fact only half a truth.

IF we go ahead with “MUS/cle” redesign *and then*, while awaiting the step by step growth of Lunar industry, build ALL of the item on Earth, BUT manufacture the “MUS” component out of metal or volatile elements which the lunar community cannot, or not yet, economically extract from the available regolith soils, we will be shipping to the Moon not only a needed item, but, as a relatively cheap bonus, providing a “**yoke sack**” of Lunar Deficient materials. Once the settlement can self-manufacture the appropriate “MUS” parts, the original Earth-made parts can be cannibalized for their content as they are eventually replaced. Such endowments will enable the settlers to make an end run around their deficiencies.

“MUS/cle” is a radical growth strategy to guide the planners of lunar industrial diversification in setting priorities and schedules. More, it is a strategy to radically filter the design of anything and everything that is shipped to the Moon from day one on. At first the payback will be but a promise, but eventually, religiously pursued, the “MUS/cle” strategy will outperform any savings bond. “MUS/cle” must be a key instrument in the “Bootstrapper’s Toolbox”. MMM



Using Hitchhiker and Bonus Imports to Hasten Settlement Self-Sufficiency

by Peter Kokh

Three Opportunities for strategic substitutions

There are three basic categories of opportunity to ship to the Moon badly needed “Lunar deficient elements” - strategic metals and volatile feedstocks - virtually **“for free”**. That is,

> *the freight is actually being billed to other import items, and would still be levied … whether these opportunities are seized or not*.

These are **(1)** containers and packaging materials or “tare stuffs” used to ship the principal items on the Manifest; **(2)** parts and components of imported items that would normally be made of elements in which the Moon is already well endowed [see the end of the “MUS/cle” article just above]; and **(3)** cannibalizable parts of the shipping vehicle or of its outfitting that either are not needed for the return trip to Earth and could be replaced there, or which could be replaced with Lunar substitutes upon arrival on the Moon.

In all three cases, play in the “substitution game” is initiated on Earth. In the second and third case, there is a “counter” or “complementary” substitution made on the Moon. In the second case, this match move could be delayed for some time, the endowment being “banked” in the imported item as it is being used [see the previous article].

What substitutes for what?

On the one hand, the stuffs, parts, and components in question are those that would normally be made of elements for which the settlement has no need, namely, those which can be produced economically on location: oxygen, silicon, iron, aluminum, and titanium especially. The operative rally cry here is **“No Coals to Newcastle”** i.e. no ice for the Eskimos, no sand for the Saudis, etc. Shipping or co-shipping items so formulated constitutes no less than a criminally wasted opportunity to bootstrap industrial diversification.

Instead, we want to substitute other metals such as copper, zinc, lead, gold, silver, platinum, etc., or alloys rich in them such as duralumin, monel, bronze, brass, pewter, etc. Where such substitution is impractical, an alternate option is to preferentially use stainless steel or any of several other industrially desirable steel or aluminum alloys for which the alloying ingredients cannot be easily produced on the Moon.

Some constraints apply: the substitute metals must be formulated to perform adequately, and *must not involve added weight*. The trick is to avoid paying a weight penalty in substituting heavier metals for lighter ones by using less of them or by other tricks. If this pitfall is avoided, substitution costs aside, the actual transportation costs will be nil, charged as "overhead" on the bill for the principal shipment, whether the helpful endowing substitution is made or not.

As to oxygen, it is a principal component - often in the 50% range - of paper, cardboard, wood, plastics, styrofoam, and other materials often used as containers, packaging wrap, separators, and fill. Instead, it will be to the settlement's great advantage to substitute tare stuffs formulated from low polymer hydrocarbons that can easily be broken down into the constituent hydrogen and carbon - both very precious on the Moon - or used as chemical feedstocks in Lunar industries.

Other substitution possibilities include soaps and waxes and friable or biodegradable compositions rich in those agricultural micro-nutrients or fertilizers in which lunar regolith soils are impoverished. A stuffing and cavity-filler option that could sometimes be appropriate would be to use air- or freeze-dried luxury food items (to be reconstituted with water made with lunar oxygen) (e.g. fruit, milk, eggs, spices) not likely to be produced in the early stages of lunar agriculture and which would add much to special occasion menus and to over all morale and morale-dependent productivity. Such items (along with human wastes from arriving ships) will be much valued accumulating additions to the local biosphere.

Oxygen is also an unnecessary 21% of the Earth air with which cargo holds would normally be pressurized. Instead we could use pure Nitrogen, the extra 21% most appreciated on the Moon. For the return trip, the holds could be pressurized with Lunar Oxygen, either alone or buffered with Argon and Neon scavenged from the regolith by modest heating.

As every gram of pest potentially takes the place of *many* pounds or tons or food or product in the food chain, pressurizing holds filled with seeds and seedlings with pure Nitrogen, heated to 65° C (150° F) or so could be doubly important. Attention to a whole host of "little" opportunities like this could make the difference to settler self-sufficiency. Lost nickels and dimes add up quickly to real lost dollars.

"Changing the Rules":
Cannibalizing Outbound Vehicle Equipment

Passenger and Cargo ships alike bound for the Moon will contain many components, parts, and items of outfitting that are either not strictly needed for the trip home, or which could be replaced by Made-on-Luna fabrications for the trip back to Earth. If these ships are deliberately designed and outfitted for cannibalization, the cost of off-the-shelf assembly-line-item reoutfitting *per flight* could actually be less than the customary one-time individually customized outfitting that has become NASA's one-trick pony.

Certainly this will involve a major paradigm shift for those spacecraft designers and their cheering sections who currently are aware of only two sacred cow choices: Expendable and Reusable - *neither of which* are anywhere near appropriate for opening the frontier. These two are like Thesis and Antithesis. The *Synthesis* is to send ship[parts] one way to the frontier for "Reassignment" there. So add Reassignable to Expendable and Reusable. It's a frontier door-buster.

Until industries are in place to fabricate replace-ment parts, only those items not actually needed for the trip home can be removed upon Moonfall for cannibalization. Gradually, other parts can be replaced on the spot with prepared Lunar fabrications. We'd be removing items made of Lunar deficient metals and alloys and volatiles and replacing them with items made of Lunar abundant materials (iron, aluminum, glass, glax, ceramics etc.) from basic settler industries.

What type items are we talking about? Nonstructural (akin to non-load-bearing) interior partitions; floor, ceiling, and wall panels; interior doors and trim; fuel tanks, eventually even cargo holds, platforms, exterior booms and beams etc.

For ships carrying settler recruits one way and returning empty except for crew, the list includes the partitions and decor panels of individual quarters, dishes, cutlery, and food preparation equipment, cabin furniture and furnishings, entertainment equipment and libraries, beds or berths, bedding and towels, sinks and toilets, even snap-in/snap-out copper wiring harnesses. If you use your imagination, the list gets surprisingly long and potentially all-inclusive.

Indeed, we'd have the choice of either stripping the passenger cabin or removing it wholesale to be mated to a new chassis and used as a surface coach! Or perhaps covered with regolith and used as a construction shack in the field! Even here, we'd want to have as much as possible of the cabin and its original outfitting made of Lunar deficient materials for gradual retrofitting replacement with local fabrications allowing the original materials eventually to be cannibalized.

Best of all, the fuel expended in getting all this accessory equipment to the Moon gets billed as part of the passenger fare or cargo freight *whether any of this stuff is removed or not*. So IF we designed the craft and its outfitting for this kind of wholesale reoutfitting each trip, using "knock-down" assembly techniques to make the job a breeze, the settlement can get all this "loot" virtually for free.

If you think about it, the whole concept of Reassignability absolutely shatters up till now universally accepted fuel to payload ratios. Potentially, everything except fuel becomes payload. And that changes the economics of opening the space frontier *quite independently* of whether or how soon or how much we realize cheaper access to Earth orbit.

Earthside Entrepreneurial Opportunities

Formulating and fabricating items out of elements scarce on the Moon instead of those abundant there may or may not lead to terrestrial applications. That depends largely upon entrepreneurial imagination and market testing. Making tare items (containers and packaging etc.) of alternate materials should certainly lead to marketable products for consumers who are becoming increasingly sensitive to the environmental impact of everything they use. The idea of making things to be reassigned and/or cannibalized is sure to have applications both in the consumer products field and in the continued opening of terrestrial frontiers like Antarctica. Imagination is the only limit.

The Bottom Line

To a lunar settlement, every pound or kilogram of imports or co-imports "along for the ride" made of elements economically producible on site "costs" a pound or kilogram of dearly needed "lunar deficients", hard-to-do-without elements not locally producible, that could have been imported instead for the same import bucks. This is the kind of opportunity that a for-profit operation seeking to open the frontier would eagerly seize upon. It is also the kind of opportunity that deficit-jaded government operations routinely shrug off.

Taking the pains to reformulate these potentially free "stowaway" imports will slowly but inexorably build up substantial endowments on the settlement site that will go a long way towards removing the severe industrial handicaps under which the pioneers must otherwise operate - and all virtually free of real added cost. The fuel expended to get these items there, reformulated or not, is in effect a hidden import tax. As this tax must be paid anyway, it'd be unforgivable not to use the bootstrap opportunities involved. MMM

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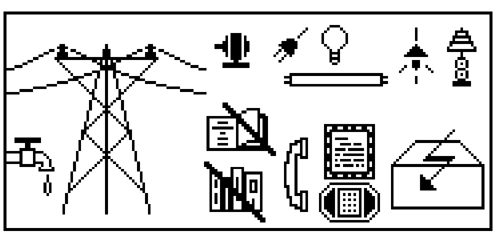
UTILITIES ON THE MOON

<< Almost no Copper, very little Hydrogen or Carbon >>

These are some of the more salient Lunar Facts-of-Life that severely constrain the design and operation of Lunar Utility Systems.



Other handicaps include the lack of lead, silver, gold, platinum, tungsten, and key ingredients for known exotic high temperature (that of liquid oxygen or above) ceramic superconductors. Utility systems must be designed to maximize dependence on *available* Lunar substitutes. For a glimpse of how future Lunar Utility systems may operate read the articles below.

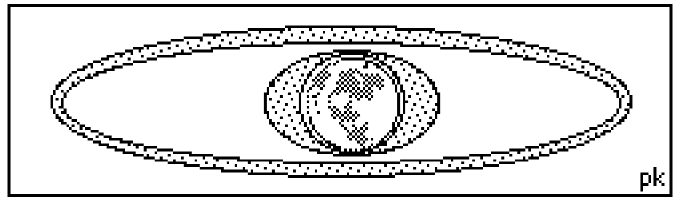
[IN FOCUS:]

Towards a Definition of "Spacefaring"

Comentary by Peter Kokh

Whatever the debate about space-spending, we have long since become a **space-using** and **space-dependent** civilization. In the past three plus decades, our way of life and economy has grown a second set of roots taping the fertility of space to complement the fertility of the soil. Communications satellites, weather satellites, remote sensing and thematic mapping satellites, global positioning satellites, search and rescue satellites, navigation satellites, etc. Not to forget a second layer of data relay satellites that tie them all together.

In addition to the various onion peel "-sphere" levels of the Earth itself, and of its hydrosphere, biosphere, and atmosphere, we have subtly become inextricably bound up with the "**vantagesphere**", orbital space from just above the atmosphere up to and including the Clarke orbit or geosynchronous orbit 22,300 miles up. In the past century, we have gone from a 2-dimensional surface-hugging civilization, to one increasingly dependent upon the lower atmosphere for travel, traffic, and terror, to one systemically present in a volume several times that of our native niche.



Does all this make us "spacefaring"? Sometimes you do see this word in print as an epithet for the U.S., Europe, Japan, and the former Soviets. But most of us rightly suspect "we ain't there yet!" Let's look at the millennia-old parallel of our intervolvement with the Sea.

SEA far ing: *adj.* **1**. traveling by sea. **2**. following the sea as a trade, business, or calling.

To follow this precedent, we would not be a spacefaring civilization until we routinely travel and do business "by space". And the implication is that we engage in such activities in person, not by robo-proxies.

What have we now? Two space agencies that are capable of sending out crewed scouting missions of which only one all-too-hastily canceled series ventured so far as the first rock past the sheltered lee-space behind the Van Allen Belt breakwaters. Rather than space-faring (on a par with open-water sailing) we are still timidly "coastal". We have a few lighthouses and buoys so to speak in our satellites.

Our mariners have only gone out on "scientific expeditions". We do not yet routinely travel "by space", not even timorously hugging the atmospheric shores. We will not reach that stage until transatmospheric aerospaceplanes begin first chartered, later scheduled, service between the continents.

The next, still "mommy-hugging" step would be permanently crewed outposts and then tourist facilities in sheltered coastal orbits. Yet when we reach these stages some 20-30 years hence, if we have progressed no further, we will still not have earned the right to call ourselves "spacefaring."

To follow our parallel we have only *thought* about "going deep-sea fishing" for food (read non-terrestrial materials and space-sourced energy). We have yet to set up a "contra-coastal" outpost on an opposite "shore" of any 'island' or 'continent' other than our 'homeland' coast. Not a cent or our trade in any commodity other than information is routed "by space". No tourists travel "by space" to "foreign" shores or even take "cruises" - on *either* side of the breakwater.

Much effort has gone into incessant debate over the Mission and Vision Statements of the National Space Society. The early consensus is first, that we will have become spacefaring when appreciable numbers of people routinely *live* and *work* "in space". Those who imagine that this milestone is satisfied by the establishment of "working" outposts *within* the sheltered "breakwater" — and there are many — clearly do not share the core vision of the co-founding L5 Society. We have called for the establishment of communities *beyond* Earth. It is now high time to clarify that statement:

> "Beyond Earth" means beyond geosynchronous orbit. That is, the "coastal space" of the vantage-sphere is *still* an intrinsic part of Planet Earth.

In addition to this qualification, we ought to state explicitly that we aim at the establishment of an **Earth-Space Economy**, in which "fishing at space" for energy, and resource development in the open "sea" or "on other shores" is begun in earnest and takes on an ever increasing importance. Only then will our civilization establish viable off-shore pockets or colonies, and only then will be doing business, and some of us earning our livelihood, "at space".

This will all happen gradually. We have yet to do real prospecting on even the closest shore, that of the Moon. Once a decision is made to start accessing resources beyond the break-water, our first outposts will be small, and contain only rotating crews who have volunteered for limited tours of duty.

We will then, and only then, first be on the verge of becoming a "spacefaring" species. When the first real settlement comprised of life-settlers *and their families* is established to pursue non-terrestrial resource development and *proves* itself viable and capable of providing for the bulk of its own material needs *and* able to trade *profitably* for the rest — *then* we will have crossed the threshold — *just*.

Additional settlements and outposts, some lunar and planetary, others in free space, will follow. The range of our resource-gathering and foraging and of our industrial agriculture-based biospheres will slowly expand beyond the hinter-space of the Earth-Moon twin planet system. When our settling and resource gathering reach to Mars and the asteroids we will graduate to being System-faring. Whether we will ever develop beyond that to fare the boundless interstellar spaces will be an open question perhaps for centuries.

At any rate, *it is clear we have not yet begun*. While the current winds are far from favorable, we *can* still busy ourselves with make-or-break *precursor* tasks. Courage! Do! **PK**

utilities infrastructure

How to best transport water, electricity, and information within and between settlements?

> **[PUB lic] u TIL i ty:** a business enterprise, such as a private or quasi-private public service corporation, chartered to provide an essential commodity or service to the public, and regulated by government.

Lunar Industrialization: Part III by Peter Kokh

Every human, civil, or industrial operation, function, or activity that we have examined in MMM promises to be transformed by its transplantation to a lunar or space settlement setting. What we call "public utilities" will be no different. Some of these transformations will be due to the characteristically unique set of economic constraints that will operate in the early settlement period. Other differences will flow from the physical nature of the host environment. Often from both.

"MUS/cle" and the Local Production of Utility System Components

Some utility system components are complex and might not be suitable priorities for settlement self-manufacture until the productive population is larger and the local industrial complex is well into diversification. Other items — happily often those which will account for the greater weight fraction of the total system — might well be locally made early on, helping to keep a lid on imports.

For example, supply and drain pipe, and shortly after most common fittings for a **Water Utility** may be produced from local iron (if an anticorrosive treatment other than zinc-based galvanizing can be found) or from Glax™, glass/glass composites (if not). Valves, meters, and regulators totaling a mall mass fraction of the system, could be upported. Drainage pans for planter beds could be made locally of Glax, or sulfur impregnated fiberglass. Flexible water hoses might have to be forgone unless used only sparingly, in very short lengths — for they would have to be brought up from Earth.

To deliver water over long distances, it will make more sense to pipe the constituent Hydrogen either by itself, or with Carbon and Nitrogen, also needed everywhere, i.e. as methane CH_4 and ammonia NH_3. At the destination, these gases could be burned with locally produced oxygen or run through electricity- and water-producing fuel cells during the nightspan.

For the **Electric Utility**, the mass-fraction set priority will be to locally produce cable and other media of power transmission, at least initially importing switches, outlets, relays, breakers, and meters etc. Later parts of these can be locally made, following the MUS/cle strategy. For more on this see "Wiring the MOON" and "Let There Be Light", below. For long distance transmission, if locally made superconducting cable is not feasible, it may make more sense to transport electricity "virtually" in the chemical equivalent of gases that can be oxidized to produce electricity at the user destinations.

Rethinking Utilities

Not only must utility system components be selected, and in some cases even redesigned afresh, to permit local manufacture of as much of the system mass as possible, in other cases whole new approaches must be adopted (per the examples above, using gasses to virtually transport water and power). In every case, the Utility must adopt a philosophy of operation altered from the one, or ones, which worked quite well on biosphere-coddled, mineral- and volatile-rich Earth.

The water company, for example, may require many industries to operate independent self-contained water treatment loops, their original water allotments in effect becoming "capital equipment". The utility may also require separate drainage systems for diversely "dirtied" waste waters to simplify treatment. ["Cloacal vs. Tritreme Plumbing" in MMM #40 NOV '90 p4 .>> MMM Classics #4]. Hydro-Luna will also be aggressively involved in finding new cheaper sources of water, or rather hydrogen, to make up inevitable losses and permit settlement growth, especially if lunar polar cold traps are found to be dry.

On the Moon there is likely to be a new boy in town, the **Atmosphere Utility**, charged **a**) with the makeup and expansion supply of nitrogen (and possibly a greater fraction of other, lunar producible buffer gasses like argon etc.) and oxygen; **b**) with maintaining their freshness and low dust count; and **c**) maintaining an equitable range of temperatures throughout the sunth (lunar 28.53 Earthday-long dayspan-nightspan cycle) and various agreed upon growing seasons, harnessing the conduction, convection, and radiation of heat.

These charges will require systemic cooperation with the Water Utility, both in maintenance of air quality through misting and dehumidification cycles, in fire prevention, and in temperature control, To do its job, this Utility may need to take a page from the Water Utility and supply not only a fresh air supply system but a stale air return system as well.

Several Utility -relevant articles follow.

Relevant READINGS FROM Back Issues of MMM

[included in MMM Classics #1]
MMM # 4 APR '87 "Paper Chase", Kokh
MMM #7 JUL '87 "Powerco", Kokh

[included in MMM Classics #2]
MMM #14 APR '88 "Electric Options", J. Davidson, R.J. Miller, L. Rachel, G. Maryniak

[included in MMM Classics #3]
MMM #23 MAR '89 p4 "Gas Scavenging", Kokh

[included in MMM Classics #4]
MMM #31 DEC '89 p3-5 The PRINZTON Settlement design and "Multiple Energy Sources" , P. Kokh, M. Kaehny, M. Mullikin, L. Rachel, J. Suszynski; "HydroElectric Storage Systems?", Mullikin and Kokh; ""The Laser Power Tower", M. Mullikin
MMM #40 NOV '90 p4 "Cloacal vs. Tritreme Plumbing", Kokh

[included in MMM Classics #5]
MMM #43 MAR '91 p 2. "Lunar Power Storage", A. Reynolds
p 4. "Dayspan", "Nightspan", P. Kokh

[included in MMM Classics #6]
MMM #51 DEC '91 p3. "Everfresh", Kokh
MMM #52 FEB '92 p5 "Xititech: Dept. of Xity Biosphere", Kokh

"No grimmer fate can be imagined than that of humans, possessed of god like powers, confined to one single fragile world."

-- Kraft Ericke

Superconductivity on the Moon

by Peter Kokh

Uses & Obstacles

SU per CON duc TI vi ty: the ability of some metals, alloys, and compounds, within strict temperature limits and magnetic loads, to carry electric current without power loss, given the total absence of electrical resistance.

Discovered by Dutch physicist H. Kamerlingh-Onnes in 1911 while working with Mercury, Hg, at low temperatures, superconductivity has led to some invaluable applications, yet at the same time never lived up to its hype. The phenomenon is the heart of MRI magnetic resonance imaging used in cat-scan medical diagnostics, in gyrotron radio frequency devices, in ore refining, and in research on magnetohydrodynamics. It is also used in Physics in new super colliders, in magnetic shielding for experimental tokomak fusion reactors, and for generating radio frequency cavities. Electronics applications include defense systems, Superconducting Quantum Interference Devices or SQUIDs, infrared sensors, oscilloscopes, and electromagnetic shielding.

Researchers have dreamt of applications in computing (semiconducting superconducting hybrids and active superconducting elements), for energy production (fusion or magnetohydrodynamics), energy storage rings, and power transmission. In the transportation field, the lure is high speed vibrationless mag-lev trains and MHD ship propulsion.

The damper todate has been the very low temperatures and high refrigeration costs of existing superconductors. The new high temperature 1-2-3 copper oxide ceramic superconductors that could use cheaper liquid nitrogen cooling are very brittle and can only be formed into usable wire by sophisticated processes and roundabout end-run methods. Further, some of them are all too easily quenched (to normal conductivity or resistivity) by useful power (amp) and magnetic loads.

Nonetheless, it is only a matter of time before some of these long heralded applications become reality - *on Earth*. On the Moon, it is another matter. For some highly useful applications where the amount of superconductive material is small, e.g. MRI medical equipment, whole devices could be simply upported from Earth.

But for applications where lots of superconductive wire or cable is required, as in electric power storage rings or long-distance power transmission, only superconductors whose constituent elements are largely, if not wholly lunar-sourceable, will make any sort of economic sense. The hitch, of course, is that ALL the new higher temperature materials, as well as the most of the higher end of previously explored low temperature superconductors, rely on some elements that we are unlikely to be able to ever produce economically from known varieties of lunar regolith soils.

Further, liquid Nitrogen will not be an economic choice for refrigerant on the Moon. While some Nitrogen will be produced as a byproduct of Helium-3 harvesting operations, all of it may be needed for Biosphere support and as the atmospheric buffer gas of choice. Instead we can either use Liquid Oxygen, or Liquid Argon, Neon, or Helium(-4), the last three also byproducts of Helium-3 harvesting operations.

LIQUID REFRIGERANTS FOR SUPERCONDUCTORS	
Helium	4.23 °Kelvin (above absolute 0)
Neon	27.04 °K
Nitrogen	*77.32 °K*
Argon	87.33 °K
Oxygen	90.16 °K

While Oxygen will be the most economic choice by far, and while many of the new superconductive materials have a critical temperature above that, a comfortable 15-20° margin is required for feasible application. That means we'd need superconductor with a Tc in the 105-110°K range, or above.

Inert Liquid Argon, potentially relatively abundant, lies in the same temperature region as Liquid Oxygen, but may be preferable if LOX is too chemically reactive and causes maintenance problems. If the only economically producible lunar superconductors require lower temperature coolants, we would have to use Neon, or Helium.

Of the more abundant elements on the Moon, both Aluminum and Titanium are superconducting, but at the very low temperatures of 1.2°K and 0.4°K respectively, far too low for even Liquid Helium to maintain. Prior to 1986, the highest Tc values were for Niobium alloys. There is some, very little, Niobium on the Moon, and it may be a long time before we can economically produce it there, if ever. The top marks are 23.2°K for Niobium 3 Germanium (present but rare), and 20.3° for Niobium 3 Gallium (ditto). But Niobium 3 Aluminum at 18.6°K and Vanadium 3 Silicon at 17.1°K are not far behind. Given known lunar abundances, the latter, V_3Si, would be the best bet, coupled with Liquid Helium as refrigerant.

With the totally unexpected discovery of higher temperature superconductivity in cuprate oxide perovskites (natural and synthetic metallic oxides with a 3D crystalline structure) expectations soared. The first was $La_{2-x}Ba_xCuO_4$, lanthanum-barium-copper-oxide, with a Tc of 38°K. Since then, many substitutions along with many adjustments of relative abundances have been tried, resulting in materials boasting critical temperatures as high as 125°K (as of 1/91).

Various rare earth elements (potentially extractable from lunar KREEP soils) have been substituted for Lanthanum (Y, Ho, Nd, Sm, Eu, Gd, Er, Lu); Strontium (present in low amounts on the Moon) and Lead (vanishing traces only) have been substituted for Barium (present in low amounts). But so has Calcium, which is superabundant on the Moon, especially in highland soils. And encouragingly, Calcium-incorporating formulations exhibit some of the highest Tc values in the 80-125°K range. However, Thallium, a lunar trace element, is part of some of these formulations. And Tellurium or Bismuth, hard to find on the Moon, are part of others.

The big hitch remains Copper which would have to be upported at great expense from Earth or brought in from an asteroid strike. In 126 Journal Papers published in '86 and '87, every one dealt with a cuprate oxide. We know of one Bismuth Oxide with a Tc of 30°K. MMM would be happy to hear from readers who know of mold-breaking research.

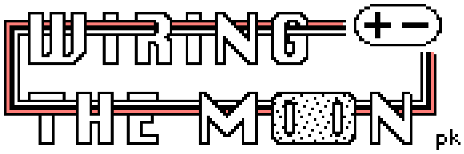
In the same column in the Periodic Table of Elements as Copper are Silver and Gold, likewise not lunar-appropriate choices. In the same Period or row as Copper are to the right (lower atomic numbers and weights) Sc, Titanium, V, Cr, Mn, Fe, Co, and Ni. Fe (iron) as a magnetic element would not be useful. Titanium is the most abundant of the others. **MMM would like to see experiments with Ti, V, Cr, and Mn oxides.** To the left of Copper in Period 4 is Zinc, also very scarce. But above and to the left is Aluminum, the most abundant lunar metal. Above and to the right is Magnesium, another abundant lunar metal. **Has anyone experimented with 1-2-3 aluminum or magnesium oxides?** If you know of any such research, or know why such avenues of research might be dry wells, please write.

What complicates the matter further is that all of these ceramic formulations are very brittle and cannot be formed directly into wires. However, they can be sputtered on to other substrates as films and made into filaments within a copper matrix. MMM suggests that if we can "smuggle" in enough copper (see last month's "STOWAWAY IMPORTS") or "ready-to-sputter" preformulated super conductor material, we try sputtering it onto aluminum rods, or better, tubing, and cables made of these. Of course, if we could locally source all the ingredients except the copper, that would be better yet.

What then? **Power Storage Rings** to store without loss all the surplus electricity generated during the 14.75 day long dayspan for night use would be Priority #1. Designs for such facilities in the 20 megawatt range have diameters of 150 meters. Lunar lavatubes large enough to accommodate such facilities should not be hard to find. This would make tunneling or excavation unnecessary. Power Storage Rings would be vastly superior to other means of nightspan power storage like fuel cells, hydroelectric reservoirs, flywheels, gas storage, or eutectic salts. Storage rings would free the settle-ment of an appreciable (but not crippling) operating handicap.

We might see **mag-lev trains** (most desirable — given that aviation is not a long-distance travel option) at any rate — *if* the superconductor is aboard the train car, not squandered along the guideway rails. Mag-levs are so desirable that once population density and dispersal demands, the SC motor units could be simply imported from Earth ready-to-run.

Power transmission is a much more problematic application. Much superconductive material would be required, almost demanding lunar fabrication from available lunar materials and dependent upon lunar-available refrigerants as discussed above. Such lines would have to be buried into the surface for refrigeration purposes, adding to the expense. As unlikely it may seem that all these constraints can be met economically, the payoff could be truly enormous. An unbroken "**Dynequator**" power transmission line girdling the Moon would supply instant power from sunlit areas to darkened areas with virtually no power loss, support flexibly spaced mass drivers and suborbital launch-land tracks. Spurs would reach communities not on the "mainline" circumlunar "trunk" route. Mag-lev trains (the "EverEast" and "EverWest") would ply the route. Transmission of Lunar Solar Power to Earth would be greatly enhanced. So research please! MMM



The order of the day will be to minimize the use of both **copper** wire and **plastic** sheathing

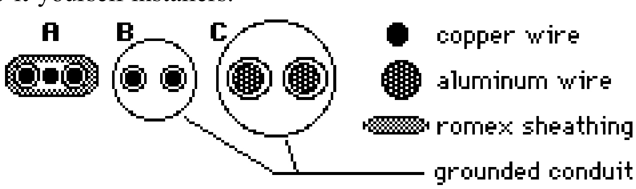
By Peter Kokh

Until 1966, Copper was the exclusive conductor of choice both for long-distance electric power transmission and for wiring systems in individual buildings and vehicles. For Copper is both economically producible (since 3000 B.C.!) and the best conductor known. In contrast, Aluminum, the second best conductor, was first introduced to the public in this century as a semiprecious metal and did not become truly affordable until mid-century. By the mid-60s, its price had fallen low enough that contractors could save as much as $200 a house by installing wiring systems that used Aluminum.

Aluminum wiring soon earned a very bad name. The problem was that the outlet receptacles used with it had steel terminal screws, an unwise and inappropriate choice that lead to “dangerous overheating causing charring; glowing; equipment malfunction; smoke; melting of wire, wire insulation, and devices; ignition of combustible electrical insulation and surrounding combustible materials; fire and injury and loss of life.” So stated the U.S. Consumer Product Safety Commission, plaintiff, in its successful suit against Anaconda and 25 manufacturers and suppliers, in banning “Old Technology” Aluminum Wiring Systems in 1973.

While Aluminum wiring has been little used since, a perfectly safe and CPSC-approved “New Technology” system is available. Very simple: just substitute *brass* terminal and connection screws. So aluminum wiring systems for the Moon are ready to go. The amount of copper contained in the brass screws is really trivial in comparison to the amount saved by substituting aluminum wire. Until outlet and switch devices can be made substituting lunar glass or porcelain for the plastics now used, such devices - with brass screws - could be simply imported. They do not weigh much and are not bulky.

But that only meets half the challenge. There is the matter of all that carbon and chlorine based plastic sheathing! We could first of all greatly reduce the amount of sheathing needed by giving up modern Romex cable for older technology rigid aluminum conduit (or glax - glass/glass composite) or for the flexible metal conduit (BX) used by an earlier generation of do-it-yourself installers.



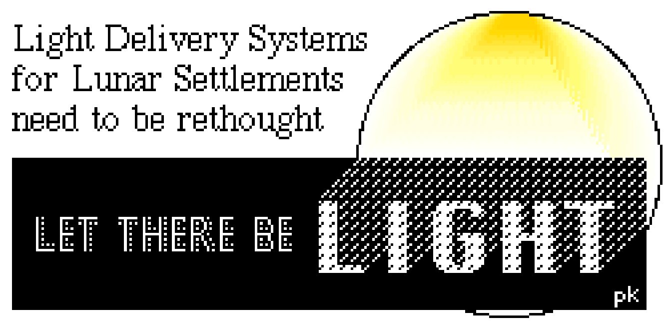
KEY: **A**. Modern flexible plastic sheathed ROMEX cable
B. Rigid or flexible grounded conduit, copper wire
C. The same with aluminum wire

Either way we save the shared sheath which makes up the romex, and as a bonus (with aluminum conduit) save the grounding (earthing) wire. We’d still need insulating sheathing for the individual hot and neutral wires, and about 67% more of it because of the switch to Aluminum which needs a larger cross-section to carry the same current as Copper.

The next step in designing a lunar-appropriate wiring system is to devise lunar-producible wire sheathing. Fiberglass fabric is one place to start. If you’ve ever seen a pre-WWII lamp, you may have noticed the frequently frayed cotton fabric-covered lamp cord wire. If some plasticizers are needed to keep the fabric sheathing supple, perhaps some thio-silicone (see MMM # 63 “SILICONE ALCHEMY”) could serve.

Other ways to save include lower voltage systems (like the 12 volt systems used in recreational vehicles and remote site cabins) and tighter, more centralized distribution networks. On this, more below.

Finally, a considerable amount of copper is used for the wire bindings of electric motors and generators. It will be desirable to begin producing early on the heavier commonly needed motors and generators on the Moon. Has anyone experimented with aluminum motor bindings and gotten past any initial discouraging results to produce something workable? MMM would like to know. If you know, write.! MMM



To minimize the mass fraction of bulb and other light system components that must be imported, careful, even novel choices might be in order.

By Peter Kokh

I have never seen a reference that gives any indication that anyone else has ever considered the unwelcome problems posed in the continued importation to a lunar settlement of lightweight but bulky and fragile (therefore over-packaged) light bulbs and tubes. It would seem to me that the lunar manufacture, or at least final assembly, of such devices would be somewhere in the upper third of the list of priorities. The problem is that each of the growing number of diverse lighting bulbs and tubes incorporates some elements not native to the Moon in economically producible abundances.

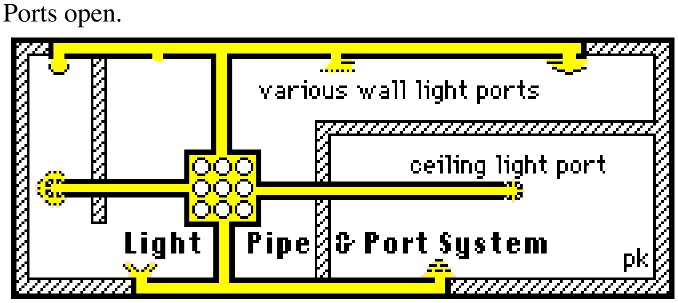
Our familiar everyday **incandescent** light bulb is quite reliant on tungsten wires and filaments for which there is NO *practical* substitute. The amount of tungsten involved is, however, trivial, and could be affordably imported, preformed and ready to be assembled with Made-on-Luna glass bulbs and mounts. The screw-in or bayonet base can be aluminum with a minimal amount of brass needed for the contact points. The evacuated bulb can be filled with lunar Argon gas. Available coatings include phosphorus produced from known regolith KREEP deposits. Light bulb manufacture is among the most highly automated, with about a dozen people needed to make most of the incandescent bulbs used in the U.S. (per manufacturer). Lunar production would not hog precious personpower.

High intensity halogen lights would necessitate the importing of either bromine, iodine, or fluorine gas along with tungsten filament. To save energy, other light bulb types and fluorescent tubes may be are preferable. But energy savings must be weighed against the gross mass of ingredient materials required that must be imported on an ongoing basis.

Early **fluorescent** tubes were filled with mercury gas and had UV-sensitive phosphorescent coatings of calcium, magnesium, or cadmium tungstate; zinc, calcium, or cadmium silicates; zinc sulfide; borates of zinc or cadmium; cadmium phosphate; finally *calcium phosphate*. Only the last would be a good choice for lunar manufacture.

In addition to the phosphor used, a relatively small amount of activator to facilitate its excitation is necessary: among these copper, silver, antimony, and bismuth are not lunar-appropriate; thallium may be so someday; and only manganese will be available locally any time soon. However, the small amounts needed should not be a problem to import. Greater challenges are the sophisticated process needed to produce the coating in 2-8µ size and the organic binding material needed to coat it on the glass.

The recent development of **Light Pipe** technology suggests an altogether different approach to indoor lighting on the Moon. Instead of a multiplicity of individual lamps and light fixtures, a network of Light Pipes whose rib-faceted inner surfaces channel light without appreciable loss to locations remote to the light source could be built into each building, ending in appropriately spaced and located Light Ports. A central bank of efficient high-pressure lunar-appropriate sodium vapor lights could feed the network during nightspan, sunlight feeding it by dayspan, to form an integrated light delivery system, part of the architect's design chores. Delivery Light Ports could be concealed behind cove moldings to produce ambient ceiling illumination or end in wall ports that could be mechanically variably shuttered or dimmed from full "off" to full "on". If the reverse side of such shutters were mirrored, the 'refused' light would just go elsewhere and not be lost. A low voltage feedback loop could match supply, the number of central bank lamps "on", to the number of Light Ports open.



Wall and Ceiling Light Ports could then be fitted with any of a growing choice of consumer purchased and artist designed decorative plain, etched, or stained glass; or pierced metal diffusers; or fiberglass fabric shades. Such a system might allow the number of types of bulbs that need to be manufactured to be minimized, allow the use of the most efficient bulb types, appreciably reduce the amount of wiring needed, and still allow wide decorator choices. MMM

TELECOMCO

On a world where paper and other organic infomedia are semiprecious, the local Phone Co. must do more.

by Peter Kokh

A generation or more ago, our vision of what the future would bring was dominated by expected improvements in transportation and the destinations any new means of travel might open up. In fact, the pace of futurization of the world has been paced by unforeseen spectacular revolutions in communications and electronics, including computers, closely followed by high tech new miracle materials. It is the small things that have made the biggest difference. This theme is likely to continue with novelty on the electronics and communications front continuing to pace everything else.

In MMM #4 APR '87 "PAPER CHASE" we listed some ways in which developments in electronics and communications could obviate much of the need for paper. Many of these developments are well on the way and will come because they will be attractive in the terrestrial market. Videophones, introduced at EXPO '67 in Montreal, and held up since owing to the capacity of phone lines, high definition television, CD-ROM libraries for those with home computers, advanced cable systems, interactive television, smart home control via the phone from remote locations, and much much more is just around the corner if not already testing the market.

For lunar use, the emphasis need only shift from hard-copy supplement to hard-copy replacement. Personal libraries will remain a necessity to protect from the totalitarian vulnerability of centrally controlled data systems unless these are multiple and competitive. Storage for such libraries can be on compact disks or any of a number of other possible media. The question arises: once local demand makes local manufacture economically desirable, which storage media can be manufactured on the Moon from local resources?

For those content with accessing central libraries over suitably capacious phone lines there must be a) no busy signal and b) personalizable user-end finders that follow each reader's stated personal tastes and interests, continually self-correcting for actual selection patterns. This will be especially desirable for electronic newspapers and magazines. Software to make such a system work is fast emerging from the realm of fiction.

To display the selected items, whether from one's personally stored library or from a central stack bank, better screens must be developed that not only induce no more eye fatigue and strain than the printed page but are as easy to scroll as one now flips through the pages of a paperback or encyclopedia. And such screens or "Readers" must be as easy to carry around as a book. Larger versions for in-home use must be as comfortable as a newspaper - or tabloid, for those so addicted. It should be easy to cut & paste whatever one reads or looks at on screen into personal electronic scrapbooks or posterboards.

Personal Readers may indeed generate a market for personalized Reader Jackets or Covers. On the Moon, the romance of the book and the printed word will continue in transfigured form - all thanks to the phone company and computers made for those who don't compute. MMM

Letting the Right Hand Know

ENCYCLOBIN INC.

What the Left Hand is [by]doing

"A question of not wasting spent personpower"

By Peter Kokh

Making the most of energy and personnel will be very important anywhere on the space frontier where existence must be eked out in barren surroundings untransformed by eons of living predecessors. Support from Earth will be dear, no matter to what cost/per kilogram launch expenses fall. To waste no import crumb, to put to best use every scheduled productive hour, to get the most out of the talents of available personnel, it will be vitally important to keep track of things of which we are by habit oblivious in our terrestrial "business as usual". The settlement with the cavalier attitude towards loose ends will fail. The one that ties up those loose ends in bonus bouquets will thrive.

What is needed is a hyper-organized or multi-dimensional matrix type data base in which the settlement can keep track of every gram of reject and byproduct and waste in every category of material from all its industries and enterprises. Any enterprise would be able to access this resource bank and find out which of its needs is available, where, and for how much. Any discarded material has already had work done on it - if only the sorting, and putting that expended work to profitable use, instead of losing it in a default waste regime, will enhance by that much the net productivity of the community.

Relatively unprocessed tailings, partially processed slag, fully processed reject material; solids, liquids, gasses, even waste heat: these are all things worth keeping track of if one wants a leg up on the formidable odds against success of the settlement. Such items can then be banked where produced or moved along specific routing channels to some surplus commodities exchange warehouse. Purchases can be direct two party affairs or mediated by the utility as a special broker.

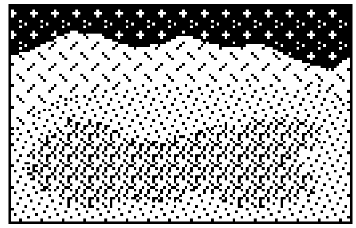
Using "partially cycled" or "precycled" items makes as much economic sense as using "recycled" ones. It keeps down the cost of manufacturing new goods, can be the source of new enterprises, and helps minimize the material impact upon, and disturbance of, the host terrain, thereby stretching resources that future generations will need as well.

An "Encyclobin" Utility would be a publicly regulated enterprise to keep track of all such items and charged with facilitating their fuller use as potential resources. By keeping track of *byproducts* unwanted by each producer, it will help inform the "right hand" of what the "left hand" is "*bydoing*" so to speak. Personal talents, expertise, and experience ought also to be listed for help in putting together teams for new projects. Encyclobin would serve as a finder service, for which there would be a fee to help maintain and grow the system.

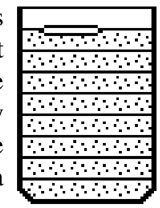
The **University** might run such a system to best categorize everything, trace potential connections, and suggest novel applications to enterprise. Waste not, want not! MMM

MMM #67 - JUL 1993

What if the Moon's "Lost Lakes" are Dry?



[**L**] There is now some strong circumstantial evidence that polar 'permashade' 'cold traps' do *not* hold *significant* reserves of water ice, any ice long ago sublimated.



[**R**] Yet the Moon's water glass is 89% full. As much water as we could dream of — 8/9ths of it is already there in the oxygen bound up in the regolith sands. "Dry water" to be sure. And only a relative 'puddle' of wetting hydrogen is to be had from the same source. How to industrialize a dry Moon?

Hydrogen: The "Water-Maker"

Lunar Industrialization: Part IV by Peter Kokh

LUNAR POLAR ICE FIELD RESERVES.- NOT ?

The '88-'91 drive to design, fund, build and fly **Lunar Prospector** and the current drive to get Congress to pass the **Lunar Resources Data Purchases Act** have both been hyped on the possibility of finding lunar polar permashade ice fields, hopefully extensive enough to "fuel" *early and accelerated* utilization of Lunar resources, and thereby jump start a spacefaring civilization. *Even if* the results are negative and lunar "cold traps" are dry, we still need both Probe and Act to put together a global geochemical map of lunar resources upon which to base alternative plans for economic development.

And dry they probably are. Francis Graham who first suggested the method by which episodic increases in the incidence of cometary impacts on the Moon could lead to cold-trapping of significant volatile reserves, is very pessimistic. The suggested mechanism may have actually worked to store up water ice and clathrates, water and carbon oxide ices mixed along with other frozen volatiles. But the point is that "loss mechanisms" must also have been at work, inexorably vaporizing and dissipating any temporary deposits. While the "Sun doesn't shine" over lunar polar permashade craters, the Solar Wind and Cosmic Rays share no such inhibitions. If at various times in Lunar history, polar ice fields have existed -

for a while - all the evidence today is that there are none now.

First, a test that is relatively easy to do from Earth, and has been done by Graham, is to search for a sodium vapor cloud over the lunar poles. If cometary volatiles were preserved there, they would include sodium compounds which would be slowly eroded by Solar Wind and Cosmic Rays to leave an ever dissipating but constantly renewed sodium vapor cloud. This is not present, at least above any density threshold that would indicate economically significant amounts of water ice.

Then **Galileo**, on its 2nd momentum-boosting pass through the Earth-Moon system, looked down over the lunar north pole and found - *nothing*. Diehards still hope, but a Las Vegas bookie would offer very high odds *against* an ice find. We still need to field a Lunar Polar Orbiter with a gamma ray spectrometer for geochemical mapping. But time is awasting if we postpone work on alternate plans to industrialize the Moon while we wait upon results probably not forthcoming.

Why then, you ask, does there seem to be a surprisingly extensive polar ice cap on Mercury, so much closer to the searing heat of the Sun, and not a similar one on the Moon? First we must mention that this "discovery on Mercury" is still in dispute. But let us suppose it will be confirmed by corroborating, less circumstantial evidence. The question then remains, why much hotter Mercury and not the colder Moon?

Overlook the relative proximity to the Sun for a moment, and look at the other factors in play. **1)** Mercury has ten times the Moon's mass, therefore a deeper, more voracious gravity well with which to entice comets and cometary fragments which wander to close to its Charybdian maw. **2)** Due to tidal "locking" effects so close to the Sun, Mercury's day-night cycle is 6 times as long as the Moon's. This long wait from sunset to sunrise coupled with Mercury's twice as great surface gravity would allow a significantly greater fraction of cometary volatiles vaporized on nightside impacts to reach and freeze out over polar cold trap areas before the Sun next rose. So even if the loss mechanisms are the same, Mercury should attract and store much greater water ice and other volatile reserves to begin with, and unlike the case for the Moon, probably at a rate high enough to overwhelm steady erosion.

But what if there *is* some lunar polar ice?

If, against the odds, some precious dust-cover-preserved ice ponds are found at one or both lunar poles, full development (which to paraphrase a proverb "cannot live by ice alone") will demand settlements elsewhere on the Moon, not just in the "Ice Fields". If in the north, a probably larger companion town might be sited amid mixed mare-highland soils revealed by Galileo north of Mare Frigoris, there to better access "the rest of lunar resources". If in the south, a similar mare-highland soil interface site would need to be exploited.

And if there is indeed *none*?

Whether or not we successfully engineer (thermo-) nuclear fusion power plants and begin large scale Helium-3 harvesting would be critical. Helium-3 is not a solitary lunar endowment. Along with it, the Solar Wind buffeting the Moon for billions of years has deposited much greater amounts of hydrogen, carbon, nitrogen, and garden variety helium-4. These could be efficiently harvested as byproducts. It has been estimated that with enough $_3$He to fuel all the fusion plants needed to provide all the electricity the U.S. uses every year, enough H, C, N could be milked from the regolith soils in the process to fill all the needs of a settlement town of 25,000.

Meanwhile, there is a consolation prize to the dry Moon - there are no floods, sudden downpours, no freeze-thaw cycles, no hydrostatic soil pressures to plague builders. In that respect, the Moon is an easy place *to build*.

Hydro Luna

MISSION DIFFICULT: Supply Enough Water to a Parched World to enable it to Grow and Thrive.

By Peter Kokh

What if we can't engineer fusion plants to burn Lunar Helium-3? Where do we get the hydrogen to mate with Lunar Oxygen to make needed water?

No matter what the size of proposed lunar settlements, no matter how efficiently we design their industries and farms to work, we will need relatively large amounts of water. For just the biosphere alone, if we are to mimic human to biomass to water ratios that work on Earth, we are talking lots of water. As for industry, we've never had to do without abundant water, and learning to do so could be a damper on growth. Though if we anticipate the need to learn such new tricks, the spin-offs for dry and desertifying regions of Earth could be significant.

Yes, we do already have 8/9ths (89%) of all the water we could ever want on the Moon, in the dry component of oxygen chemically bound up in lunar rocks and soils. But the wet "water-making" component of *hydrogen* is a vanishing trace in lunar "topsoils" by comparison. With any amount of regolith moving operations, in building, road-making, and soil sifting for agricultural use, we *will* get some little hydrogen. But without extensive Helium-3 harvesting, this will not be enough to sustain a thriving operation. The same goes for the other life-critical and industrially necessary volatiles, carbon and nitrogen. So what are our options. First questions first.

Do we import Water(-ice) or just Hydrogen

The initial outpost, prior to on site lunar oxygen production coming on line, will need to import water, not just water-making hydrogen. Once we can produce enough oxygen to mate with Earth-sourced hydrogen to meet our water needs, the operative question is "how much (energy) does it cost to ship H_20 instead of H_2 alone" - versus "how much (energy and amortized capital equipment) does it cost to free O_2 from rock".

On the one hand we have a liquid fuel expenditure on Earth. On the other we have limitless free available Solar Power on the Moon - once the necessary capital equipment both to extract the oxygen and to make solar panels is in place. The solution to this equation may change over time.

As soon as the outpost or settlement reaches a certain critical size, it will make far more sense to import just hydrogen. But both since hydrogen is relatively difficult to store and handle in the pure state, and since we also will need large amounts of carbon and nitrogen, a significant amount of the hydrogen to be imported will most efficiently and cheaply be shipped as Methane CH_4 and Ammonia NH_3 and other CH, NH, and HCN combinations useful as feedstocks.

Hydrogen "payments in kind" from Earth

If either Lunar Solar Power arrays are built or Solar Power Satellites constructed (or some mix of the two) to supply Earth with badly needed electrical power, by far the greatest market for that power will be the "Urban Tropics". Forget the current imbalance of industrial might between the industrialized nations and the Third World. That may become a historical trivia item as within a generation we come to see 80% of the world's urban population living in the Third World Urban Tropics. Put another way, two decades from now, for every urban dweller in Anglo America, Europe, the former Soviet Union, and the developed Pacific Rim nations, there will be four in Latin America, Africa, and the rest of Asia!

Mexico City and Sao Paulo are just the first of many coming super cities dwarfing historical giants like New York, London, Tokyo, and Moscow. Once sleepy colonial burgs like Lagos, Nairobi, Karachi, Jakarta and others are even now burgeoning beyond all expectations. That's where the really insatiable appetites for space-based solar power will arise. Their only other option is to exhaust the world's fossil fuel reserves, environmental safeguards be damned.

Power delivered to tropical coastal water rectennas can be used to electrolyze sea water. Mountainslope sites suitable for launch tracks with which to inexpensively launch hydrogen (or methane and/or ammonia) canisters to orbit are also the exclusive province of the Tropics. It is off-peak power from these nearby SPS-slaved rectennas that will be used to launch volatile 'gold' in partial payment for the electricity delivered.

MOUNTAINS MADE FOR LAUNCH TRACKS

Mt. Cayambe	Ecuador	0°	18,996 ft. = 5,790 m.
Mt. Cameroon	W. Africa	4°N	13,350 ft. = 4,069 m.
Mt. Kenya	E. Africa	0°	17,038 ft. = 5,199 m.
Mt. Kinabalu	N. Borneo	6°N	13,551 ft = 4,101 Ím.

Thereupon canisters of hydrogen, methane, ammonia, cyanogen, and other volatile combos will await "barging" to the Moon in a reserved Earth Accumulation Orbit - EAO. A promising scenario, but can we do better? If so, such a two-way trade, electricity for hydrogen etc. may be phased out in time.

Lower Delta V to and from other volatile sources

It has been realized for some time that it takes less fuel to deliver and/or retrieve a payload of set mass from some low-gravity worlds such as Earth-approaching asteroids and comets. For example, volatiles - capital costs for delivery aside - can be shipped from either of Mars two diminutive moons Phobos or Deimos to a lunar surface site for one-third the fuel cost of shipping them up Earth's deep and steep gravity well.

Fuel costs, of course, are not the only consideration. The needed processing and other equipment must be delivered. It will cost more to ship needed personnel to Mars orbit. And launch windows are far less frequent, 25 months apart in comparison to potentially daily Earth-Moon traffic, meaning that it will be much more difficult to set up "pipeline" style operations as opposed to mere "payloads of opportunity".

The same holds true for Earth-approaching asteroids. At least with Phobos and Deimos, there is the bonus that between launch windows, the facility can serve to support ground-based exploration and settlement of Mars. This may be enough to tip the scales in their direction (at least if their the richness and extent of their volatile content is found to be comparable) as opposed to 1982 DB, for example, recently given the permanent name of Nereus.

Asteroid and Comet Shepherding

Some Earth approaching objects, those with orbital periods closer to a year in length, require even less Delta V (powered momentum change to effect a rendezvous orbit) than do Phobos and Deimos. However, it is one of the most common errors to overlook this basic hard fact of orbital mechanics: the closer two orbits in period to one another, the less frequent the average launch window spacing. For many Earth-approaching objects, launch windows open up many years, even decades, apart.

For this reason, in the search for easy access volatiles, it makes far more sense to select small volatile-rich objects that can be patiently shepherded into new orbits around the Moon, the Earth, or into one of the Earth-Sun Lagrangian zones to and from which access can be had at any time. And if we are going to go through all the trouble to set ourselves up this way, it makes little sense to target carbonaceous chondrite type asteroids with a 20% volatile content when there may be in similar orbits "Comatose Comet" hulks, surface dust and tar backfall choking off all venting from the nearly 100% volatile core. These, if there be any, will be by far the richest prize literally worth bagging, the easiest to reach, and yet the most challenging to tame and harness. How to shepherd so potentially wild an object to its new parking orbit needs much more brainstorming than has been given it to date.

Herded into Earth-Sun L4 or L5 or more daringly into High Lunar Orbit (HLO), such a quarry will become the wellhead of a continuous pipeline-stream of volatiles to lunar surface depots and distribution points. But whether we are talking about orbital cachés of volatiles from the Earth or from some other source, low cost of delivery down to the lunar surface itself is something more easily requested than achieved.

From HLO to the surface

The lunar accumulation orbit (LAO) or accretion disk, even the teledeorbiting tug motors, present no formidable engineering difficulty. But in the infall from lunar orbit, any object will pick up considerable momentum which must be shed somehow, and with as little fuel cost as possible, to keep down this final "balloon payment" on the volatile delivery bill. Unlike the case for deliveries to Earth's or Mars' surface, there is no atmosphere to absorb this energy as heat in "aerobraking". What options might we have?

Chicago inventor Ed Marwick patented an elaborate system of forced passive deceleration which he calls "edportation" or "crashportation". Inert payloads for lunar delivery in canisters with generous ablative nose cones possibly made of solid hydrocarbons would be precisely deorbited to enter a manmade sloping cavern in which they would be bombarded with increasingly dense jets of lunar regolith dust, until they crashed into the end of the cavern at greatly reduced speed. This system would require no onboard fuel for the maneuver but still need surface power to operate the dust jets. Conceivably some of that power could be steam-generated by piping water through the heated and/or glassified dust splatter as it fell to the cavern floor after impacting the incoming payloads. This would make the process much more efficient.

Getting bolder in our brainstorming, might mini-payloads be decelerated by dust jet or laser only to a range of 1000 kph or so? That is a speed that turbine blades can handle. The remaining momentum of the incoming payload could be used to produce energy. More energy would be spent reducing payload speed to this turbine-tolerable level than could be conceivably generated from the turbine. While there would remain a net energy cost to landing inert payloads on the Moon, this cost would be somewhat minimized in this way.

Passive reception is another option. The incoming payload enters a buried lavatube via a sloping shaftway, there to impact and vaporize against the far inner surface. The vapor would condense on the walls and freeze. If the surrounding rock heated sufficiently from the pace of incoming payloads, this frost or ice wall-crust would melt and drip to pool on the floor. Perhaps some of the heat could be harnessed to produce energy. In such a system, some of the kinetic energy of the infalling payload would be harnessed and there would be a net gain.

Perhaps these are all naive expectations. MMM would welcome you physicists out there taking a look at this and similar schemes designed to avoid paying the full energy bill for safe-landing inert commodity payloads.

Active “coldtrapping” of hustled exo-volatiles

The precious hoard of hydrogen and other lunar exotic volatiles, if delivery rates exceed then current demand for new “capital endowments”, can be stored indefinitely by active cold-trapping in lunar lavatubes or even in surface permashade zones where subsurface volumes are not available. Permashade zones can be natural lunar polar crater areas, or manmade through the erection of shade walls, in areas far enough N or S of the lunar equator to make this method practical. A shade wall would have a banked curvature convex to the path of the Sun across the Sky, i.e. in the plane of the ecliptic and lunar equator.

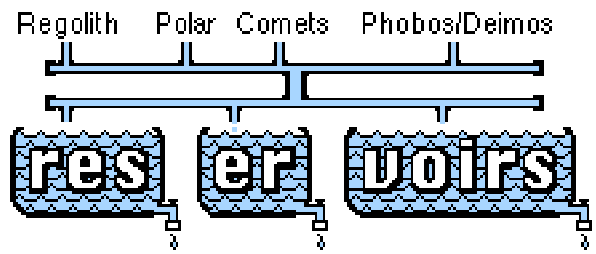
Volatiles to be shipped to outlying sites in steady-enough and high-enough volume can be piped. For this purpose methane and ammonia would be best. They are easily handled and can be “burned” efficiently with lunar oxygen in fuel cells to produce welcome power at the final use site.

Water (hydrogen) as capital (endowment)
(as well as other exotic reagents)

If hydrogen is to be a major form of payment for space-based electricity delivered to Earth markets, it might as well serve as a “currency hardener” (analogous to the role of gold up until quite recent times). Indeed one can think of few more appropriate names for the lunar currency base note (if a new term is picked other than dollar or pound etc.) than the “Hydro”. An alternate name would be the “Tanstaafl” (Heinlein’s acronym for “There ain’t no such thing as a free lunch” in “The Moon is a Harsh Mistress”. If the Hydro ⊕ were chosen as the dollar-analog, the Tanstaafl could serve as the penny.

A volatile hustling authority with czarist powers

Finally, a quasi-governmental authority with real authority to bring needed technologies online and apply them to the job of securing an ample volatile supply in secure reservoirs for lunar settlement use is needed. This authority should be settlement-owned. On the analogy of Hydro-Quebec it might be named “**Hydro-Luna**”. It is Hydro-Luna that would push the opening to the asteroids, comets, and even Mars - as well as mastermind energy sales to Earth.



By Peter Kokh

Certainly for smooth running and timely growth of lunar settlement and industrialization we will need substantial water reserves in excess of those actually in domestic, agricultural, commercial, and industrial cycle use. In addition to the recreational uses of water in deodorized stages of treatment suggested in the article that follows, additional fresh reserves can be used for recreational and landscaping use. The in sight availability of such reserves will be reassuring to the settlers, and obvious drawdowns a cause for political concern and action. Such extra open water reserves could support wildlife and additional luxury vegetation. Another use of fresh open water storage is as a heat sink to control the climate of the settlement biosphere.

Inactive storage of water-ice made from hydrogen co-harvested in Helium-3 mining operations or brought in by Hydro-Luna from various off-Moon sources can be cheaply provided in lava tubes. The first waters would quickly freeze and self-seal the tube from leakage. When needed, ice could be cut and hauled by truck or conveyors to pressurized areas for thawing and use.

Handy lavatube storage will be available in many mare areas and will be a consideration in choosing settlement sites. Where settlements or outposts are desirable in areas devoid of such underground voids, there are other options: Hydrogen gas can be stored above ground in pressurized tanks, but to prevent leakage and other problems, a better way to store it would be as methane or ammonia, either liquefied or as pressurized gasses. Conveniently, it is in such form that out-sourced volatiles will be imported in the first place. Further, storage in this form is very versatile allowing volatiles to be drawn down, resupplied, or shipped elsewhere all by automated pipeline systems. As a bonus, at the use market destination, they can be run through fuel cells or steam turbine boilers to generate electricity as well as water and other volatile products.

Both methane and ammonia have major agricultural and industrial uses. In both cases, introducing added water into these cycling systems through this form makes elegant sense.

How much of a Water Cushion should the settlement strive to maintain? New water must be added not only to support growth in population, agriculture, and industry but to make up for inevitable losses. While major attention must be paid to preventive strategies to minimize losses of water in the various loops, accidental and other difficult to prevent losses will still occur. These need to be made up and the rate at which such make-up additions are needed will greatly affect the local "cost of living" and indirectly, the "standard of living."

It would be wise to have a 2 year reserve sized not only for make-up use but also for planned growth. With quick additions difficult, planning and foresight are needed. MMM

The Settlement Water COMPANY

Care and Treatment of a Finite Resource

By Peter Kokh

Industrial Exclusions: "Closed Loop" water systems for some industries

While even on Earth, abundant water for industrial use is not something everywhere to be had, in general, water supply is simply a matter of location. And given a wise choice of location, both the supply is cheap and the discharge is easy.

Water is used to move raw materials - in slurries. It is used alone or with detergents as a cleaning medium. It helps separate particles by size - powders floating to the surface, heavier particles precipitating to the bed. Doped with emulsifiers it helps separate suspended materials normally impossible to separate.

Water itself serves as a chemical reagent. But more frequently it is used as a delivery medium for other more reactive dissolved chemical reagents.

A fine-tuned jet of water under pressure can be used as a cutting and shaping tool. Pressurized abrasive suspensions can wear away stubborn surface deposits.

Water is used in enormous amounts to cool by carrying off surplus waste heat. Combined with a heat source, it becomes a source of considerable power - steam! - the genie that unleashed the industrial revolution!

Its hard to see how we can even talk about industrial operations on the Moon if water is a scarce item! Clearly, in a situation where the water source is not constantly and automatically replenished, an abundant *naturally cycled* freebie, it becomes instead a very finite *capital endowment* that can only be replaced at great cost. Even if replacement charges can be lowered to mere thousands of dollars a ton or cubic meter, water *will* be "fanatically" recycled.

Nor would it make sense to funnel point source industrial discharges laden with particulates and chemicals into the general residential-commercial water system of the host settlement community. It will be far more efficient for each industrial operation to recycle its own discharge water - water that is *still* dirty in a *known and limited way* - before it gets mixed with differently polluted discharges from rather diverse industrial operations elsewhere.

Industrial operations then ought to have closed loop water systems. Not only does this make the job of water treatment much easier and simpler, it provides strong incentives for more conservative use of water contaminants in the first place. Plant engineers responsible for the water cycle will want to keep their job as simple as possible. Chemical agents used in industrial processes will be chosen not only for how well they work, but for how easily and totally they are recovered.

Where water is used for cooling, there will be strong incentives to cluster facilities that discharge heated water with operations that could put such a heat source to good use. A "thermal cascade" then becomes a natural way to 'organize' an industrial park - 'organically'. An alternative is simply to store heated water for nightspan use to even out indoor and middoor (pressurized commons) temperatures throughout the sunth (lunar dayspan-nightspan cycle 28.53 standard 24 hr days long).

Double Duty Storage of Water Reserves and of Water-in-Treatment

The water utility - both that of the Settlement at large and those in-house systems used in lunar industry - will have three types of water "pools": **a)** clean, ready-for-use reserves, **b)** waste water awaiting treatment, and **c)** water in process of treatment (settlement pools or cooling ponds, for example). For the first two categories, there are both essential and luxury morale-boosting uses of water that are quite compatible.

Stored water can be put to good use in maintaining comfortable temperature and humidity conditions within the settlement. By freezing and or boiling some of the supply at appropriate times in the dayspan-nightspan cycle, the water reserves can act as a heat pump, be part of a heat-dump radiator system, etc. For water in treatment, distillation during boiling can work triple duty both to clean the water, regulate thermal levels, and produce power via steam.

Recreational use of stored water is not something to be overlooked. Even water in later "deodorized" stages of treatment may be clean *enough* for fountains, gold fish ponds and trout streams, and for boating lagoons and canals ("no swimming, please"). Nothing does more to boost the general ambiance and feeling of being in a "paradise" than generous, seemingly profligate, but totally self-conserving use of water. Judicious use of water reserves will be a primary function of the settlement water utility.

Making Treatment Easier - Smart Drainage Systems

As was pointed out above in the discussion of closed water loop recycling systems for individual industrial operations, it makes sense to keep separate, waste waters that are still diversely and relatively simply dirtied. Why mix waste water from a can-making company with that from a canning operation? More, why mix either with agricultural runoff? Or agricultural and garden and landscaped area runoff with human waste drains, or any of the above with bath and shower water?

In a previous article, "CLOACAL vs. TRITREME PLUMBING", MMM #40, NOV '90 p. 4. [order by SASE plus 25¢ or loose stamp from MMM Reprints c/o LRS], we discussed a revolution in drainage philosophy, the first great leap forward beyond the Cloacal (one hole) system invented in Mohenjo Daro (200 mi. NNE of modern Karachi, Pakistan) about 4,000 to 4,500 years ago. Simply put - separate color-coded or otherwise differentiable drainage lines for diversely dirtied waste waters so that they can be separately and more simply treated and recycled. Here on Earth, where in every established community drain lines and pipes make up a major component of entrenched (both senses!) infrastructure, it would be prohibitive to replace them with a more sensible network.

But on the Moon, where we are starting from scratch, the additional upfront costs of "doing drainage right", will pay off immediately in lower upfront costs of treatment systems, as well as continually thereafter in lower operating costs for the whole communal water system.

Double hulling, drip pans, leak sensors

When it comes to the Earth's waters, Nature clearly pays no head to the Proverb: "a place for everything, and everything in its place!" Even if the settlement shares a common megastructure atmospheric containment hull, it will be sound practice to keep water drainage systems and basins leak free, or at least leak-monitored and controlled. The separate drain lines might still be clustered over a common drip gully or gutter. As with modern gasoline (petrol) underground tanks, double hulling would be a wise policy. What is flowing or pooling around loose, even if technically still within the biosphere, is neither being effectively used nor recycled in timely fashion.

Humidity Control

Humidity could be a problem, especially given the high concentration of green vegetation needed to maximize the biological contribution to the clean air & clean water cycles. Plants transpire lots of moisture into the air.

While writers dream of biospheres in which "it rains" from time to time, for it to rain naturally may require an insufferable prior buildup of humidity, with all the damage that can do (mold etc.) in addition to simple discomfort. Instead, giant muffled dehumidifiers will be needed, and the nectar they wrest from the air will be the start of the clean drinkable water cycle. Yes rain cleanses the air of dust and other contaminants, but so can the artificial rain of controlled periodic misting, the abundant use of fountains and waterfalls, etc.

Rules — Protocols — Restrictions

Even water-dependent cottage industries, households, and individuals will have to accept some responsibility for wise use of the "liquid commons", if they are to continue to enjoy its freshness, cleanness, and adequate abundance. Students may well be taught good cleaning, bathing, cooking, and gardening water use in unisex home economics courses.

Graduating youth may enter a Universal Service and spend some time manning all the infrastructure utilities upon which lunar survival is closely dependent, including the water treatment facilities. This too will foster thoughtful citizenship.

Water use might well be metered by progressive rates: rather reasonable prices for reasonable amounts; unreasonable prices for unreasonable amounts. Some home enterprises may need to seek Utility help in setting up closed loop water purification systems of their own: fabric dyers, for instance.

Mail Order Catalogs of items available to Earth may have pricing tariffs favorable to the import of items high in H, C, N, for example, and unfavorable to the import of items for which lunar-sourceable substitutes are currently "on line".

Agriculture and Horticulture:
Drip-Geoponics versus Hydroponics

In agriculture and home gardening alike, the naturally buffered, lunar regolith-using geoponics systems using drip irrigation should be more economical than hydroponic systems that import all nutrients from Earth, not just some of them. Water use in such systems can be controlled well enough, and indeed natural soil farming may be an "organic" part of the water treatment cycle. Here, as elsewhere on the Moon, water can't be used casually anymore.

Xeroprocess

xe ro- (ZEE ro): from Greek ξεροs, "dry"

Those planning industrial operations on the Moon might well take a page from Xerox.

By Peter Kokh

To go a step beyond the water conservation and treatment strategy of closed industrial water loops, the settlement authority can offer processing and manufacturing enterprises various incentives to design and engineer water "out of the process" in whatever use category this is practical.

For producers of metals and other basic materials to be used in lunar manufacturing, it is especially important to attempt to redesign tested and familiar methods, sometimes scuttling them altogether, to find regolith handling and sortation and beneficiation systems that use as little water as possible. For example, piped or trough-borne slurries can be replaced with simple conveyor systems. In pressurized quarters, air assists can be added, especially for separation of materials by particle size, powders from heavier grains. Vibration sifting can be factored in, especially in the unpressurized "outvac".

The alternative is to provide relatively voluminous capital water endowments to such processors, along with all the water treatment equipment to create a closed loop. Xeroprocessing methods could result in a significantly reduced tonnage of capital equipment and endowment to be brought to the Moon. This translates to an earlier startup for the industry in question. If it is a keystone industry, that would be vital.

Water-based chemical treatments will be more difficult to do without and in that case the used doped waters must be recovered and recycled. Yet it is certainly worth brainstorming waterless methods, one industry-specific application at a time.

It is unlikely there will soon be anything that mimics our petroleum-based synthetic chemicals industry with its myriads of sophisticated derivative products rich in the exotic volatiles the Moon lacks in carefree abundance. Such products where it proves impractical to do without them, are better imported ready to use, leaving the associated industries, their capital equipment and discharge and waste problems alike, back on Earth where they can be better handled. Thus the use of water based emulsifiers and other organic agents in early lunar industries is unlikely in the first place.

For cleaning, sonic methods may do in some uses. In others, such as degreasing, water-based methods in closed loop systems may be the only practical option - unless alternatives can be found for the occasioning use of lubricants and grease in the first place - here is the place to start in ‘option-storming’.

In using fine-tuned jets of water under pressure as a cutting and shaping tool, typically relatively small amounts of water are used and simply recycled. This judgment may also apply to some uses of pressurized abrasive suspensions in surface cleaning and treatment. Still, it is certainly worth exploring xero-process methods in both cases.

For cooling, little treatment if any is needed of the used water and it can be immediately recycled. Yet other methods are certainly preferable especially if the amounts and types of heat production allow. Options include heat pipes (possibly incorporating eutectic NaK, a Sodium-Potassium alloy that is liquid at room temperature) combined with surface radiators. If the heat could be useful for application in another part of the process, or in a “next door” companion industry, this needs to be considered in a decision whether or not to use water-assisted heat transport and whether or not to tie that into a power cogeneration scheme using steam.

If the industry’s processes are segregated into energy intensive and heat producing operations that can all be done in dayspan, and labor-intensive and heat absorbing operations that can be postponed and reserved for nightspan, then heat-pumping thermal output into and out of a water-ice reservoir makes sense. But as soon as a NaK production facility is on line and can meet the demand, substitution of this lunar-sourced eutectic alloy for water as a heat bank would save enormously on capital costs, translating to earlier startups and faster diversification.

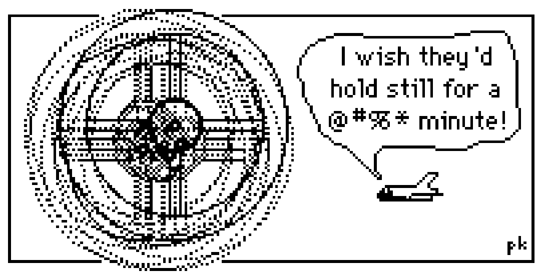
Since it does come down to significant differences in required initial import tonnage and consequent time-is-of-the-essence diversification timetables and decisions, the choice may not be left up to industry. Where the settlement’s industrial and enterprise Review Board deems it practical, xero-processing and xero-manufacturing methods may be mandated, especially if already pre-developed. Whether a potential joint venture partner uses xero-industrial methods will then also make a difference in submission of a wining bid.

And what about agriculture and food processing? In the absence of regular-enough rainfall, plants and crops must be irrigated, and salts leached from the soil must be carried off along with waste fertilizers and pesticides. At food processing facilities, produce has to be washed, cooked or blanched, and often water-packed. Each specific step and operation has to be analyzed to see if it can be redesigned for either waterless methods or at the minimum for water use methods that cut down on the total capital volume of water needed as well as make the treatment and reuse of that water easier.

Nor can we wait for any of this until we are on the Moon and it is time to add a new startup industry. If we are not prepared to hit the ground running with enterprises thoroughly redesigned for lunar-appropriate methods, then valuable time will be lost one way or the other. Either we choose to pay the piper by bringing up a greater and costlier mass of capital equipment and capital water endowment for inappropriate operations, forcing a delay in ability to import additional industries, or we tread water waiting for an industrial operation to be redesigned *then* - something that could have been done already.

So how do we see too it that when we need them, industries and enterprises using lunar-appropriate methods such as xero-processing are thoroughly thought out, engineered, field tested and debugged - already to go? One way is to set up an **Institute of Lunar Industrial Design**, NOW! This could be part of a **University of Luna - Earthside**, also set up now, not on the undergraduate teaching level, but on the graduate industry-subscribed research and development level. We propose to see to it that this is done, ready for its debut at ISDC ‘97 (in Milwaukee? hint, hint!)

MMM #68 - SEP 1993



“Colombian coffee is served in Sector Six!”

How do you dock with a spinning space station or space settlement? At the unspinning central hub you say? But what if the spinning torus or cylinder is temporarily off balance, the masses inside not evenly enough distributed along the rim? In that case, from the viewpoint of an approaching ship, the hub would appear to oscillate eccentrically about the true “center of gravity” shifted somewhat from the “center of structure” by centimeters, even meters, making docking tricky, if not dangerous. Solution? See ⇓ “Roundtables in the Sky”

BUREAUCRATIUM

From the Space Frontier Foundation e-mail message service* OPENFRONTIER@delphi.com - 10/16/’93

Nuclear Scientists at Harwell have discovered the heaviest element in the Universe, which they have named Bureaucratium. This extraordinary element has no protons or electrons, and its atomic number is zero. What it does have is one neutron, eight assistant neutrons, ten executive neutrons, 35 vice-neutrons and 256 assistant vice-neutrons. These parti-cles are held together by a force that involves the continuous exchange of meson-like particles called 'morons'. Bureaucra-tium is completely inert but can be detected since it impedes every reaction it comes into contact with.

Contributed to the Space Frontier Foundation by Arthur C. Clarke

Lunar Industrialization: Part V by Peter Kokh

Cornucopia Crops

Settlers can't live by bread alone! Farm "Pods" can churn out many other needed products

Relevant READINGS FROM Backissues of MMM

[included in MMM Classics #1]
MMM #4 APR 87 p9 "Paper Chase", Peter Kokh

[included in MMM Classics #2]
MMM #13 MAR 88 p8 "Apparel", Peter Kokh
MMM #15 MAY 88 p5 "Threads", Aleta Jackson

[included in MMM Classics #4]
MMM #40 NOV 90 p6 "METHANE", Peter Kokh

[included in MMM Classics #5]
MMM #48 SEP '91 p8 "Naturally Colored Cotton", P. Kokh

[included in MMM Classics #6]
MMM #55 MAY 92 p9 "Agri-Garments", Michael Thomas

INTRODUCTION

To date, Experimental Lunar Agriculture has concentrated on the production of fresh vegetables needing little or no processing (lettuce and salad stuffs) and on such staples as the potato (Ted Tibbits at the University of Wisconsin Biotron) and wheat and soybeans (Bill Easterwood at EPCOT Center).

But this is just a start. Not only will Lunar farm pods eventually produce far more food crops than those experimented upon to date, but it will be called upon to grow crops for quite other purposes. Fiber for clothing, toweling, and furnishings will be especially important. Household preparations, cosmetics, pharmaceuticals, and chemical feedstocks will take their place as well in the agricultural sector of the settlement economy. Anything organic that consists in major fraction of lunar-sourceable oxygen is potentially cheaper to grow on site rather than import from Earth. Different frontier communities will have their specialties, and trade between them should be brisk.

As an industrial activity, lunar agriculture will start as "small potatoes" yielding "produce" only that has to be "home made" into meals. Farm pods will be highly automated, saving labor for mining, materials processing and manufacturing of building materials and energy stuffs for export as well as for use on the frontier to defray imports.

Food processing, which in America employs far more people than does food growing, will be insignificant at first, starting up essentially as part-time after hours cottage industry. As the number of people on the frontier grows, economies of scale in other areas of industrial activity will gradually make it possible to justify a growing primary employment in the food industry. Condiments, sauces, gravies, preserves, baked goods, precooked packaged meals, will no longer be flea market items but take their place beside "produce" in "grocery" stores.

The demand will be augmented by the growth in the number of small outposts of humanity - on the Moon, in space, in space ships, among the asteroids etc. Small incipient outposts would be stuck in the "salad bar" mode indefinitely if it were not for trade with larger more agriculturally diversified settlements on the Moon, out in L5, or elsewhere.

Agriculture will slowly emerge as a major sector of the industrializing lunar economy. To turn an old phrase on its head, pioneers can not eat, nor clothe themselves, by metal, glass, and ceramic alone!

Cotton Plant Byproducts

In a response to a question about the possibility of growing cotton to meet clothing needs, Dr. Tibbits gave the sort of horse-blindered response typical of a specialist unaware of the universe at large. "That would mean withdrawals from the lunar biosphere, making it inefficient. We can't do that!"

To the contrary, if a non-luxury settlement need *can* be met with an agricultural product that is 50% lunar oxygen by weight, and the only remaining viable option is to import something with 0% lunar content, then net efficiency of the farming unit be damned. It is the *gross* efficiency of the Settlement *with all its systems* that is *the* bottom line.

The "synthesis position" here is that any and all farm products withdrawn from the settlement's biosphere must be processed, treated, and fabricated *solely in ways that allow* the item, material, or preparation to be *eventually* recycled and/or returned to the biosphere by composting. This holds of fibers, fabrics, and dyestuffs as well as of cosmetics and household preparations. We need to keep our eyes on this larger picture.

From the point of view of the plant species chosen for cultivation, in the interests of efficiency we *ought* to be looking for suitable ways to use the parts of the plant not normally eaten, as well as ways to derive food and other products from the composting remnant waste biomass. "Waste not, want not" must be the watchword of Lunar Agri-Business.

It seems quaintly out of touch, however, given all the ongoing progress in plant breeding, genetic manipulation, and biomass treatment, to reject a suggested crop on the grounds that too large a portion of the individual plant does not serve the primary purpose for growing it. What is to prevent the recombinant DNA researcher from putting into future cotton plants genetic instructions that make the rest of the plant a) edible; b) a source of pharmaceutical or other desireable compounds? The cotton plant - its not just for Haines anymore!

Recombinant DNA opportunities aide, three more conservative measures suggest themselves. First it is possible to develop varieties to maximize yield and minimize "waste". Second, we ought to be looking at the waste of the unaltered plant as potential feed stock for useful by-products.

Third, biomass waste for which no useful purpose has been found does not have to go on the compost heap to produce "nothing but methane and mushrooms", useful as both may be. In Wisconsin, Biotronics Technologies (W226 N555B Eastmound Dr., Waukesha WI 53186) has developed - for NASA - "biodigesters" which turn "waste" biomass into an edible tofu-like product that can be used as a food supplement or staple. These devices are demonstrating an efficiency of 98% — that is, there is a stubborn inedible residue amounting to no more than 2% the original biomass weight. We can dismiss the dismissers of cotton, then. Yet more research is needed.

The primary reason for raising cotton in space frontier farms remains fiber for clothing, bedding, toweling, cushions etc. Cotton is still the most comfortable fabric known to man, and happily the one with the largest oxygen content, making it the least expensive of all fabric options for any settlement or outpost dependent mainly on lunar resources. (Those who wish to try Jockey shorts made of fiberglass are welcome to do so.)

However, we currently subject cotton to a lot of treatments that would be inappropriate in a closed lunar biosphere. Mercerizing, which treats cotton yarns or fabrics under tension with caustic alkali in order to increase strength, luster, and affinity for dyes is an "*unkosher*" no-no — *mixing organic and inorganic materials* renders the latter unfit for recycling (i.e. the precious hydrogen and carbon content). Use of inorganic dyestuffs is out for the same reason.

Happily, breeding of new cotton varieties in which the fiber is "naturally colored" has already reached the market. Yellow-tan, rich brown, and green *naturally-colored* clothing, sheets, and knits bearing the *Foxfiber* brand are now available - with blues, yellows, and lavenders under development. This obviates the dying process altogether, along with the stress even vegetable dyes put on tightly recycling water systems.

All this means that the Cotton Goods Industry on the space frontier will look quite different from the one we are used to, even considering only the traditional fiber products. That industry will meet several important settler needs. Further it should provide a source of export income marketed to all pockets of humanity from low Earth orbit on up. For once the start up costs are amortized, Made-on-Moon cotton goods should be cheaper to deliver anywhere in space than those manufactured on Earth's nearby but gravid surface.

But if cotton can be used to produce not only fiber and oil (cottonseed) but now also food (tofu) and maybe other products, it will join the prestigious company of other already well established "cornucopia" crops. As it happens, many of these versatile plants are also well known in the southern United States. We discuss some of them below.

Sweet Potato Byproducts:
Peanut Plant Byproducts:
Soybean Products:
The George Washington Carver Story

George Washington Carver 1864-1943, pioneer black botanist and chemist working at Alabama's Tuskegee Institute, motivated by a desire to improve the economic conditions of southern farmers, gardeners, and orchard growers, and driven by the conviction that "every waste product is an undeveloped natural resource", developed and patented over 300 useful byproducts of the sweet potato, and a hundred-some byproducts of the peanut. He also worked with the soy bean, velvet bean, and pecan. His research career spans the period '97-'37; his most creative work taking place in the 1910s and 20s.

Food byproducts included flours and meals, six breakfast foods, candies, donuts and breads, flavorings for ice-cream, a milk and derived ice cream and buttermilk, a worcestershire-type sauce, a soy-like sauce, a coffee-like drink "superior to Postum™", curd cheeses similar to Neufchatel and Edam, soft cheeses, a peanut milk from peanut flakes and water, a relish, punches and fruit juices, vegetarian steaks and meats, and more!

Other products included such diverse preparations as inks and facial pomade creams and perfumes, soaps and glues. He even patented a fabric, Ardil™, about which I was able to learn nothing at all.

Whatever food processing system he was using at the time yielded a residue, of course, and he looked at that residue (similar to mining tailings etc.) as a challenge and opportunity, as something pregnant with new possibilities. He experimented endlessly and prolifically with an open mind.

How many of his inventive concoctions and preparations are being marketed today? I don't know. Assuredly many of them must have been of inferior quality, from a consumer point of view, to alternatives on the market from other sources. For us the question is a rather different one. On the early space frontier - a brave new world laden with "rough edges" - when importing ready-to-use food luxuries, cosmetics and household preparations will be pricey if not prohibitive, could some of Carver's patents be used to create a home-grown supply of some of these items on the Moon and in Space Settlements?

The answers will expectedly be a mixed bag. Without a detailed item by item patent search, it is impossible to say which of Carver's inovations require major secondary ingredients that will have to be imported. Some lines will offer more promise than others, to be sure. But for those interested in honing the edges of the rough early frontier, and making it a more attractive opportunity for settlement, a good deal of scholarly research awaits.

First (and none of this was I able to do at the central Milwaukee Public Library), √ get a definitive list of all of Carver's patents, if possible with the dates and patent numbers (but at least the dates); second √ look up each patent in question to uncover which processes and *secondary ingredients* he used in each case.

Some possible RESEARCH SOURCES for you to start with: national, state, and regional Peanut Growers' Associations, Sweet Potato Growers' Associations, etc. The Tuskegee Institute.

Even apart from a detailed look at Carver's work, it should be apparent to anyone observant that crops like the **Peanut** yield diversified products: raw, salted, and roasted peanuts; peanut butters and candies, cookies, and frostings (even milk shake flavorings, and I've stumbled on a soup recipe with a surprisingly complex and pleasing taste!) derived from it. The crushed peanut "cake" (minus the oil which itself is the start of a whole other family of products, some of them industrial) yields flours and meals.

Cellulose-rich peanut shells (36% of the pod weight is here) are a source of fiber - they even come in different hues depending upon soil chemistry. The fiber is not as hard as wood, nor as soft as paper. Peanut shells are also easily turned into a suitable craft material for children's temporary creations, easily recycled later provided any decor materials used with it are kosher (organic and themselves biodegradable like vegetable dyes). They can be cut, shaped, filed and filled, painted, glazed, glued, and strung. Their use on the space frontier for this purpose would help stimulate young creative and artistic imaginations, used in whole or part to make toy people, animals, abstract designs, and jewelry. Even peanut shell sawdust with an organic binder makes a workable child's clay.

The top of the peanut plant is used as fodder along with the press cake of peanut seeds. Does not such a crop, with its promise for food sector industrial diversification, merit serious consideration for a major place on space frontier farms?

The Sweet Potato, Soy Bean, Peanut and other multi-use crops are also key to enriching and diversifying not only space frontier menus, but the whole existence of the pioneers. Those planning lunar and space agriculture have to take off the horse blinders and start looking beyond the salad bar - *way beyond!* Rather it is the single use crops that should be after-thoughts. This amounts to a revolution in current thinking.

We cannot wait until CATS, Cheap Access To Space, suddenly opens the gates to the frontier to start thinking about these things. The time to roll up the sleeves and put on the thinking cap is now. MMM

Saproculture & Saprochemicals

Fungi, Mushrooms, and some Orchids are among the better-known plants which grow on decaying vegetable matter. Many of these plants are poisonous. In addition to the well known variety known as *the* mushroom, *agaricus campestris*, there are many other species of mushrooms which are not only edible but almost addictively delicious and delicate. There seems to be a widespread myth, moreover, that such plants offer empty taste without real nutritional value. Not so!

Where there is agriculture, there will be waste biomass with which to make compost or feed the biodigesters. Why then limit food production to the anabolic photosynthetic part of the biocycle? If food, especially something to add diversity and interest to limited frontier table fare, can be teased out of the biomass decomposition cycle, that makes the whole farming process that much more efficient.

While there is, to be sure, a minority with insensitive taste buds who do not appreciate fungial foods, for the sake of the rest of us there ought to be concerted research on home growing of other mushroom and truffle varieties now mainly picked in the wild. Next you can experiment with ways of serving and preparing your harvest: stewing, sautéing, frying, grilling, stuffing, etc. (The Encyclopedia Brittanica under "Mushrooms, Cookery of" even gives a recipe for "mushroom ketchup"!) Here is yet another space research project for you home gardener types. Our spiritual descendants sitting down around space frontier dining tables will remember you when they say grace.

But let's go one mighty big step further. Wouldn't it be utterly amazing if the various catabolic processes at work in the compost heap or the biodigester did not produce liquors and exudates that could serve as alternative feedstocks for a frontier chemical industry. Here is a whole new field of research for you organic chemists out there. Why not take a stab!

Bioextraction of Trace Elements

In MMM # 63 MAR '93 Lunar Industrialization, Part I, "BENEFICIATION", p4 we tried to stress that the elements present in the "oreless" lunar regolith in major abundances can not adequately underpin an autonomous industrial base, that we need to learn to efficiently extract other elements present in parts per thousand, parts per million, even parts per thousand concentration. This is a tall order for tried and true chemical engineering methods, especially for the lesser trace elements present. There is another tack: Bioextraction.

We can start with soils known to be atypically enriched with the desired elements. Fra Mauro basalts (Apollo 14 *Antares* mission) are richer in Br, Cl, F, Pb, Zn. KREEP soils splashed out from the Mare Imbrium impact have Cl, Pb, Br, Zn, and Ag on grain surfaces, in higher than expected ppm and ppb concentrations. These are all water-leachable.

Leach water from such soils can then be used to host element-concentrating bacterial and other cultures. Harvested bacterial, microbial, or yeast material would then provide us with an organic "ore", a higher plateau from which to then apply standard chemical engineering methods.

Bioextraction can be piggybacked on the importation of soils into pressurized farming areas, or practiced separately. Either way, it is critical to lunar industrialization. MMM

Arborculture, an alternate path?

A couple of years ago I read a short illustrated piece on something dubbed "arborculture", probably in Popular Science or Popular Mechanics, but I haven't turned up the actual source. In this proposed alternative to "agriculture-as-we-know it", the *sole* conventional crop grown would be a species of fast growth soft pulp tree.

The harvested pulp would then be finely powdered and, with water added, become a nutritious broth for a wide variety of specially engineered bacteria which would thereupon busily and efficiently produce all the end-use food and fiber tissues and other organic products we desired with near zero biomass waste for extremely high food growing efficiency.

The proposal was not specifically put forward with the space frontier in mind, but the potential suitability should be obvious. Something to keep on the lookout for - MMM

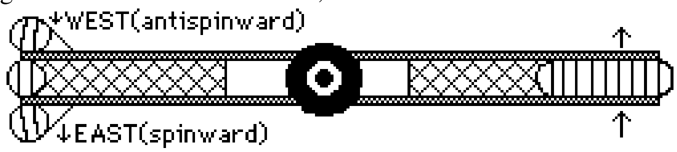
"Always listen to experts. They'll tell you what can't be done and why. Then do it." - Robert A. Heinlein

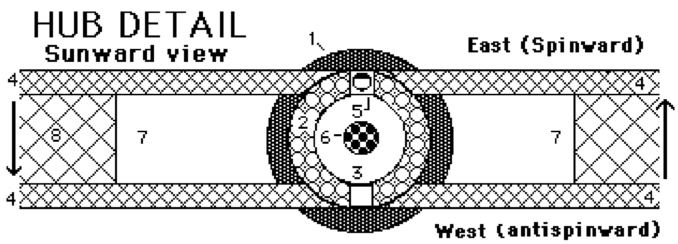
a "FLOATING" HUB

for a Wheeled Space Station

By Peter Kokh and Doug Armstrong,
Copernicus Construction Company

INTRODUCTION: In “The Frontier Builder”, our definition and design exercise for an Earth-Moon cruise hotel with artificial gravity [Cf. **Moon Miners’ REVIEW** # 12 JAN ‘93 pp. 2-8], we pioneered the idea of a floating hub to handle the shifting center of gravity that might occur in our dumbbell shaped structure as people and supplies are loaded and unloaded or shift from one end to the other. This worked well in the *special* case of the dumbbell because the potential center of gravity shift occurs along a fixed axis. For those who do not get Moon Miners′ REVIEW, this is summarized below.

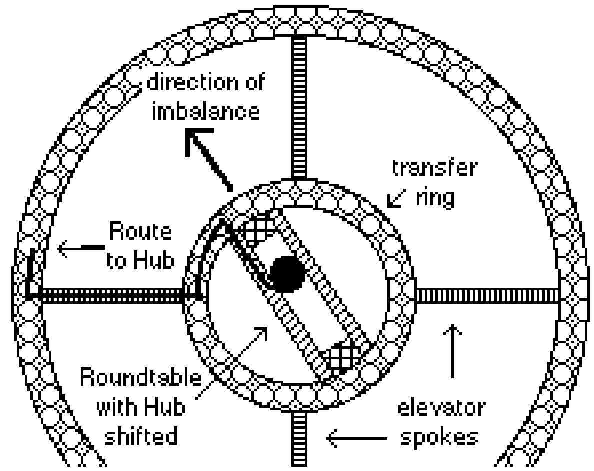




> **(4) Twin elevator shafts** bind the spinning Transitel ensemble. The two shafts are in the plane of rotation, with the center of rotation in between them.
>
> A **central bay (7)** is free of cross bracing **(8)** to allow free floating room for hub core, linked between the elevator shafts to sunward co-floating flywheel-flareshield complex **(1)**. The twin shaft boom is long enough to maintain an average 145 meters between the mid-decks of habitat wing and the floating **hub core (3)**.
>
> The average actual distance from floating hub to either wing depends upon the weight ratio of the two sections, which need not be maintained at 1:1. Hub core free-floats the rails along the inside edges of the twin elevator shafts. A pair of gravimetric sensors attached to the hub rail-riding mechanism in each direction along the twin elevator shaft boom allows it to find and follow the actual center of rotation, no matter how the masses are split between the two ends of the “dumbbell”. As weights shift, either the nominal 1/6th G gravity level can be allowed to shift as well, or the nominal 1 RPM can be shifted by a flywheel **(1)** to compensate for shortening or lengthening of the Hotel Wing to hub radius.
>
> The hub core has **docking port** complex **(6)**. A pair of **Transfer gates (5)** along with the Rendezvous Vestibule towards the outer rim of which they are placed, are spun up from 0 RPM to 1 RPM coming to rest with its transfer airlock over the elevator shaft. Elevator cage (in **5**) is shown in position at one gate. Cage with weighted free-pivoting pressurized compartment stops opposite airlock of transfer gates in Rendezvous Vestibule for passenger transfer. The stop is triggered by the floating presence of the transfer gate, not to a fixed position on the elevator shaft.

In a wheeled or torus station or settlement, the case is not so simple, as mass displacement is not confined along one specific vector. Thus, at first consideration, the floating hub concept seemed to offer no *general* solution to the problem of oscillating center of gravity, off center from the design center of structure, an obstacle for docking at a non-rotating hub.

But a second look at the problem yields a potential solution inspired by the venerable railroad yard roundtable.

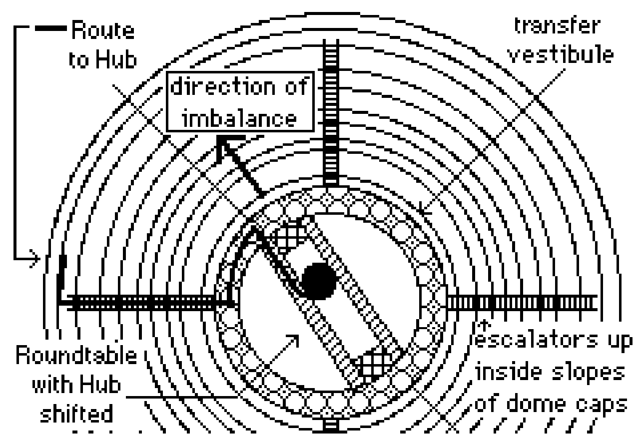


“ROUNDTABLE” HUB. The hub floats in the central bay of a rotatable twin shaft roundtable with available “stops” every few meters or degrees (5°?) along inner transfer ring.

In this concept, the 4 (as illustrated, or 6) spokes of the wheel would attach to a second fixed co-rotating inner vestibule torus. Every few meters along its inner periphery there would be gates by which transfer can be made to the floating hub in the central bay of a rotating, imbalance-following twin-shafted roundtable. As in the simpler dumbbell design, both roundtable alignment and hub position would be set by electric motors attached to gravimetric sensors.

In such a system, temporary imbalances (everyone attending a concert in section C; Colombian coffee being served in section B; construction in section A; meteorite damage in section F; etc.) would still allow easy, trouble-free docking at a center of gravity hub flexibly displaced from the design center of structure.

This concept should be adaptable to an O’Neill colony structure as well.



“ROUNDTABLE” HUB at either hemispheric cap end of a classic O’Neill Cylinder Space Colony structure. **CCC**

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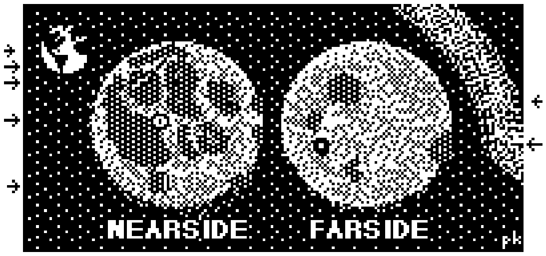


"Must See" Sights for Tourists on the Moon

Anyone coming to the Moon will see and experience quite a bit, enough to acquire a lifetime of memories, just in the landing and departure process and in the short taxi from the pad to the settlement airlocks — without having to go out on special expensive surface excursions. All the same, it would be a shame to make a half million mile round trip without getting to see up close a typical range of Moonscape terrain, and if possible, at least some of the best this world has to offer. See "7 Wonders of the Moon" below.

Producing for Export: Bringing Home the "Bacon & Brass"

by Peter Kokh

Relevant READINGS from Back Issues of MMM

[included in MMM Classics #1]
MMM #2 FEB 87 p3 "Essays in M": M is for Market

[included in MMM Classics #3]
MMM #22 FEB 89 p3. "!st Exports"

[included in MMM Classics #4]
MMM #32 FEB 90 p4 PRINZTON; Part VI:
C. Lunar Export Categories;
D. Export Destinations;
E. Strategies to Increase Exports.

Despite a dedicated "MUS/cle" program [MMM # 18 SEP '88 pp. 3-4 "Lunar Industrial MUS/cle", and MMM # 65 MAY '93 pp. 7-8 "The Fast Road to Lunar Industrial MUS/cle and the Substitution Game"] and an aggressively played "Substitution Game" [MMM # 65 May '93 p.3.]. there will still be a stubborn core of costly imports, including, most importantly, the "passage" of settlers themselves. Frontier settlements must pay this bill with the coin of export earnings. Accordingly, with all due respect to the law of diminishing returns (i.e. there comes a time when added effort does not yield commensurate reward), every opportunity to diversify exports and take advantage of new market niches must be explored.

The "Cost of Living" on the Moon may well be astronomical, measured in dollars. But the Lunan "Standard of Living" may be quite comfortable nonetheless — if Lunans can find enough ways to pay the bills. We think they can.

In theory, the export *potential* for lunar settlements is both much broader and much deeper than most would suspect. In reality, everything will depend upon 1) how fast the lunar economy can diversify, 2) how favorable is the climate and support structures for entrepreneurial initiative, and 3) how fast the productive sector of the settlement population can be made to grow. All three of these questions deserve articles or series of articles in their own right. We'll treat each of these topics in future issues. Right now we want to explore the *potential*.

Lunar Exports to other Space Markets

If the first rule of import policy is not to import more of what you already have (the so-called "no coals to Newcastle" policy i.e. the Moon should avoid importing items rich in silicon, oxygen, aluminum, iron, titanium, calcium, and magnesium) the first rule of export policy is just the reverse. The settlements must strive to exploit the potential market value of those very same indigenous assets to the fullest. All lunar development scenarios start out in this same direction. And then they pull their punches.

Let us take oxygen for our first example. It is now the common wisdom that production of liquid oxygen be given first priority. This oxygen would be intended for use as rocket fuel oxidizer to help reduce the fuel cost of imports, and to make water for the settlement by combining it with imported hydrogen in fuel cells, a process which will recover, hopefully during nightspan when it is needed most, some of the energy which went into its production.

Liquid "lunox", would not only be used for Moon to Earth travel, but could also be delivered at a substantial competitive price advantage to low Earth orbit, where it could help refuel new outbound deliveries. But this seems to be the limit of imagination in published scenarios.

By the same token (oxygen can be delivered to LEO from the Moon at substantially lower cost than it can be resupplied from the much nearer surface of Earth just below), Lunox should be combined with hydrogen brought up from Earth to make *all the water used in low Earth orbit* facilities: space stations; tourist resorts; orbital processing and manufacturing facilities, etc.

Pressing the advantage a step further, the cost is still more than competitive if the lunar oxygen arrives in LEO *already combined* with terrestrial hydrogen to make the water and protein and carbohydrate in food tissues. Of course these savings will be maximized if only dehydrated or concentrated food product is shipped from the Moon, along with the oxygen with which to make the water needed to rehydrate it. In short, there is a market in LEO for lunar agricultural products — in LEO *and any other space location* at which on site food production is inadequate to fill the need.

Lets extend the argument to building materials made from lunar regolith soils: metal alloys, ceramics, concrete, glass, fiberglass, and glass-fiberglass composites ("Glax"). It may well be that the biggest market for such products is in construction of space-based facilities: new and more spacious space stations, orbital resorts and factories, solar power satellites, space construction camps and space settlements etc. But just as on the Moon itself, there is a substantial secondary market for these materials in utility system elements and in furniture and furnishings, these very same items can be produced in excess of local lunar need for export to all of the above space markets.

On the Moon, the cheapest fabric will be locally produced naturally dyed [see MMM # 48 Sep 91 p. 8] cotton since it is an unrivaled 50% lunar oxygen by weigh. Given the lower fuel costs needed to bring it to market in LEO and other space sites, lunar cotton and the apparel made from it should be marketable at a real price advantage over fancier cottons and other fabrics produced on Earth. This argument extends to other cotton uses as well: upholstery material, toweling, bedding etc. Lunar grown linen will enjoy a similar advantage.

In short, the Moon will not only **build** the bulk of future space facilities, but **outfit** and **furnish** them, and **feed** and **cloth** their occupants. That's a diversified export basket!

But we can do more. There are many items that we can expect to be in demand in the various space locations but on which lunar enterprises will not soon, if ever, be prepared to enter a *complete* bid. Yet *if* lunar appropriate industries can supply some of the weightier components - according to the MUS/cle scheme - then the potential cost savings through lunar sourcing may make it attractive to assemble the needed items in space, using lunar and terrestrial components both.

We are talking about products in which "the works", the complex, often electronic, and sometimes lighter weight subassemblies that can only be manufactured by sophisticated techniques on Earth require for completion a casing or cabinet or body or support structure that is functionally simple enough to be made of a wide variety of basic materials, and often (not always) comprises the more massive fraction of the total item. These latter less demanding components can be manufactured on the Moon just as easily as on Earth. Items in this category include major and minor appliances, machine shop tools, vehicles - yes, even space vehicles. See the article "COSMOTIVE, INC." below.

Its simple, really! The same industrial "MUS/cle" strategy that can help lunar settlements minimize the total tonnage of imports they need to survive and grow, also provide them with a strategy to maximize their collective penetration of other space markets.

Lunar Exports to Space Markets
OXYGEN (air, rocket fuel, water constituent)
OXYGEN-RICH (food, cotton goods, farm products)
BUILDING MATERIALS (iron & steel, aluminum, titanium, magnesium; ceramics, concrete, glass, fiberglass, glass-fiberglas composites)
MANUFACTURED GOODS (furniture & furnishings)
COMPONENTS (tanks, shelter, vehicles, machines, appliances, and more)

Lunar Exports to Earth Surface Markets

None of these strategies will help Lunans come up with items to sell directly to Earth. All of those categories in which lunar enterprises can be competitive in Earth orbit and beyond will on Earth itself be far more cheaply purchased from even the most exclusive and expensive of terrestrial suppliers.

Space-based energy will clearly be the most profitable of the Moon's exports to Earth itself. This trade will be indirect in the case of solar power beamed from satellites and relay stations constructed in space largely of lunar materials. If lunar surface-based solar arrays are used, profits may be higher even if energy collection-transmission efficiency is less.

Lunar Exports to Earthside Markets
ENERGY (lunar built solar power satellites; lunar solar arrays; helium-3 fusion fuel)
TOURIST EARNINGS ETC. (lunar vacations, use of lunar owned facilities and vehicles elsewhere)
MANUFACTURING LICENSES
GEOSCOPY (lunar remote sensing installations)
MISCELANEOUS (souvenier giftware, arts and crafts, movie studios, television productions)

And then there is Helium-3. If fusion power becomes a major player in the terrestrial energy supply mix, and if the exploitative (in the worst sense of the term) "see-want-take" regime has been rejected in favor of "purchasing for fair value" *from those who live where the supply is to be found*, the percentage of profits from the energy trade that flow directly into lunar coffers could be the greatest.

A very respectable second Moon to Earth export could be tourist experiences. See the article "TOURIST EARNINGS" below. For a long time this market will be small, limited to the slowly growing "jet setter" class given to vacations that are well out of the ordinary and well beyond common means.

For those who can only dream about in-the-flesh travel beyond Earth's atmosphere, film making studios on the Moon will take in some small fraction of the terrestrial entertainment dollar supplying the Earth-bound with the vicarious second best. Lunar TV stations carrying sports events and dance spectaculars unique to the Moon's fractional gravity ("sixthweight") could someday earn a respectable portion of the terrestrial commercial advertising dollar.

Then there is income to be earned from the sale of manufacturing licenses for processes and products developed on the Moon but for which there is potential demand on Earth *if* shipping costs can be factored out. At the other end of the spectrum, for those who don't have to ask "how much does it cost", there will be a small luxury trade in lunar souvenirs and giftware, furnishings and fashions, jewelry etc.

Geoscopy - dedicated scanning of the Earth's surface, is an area in which lunar surface installations may in some instances be less expensive to deploy, cheaper to maintain, and less constrained by size and mass restrictions than those incorporated into Earth orbiting satellites. Interferometric remote sensing in the full range of the visual spectrum as well as in other ranges of electromagnetic radiation could become a modest money earner.

The list above is by no means either definitive or all inclusive. Yet you can see that it includes energy, materials, manufactures, arts and crafts, experiences, and services. On Earth those nations do best over the long haul that are not dependent on just one narrow export category but rather have diversified their export offerings with a wide range of mineral, agricultural, and manufacturing products - and services. It will be no different with nations whose homelands lay beyond Earth orbit. Earning too large a fraction of the trade dollar from just one item is a prescription for disaster. Such monocrop or monoproduct reliance makes a national economy vulnerable, wide open to collapse if another cheaper source is found for their one and only commodity.

It takes all kinds of people with all kinds of talents to make a society. It takes all kinds of products and services to make an economy. So too, it takes all kinds of products and services to make a healthy export base. The lunar frontier economy has this potential to fill this mold someday, and it should be able to play the game well - *if* lunar industrialists and entrepreneurs exploit all the aces and play all the trump cards their adopted home world offers them. MMM

Cosmotive, Inc.

by Peter Kokh

Fuels Division

Most brainstormed Lunar Development Scenarios call for earliest possible **Oxygen** production. We need oxygen to make water, for atmosphere and biosphere, and as oxidizer for rocket fuel. The intent here is a) first to reduce the cost of return crew and cargo trips to orbit and back to Earth, and then b) to ship lunar oxygen to low Earth orbit cryogenic refueling depots to lower the cost of further Moonbound supply and resupply shipments from Earth, and finally c) to reduce the cost of expeditions to Mars and the asteroids.

While in water vapor, the combustion product of LOX and LH_2, there is an 8:1 mix by weight, the actual mix going in is a hydrogen enriched 6:1. So lunar oxygen cuts the cost of of 6/7th of the fuel mass. How can we do better?

An early and still often mentioned proposal is to use the hydrogen imported to the Moon to best advantage by first combining it with local silicon to make liquid **Silane** SiH_4 (a nominal analog of methane) and use that instead of hydrogen as fuel. While Silane is less potent than LH_2, its use promises to reduce the freight bill of sustaining the outpost or settle-ment by a significant enough percentage to be worth pursuing once the demand justifies the cost of required capital equipment. In the Silane family are other potential liquid fuels, some of which should work even better, such as Si_2H_8.

Are there other potential totally indigenous lunar fuel combinations? *In theory, yes!* Oxygen has a high enough affinity for Iron, Aluminum, Calcium, and Magnesium (all rather abundant in lunar soils) to make good fuel combinations — on paper. Most discussed are Iron, which exists in handy abundance as powdered fines, and Aluminum, which, alloyed with 25% Calcium, makes a very friable easily powdered alloy.

However, we have yet to engineer a [chemical] rocket engine that can use such fuels. It's not a matter of engineering difficulty so much as the fact of life that in none of NASA's scenarios is there more than token lunar development. Thus there is not enough perceived need to justify the expense of R&D on such fuel combinations and the motors to burn them.

Those of us interested in seeing tumble the "NASA Wall" that prevents opening the space frontier to the general public (as opposed to token elite proxies for voyeuristic grati-fication) need to find and/or encourage entrepreneurial deve-lopment of such transportation modes. Even if cheap access to space (CATS) is realized in the Delta Clipper program, the cost of shipment of goods into and out of the lunar gravity well will remain higher *than it needs to be* without the development of refueling options using "all lunar" fuels.

Once all the fuel needed to refuel a rocket bound for the Moon in low Earth orbit is produced locally on the Moon, the settlement's net bill for shipping and freight costs for needed imports the rest of the way from LEO to the Moon becomes moot. Not only will it be cheaper to import, but the fuel overhead cost of exporting will fall, increasing whatever competitive advantages that might already exist.

Hold & Hull Division

As we've hinted, space pioneers ought not to rest content with diversification of production for export and with maximizing market opportunities. They can improve their competitive position by paying themselves for the freight bill of both imports and exports. Using lunar-sourced fuels at every opportunity is just one part of this effort. Locally supplying as much as possible of the containers and vehicles used in import and export shipments will boost savings even further on items already competitive, and may make the competitive difference for other items marginally short of being so.

The idea of a Lunar Frontier Aerospace Industry will elicit gaffs of laughter from many. But recall the MUS/cle paradigm for lunar industrialization that we've previously recommended. [MMM # 18 SEP '88 pp. 3-4 "Lunar Industrial MUS/cle", and MMM # 65 MAY '93 pp. 7-8 "The Fast Road to Lunar Industrial MUS/cle and the Substitution Game"]. It is an "appropriate" lunar aerospace industry we are advocating.

Lunar industry should not concern itself with those complex, lightweight, and electronic ("cle") components which require a sophisticated industrial base to manufacture and which can be made on, and shipped from Earth relatively cheaply. Instead, frontier industrialists should concentrate on the more massive, unitary, and simple ("MUS") components. These are items that would otherwise cost a lot to import because of their aggregate weight, but which can easily enough be made in the settlement's startup industrial shops.

What is needed is a glass composites industry to start off production of tanks, body panels, spars and truss frame members, etc. Second generation industries using local iron, magnesium, titanium, and aluminum can expand the selection of aerospace products it is possible to fabricate locally.

We are talking about:

√ **fuel tank**s both for depots and on ship,
√ unpressurized **cargo holds**
√ pressurized **crew compartment hulls**
√ **aerobrake shields**
√ **truss frame members**, etc.
√ many other lesser parts that "all add up".

A Lunar aerospace manufacturer could make these components and then assemble them with imported "works" cartridges (e.g. electronics such as navigation, control, and communications consoles, engines etc.) and slip-in harnesses etc. to make complete ready-to-fly craft.

Going one step further, here is no reason why Lunar industry could not make drone **Lifting body hulls** so that exports to Earth's surface could fly nonstop from the Lunar surface aboard one way space craft the majority of whose mass was manufactured there. There is precedent aplenty for such divided manufacturing. Martin Marietta, for example, maker of the Titan rocket, only makes the rocket *casings*, and then mates them with engines and other components made by other firms like Rocketdyne.

And as for more sophisticated space hardware? Why couldn't lunar owned & operated **salvage companies** retrieve derelict satellites and other largely intact space hardware for rebuilding in lunar shops, and eventual reflight and reassignment?. Why accept preconceived limits?

¢OIN$ of the Realm

by Peter Kokh

So long as all the companies, buyers and sellers both, engaged in the development and recovery of space resources are Earth-owned, -operated, and -situated, the age of interplanetary trade will remain in the future. Everything will operate in the regime of "me see, me want, me take".

Balance sheets will be kept in terrestrial board rooms, of course, but they will compare the "cost of taking" with the profits from sales. Upfront capital investment will be risked, but not without reasonable promise of rewarding return in timely fashion. But these "balances" will be internal in nature. All monies involved will stay on Earth.

Once, however, there are settlers and settlements on the Moon or elsewhere in space who can effectively demand treatment as economic entities in their own right, and are able to bargain for a say in the terms and conditions by which the non-terrestrial resources they make available to satisfy Earth needs are delivered - then the age of genuine space "trade" will have begun. As more and more of the companies involved are settler-owned and frontier-headquartered, the settlements' collective economic bargaining power will increase.

As supply is no longer able to be taken for granted but becomes instead something to be bargained for, the balance of "deal power" will shift out of terrestrial boardrooms and into space. Supply will cease to consist solely of found resources. Instead Earth companies will have to pay for the "value added" in settler mining and processing and shipping.

When we first move past the see-want-take regime into the realm of export-import equation economics, barter arrangements will be the principal way of doing business. That is, we will be in an era in which Earth's off planet trading partners have yet to establish "hard currencies". Earth markets get so much delivered energy (and/or helium-3 shipments) in a negotiated exchange for so much hydrogen, so much micronutrient fertilizer, so much electronics equipment, so much copper, so many vehicle engines, etcetera.

The next stage of transaction measuring will involve some combination of import credits on Earth coupled with energy and resource futures on the Frontier. Deals will be made for solar energy futures, helium-3 futures, lunox futures, building materials futures, etc.

On the settlement side, the first milestone will be to balance imports with exports, or alternatively to restrict imports to what can be purchased with exports. The long range goal will be to achieve a comfortable surplus margin in that trade - with favorable long term prospects. Only then will the settlements achieve genuine, and stable, economic autonomy, something they can bank on, and with which they can confidently plan their future growth-enabling purchases.

On Earth barter still lives, especially between "hard" convertible currency nations on the one hand and "soft", inconvertible currency nations on the other. At first, trade between Earth and space frontier "nations" will probably follow this pattern. It will be very difficult base transaction "prices" on anything other than mutual supply and demand deals.

On the frontier, currencies will be established to handle transactions between settlers etc. But there, at least, there will be some shared commensurability of personal income and the cost of locally supplied goods. The price of a loaf of bread, of a pound of meat, of a month's rent or mortgage payment will bear some sane relationship to weekly or monthly income. But it will be hard to equate either frontier wages or prices to those on Earth in any direct sense.

It may cost a couple of hundred thousand dollars an hour for an Earth firm to keep a lunar worker on the job. But as we move from an Earth-based space frontier economy to the era of domestic space frontier economies trading with Earth, the situation changes utterly. A very, very pale example is offered by the comparison of household economies in Alaska with those in the continental U.S. In Alaska, the "dollar cost" of living is significantly higher. But so are the wages. The result is that the "standard" of living, how much consumer comfort a family can afford, is much more closely comparable. To be honest, comparing wages or prices on Earth with those on the Moon will be like comparing apples and oranges.

Meanwhile, as space resources and terrestrial markets for them codevelop and evolve, the relative value of specific frontier import items to that of specific export commodities is sure to fluctuate considerably. Under those circumstances, using the dollar as the medium of exchange within space frontier domestic economies would then introduce wild and uncontrollable variability.

The answer is a separate lunar or frontier currency. But until such a currency has achieved some basis of convertibility with terrestrial hard currencies, it will function more like a military "script". That is a local currency may be minted and printed to serve as the medium of exchange between settlers, but not serve as a medium of exchange for Earth-Moon trade.

Such a currency could be named "the (lunar) dollar", of course. But the settlers might just as easily christen it the "tanstaafl" after Robert A. Heinlein's acronym for "there ain't no such thing as a free lunch" in his novel "The Moon is a Harsh Mistress". After all, "paying their own way" with exports will of necessity become a national frontier preoccupation, pursued with considerable dedication and persistence. The alternative is ultimate certain failure of the settlement.

For Earth-Moon trade, lunar companies may choose to sell to Earth concerns only for payment in dollars or other hard terrestrial currencies. Additional dollars etc. will be taken in from tourists. This pool of Space Dollars (akin to Euro Dollars) could then be used to pay for imports.

As Frontier domestic economies grow in size and stability, however, some form of "solar credits" or "drawing rights" will come into being. This may be based on a precious commodity whose supply is not affected by the opening of the space frontier - if there is such a commodity - or perhaps on the cost of a set "market basket" of items delivered to a middle-of-the-gravity-gradient location such as low Earth orbit. Or, such a systemwide currency could be valued in terms of some much traded commodity whose price has proven relatively stable over the long term. This could be hydrogen or copper or helium-3 or platinum - it is hard to guess. . MMM

Tourist Earnings

FOR SALE: Unforgettable Experiences & Unequaled Opportunities

by Peter Kokh

Profits from space tourism to be plowed back into the Lunar economy, can be earned for the Moon only to the extent that the tourist operations involved are owned, operated, and equipped by settlers. If at first this seems an unlikely scenario, consider the cost of building tourist resorts in LEO [Low Earth Orbit] from materials brought up from Earth in comparison to cruder yet comparable facilities built of materials processed from lunar regolith - the twenty-fold savings in freight charges will tip the edge to companies able to supply the latter, once the necessary upfront capital investments have been made.

Initial LEO resorts prefabricated on Earth will be small, however luxurious. Ample and spacious complexes able to accommodate a much wider range of activities (read zero-G sports and recreation) will have to await the breakthrough in construction costs promised by NTMs — Non-Terrestrial Materials. Compare 50s era Las Vegas resorts with those of today and multiply the difference by a hefty factor!

That said, earnings from the use of lunar materials to support expanded tourist opportunities in space will only flow into lunar accounts to the extent that the building materials manufacturers and construction companies involved are settler-owned and/or settlement-taxed. Unfortunately, there are ample past models for exploitative colonialist rape-theft of foreign resources to give us ample warning that without the proper legal-political-economic regime in place, space frontier settlers could well end up not seeing a penny of the profits. Indeed, some of these unsavory practices have been at least implicitly advocated in development schemes put forward by some space advocates emotionally opposed to surface settlement by "planetary chauvinists".

Assuming that we set things up right however, the construction, outfitting, and servicing of tourist facilities in LEO should provide a major market for the lunar economy. After all, tourists are *the one* thing it is far more profitable to source from Earth than from off-planet! And LEO is their handiest, least expensive "off shore" destination.

"Build it and they will come" — for the rocket-thrust experience of liftoff, for the sensation of weightlessness, and for the angelic, olympian views. Those not plagued by space-sickness will get "the experience of a lifetime" promised by the hype ads. As ticket prices moderate and demand increases it will become profitable to offer "enhanced" orbital vacations.

Exercise, sport, and even dance classes and events will exploit the opportunities of weightlessness. To make the most of the unparalleled views, there will be both "heads-up" view-plate display aids and experienced human guides to help sightseers identify and understand the geographical, geological, ecological and environmental, geoeconomic, and meteorological clues in the brilliantly sunlit panoramas below.

Picking out major and minor cities by their night lights will be a popular pastime. For astronomy buffs, the twinkle-free brilliance of the quickly shifting starscapes will bring a foretaste of heaven.

The leap from Earth Orbit tours to deep space excursions such as lunar swingbys is relatively easy. [MMM # 21 Dec. '88 pp 2-5 "Lunar Overflight Tours" available by SASE plus $1 to "LRS"] If part of the vehicles (and their outfitting) involved is "Made on Luna", some of the revenues from this extension business will help boost the lunar economy. Better yet if the companies serving this trade are settler-owned.

Tours to the L4 and L5 Earth-Moon co-orbital fields, which may be the site of considerable construction and manufacturing activity and boast settlements of their own, will also become popular early extensions of LEO tour stays. From these twin vantage points, Earth and Moon can be seen together, 60° apart, and in similar phases (new, half, full, etc.). Excursions still further out may also be available.

As to "land excursions" on the Moon, in the early days when the preoccupation will be with building and establishing the first settlements and coaxing them toward some degree of self-sufficiency, it may not be possible to "visit" the Moon except on "working tours" as part of construction or prospecting crews, much as people now pay to go on archeological "digs". Eventually, traditional "pampered tourist" type vacations will be introduced.

Such offerings will probably await the day when any and all new pressurized habitable space on the Moon is constructed of materials processed from the local regolith soils. Until then, the per square foot cost of habitat prefabricated on Earth will be much too high to squander on tourist activity for anyone other than the obscenely well-to-do.

For sightseeing surface excursions, pressurized cabins retired from Earth-Moon ferries and fitted with wheeled chassies and suitable motor units ["toads", cf. MMM # 48 SEP '91 pp. 4-6 "Lunar Hostels: Part I: Amphibious Vehicles] should be available as sleep-on go-anywhere coaches. They might be brightly colored ("Tangerine Toads"?) for safe visibility in the overly gray setting, operated by a commercial distant cousin of Greyhound (Grayspan?).

As for touring Mars, that is an altogether different set of ifs. It is unlikely there will be any sort of tourist activity out that far until tested and proven second generation *nuclear* rockets are available that can significantly reduce travel times and total cosmic and solar radiation exposures. First to become available will be tours to Phobos and Deimos, Mars' two close-in moonlets. These tours will feature extended observation of Mars from relatively high orbit (3,700 and 12,500 miles over the Martian surface, respectively).

However, much closer fleeting glimpses of the daylit side approaching and coming out of the aerobraking maneuver that ends the "cruise" out from Earth and puts the craft on a trajectory for either of the moons. Excursions to Mars surface itself may follow the lunar pattern, working tours first.

Is there a Lunar part in all this? Yes, to the extent that some of the vehicles, equipment, and provisions are lunar built, modifications of items first designed to bootstrap the unfolding of lunar settlement itself along with Earth-Moon trade. One thing builds upon the other — if we play our cards right, leveraging the most from every advantage. MMM

7 WONDERS of the Moon

An Armchair Pick by Peter Kokh

From orbit, as through any modest telescope, it will be quickly apparent that the Moon offers an unexpectedly diverse landscape. Eye-catching paintings of overimaginative artists aside (there are no craggy peaks untouched by erosion and few if any rough edges — all terrain features having been inexorably softened by the eons-long rain of micro-meteorites) this world does have some striking features all the same.

On Earth the rugged awesomeness of crustal rock outcrops and other features forged by a contest between brute geological forces and the relentless onslaughts of an ever active weather system are set in contrast to the beauty of vegetation in wild strobe-like stasis of species competing for niche space. On the sterile and barren Moon there is no such counterplay between geological awe and botanical beauty. Moonscapes, however otherwise dramatic or boring in feature, are all of one canvas in being displays of "magnificent desolation" (Buz Aldrin, Apollo 11 landing crew, 7/20/'69).

Many humans are quite insensitive to natural beauty (e.g. "when you've seen one waterfall, mountain etc., you've seen them all.") and will react to the Moon in character: "when you've seen one crater, you've seen them all". To those of us with an eye for differences and especially to those of us with an appreciation of untamed geological drama, the Moon, which bores only the boring, can boast a wealth of spectacular vistas.

As on Earth, the most spectacular views of the terrain itself will be had from the unobstructed vantage points of high ground — from crater and ridge tops, mountain peaks, rille edges, and promontory points. These overlook craters and walled plains, the frozen lava seas of the maria, straight and sinuous valleys, rolling, cratered, and chaotic terrain etc. As on Earth, there will be sights that merit only local or regional fame, and those that deserve a place on the global honors list.

Here is an armchair selection of nominees for a place on the "Seven Wonders of the Moon" list, the pick of one Earth-bound, telescope-, moonglobe-, and lunar photographic atlas-equipped student of the surface of "Earth's significant other". Only five of the Wonders on the list are surface features. Two spots are saved for extra special treats in the lunar heavens.

Five Nearside Wonders of the Moon

1. Earth itself, an apparition in lunar nearside heavens with 3 1/2 times the breadth, blocking out 13 times as much of the starry skies, and shining with 60 times as much glaring brilliance as does the Moon as seen from Earth — all in a spinning ever changing marbleized riot of blues, greens, browns, and whites. It goes through the same series of sunlit, night-darkened phases as does the Moon in our skies — with spectacular differences. "New Earth" when eclipsing the Sun during what we interpret as a Lunar Eclipse is a dark circle in the heavens crowned with the fiery ring of the sunset-sunrise line as sunlight scatters in the dust of the atmosphere. The night-darkened portion of the globe is in the last century increasingly "star-studded" with the city lights of burgeoning urban areas and oil and gas field burnoffs of "waste" natural gas and hydrogen. Meanwhile the frequent reflection of the Sun off ocean and ice accentuates the sunlit portions.

Full Earth illuminates moonscapes with sixty-some times as much brilliance as Full Moon brightens Earthscapes. This will be handy for getting about during the long lunar nights. But without a dust and water vapor laden atmosphere on the Moon, Earthshine shadows are inky black and impenetrable, and starlight is not drowned out. However, for the eye's pupils to open enough to appreciate the starry vistas, the brilliance of Earth must be baffled out of one's field of vision.

While Earthbound students can patiently study a seemingly eternally changeless Moon, lunar settlers and visitors who turn their gaze upon the Earth will have an unending drama of spectacular kaleidoscopic change to admire and study. It will be a treat without the distraction of flora and fauna and weather in the foreground, a Van Goghish canvas of color understatingly matted by black sky and gray regolith.

Astronomical painters such as Bonestel have tried to help us envision what it will be like to look upon Mars and the various other planets from the surfaces of their natural satellites. But the view from the Moon need take second place to none. Yet not all lunar settlers and visitors will be able to appreciate it with equal ease.

To paraphrase the opening sentence in Caesar's report on the Gallic Wars, "Omnis Luna in quattuor partibus divisa est": "All the Moon can be divided into four parts".

In the central part of the Nearside hemisphere, Earth is either directly overhead or at a very uncomfortably high angle above the horizon. Settlers might aptly nickname these central regions **"the Crooknecks"**. Included is most of Mare Imbrium, Mare Nectaris, Mare Serenitatis, Mare Tranquilitatis, Mare Nectaris, Mare Vaporum, etc.

"The Postcardlands" are the peripheral portions of nearside, regions in which the Earth hovers perpetually a comfortable 5-40° above the horizon. Adjacent to these, straddling the "limb" of the lunar globe which forever keeps the same side turned towards Earth are **"the Peek-a-boos"**. Because the Moon's axis is not perpendicular to its orbit around the Earth and because that orbit is somewhat eccentric and the Moon travels faster when nearer Earth and slower when further away, all the while rotating at a fixed rate, about 7° to either side of the 90° East and 90° West lines are alternately turned towards Earth and away from Earth. Together the above three regions cover nearly 60% of the lunar surface.

The remaining 40+% is in **"the Obliviside"**, the Farside heartland from which Earth is never visible. This fact sets the scene for the last two Wonders on our list.

2. Copernicus. Nearside has many striking large craters. Any amateur astronomer who studies the Moon through a backyard telescope will recognize a couple dozen by location, appearance, and name. And each will have his/her favorites.

Even to the naked eye a few craters stand out a quarter million miles away. During Full Moon, **Tycho** in the mid-south is the radiant point of bright streaks of lighter regolith splash-out that stretch for thousands of miles. Smaller **Aristarchus** catches one's attention with the superimposed brilliance of Venus. **Plato's** dark floor (Academy Plain?) can be picked out just north of Mare Imbrium, the Sea of Rains.

Through the binoculars even more can be recognized. But even though there are sixty-some other nearside craters as large or larger, easily the most striking of all, from Earth, is **Copernicus**. With its extensive debris slopes, it sits alone in southern Oceanus Procellarum, the Ocean of Storms, without neighboring rivals. **Mount Nicolaus*** at its center reveals a glory of detail. [* The author has published his suggestion that crater central peaks be known by the first name of the famous person after whom the host crater is named. They are otherwise known only as "central peak of ..."] A stunning low angle photomosaic of Copernicus taken by Lunar Orbiter 2 in late '66 was billed by the media as the "Photo of the Century". Indeed its psychological impact was without precedent.

Early settlers will have as favorites prominent craters that lie in easy excursion reach of their settlement site. And it will be these that are first offered on itineraries of tourists from Earth. As tourist support infrastructure grows, however, those sights with world-class splendor will be offered. If Copernicus is not handy to the initial settlement site(s), it will soon be reached "by beaten path" nonetheless. In low gravity "sixth-weight" it should be easy enough to build an elevator-equipped observation room-capped tourist tower 2 miles (10,000 ft., 3 km) high atop Copernicus north rim to showcase the scene.

3. The Straight Wall. In southern Mare Nubium, the Sea of Clouds, lies a 90 mile long escarpment or cliff known as "The Straight Wall". Because it runs north and south, it is cast into high relief by the rising Sun and is very prominent in even a low-power scope a day after first quarter (first or waxing Half Moon). While the "wall" is not really that high, this sunrise shadow play can be appreciated from surface viewpoints as well, especially those above the average elevation of the plain to the east [a mischievous use canonized by astronomers. The thought never crossed their ivory tower minds that the orientation of people on the surface might someday matter. What is the "eastern" hemisphere of the Moon *as seen from Earth* is really the "western" hemisphere from a lunar point of view as determined by the progress of sunrise and sunset.]. This feature probably does not deserve a thousand mile detour, but it is unique and special enough to be on the itinerary if established trade and travel routes pass nearby.

4. The Alpine Valley. Running like a *canal* through the mountainous terrain between Mare Imbrium and Mare Frigoris a couple of hundred miles east of Plato is an arrow-straight cut or trench, probably made by a massive piece of ejecta from the impact explosion that carved out the Imbrium basin. About a hundred miles long, it is sure to be a mainline route for traffic and utility lines between these two mare areas. All along the route there are high points to either side which must offer quite a vista. Some of these may one day host tourist lookouts, rest stops, and hotels.

5. The lavatubes. While we have strong evidence such features exist and in what kind of lunar terrain we are likely to find them, we have yet to actually map, much less explore, even one. These cavernous wormholes made by subterranean rivers in the still cooling lava floods that, layer upon layer filled most of the Moon's larger impact basins over three and a half billion years ago. Some near surface tubes have partially or wholly collapsed to form broken or continuous sinuous rille valleys. But many others must lie intact, invaluable geological preserves as well as handy shelter for the more volume-hungry needs of lunar settlement and industry. Lavatube exploration is sure to be an honored lunar "outlocks" activity.

Two Farside Wonders of the Moon

6. The Milky Way. One of the lesser recognized ways in which we are allowing our terrestrial environment to continue to degrade is urban nocturnal light pollution. Today there are millions of youth who have never seen the Milky Way. For those of us fortunate to live in or visit at least occasionally countryside areas well outside built-up populated areas, the sight of the Milky Way in dark star-bedazzled skies is unforgettable. But we glimpse it at the bottom of an wet and dusty atmospheric ocean. Even in mid-desert where on cold crisp nights the seeing is best, we are somewhat handicapped.

On the lunar surface, atmosphere is absent. But anywhere in the Nearside Crooknecks or Postcardlands, and part of the time in the Peekaboos, there is the distracting brilliance of Earthlight which must be baffled not only from view, but from reflection on one's helmet visor.

It is in Farside during nightspan, both Earth and Sun below the horizon, that the Milky Way shines in full undampened, unchallenged glory. To look up from such a vantage point and scan this river of starclouds as it arches across the heavens from horizon to horizon is a treat no human has yet experienced. For those with soul enough to appreciate it, this awesome sight will be *a*, for some *the*, reason to visit, or settle in, Farside. Many will choose the peripheral Peekaboos along the limb, for in these areas one can enjoy both the Milky Way, and Earthrise/Earthset, alternately.

7. Tsiolkovsky. The standard approach and landing trajectory that ships bearing settlers, tourists, and visitors will take to surface settlements will bring them in on a descent swing around Farside. Mare Orientalis, the dramatic bullseye-shaped

Eastern Sea (misnamed because it is in the *western* Peekaboos) will be the feature most watched for, if, of course, it be sunlit at the moment. But deep in Farside, again depending on the time of sunth, another spectacle awaits them, to this writer's eye the most dramatic crater on the Moon — Tsiolkovsky, aptly named after he who taught us that Earth is but our cradle, and that it was our destiny to move up, out, and beyond.

Like Plato and Grimaldi on Nearside, Tsiolkovsky's basin is flooded with mare-like deposits — in its case some of the darkest mare regolith to be found anywhere on the Moon. This only serves to set off even more strikingly the **Mount Konstantin** massif that dominates Tsiolkovsky's interior. What a perch for a monastery or shangri-la!

If the day comes when human settlements in the solar system organize in some politically cooperative way, what better site for a capital or headquarters than on Tsiolkovsky's dark flat floor south of the Konstantin massif. It is handy enough to Earth where most of humanity will continue to live for a long time to come. Yet its horizons face away from the hidden cradle world out upon a Milky Way crowned universe of unlimited opportunity. And who could pick a better name? It's frosting on the cake that those approaching from space could pick it out instantly by naked eye a half million miles out

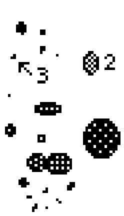
National Parks and other Preserves

Any discussion of great natural wonders would be incomplete without considering what we might to do preserve such heritage. **Scenic Preserves** would establish regulations restricting buildings, road placement, and other developments in the foreground or background visible from scenic overlook sites. **Geological Preserves** would go further, protecting not only specific viewpoints but the physical feature itself from development, some types of mining, etc. Designation as a **National Park** would signify the intention to develop tourist and other recreational use facilities nearby so that the feature could be popularly enjoyed in a controlled fashion, as well as preserved from other types of development.

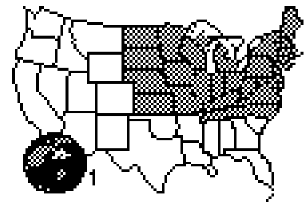
There is the added question of preservation of scenic orbital perspectives, i.e. of preventing developments that might be defacing on a large scale. Given the impotency of efforts to control forest clear-cutting in the Pacific Northwest where ugly scars that seem to grow cancerously insult anyone peering out an airplane window, lunar authorities will have to insulate themselves from the palmgrease of developers if they are to have any luck. But solving the future's problems is the chore of those alive at the time. We can but warn. MMM

MMM #70 - NOV 1993

Asteroids come in all shapes and sizes.



So, when we were asked to run an "Asteroid Base Design Workshop" at the ISDC in Huntsville, we had our participants break up into three separate groups, each brainstorming a very different scenario. 1) a major service center settlement on *Ceres* (shown left with equivalent surface area); 2) a mining/shipping operation on medium size *Gaspra*; 3) a Ma & Pa operation bringing back a mountain-sized chunk to Earth orbit via mass driver; ⇒ Part I below.



Tale of 3 asteroids

Primer & Results of a 3-track **Mission Control™ Workshop** at the '93 Huntsville ISDC

Peter Kokh* with Mark Kaehny, Bill Higgins, et alii

Workshop "Primer"

For a moment after having just been asked to chair a 2 hour "Workshop" session on "Asteroid Base Design" at the upcoming '93 International Space Development Conference in Huntsville, I had the sudden sense of dangling in space weightless without any orientation or reference to up or down, fore or aft, left or right. For as most MMM readers must realize all to well, the word "asteroid" umbrellas a lot of objects dissimilar in physical-chemical-mineral makeup and widely ranging in both size and orbital environment.

On the one hand there is Ceres, a real mini-planet in its own right. Named after the Roman goddess of grain, it lies in the middle of the Main Asteroid Belt, yet in size, if not composition, it is *quite* atypical. Are we here talking about **a Permanent Main Belt Center on Ceres**? Or on somewhat smaller but still respectably sized Pallas or Vesta?

At the other end of the scale, we have irregularly shaped mountain-size "astrochunks" that as a rule slip by undetected unless they are in unusual "Earth approaching" orbits and in fact wander within a few million miles of the Earth-Moon system. Are we talking about **a Mom& Pop Operation Shepherding a Small Astrochunk into Earth Orbit with the help of a Mass Driver**? Often ore-enriched, small enough to be mass-driveable, these rogue mountains offer the earliest opportunity for the return of asteroid resources to the vicinity of the Earth-Moon - L5 System. We should be able to find many of these mineral-rich objects in orbits handy to Earth. They would require comparatively modest fuel expenditures to reach - or to coax into stable parking orbits in Earth-Moon or Earth-Sun Lagrange point areas.

In between are many thousands of bodies ranging from potato-shapes a few miles in cross section to spheres a couple of hundred miles in diameter. Are we talking about **a Mining & Shipping Outpost on a Mid-size Asteroid such as Gaspra**, recently scanned by the Jupiter-bound Galileo probe? Middle-size asteroids are too big to alter their orbits by mass-drive but with metal- or volatile-enriched compositions that can be mined, the bounty to be shipped Earthwards. Ida and Gaspra examples. This group includes Earth-approachers like Eros and Ganymed as well as Main Belt denizens.

Each of these three scenarios offered very different set of starting points and constraints for "Asteroid Base Design". It instantly seemed clear that all three were worth pursuing. And so we put together a 3 page "primer" for those intending to participate in the Workshop, mentioning whatever we could think of that was intelligent and might be relevant about each of the three scenarios. If we had enough participants, we would break up into three groups, each "brainstorming" a radically different kind of asteroid "base" starting with the givens and constraints listed in the primer, and going - who knows where?

This strategy could not have worked out better. We had 20-some registrants and after a few introductory remarks were able to break into very even groups of 7-8 brainstormers apiece. Adopting three corners of the room, each group began spirited discussion. Eurekas and laughter and excited talk could be heard from all three tables throughout the hour and 20 minutes arbitrarily available before I called a halt and asked the leader of each group to come to the front of the room and report to all what his group had discussed.

Without exception all three group reports were excited and exciting. Each table uncovered unexpected considerations that affected the direction of their design recommendations, each had come up with surprising and ingenious solutions to the problems they had tackled. After all the reports were heard, we gave each other a rousing round of applause. The Workshop was a great success in itself, and more importantly for each of the participants, perhaps the personal highlight of the ISDC.

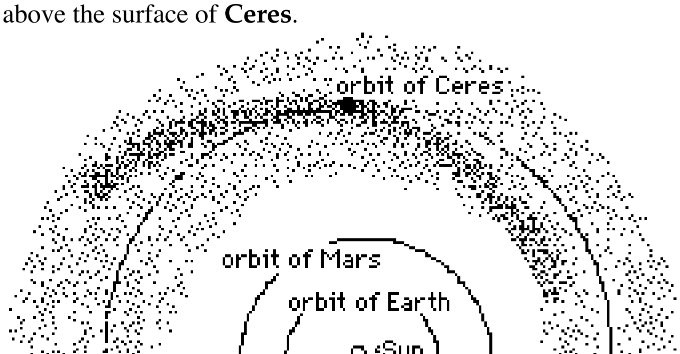
Group 1: A Permanent Main Belt Service Center on Ceres

Starting Point: Consider:

Ceres, with a diameter of 1000 km or 600 miles has a surface area equal to all of the continental U.S. *west* of the Mississippi. **Pallas** and **Vesta** each have as much surface as the U.S. *east* of the Mississippi. They are small by Earth-Moon standards, but not insubstantial!

The gravity on **Ceres** and denser **Vesta** is about 1/6th Lunar standard or about 3% Earth-normal. Enough to be a mechanical assist and keep things in their place, but possibly below the threshold of impact on the human physiology. I.e., as far as the functioning of our bodies are concerned (mobility aside) the environment there may as well be "zero-G".

Synchronous orbit lies about 782 km or 486 miles above the surface of **Ceres**.



Ceres' orbit within the Main Asteroid Belt and the swath, in relationship to Ceres' position, in which we'll find asteroids that will orbit in formation with Ceres for many decades.

If the stats for the first 100 asteroids to be discovered are typical, 44% have orbital periods within 10% of **Ceres**' so that a third of these, almost *15% of all Main Belt Asteroids lie within 60° of* **Ceres** *at any given time and remain there for fifteen years or longer before drifting out of range*. Some known asteroids (e.g. **Pallas**, **Thisbe**, **Laetitia**) will orbit in formation" with **Ceres** for centuries, even millennia. Much time and fuel energy may be saved by not having to exit Earth, Moon, or Mars gravity wells to maintain and resupply mining operations in the Main Belt as opposed to using a mini-grav well in the belt itself, say on Ceres. The fuel energy savings can be banked or spent on faster than minimum trajectories (acceleration and deceleration) to shorten trip times.

Ceres itself is a carbonaceous chondrite type, and should have a volatile component of about 20%. That means water of hydration and/or permafrost. This will be a blessing, as a resource, but possibly also a bane, as a construction obstacle. The exact proportions and makeup of its hydrated silicates, metal oxides, and permafrost water ice awaits an orbital prospector with a gamma ray spectrometer. Even if the settlement is established and planned as a Main Belt Service Center to facilitate more profitable mining operations on outlying smaller and more ore enriched bodies, it will be logical to do some mining on **Ceres** itself to provide the building materials out of which the settlement is to be made, and provide the bulk of its ongoing consumption uses.

Ceres lies 2.77 times further from the Sun than Earth-Moon and so if Solar Power is to be considered, keep in mind that collectors sized to provide a given amount of power would have to have an area 7.7 times 'normal' size.

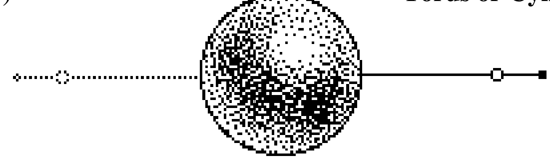
Your Mission: Explore, list, and rate options:

◊ Should at least part of the outpost settlement have higher Lunar-standard artificial gravity, a level high enough to prevent physiological deterioration beyond a Moon-proved acceptable level? If so, rate these options. Are there others:

A **Gravitrack***: part of the habitat area is a Mag-lev "train" on an appropriately banked circular track on the surface, or in a tunnel for shielding.

A **Maypole*:** part of the habitat is tethered to and spun around a pylon. The Pylon has to be tall enough (or the tether has to be tension-reelable) so that the habitat can come to rest on the surface periodically for boarding and deboarding, and for expansion, maintenance, and re-outfitting.

An **Elevator-tethered Synchronous orbit** (see specs above) **Torus or Cylinder.**



Distance to scale of orbital Sync Port above Ceres surface, showing elevator/tether and counterweight. Many of Ceres' port functions will be more efficiently conducted at Sync Port.

All of these would be combined with surface mini-g installations and facilities completing the settlement. If such an artificial Lunar-standard gravity facility is provided, what should settlement functions and areas be on board and what should be on the non-gravity-enhanced surface? Habitat areas with sleeping and off-hours functions? Recreational facilities? Industrial facilities, or at least some of these? Educational, Judicial, and Administrative facilities?

◊ What are the **power options** available, and how would you rate their feasibility and expense? Solar? Nuclear fission? Helium-3 fusion? Other options?

◊ What types of building materials could be produced from Ceres' own resources? Besides metals, ceramics, glass and composites, and concrete, are cryoplastics, serviceable in low temperature zones, an option?

◊ Besides mining, processing, and manufacturing for local needs, the settlement should serve which specifically **Main Belt Central functions**? A wide range of prospecting and mining activity within the formation-keeping sector asteroids.

- √ Outfitting, resupply, maintenance and repairs (of ships, drivers, habitats, CELSS systems)
- √ Warehousing
- √ Courts, assay offices, mining/extraction/processing R&D
- √ Hospital, prison, trauma and chemical-abuse rehabilitation facilities
- √ Boarding/day schools, eventually a university
- √ Shopping, entertainment, radio, telecommunications social mixers, restaurants, bars, brothels, etc.
- √ Home port for circuit-making "trader general store ships"
- √ Agriculture: for own needs and export to outlying outposts that can only provide a demoralizingly low portion of their own food needs.
- √ Processing, manufacturing, based on both domestic and incoming raw materials, some for local consumption, some to sell back to asteroid boondocks, some to sell to Inner, Outer System markets

Architectural Considerations

◊ A different suite of building materials (clays, hydrates, water available)than that appropriate for the Moon .

◊ Permafrost as a potential unknown construction problem

◊ 3% gravity (19% Lunar standard, 8.3% Martian)

◊ Regolith shielding overburden has negligible pressurization compensatory value (a bit more than 1/5th that on Moon)

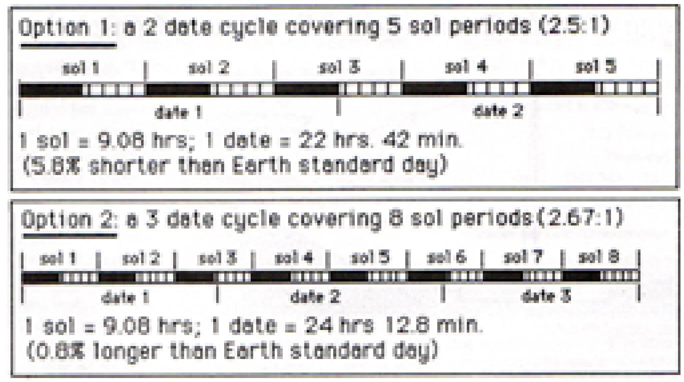
◊ Transport and personal mobility problems in mini-gravity: pedestrians, vehicles, etc.

◊ Ceiling heights in mini-gravity, hand holds and railings, moving grab-on cables, etc.

◊ Fitness considerations:

- √ Podokinetics (luxury items powered by foot pedals etc.), isometrics, and traditional exercise
- √ Gravittrak or Maypoles: "sky-side" shielding must be provided (integral, under ramada sheds, or?)
- √ Elevator-tethered space settlements in synch orbit Gravid space for work, leisure, or sleeping?

Ceres' "**day**" or "sol" is **9.08 hours** long. This could be "rationalized" in two ways. The first option is a two "date" cycle covering 5 periods and would yield "dates" of 22 hrs. 42 min. The second 'improved' option is a three date cycle covering 8 periods giving a "**date**" **24 hrs**. **12.8 min**. long. Either is sufficiently close enough to the standard day to work reasonably well. The second option comes much closer, but the varying way the lighting cycle lines up will be harder to get used to. *See graphic, top of column 2.*



* **NAME POOL: Ceres** was discovered in **Palermo**, Sicily by Giovanni **Piazzi**, on the first day of **Century Nineteen**. The mortal through which the Roman goddess Ceres passed her agricultural secrets to humanity was **Triptolemus**.

WORKSHOP RESULTS: Group 1

GROUP: Peter Kokh, Tomas L. Gonzalez, Joseph S. Kirlik, Julius M. Martin, Peter Palumbo, and Bryce Walden.

We spent some time better defining which functions the Ceres Settlement* would fill, and of these, which were appropriate for Ceres' low mini-gravity, which would be better placed in a surface artificial gravity environment, and which would best be filled in an elevator and pipeline cluster tethered synchronously orbiting space facility, the Sync Port", 486 miles above the main Surface Settlement.

ORBITAL SYNC PORT

- □ **Solar Energy facility** if practical, cabled to surface
- □ **Main Port of Call** for ships to and from other asteroid belt locations elsewhere in the solar system
- □ **Fuel Depot** for visiting ships
- □ **Light processing, manufacturing** incoming resources
- □ **Warehouse** for goods being transshipped
- □ **Traders' Market** for ships in port
- □ **Repair, maintenance, reoutfitting shops** for work that is routine, frequent, and requiring a low mass of equipment
- □ **Assay office** for incoming mining samples
- □ **Hotel** for more transient spacer use
- □ **Gym** for visiting personnel
- □ **Other recreation facilities** for transient spacers
- □ **Administrative offices** for handling routine matters for visiting spacers
- □ **Medical Outpatient Clinic** for visiting spacers
- □ **Other functions** for personnel, ships, goods in transit

SURFACE, FIXED

(some within the main settlement area, some without it)

- □ **Mining and processing** of local Cerian resources
- □ **Manufacturing** based on local Cerian resources
- □ **Refinery** for fuels, volatiles from local resources
- □ **Custom manufacturing** using imported resources
- □ **Warehousing** for all of the above
- □ **R&D facilities** and labs for processing, manufacturing
- □ **Repair, maintenance, reoutfitting shops** for work needing heavier equipment that is less routine and/or frequent
- □ **Main agricultural areas**: food for local consumption and for export to other Belt markets

- □ **Nature parks**
- □ **Gym** using heavy equipment or for exercises that are not gravity-dependent
- □ **Space port** for orbit to surface shuttles loads too big or massive for the elevator
- □ **Main, permanent Trade Center**
- □ **Nuclear Fusion** (He-3) Plant
- □ **Main Hospital**

SURFACE, GRAVID

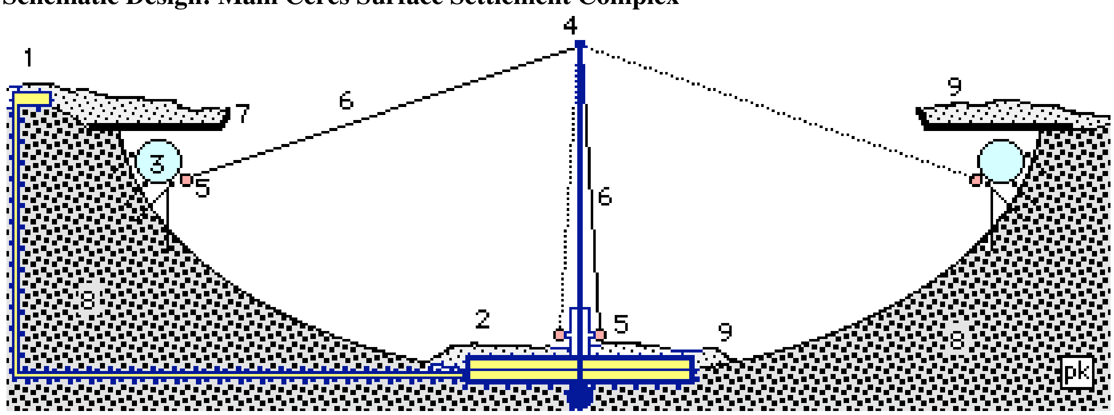
(Artificial gravity via Maypole and/or Maglev facility)

- □ Residential area (so all locals spend some time here)
- □ Schools (concern for children in developmental years)
- □ Offices (commercial, administrative)
- □ Gym for gravity-assisted exercise and sports requiring lightweight equipment
- □ Hospital recovery and rehabilitation areas
- □ Other activities and functions that require little space and little supporting equipment mass

Simply by better defining what activity or function most appropriately goes where, a much clearer picture of the Ceres Settlement Complex arises. And only with that in hand are we ready to begin looking at architectural considerations.

Next, as the design possibilities for artificial gravity habitat facilities in orbit are already fairly well explored, we spent the balance of our time discussing the engineering and design options for providing artificial gravity on the surface.

Schematic Design: Main Ceres Surface Settlement Complex



KEY: 1 auxiliary crater rim surface facilities, elevator and corridor to **2** main crater bottom natural-G installations. **3** Maglev Habitat areas with 'standard' 1/6th G lunar gravity shown 'riding' two crater slope rails, with third support rail for deceleration to stop for maintenance and adding new modules **4** "Maypole" pylon and bedrock anchor; **5** counterbalanced pair of shuttle modules (original 'starter' habitat modules prior to building the settlement expansion Maglev habitat facility), shown both at rest docked with main crater bottom facility and at Maglev matching velocity for docking and transfer of personnel especially at shift change; **6** shuttle tethers which lengthen by reeling out as centrifugal force increases; **7** cantilevered shielding retainer lip; **8** undisturbed soil and rock; **9** shielding soil.

Designing a finished, mature stage complex for Ceres without attention to how it might develop to that final level of complexity as the population grows from say a hundred or so to several thousand, would be an exercise in building sand castles. Thus there is no decision to be made *between* a Maypole-tethered artificially increased gravity habitat and a Maglev-based facility. Both are needed, and appropriate, at different phases of the settlement's growth and development.

First a suitably-sized crater must be chosen, straddling Ceres' equator, or as close to it as possible. Inside, a Maypole-based facility would be easily the simplest to install and to engineer and yet be quite adequate for initial foot-in-the-door population levels, especially if it is used just for dormitory purposes, to give everyone some fraction of the day at higher than Cerian mini-G levels. Once the initial "starter" settlement complex is in place and population growth is called for to realize the full potential of this Main Belt center of operations, a Maglev "Gravittrak™" Facility can be built.

When the first Gravittrak car modules are in place and ready to use, the original Maypole-tethered dormitories can be transformed into shuttle transfer cars to ferry personnel to and from crater bottom areas of the settlement, and by transfer there to other outlying surface installations. These shuttles are best operated in counterbalanced pairs, even if at first there is only one Gravittrak module operating. Shuttle service is needed before and after shift changes especially, and perhaps at some scheduled intervals in between.

The Maglev Gravittrak-based complex can be grown sausage-link style from one module to several, up to a filled ring, as the total population on Ceres grows perhaps to several thousand. To make sure there is enough capacity for growth, the car modules can be double or even multi-decked. But the circumference of the Gravittrak being perhaps one to several kilometers in length (depending on the speed of the modules on the track, or rpm), there should be ample room to grow before it is necessary to expand further by building an additional similarly architectured settlement at another site. As the Gravittrak modules and population grows, it will be neces-sary to add additional and larger capacity Maypole shuttle cars.

The individual car modules might be slung each in a pair of Mag-lev track riding suspension rings, within which they could freely rotate from a highly inclined orientation to one perpendicular to Ceres' surface as they are decelerated to a stop for maintenance work or for coupling additional modules. Normally operational pressurized vestibulation of the modules to one another for passage between them might be inactivated during acceleration and deceleration at such times.

Gravittrak car modules could be clustered into three "villages" according to shift. Each shift could then use artificial lighting so that its members work 'by day' and sleep 'by night'. This arrangement could also simplify shuttle docking schedules. These three villages could either be physically linked or spaced out at 120° intervals along the Gravittrak.

Of course, there can be no protruding surface installations anywhere within the crater that would interfere with the operation of the Maypole shuttles. Such things as radiators and antennae are best located on the crater rim anyway where lines of sight are less restricted. Initial antennae will be relegated to auxiliary standby usage once the Sync Port is built overhead in orbit and the elevator-pipeline-cable-tether complex is in place. For then communications will be routed by cable to orbit-based relay antennae.

On the crater rim, there needs to be a Depot with multiple docking ports for surface transportation to outlying facilities such as mining and processing plants, He-3 fusion plant, and of course to the settlement's auxiliary spaceport used for spacecraft large and small having a reason or desire to land directly on Ceres' surface rather than dock at the Sync Port.

Attention was also given to modes of personal mobility in Ceres' low mini-gravity environment. This can be taken up separately. In sum the workshop's Ceres' team was quite excited about its satisfying brainstorming results. Others are free to use any of the above as a basis for further work. **PK**

NEXT MONTH: [FEB 1994 MMM #71 included in MMM Classics #8] PART **II:** A mining and shipping operation on mid-sized Gaspra; Part **III:** A Ma & Pa operation bringing back a mountain-sized chunk to Earth orbit via a mass driver.

APPENDIX

[from MMM #61, DEC 1992]

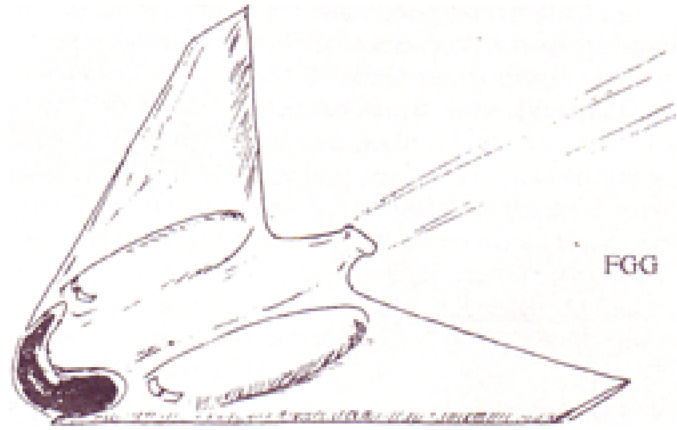
Large Floating Structures on Jupiter

by Francis G. Graham

The large floating cities envisioned by Kokh in the concluding chapter of the Xities series indeed would be excellent laboratories for the further exploration and utilization of the gas giant planets such as Jupiter, Saturn, and Uranus using technology one century of human progress more advanced than ours. These types of planets contain elements in solar abundance needed to perform the most difficult of all space missions, i.e., construct and power starships of the type envisioned by John MacVey in Journey to Alpha Centauri, which attain a small percentage of the speed of light using enormous fusion power.

In addition, large gas giants are foreseeably the only planets we will easily be able to detect around other star systems, using infrared excess, radial velocity variation, or perturbation methods, from Earth-based or Earth-orbiting telescopes. Hence the technology to utilize them as bases, or as resource gathering centers for restocking preparatory to another interstellar voyage is important, whether by "generation travel" human colonies or long-lived AI [artificial intelligence] machine systems.

Aerostat Xities in the pre-interstellar age would likely be useful as bases conducting technological experiments in resource utilization of the gas giant planets, possibly then preparatory to the development of interstellar systems.



Twenty years ago I too suggested large floating structures in the atmosphere of Jupiter, driven by ice-water cycle engines. The floating bases could be connected by a transportation net of "inverse jets", i.e. aircraft with an oxygen supply and intakes for hydrogen. It was at Bruce Hapke's Planetary Physics class in 1978 that I first made this suggestion publicly. On Jupiter, the oxygen would be freed from atmospheric compounds such as water vapor, by dissociation. **FGG**

[**Francis Graham** is **Editor of Selenology** quarterly of the **American Lunar Society** of which he has been a past president. He has an association with the Allegheny Observatory in Pittsburgh, and teaches at Wright State University in East Liverpool, Ohio. An SSI Senior Associate, he has done Earth-based observations for sodium vapor over the Lunar poles leading to a pessimistic conclu-sion about the chances of appreciable caches of water ice there.]

[from MMM #62, FEB 1993]

IN FOCUS: *Convincing Economic "Case for Mars" yet to be made*

Commentary by Peter Kokh

Mission scenario development has continued to make progress towards the technical and logistic doability of limited engagement crewed exploratory excursions on Mars. Brainstorming of settlement scenarios, however, lags far, far behind.

The claims for the settleworthiness of Mars have become unexamined rote recitations too many take for granted:

√ Mars has marginal similarities to Earth: a day of similar length, four seasons, about the same area of land surface, and a gravity level intermediate between Earth's and the Moon's.

√ Mars, unlike the Moon, is not deficient in any of the elements needed to support life: nitrogen, carbon, and water-ice. Thus future Martians can both better provide for their own food production and other agricultural needs and locally process and manufacture a greater percentage of the various material goods they need or desire than can settlers on the Moon.

√ Mars is the most "terraformable" surface venue in the Solar System with its higher gravity, initial air- & sea-stuffs, etc.

But Lost in the above argument are some very brute economic facts. The Moon HAS abundant trade assets, namely Earth-deficient energy fuels and/or aids in producing them (solar power gathered on the lunar surface or in orbit and beamed to Earth; Helium-3, the ultimate fusion fuel) to trade for things it lacks and/or cannot yet self-manufacture, or for which it cannot yet realize locally-supported substitutes. This more than makes up for Mars' alleged "non-deficiencies" because it also promises enough of a surplus to support the costs of Lunar settlement itself.

Mars, in contrast, would seem to lack *sufficient* Earth-marketable assets. These will be needed *in quantity* to pay the costs of settler passage, settlement construction, and establishment of the needed capital industries to make the planet self-sufficient.

Yes, Mars' exotic scenery will surely draw ultra-affluent tourists and the occasional super-lottery winner. And as the gap between the rich and everyone else continues to widen obscenely on Earth, there is likely to be some tourism with trickle-down wealth sufficient to support a token Mars-side settlement necessary to cater to it. But unless transportation costs come down by more than even the most optimistic of us can today imagine, that traffic does not promise to be enough to pay for even those on site tourist facilities that budget travelers on Earth have long taken for granted, let alone trickle down to support a general settlement economy for those seeking a "fresh start" chance on this "New New World". Tourism *of - not on* Mars may really 'flourish' only as an armchair diversion for those remaining comfortably on Earth, vicariously immersing themselves in expensively gotten travelogues or real-scenery virtual reality personal explorations - without long fortune-draining travel times to and fro. .

This picture does not change even if the tabloids are right and there are gargantuan pyramids on Mars built by alien visitors from the stars (and if pigs begin to fly). Even such an unbeatable draw as that would not alter or render moot the underlying economics of tourism. When and if there is *some other kind* of economic cake, tourism *will* provide the frosting. It cannot jump start the Martian economy all by itself.

On the Other Hand ...

Phobos and Deimos, Mars two mini-moons, have as yet unconfirmed reserves of water-ice or water of hydration and carbon compounds that would be very attractive to Lunar settlements. "PhD" traffic to the Moon, perhaps in the form of refined liquid ammonia and methane, *does* offer one avenue of revenue to support activities on the Martian surface. But the amount of cost-defraying profit made here depends on how fast a trailblazing Lunar economy develops. Since the PhD gambit is an integral part of a Lunar "trickle down" scenario, the realized profits may at best be only enough to permit the Martian frontier to open slowly in comparison - especially if PhD does not have a corner on the market for "Lunar-deficients". And this could be the case depending how quickly alternative, potentially richer, asteroidal sources come on line.

What about ...?

Might early explorers find something already existing on Mars like a rare mineral valued for manufacture or perhaps prized for sculpture? Or might they stumble upon an inexhaustible lode of gemstones of unmatched quality or character?

Let's do a reality check here. The few elements that Earth needs in greater quantity than it has will be more economically sourceable on the Moon (Helium-3) or on Earth-approaching, even Main Belt, asteroids (strategic metals: platinum, cobalt, etc.). As to minerals and natural gemstones, elements in combination, these are produced by geological processes, and by all standards but one, Mars has been far less geologically active than Earth. As a result, the Martian repertoire of minerals is likely to be both less diverse and less abundant than Earth's, with little chance of something new, strange, or exotic enough to be marketable.

The exception is fixed-site volcanism. On Earth, crustal plates drift over fixed magma hot spots to create strings of volcanoes like the Hawaiian Islands. On Mars, with some spectacular crustal rifting (Valles Marineris) but no drifting plates subducting or overriding one another at their boundaries, similar magma hot spots have built up very high shield volcanoes over very long periods of time. This process is most unlikely to produce strategic mineral wealth galore, but just may have produced the ultimate "King Solomon's Mines." If so, is this the sort of wealth which can finance a general opening of the Martian frontier? My guess is no.

Another possibility one can conjure up is that for some heaven-can-imagine-what reason, pressurized agricultural facilities on Mars will be able to produce unique fruits, grains, pharmaceuticals, dyes, or fibers that cannot be matched on Earth and which will be much in demand. One can think of two Mars-special niche features which might underpin such a development. The first is the 3/8ths Earth-normal gravity. It is hard to see where this could lead to a produce improvement that the 1/6th Earth-normal gravity on the Moon couldn't beat. The second is the possibility of bioengineering unique "Mars-hardy" plant varieties that can establish a foothold and thrive "outdoors" on the surface in a thickened carbon dioxide atmosphere once "terraforming" is already well underway. This is not at all implausible. Moreover, it is a scenario that can be "forced", in anticipation of such someday terraforming, in special atmosphere greenhouses. The weakness of this long-shot argument is that, save for the low gravity, similar conditions could be produced in special greenhouses on Earth itself.

A variation on this theme is the far-fetched chance that something growable only on Mars would provide, at last, the fabled fountain of youth. Fat chance! If living on Mars should prove in any sense more healthful than living on Earth, there'll always be the negative tradeoffs of the dangers involved in relocating there in the first place - the long space voyage etc. No matter, for health is not exportable, not a cash crop.

In the meantime ...

So how pessimistic should we be about establishing a plausible Economic Case for Opening the Martian Frontier? Pessimism is the refuge of those unwilling to do anything to change the odds. Those of us with a faith in the future of Mars, one that we refuse to surrender, have homework to do.

First, we must push hard for thorough geochemical exploration of Mars, and for the laying out of the planet's "economic geography" in thorough detail. Not only would this be necessary to plan the settlement of Mars in a rational manner to maximize *earliest* economic self-sufficiency, it is our only hope for finding any yet unknown elixir or manna or klondike on Mars that might help pay the bills for pioneering it. Its not enough for us to trust that the ivory tower curiosity of planetary scientists will lead them to plan an adequate geochemical and resource exploration of the planet to do the job. Our pragmatic interests go well beyond their intellectual ones and we must pace them, not they us.

Second, we must work to pre-develop, debug, and miniaturize the capital equipment it will be necessary to bring to Mars to make use of on site materials. This will promote the earliest possible "break-even" point in the self-manufacturing of the bulk of the settlement's material needs.

Third we must support development of efficient agricultural production units suitable for Mars. Beyond that, we need to support an imaginative and vigorous program to identify potential "Mars-hardy" plant varieties and develop them by all means available into a pantry of species that will thrive in "enhanced" Martian conditions, i.e. in thickened CO_2 Mars air.

While we may not uncover a miracle economic linchpin, we will be *lowering the formidable economic threshold* for settlement. And while we may not be hastening the day when humans finally set foot on Mars, we will be doing something to make sure that that gambit, once finally played, is not another stalemate à la Apollo. For we will have done something towards making it possible to extend and expand our presence there in the direction of permanent settlement. And that's one hell of a lot more than will be achieved by those who merely push the politicos.

So why whimper? Suspend judgment on the eventual outcome and begin to whittle away the negative odds. Be the spiritual ancestors of Martians perhaps yet unborn. **PK**

[from MMM #67, JUL 1993]

April's (MMM # 64) Biosphere II articles.

5/17/'93. The April, 1993 articles on Biosphere II were of great interest, and very timely in view of the imminent completion of the first crew's tenancy.

The project bookstore informational material seems to indicate understandings as follows:

- all the biomes at Oracle will likely stay in place (in support of the 'Earth stewardship research' component of the mission).
- a biosphere off-planet does not necessarily have included all of the Biosphere II biomes (the original mission is changed in part, off-planet). Some Biosphere II biomes may be deleted in favor of an enlarged food/CELSS-type approach.
- while Biosphere II mimics Earth ecosystems, progress to that end can only be partial. There will always be a minimum of machinery content in back-up, for the foreseeable or indefinite future.
- enclosure spaceframe design is predicated on considerations of the S.W. U.S.A. location of the project and of the 'Earth stewardship research' mission. An enclosure spaceframe off-planet would be designed to suit the new mission/location, with artificial lighting included as required.
- the present crew's task includes best effort at maintaining equilibrium among the many variables, to establish what is immediately achievable. Of course, operations of extremely long range are envisaged, and the project seems to anticipate considerable evolution/resolution as data is acquired over the long haul.

Michael Ross, Toronto, Canada

[from MMM #68, SEP 1993]

Hydrogen Harvesting Without Helium-3

7/17/'93. MMM #67 pp. 3-5 "HYDROGEN, the water-maker: Industrial Grease" and the "HYDRO-LUNA" article that follows, would seem to give the impression that *if, and only if,* we do lots of regolith sifting in the course of Helium-3 harvesting, will lunar settlers realize the *co*-harvesting of ample amounts of hydrogen (with which to make water) as a byproduct. The implication to the reader is that *if*, in the prevailing politico-techno-economic climate of the time, "Bottom Line Economics" mandates Solar Power Satellites or Lunar Solar Arrays instead as the principle mode(s) of supplying Earth with clean space-based energy, *then* lunar surface settlers will have no recourse but to turn to off-Moon sources of hydrogen such as the moons of Mars, carbonaceous asteroids, or 'comatose' comets.

Yet consider this. Many millions of tonnes of regolith will need to be moved and/or processed *either* in onsite lunar manufacturing of lunar solar power arrays *or* for mass driver export to SPS-construction camps located at L-4, L-5, or elsewhere. While I am not able to compare the volumes of regolith that would need to be processed in each of the three scenarios to provide a similar amount of power to Earth, say a quad (would some knowledgeable reader please help me out here?), I am willing to bet that in *all three* scenarios, the amount would be sufficient to yield a surprisingly generous amount of hydrogen.

Still, we would do well not to take such a co-harvest for granted. Helium-3 people *do* often talk of co-harvesting other volatiles - after all, they *are* heating up the regolith in the course of which process *any* volatile atoms adsorbed to the soil fines will *all* be liberated. But Lunar Solar Array and Solar Power Satellite people rarely make any mention of the possibility. The latter (L5rs) especially would seem to prefer routinely wasting this resource by using a mass driver to export regolith en masse to space *as it is, without prior heating* to harvest volatiles for lunar use (or *any* kind of prior on-surface processing that might require *added* on-surface personnel!) Indeed, lunar surface development seems something they have an unspoken need to minimize, preempt, or even squelch. As such, this would constitute an exploitive rape of local resources in the worst traditions of classical imperialist colonialism.

I feel rather confident, however, that such extremist planetphobes will not have their way. We will have *both* space and surface settlements *and* there will be a strong, healthy symbiosis between these two arenas of cradle-breaking civilization.

Thomas Heidel, Milwaukee, WI **end MMMC #7**